Input substitution and technological development on Finnish dairy farms for 1965–1991

Empirical application on bookkeeping dairy farms

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ACADEMIC DISSERTATION
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The study presents an attempt to gain a better understanding of the input substitution and technological development on Finnish dairy farms. The dual approach of the neoclassical production and cost theory is applied. A system of derived demand and cost functions is estimated using a representative dairy farm data and panel data of bookkeeping Finnish dairy farms. The flexible translog cost function is utilized to solve the empirical research problem. The cost function study is chosen, because it makes it possible to study production of farms operating in the area of decreasing average costs.

According to the results, inputs are for the most part substitutes with each other. With the existing production technology, the substitution of inputs for other inputs is inelastic. The own price elasticities are also inelastic. Technical change is purchased feed-saving and other inputs-using. The average annual rate of technical change was 1.3 percent. The new production chains resulting from technical change have made it possible to increase the size of dairy farms. Increasing the size of dairy farms should be allowed so in order to make it possible to utilize the advantages related to the economies of size.

Key words: dual approach, elasticity of substitution, flexible functional forms, input demand, panel data, representative farm data, technical change

1 Introduction

1.1 Background for the study

Agricultural production in Finland has undergone a rapid change since the early 1960s. Changes in agriculture are closely linked to the development of the national economy. The rise in the standard of living created new jobs, which attracted a labour force, especially from small farms. The population of the countryside has decreased by over half a million people during this period of time, although the population of Finland has increased by about 300,000 persons.

As a result of the change, the labour force tied to agriculture has dropped from 450,000 to the present estimation of 150,000 persons (Etla 1993, p. 106). At the same time, the net capital stock of agricultural production buildings, machinery, and implements has increased over 1.5 times. The rise in the total productivity in agriculture has varied between 2% and 4%. However, the changes have not led to improved profitability in agriculture (YLÄTALO 1987, p. 2, 70–71).

The incomes of agricultural entrepreneurs have remained smaller than those of people working in other sectors (PUURUNEN 1990, p. 77–88). The low incomes and the fact that farmers are very much tied to their work has made it difficult to find young people who are willing to continue farming, especially on dairy farms (RYHÄNEN 1989, p. 50). This has resulted in a rapid decrease in the number of dairy farms. During the research period close to 200,000 dairy farms stopped production. At present, the number of dairy farms is under 35,000.

Finnish agricultural policy has been characterized by conflicting interests and widely different views on agricultural policy between interest groups like political parties and labour market organizations. In this kind of atmosphere, the realization of any long-term agricultural policy has been problematic. In addition, as a result of the vast overproduction, the objectives in the regulation of milk production have mainly concerned restricting production. Consequently, dairy farms were largely excluded from the active development measures, for example, size restrictions were placed on dairy farms.

How did the problems come about? After the Second World War, it was not possible to import food. Instead, the Finnish government encouraged more efficient and increased agricultural production to make up for the food shortages. At the same time, the "social problem" of homeless families was addressed. This resulted in growth in the number of farms and a decrease in the average farm size. As a result of the increased arable land area and the more efficient production in the 1960s, the shortage of food gradually turned to overproduction.

In addition to the need to solve the present problem of overproduction, the need to develop the dairy farms increased at the same time. Despite measures to restrict production, in the long run economic factors will determine the trends in agricultural production. Small, labour intensive dairy farms will become unprofitable and give up production. The present small average farm size and the relatively large share of small farms make it impossible to use inputs in an efficient way at the level of the national economy.

When developing dairy farms, it is essential to know how the resources should be allocated to milk production. There are very few reliable research results available on the use of production inputs on dairy farms in Finland. Consequently, the study of the use of these inputs was chosen as the central objective of this study.

The initial assumption of the study is that a milk producer acts so as to optimize the economic result of production. In addition, it is assumed that labour and capital are the factors by means of which milk producers organize the production of their farms. As a result, the use of labour and capital also describes indirectly the abilities and entrepreneurship of the milk producer.

In addition to optimizing the economic result, the milk producer may have other objectives, for example, enough leisure time, avoiding risk, and independence (BRANDES et al. 1980). These factors are impossible to measure in an exact and reliable way, so that research on the effects of these factors is excluded from the study.

1.2 Objectives and significance of the study

The objective of the study is to examine the effect of the change in the relative prices of inputs and the technological development of production on the derived demand for inputs of dairy farms. In other words, the aim is to study how the change in the relative prices of inputs and technological development affect the production technology of a dairy farm. The study provides information on to what extent inputs can substitute each other, as well as on how technological development has influenced the demand of individual inputs, resulting in an increase in the demand for certain inputs and a decrease in the demand for the others.

There has been very little research on the possibilities for input substitution on Finnish dairy farms. However, awareness of these possibilities is important from the viewpoint of the needs of both dairy farms and agricultural policy. Knowledge on the relations between the inputs is essential in developing dairy farms and in directing agricultural production.

According to the production and cost theory, a change in the relative prices of inputs affects the actions of dairy farms. When relative prices change, the milk producer should know which inputs are substitutes and which ones are complements of each other, and the extent to which input substitution is possible so that the producer could strive to adjust production in an optimal way. In the study it is tested if milk producers follow the assumption of rational behaviour, which is assumed in the production and cost theory. It is also examined to what extent the production technology of the farm has changed, along with the technological development. It is necessary to know the earlier technological development in estimating the effect of future changes on the demand for inputs. In addition, in making decisions on agricultural policy, e.g., incidence of taxation, it is useful to know how the change in the price of an individual input influences the demand.

In most Finnish studies and publications related to the use of labour and capital, the use of capital in agriculture has mainly been examined at the macro level (Ihamuotila 1972, 1983, Ylätalo 1987). In the macro level studies the main emphasis has been on finding out the capital stock of agriculture. In addition, the studies have concentrated on research into the productivity of agriculture, as well as of the changes in the amounts of capital and labour inputs used. In the study of the reasons for change in the agricultural sector, evidence for the theories has usually been searched for in the observation series included in the total statistics.

The studies made so far have provided important results on the significance of capital in agricultural production, but these results give only a rough picture of the use of inputs on dairy farms. There is very little empirical research results available on the use of labour and capital, and the relations between them on Finnish dairy farms.

1.3 Approach to the research problem

In this study, the neoclassical production and cost theory is applied in examining the use of inputs on dairy farms. The dual approach is used to solve the research problem. Based on the neoclassical production and cost theory, it is assumed that the production function describes the technical relationship that transforms inputs into output, dairy farms aim at minimizing costs, and the prices of inputs and products are exogenous.

The neoclassical framework is well suited for both theoretical and empirical factor substitution studies, and thus it was chosen as the theoretical point of departure for the study. According to Varian (1992, p. 23), profit maximization has been the basic assumption in most economic analyses of firm behaviour. This assumption provides an exact framework for the analysis and testing of the results. The neoclassical production and cost theory describes the production process of an enterprise, which means that conclusions can be made logically on the basis of the theory.

The study is based on a long-run examination, which means that all costs are assumed to be variable costs. In the short run all costs of milk production cannot be considered to be variable, but some of the costs, e.g., the cowshed, is in the short run quasi-fixed. By means of the cointegrated time series and the error correction model linking these, it is possible to incorporate a long-run and short-run study through the theory of statistics (Hendry 1991, Engle and Granger 1991). In connection with the attempt to solve the research problem, it will be examined if the input demand system of milk production can be modelled into an error correction model.

In the beginning of the 1970s, after the energy crisis, research in general economics and in agricultural economics was to an increasing extent directed to the investigation of the substitution possibilities among inputs. The study of the substitution possibilities also gave a powerful impetus to the development of new functional forms.

In this century economists have strived to find a connection between the mathematical methods of representation and the neoclassical production function. However, some economists took a different view of the problem (e.g., Diewert 1971, de Janvry 1972, Christensen et al. 1971, 1973). They started developing flexible functional forms, which greatly increased the possibilities for an empirical application of the neoclassical production and cost theory. These functional forms are used to solve the research problem.

The theory of the study and the grounds for the approach chosen are presented in Chapter 2. The first part of the chapter is based on literature, and it deals with the properties of the production possibility set and the production function by examining these from the viewpoint of the milk producer. Then the dual approach, which is the main approach in the study, is presented. In the dual approach the main emphasis is on examining the derived demand of inputs and input substitution, as well as in determining the elasticities of substitution. Chapter 3 provides a theoretical examination of the possibilities to incorporate the short-run and the long-run study. The Finnish and international publications related to the research topic are reviewed in Chapter 4, and the theoretical model of the study is presented in Chapter 5. The development of Finnish agriculture during the past three decades is described in Chapter 6, and the research data is presented in Chapter 7. The results of the study are presented in Chapter 8. Chapter 9 presents an examination of the results and conclusions, based on the research results and the theory, and on the basis of the information provided by the results, the possibilities to develop the production of dairy farms are discussed.

2 Application of the dual approach of the neoclassical production and cost theory on Finnish dairy farms

The neoclassical production and cost theory, and the basic findings it has provided, have established their position in economics during the past decades. No serious alternatives to the neoclassical production and cost theory have been developed. The most remarkable progress in the research on production economics has been achieved in improving the generality of the results of the neoclassical production and cost theory. In the past few years the main objective in the research of the production and cost theory has been to make it possible to describe more complicated production processes than earlier, and to improve the testability of the models used in the empirical study.

The dual approach and the flexible functional forms developed in the past two decades have expanded the application possibilities of the production and cost theory considerably. There are concrete advantages in the dual approach in applied economics, in particular. The demand and supply functions determined directly from the dual function simplify the analyses considerably, compared to the primal studies, because in determining them no nonlinear equation systems that are difficult or impossible to solve are needed. In the dual approach it is possible to describe the production technology in certain circumstances equivalently by means of both the primal function and the dual function (Diewert 1982, p. 535–547). In this case, it is assumed that the prices of inputs indicate the same things of production technology as the amounts of inputs, and that enterprises aim at maximizing profits and/or minimizing costs.

It is essential for a milk producer to be familiar with the production technology, because this determines the limits within which the actions of the dairy farm are possible. In the beginning of the study, a brief description of the production technology in milk production is presented. In this study the economic behaviour of the milk producer receives special emphasis, so that an exhaustive account of the dual approach that is central in the study is presented, to the extent that it is needed to solve the empirical research problem.

2.1 Theoretical description of the production technology in milk production

When planning milk production, the first task of a milk producer is to examine the combinations of inputs by which production is feasible, within the framework of the existing production technology. The technical production possibilities facing dairy farms can be described by a production possibility set, which gives all feasible input and output combinations. Thus the production possibility set is a subset of R^n. Consequently, the production possibility set provides a complete picture of the production possibilities of a dairy farm.

The production plan of a milk producer can be presented as a list that includes both inputs and products. Some goods, like barley, on a dairy farm may be, simultaneously, input (feed for animals) and product (cultivation of grains). Thus, it is expedient to present the inputs and products as netputs. If the netput of a good i is positive (negative), the dairy farm produces more (less) of the good i than it uses. This can be presented exactly as a production plan on a netput vector $y \in R^n$, where y_i is negative if the good i is a net input, and positive if the good i is a positive netput.

At the loss of generality, the inputs and outputs are dealt with separately, because this kind of representation is considered intuitively useful (e.g., McFadden 1978a, p. 6, Chambers 1988, p. 252, Varian 1992, p. 2–3). Thus, $x = (x_1,...,x_n) \in R^n_+$ describes a positive input vector, and $y = (y_1,...,y_m) \in R^m_+$ describes a positive output vector. With the existing production technology the production possibility set T, which gives all technically feasible combinations of (x,y) can be defined as follows:

$$T = \{(x,y): x \text{ can produce } y\} \tag{1}$$

The properties required of T are presented in Appendix 1.

The technological knowledge and the laws of nature determine largely the production possibility set of a dairy farm. However, the production possibility set may be more limited in practical decision-making on a dairy farm due to, e.g., restrictions on production, natural conditions, and environmental factors. Also, on a dairy farm the production possibility set in the short run may differ from that of a long run, so that in an investigation of dairy farms it is essential to separate short-run and long-run production plans from each other. In short-run production plans quasi-fixed factors are considered to be factors that restrict production. In the long run all inputs can be considered variable inputs. In practice, distinguishing the short run and the long run, in milk production, from each other is not a dichotomous phenomenon.

The short-run study can be presented exactly as the short-run production possibility set $T(z) \subset T$, in which the vector $z \in R^k_+$ describes the production restrictions in the short run. Vector z is, for example, a list of maximum amounts of inputs and products that are possible in the short run. A more detailed account of issues related to short-run and long-run studies is presented in Chapter 3.

When the production technology in milk production is examined, the production possibility set presented above can be simplified. Other products related to milk production can be considered by-products of milk production, in which case we shift from the technically efficient production plans, transformation function, to the production function, which describes the maximum scalar output as a function of inputs, instead of maximal vectors of netput. Thus, the model for the production technology on farms that specialize in milk production can be formulated so that the output is presented as one aggregate output.

In general, heavily aggregate data have been used in empirical studies based on the production and cost theory that have been applied to agriculture (e.g., RAY 1982, GLASS and MCKILLOP 1990, RYHÄNEN 1992). According to the production and cost theory, as little aggregation as possible is an objective, so that in more recent studies the degree of aggregation has been reduced, and the studies mainly concentrate on examining the production technology of one production line (e.g., TIFFIN 1991, THIJSSEN 1992a, b). In these studies the netput bundle (x,y) has been formed from the scalar y and vector x, so that x can produce y.

From the viewpoint of this study, it is expedient to present the production technology as an input requirement set, which can be presented as follows:

$$V(y) = \{x \in R^n_+ : (y,x) \in T\} = \{x: f(x) \geq y\}. \quad (2)$$

According to the definition given above, V(y) is the set of positive input vectors $x = (x_1,...,x_n)$, which produce at least output y. The input requirement set corresponds to the traditional isoquant, except that it also includes non-efficient input bundles. The boundary of V(y) at a certain output level is the same as the isoquant of this output level (see UZAWA 1964, p. 216). Thus, the isoquant is the set of efficient input vectors, which produce exactly output y.

In the traditional approach of the neoclassical production and cost theory, production technology is presented by means of the production function indicating the physical and technical relations (e.g., HEADY 1952, BRADFORD and JOHNSON 1953). Production function describes the technical relation between the inputs and output, which means that it does not include any economic content. The production function is presented as follows:

$$y = f(x), \quad (3)$$

where the scalar y is the maximum output that can be produced by means of the existing production technology in a certain period of time. Positive output can be achieved by utilizing the non-negative input vector $x = (x_1,...,x_n)$ in production.

Independent of how the milk producer defines the supply of his product, it is profitable for him to produce this output at as low a cost as possible. From an economic viewpoint, the production possibility set and the production function determine the limit to the optimization problem. The production function defines unambiguously the technical restriction of the optimization problem.

This study is based on the assumption that there is a production function for dairy farms, which describes the connection between the inputs used during a certain period of time and the maximum output produced by means of these inputs. When analysed from the economic viewpoint, the production function is expected to have certain properties, which means that the production function must be theoretically well defined (see Appendix 1 and 2).

2.2 Traditional approach in empirical study of production technology

The properties of the production function presented in Appendix 2 have usually been adequate for the purposes of theoretical analyses of the traditional or primal approach, but in most cases they have not been fully adequate for empirical analyses (CHAMBERS 1988, p. 36). In empirical studies it has often been necessary to set additional restrictions on the production functions in order to make the production and cost theory and the research techniques consistent with each other. In connection with this, assumptions on the homogeneity, homotheticity, and separability have been made.

In empirical studies homogeneous production functions of degree k have frequently been used, in which $f(\alpha x) = \alpha^k f(x)$. The best known homogeneous production functions are the Leontief, Cobb-Douglas and CES production functions (NADIRI 1982, p. 457–459). Homogeneous production functions have proven useful in empirical applications. For example, the proportional changes in all individual inputs that change the scale of production are reflected exactly by the same proportional change in an aggregate input. Agricultural economists have frequently used the Cobb-Douglas production function in their analyses.

The production function is defined as homothetic, if it can be presented in the form f(x) = g[h(x)], where h(•) is homogeneous of degree one, g(•) is a monotonic function, and g and h are twice differentiable (VARIAN 1992, p. 18). Homothetic production functions are functions which generate linear expansion paths emanating from the origin, when the prices of inputs are constant. Every homogeneous production function is also homothetic, but homothetic production functions also include non-homogeneous production functions, in which the returns to scale may vary as a function of output (SANDLER and SWIMMER 1978, p. 357).

When the number of inputs increases, the estimation of an empirical model has usually been considered difficult, even impossible. This restriction has often forced economists to employ a smaller number of inputs in empirical analyses than in theoretical analyses. Homogeneous techniques and a relatively small number of inputs has often proven to be a useful approach in solving empirical problems.

As a definition, inputs x_i and x_j are separable from the input x_k (BLACKORBY et al. 1977, p. 197), if

$$\frac{\partial}{\partial x_k}\left(\frac{\partial f/\partial x_i}{\partial f/\partial x_j}\right) = 0, \quad i, j \neq k, \qquad (4)$$

i.e., the slope of the isoquant in the dimension i,j is not affected by what occurs in dimension k. The location of the isoquant in the dimension i,j may change as a result of a change in the dimension k.

The assumptions of the homogeneity, homotheticity, and separability of the production function restrict the possibilities to use the different functional forms in empirical analyses considerably. In general, this has not been considered a major problem. Econometric techniques have been applied, according to the restrictions mentioned above. The assumption of strict separability and homogeneity (Cobb-Douglas, CES) provided a good point of departure for the estimation of economic parameters for many decades. However, compromises had to be made between the generality, and the analytical or empirical flexibility.

2.3 Application of the dual approach in the study of the economy of dairy farms

In the research on agricultural economics based on the production and cost theory practiced in Finland, the physical and technological production possibilities of agriculture have traditionally been examined by means of the production function (e.g., RYYNÄNEN 1970, HEMILÄ 1983, YLÄTALO 1987). The dual approach was chosen for this study because it makes it possible to formulate the model applying the production and cost theory directly into a form that describes the causal economic relations. Also, in an empirical study the research methods of the dual approach can be more easily and exactly dealt with mathematically and in the data processing than the methods of the traditional approach, which means that there are significant advantages in the use of the dual functions (profit and cost function), compared to the traditional approach.

The development of the dual approach of the production and cost theory was started by Hotelling and Samuelson in the 1930s and 1940s (MCFADDEN 1978a, p. 5). According to McFadden, the publication of Shephard in 1953, where the duality between the cost and production function is presented, can be considered the breakthrough of the dual approach. In the 1960s, the dual approach was further developed (e.g., MCFADDEN 1963, UZAWA 1964). From the viewpoint of empirical studies, the development of flexible functional forms was decisive (DIEWERT 1971, CHRISTENSEN et al. 1971, 1973). In the 1970s, McFadden developed, with his colleagues at the University of Berkeley, the foundations for the application of the dual approach in empirical study. According to CHAMBERS (1988, p. 121), the research results of McFadden and his colleagues caused the research in empirical production economics to turn in completely new directions.

2.3.1 Economic behaviour

According to the neoclassical production and cost theory, the basic assumption in this study is that entrepreneurs aim at maximizing profit. According to the theory, the actions of an entrepreneur are optimal, when the marginal revenue is equal to the marginal cost of production. This determines the output level chosen for production and the quantity of inputs used by an optimally acting entrepreneur. When an entrepreneur determines his optimal activity, he also has to take into account the factors restricting production. The technical production possibilities and the markets (the consumption of the products) are the most common factors restricting production in the enterprises.

The behaviour of the milk producer in the markets can be approximated by means of the assumption of pure competition (see e.g., Debertin 1986, p. 9–11). In the conditions of pure competition the entrepreneur is assumed to possess complete knowledge of the prices of both products and inputs.

From the viewpoint of a milk producer, the input markets in milk production may be considered to fulfill the preconditions for pure competition, at least with respect to the fact that it is not possible for them to influence very much the prices of inputs they have acquired through their own actions. The product markets of a dairy farm are not based on pure competition, rather the prices of products are agreed on in advance during the farm income negotiations. At the farm level the quantity of milk production is regulated by the state, which means that the equilibrium of milk production can be described by means of profit maximization at a certain level of output, instead of unrestricted profit maximization.

If the conditions mentioned above prevail, milk producers cannot influence the prices of inputs or products in a decisive way through their own actions. Thus, from the viewpoint of a milk producer, the prices of both inputs and products are exogenous.

2.3.2 Study of economic activity

On the basis of the previous chapter it can be assumed that a milk producer takes the prices of both products and inputs as given. The aggregation assumption made in connection with the theoretical description of the production technology in milk production makes it possible to write the problem of profit maximization on a dairy farm in the following form:

$$\Pi(p,w) = \underset{x \geq 0}{\text{Max}} \{pf(x) - wx\} = \underset{y \geq 0}{\text{Max}} \{py - C(w,y)\}, \quad (5)$$

in which the scalar p is the price of output, vector $w = (w_1,...,w_n)$ presents the prices of inputs, and the quantity of inputs used is described by the vector $x = (x_1,...x_n)$. The profit function of a dairy farm $\Pi(p,w)$ gives the maximum profit as the function of prices. Applied to the research problem, the restricted profit function can be presented equivalently with the cost function

$$C(w,y) = \underset{x \geq 0}{\text{Min}} \{wx: x \in V(y)\}, \quad (6)$$

where the cost function indicates the minimum cost at a certain output level, when the prices of inputs are equal to w. When the level of output has been determined in advance, the return is also fixed, in which case the profit of a dairy farm can be maximized by minimizing costs. The connection between the ways of presenting the equation (5) is presented in Appendix 3.

The cost function is more useful than the profit function in the study of the economic actions of Finnish dairy farms, because in the case of the cost function both decreasing and increasing average costs are possible. The profit function can be used in the study of the economic actions of a dairy farm only in the area of the average cost curve where the average costs increase.

The use of the profit function in the study of the economic actions of dairy farms can be illustrated as follows. Let us assume that conditions of pure competition prevail, and the behaviour of the milk producer is in accordance with the profit maximization assumption. In this case, the marginal cost is equal to the marginal revenue. In these conditions the marginal revenue is constant, and is equal to the price of product p, so that the elasticity of size can be calculated as follows:

$$AC/p = C(w,y)/(py), \qquad (7)$$

where AC is the average cost. In formula (7) it can be seen directly that a rationally behaving milk producer produces milk only if the ratio according to formula (7) in the long run (all inputs are variable) is not larger than one, because profit cannot be negative in the long run (cf. Chambers 1988, p. 124–125). If the ratio is more than one, a rational milk producer should expand the enterprise or give up production gradually. Support for this reasoning can be found in the current situation in milk production in Finland. Within the framework of the technology it would be possible to increase milk production on individual dairy farms, but the milk quotas prevent the increase of the farm size.

The development of dairy farms seems consistent with the theory. Since an increase in farm size has been prevented, many farms have given up milk production. During 1985–1993, over 30,000 dairy farms quited production. At the end of 1993, the number of dairy farms was a little over 34,000. The rapid decrease in the number of dairy farms provides evidence for the fact that the preconditions for profitable milk production have been weak. On the basis of this, it seems that dairy farms operate, on the average, in the area of decreasing average costs, for which the profit function has not been defined. In this case the restricted profit function, which can be presented equivalently with the cost function, can be used to solve the research problem.

In the literature on agricultural economics the economies of size is a problem area that has been dealt with extensively. According to the literature the research results deviate from each other, but most studies have arrived at the conclusion that in agriculture the average costs decrease as a function of output (see e.g., Heady 1952, p. 349–350, Hoch 1976, p. 746–748, Smith et al. 1986, p. 719–720, Castle 1989, p. 574–577). It should be noted, however, that the empirical research results related to the economies of size are local, which means that they do not tell the absolute truth.

According to Quiggin (1991, p. 36), in the world of risk and uncertainty the optimum output level will be either in the constant or increasing returns to scale area. This is characteristic in agricultural production, and most studies on the economies of size of agricultural enterprises have provided evidence for this (cf. Heady 1952, p. 350). In addition to the traditional U-shaped average cost curve, evidence for an L-shaped average cost curve has also been found, in which case the production technology is first described by the increasing returns to size and finally by the constant returns to size.

Even if, according to the theory, the cost function study is a more useful approach in the examination of the economic behaviour of Finnish dairy farms than the profit function study, there are also limitations in its use. In the cost function study it is assumed that changes in the prices of inputs do not affect the level of output, so that the indirect effect of the changes in the prices of inputs on the output level is not taken into account.

The profit function study makes it possible to define the change in endogenous output. Milk production restrictions began in 1970, and the measures to restrict production finally led to the production quota system in 1985. In the production quota system it is not profitable for a dairy farm to exceed its milk quota, which means that the theoretical basis for the definition of the change in endogenous output does not exist. The measures to restrict milk production have been presented in detail, e.g., in Kola's (1991, p. 122–126) study on the regulation of production.

The cost function study is appropriate for the examination of the behaviour of Finnish dairy farms, because it is well suited for the study of the behaviour of enterprises that do not operate in the conditions of pure competition in their product markets (Jorgenson 1986, p. 1884). In regulated production the price of a product has been determined, e.g., by agreements, as is the case in milk production. Thus, the demand for milk is determined according to a regulated price, which means that, under these preconditions, the level of output is exogenous. In this case, the necessary conditions for the optimum in milk production can be derived from the cost minimization.

It should be noted that the cost function study is not incompatible with profit maximization behaviour. The profit function can be presented, so that at a certain output level, the difference between the total revenue and total costs is maximized. In other words, when the profit is maximized at a certain output level on a dairy farm, the costs are, at the same time, minimized at this output level. If this was not the case, it would be possible to produce milk cheaper, which would no longer be a question of profit maximization.

This can also be presented by means of elasticities. Let us assume that the maximum profit is achieved at the output level y^*. In this case the elasticity of size solved from the profit function is equal to the elasticity of size solved from the cost function at the same output level, i.e. $AC(y^*)/MC(y^*)$. This connection is realized since the profit maximizing first order condition states that the output price is equal to the marginal cost at this point (formula 7).

2.3.3 Cost function study

In the latter part of this study the economic behaviour of a dairy farm is examined on the basis of the cost function. In the study it is assumed that a milk producer chooses the quantity of inputs to be used, so that the costs are minimized at the output level determined in advance. In the form of a cost function the research problem is presented as follows:

$$c = C(w,y) = \min_{x \geq 0} \{wx: x \in V(y)\}, \tag{8}$$

where $w = (w_1,...,w_n)$ is the vector of the positive input prices. A milk producer chooses for production the input bundle x, which minimizes the cost $c = wx = \sum_{i=1}^{N} w_i x_i$ at a given level of output. Thus, the cost function defines the minimum cost of production, when output y, which is determined in advance, is produced during a certain period of time at input prices w. Consequently, in theory and in practice minimizing costs is equal to maximizing profit at a certain level of output.

2.3.4 Properties of the cost function

In order to achieve economic content, restrictions must be made on the cost function, as was the case with the production function. C(w,y) depends on the production technology, which means that the production technology determines the limits within which the minimization of costs is possible (see Appendix 2). The properties of the cost function according to the technology restrictions are (Chambers 1988, p. 52–59):

1. $C(w,y) > 0$, $w,y > 0$, non-negativity;
2. if $w' \geq w$, then $C(w',y) \geq C(w,y)$;
3. concave and continuous in w;
4. $C(\alpha w,y) = \alpha C(w,y)$, $\alpha > 0$;
5. if $y \geq y'$, then $C(w,y) \geq C(w,y')$;
6. $C(w,0) = 0$, no fixed costs; and
7. $\partial C(w,y)/\partial w_i = x_i(w,y)$, x_i is the demand vector of inputs. C(w,y) is twice continuously differentiable.

According to property 1 of the cost function, it is impossible to produce a positive output without costs. According to property 2, the rise in the price of any input x_i cannot reduce costs.

Property 3 is difficult to perceive intuitively. Let us assume that the price of one input changes, while the prices of other inputs remain unchanged. If the price of an input rises, the costs cannot decrease (property 2), but they may increase at a decreasing rate. This is possible because, as the input becomes more expensive and the prices of other inputs remain the same, the cost minimizing dairy farm substitutes other inputs for the relatively more expensive input. According to property 3, inputs are substitutes with each other, if the dairy farm can shift from the relatively expensive inputs to the use of other inputs. In this case, the increase in the price of input x_i reduces its use, and increases the use of other inputs. If C(w,y) is linear, the input bundle is completely fixed, which means that substitution between inputs does not occur.

Property 4 describes positive linear homogeneity, where only relative changes in the prices have an effect on the optimum. If the prices of inputs change in the same proportion, the choice of inputs that minimizes costs does not change. According to property 5, increasing output cannot result in lower costs. According to property 6, a zero output does not cause any costs, so that the examination is directed to the long-run cost function.

According to 7, the twice differentiable cost function has a property that is called the Shephard's Lemma. By means of the Shephard's Lemma it is possible to determine the cost minimizing derived demand functions from the cost function. The demand for inputs x_i, which minimizes the costs, is equal to the partial derivatives of the cost function with respect to input prices w_i. Due to the Shephard's Lemma it is not necessary to define a production function corresponding to the cost function, which means that it is not necessary to solve the complex algebra involved in deriving the input demand functions using the production function and Lagrangian techniques (Diewert 1987, p. 692).

According to Binswanger (1974, p. 377), in applied production analysis there are certain advantages in the cost function study, compared with the production function study:

1. In a cost function study it is not necessary to impose the homogenous production function of degree one. The cost function is homogenous of degree one in input prices regardless of the homogeneity properties of the production function, because doubling the prices of all inputs also doubles the costs, but does not affect the input ratios.
2. The prices of inputs can be considered more independent variables than the quantities of inputs. An entrepreneur makes decisions on the use of inputs on the basis of the exogenous prices, which means that the quantities of inputs used become endogenous variables.
3. Inversion of the matrix is not needed in solving the elasticities of substitution, and thus estimation errors can be avoided.
4. The cost function study reduces estimation problems and it is well suited for a translog-function, because it is linear in logarithms.

Pope (1982) discussed in his article the significance and applicability of the dual approach in the applied economic study. According to him, the approach used in the study should be chosen based on the objectives of the study. When defining the elasticities of substitution the cost function is more useful than the production function (Pope 1982, p. 347). The estimation of marginal products from the cost function involves the same problems as the estimation of the elasticities of substitution from the production function.

The cost function study also makes it possible to solve the cost minimizing demand vector as a multi-stage cost minimization problem, if the number of inputs analysed is great. In this case, it is assumed that production technology is homothetically separable (Fuss 1977, p. 89).

For example, in a two-stage cost minimization problem, the aggregate price index of different types of feed, for example, is first optimized by means of the translog-function. Hulten (1973) has shown that the Divisia index is the best choice among the index numbers. Fuss (1977, p. 96–97) has shown that the Divisia index, which is an ideal index, can be described exactly as a linearly homogenous translog-function, so that the aggregate prices of the first stage can be used in optimization in the second stage.

In an empirical study the modelling of the multi-stage cost minimization problem for milk production in Finland is problematic, because accurate data on, e.g., the cost shares of the different types of feed, are not available. The multi-stage method has been used in the empirical studies of the demand behaviour of consumers. It is suitable for determining the elasticities of demand and substitution of the submodels of beverages, food, clothes, etc., after which the elasticities of demand and substitution of aggregate consumer goods can be examined (see LAURILA 1994).

2.4 Comparative statics

2.4.1 Effect of changes in input prices

According to the properties of the cost function, the relative increase in the price of an input reduces its use. Let us assume that the prices of all inputs increase simultaneously, so that the price vector of inputs is multiplied by the positive scalar. Thus, according to the linear homogeneity of the cost function, the costs rise in the same proportion as prices. The linear homogeneity of the cost function ($k = 1$) means that the derived demand functions are homogeneous of degree zero in input prices, because the partial derivatives of a function homogeneous of degree k are homogeneous of degree k-1 (CHIANG 1984, p. 411–413), i.e., the cost minimizing demand for inputs does not change, because an equal proportionate change in the prices of inputs does not lead to a change in the demand for inputs.

Derived demand can be derived directly from the cost function. Let us assume that $C(w,y)$ is twice continuously differentiable at (w^*,y^*). Applying Shephard's Lemma, the assumption of differentiability ensures that the cost minimizing input demand function $x_i(w,y)$ exists, and it is once continuously differentiable at (w^*,y^*) (DIEWERT 1987, p. 692). Define $\partial x_i(w^*,y^*)/\partial w_j$ to be the NxN matrix of the partial derivatives of the N derived demand functions $x_i(w^*,y^*)$ with respect to N prices w_j ($i,j = 1,...,N$). According to the Shephard's Lemma,

$$\partial x_i(w^*,y^*)/\partial w_j = \partial^2 C(w^*,y^*)/\partial w_i \partial w_j, \quad (9)$$

where $\partial^2 C(w^*,y^*)/\partial w_i \partial w_j$ is the Hessian matrix of second order partial derivatives of the cost function at (w^*,y^*). According to the Young's Theorem, the twice continuously differentiable cost function has a property according to which $\partial^2 C(w^*,y^*)/\partial w_i \partial w_j$ is a symmetric NxN matrix. Since the cost function is concave in input prices, and twice continuously differentiable with respect to input prices at the point (w^*,y^*), the Hessian matrix must be a negative semidefinite matrix. Consequently, the derived demand has the following properties (MCFADDEN 1978a, p. 47–48):

$$\partial x_i(w,y)/\partial w_i \le 0 \quad (10)$$

$$\partial x_i(w,y)/\partial w_j = \partial x_j(w,y)/\partial w_i \quad (11)$$

Property (10) is a restatement of property 2 of the cost function, where a rise in the price of an input cannot increase its demand. Property (11) is a symmetry property, which can be used in testing the properties of the cost function, as well as for reducing the number of parameters to be estimated (FUSS 1987, p. 996–997). Property (11) is a technical result from the differentiability assumption of the cost function and the derived demand functions, and its use in empirical study may reduce problems related to statistical mathematics (FUSS et al. 1978, p. 229).

The elasticities of substitution are usually considered a suitable way of measuring the substitutability of inputs with each other, because they are unit free measures. The derived demand elasticity is regarded as a natural measurement for the substitution between inputs. Using the terms of the cost function, the derived demand elasticity is presented as follows:

$$\begin{aligned} e_{ij} &= [\partial x_i(w,y)/\partial w_j]/[x_i(w,y)/w_j] \\ &= \partial \ln x_i(w,y)/\partial \ln w_j. \end{aligned} \quad (12)$$

According to the Euler's Theorem and equation (12), with a linearly homogenous cost function (FUSS et al. 1978, p. 232)

$$\sum_{j=1}^{N} e_{ij} = 0 \quad (13)$$

and according to equations (10) and (12)

$$e_{ii} \le 0. \quad (14)$$

These results are important from the viewpoint of the empirical study, because they make it possible to examine the derived demand behaviour in a systematic way on the basis of the properties of the cost function. The elasticities of substitution derived from the cost function are presented in Chapter 2.6.3.

2.4.2 Effect of changes in output

According to HANOCH (1975, p. 492), returns to scale can be presented in two different ways:

1) Returns to scale is the relative increase in output, as all input quantities are increased proportionally along the scale line from the origin in input space (measured by means of the elasticity of scale).
2) Returns to scale (size) is the increase in output relative to costs for variations along the expansion path in input space, which means that returns to size are determined from the expansion path of the enterprise. In this case, the prices of inputs are fixed, and costs are minimized at all output levels (measured by means of the elasticity of size).

The elasticity of scale and size are equivalent everywhere when the cost minimizing points are located along the scale line (STEFANOU and MADDEN 1988, p. 126). This is realized only for homothetic production functions. Usually the elasticity of scale and size deviate from each other. The difference is presented in Figure 1.

Let us assume that a dairy farm operates at point A, where the elasticity of scale and size are equivalent. In addition, let us assume that the output increases, whereas the prices of inputs remain unchanged, in which case the dairy farm shifts to point C on a new isoquant. The shift results from the change in the output on the scale line (A–>B), and the reallocation of the cost minimizing input bundle (B–>C). The elasticity of size measures the change of costs from point A to point C. The elasticity of scale measures the change on the scale line when we shift from one isoquant to another (A–>B). According to this, the measurements are equivalent only if the cost minimizing points are on the scale line. In that

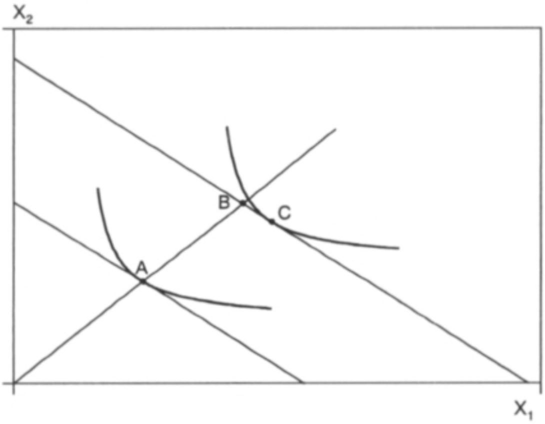

Fig. 1. Elasticity of scale and size (CHAMBERS 1988, p. 73).

case, the elasticity of size is dependent only on output (see proof in SANDLER and SWIMMER 1978, p. 354–355).

In milk production the input ratios, presented by the minimum cost combination of inputs, usually varies as a function of output. An example of this is the different combinations of the labour and capital inputs on small and large dairy farms. Thus, the elasticity of size is more appropriate in examining the economy of dairy farms than is the elasticity of scale, because the latter does not usually correspond to the economically best choice (cf. STANTON 1978, p. 729–730).

However, homothetic techniques have been popular in applied production analysis. First, because homotheticity implies that all inputs behave so that they do not reduce output; and, secondly, in homothetic production functions the optimum input ratios are independent of the level of output. In addition, the assumption of the homothecity of the production function has made it possible to treat the inputs as one aggregate input. When the cost function is consistent with the homothetic production function, the elasticity of size is independent of the prices of inputs (e.g., OHTA 1974, p. 63–65).

Usually the returns to scale definitions are global in nature. However, it is possible that increasing returns to scale (size) prevail in the case of certain quantities of inputs used, and decreasing returns to scale (size) in the case of other quantities of inputs used (VARIAN 1992, p. 16–17, 88–89). In such a case, a local definition is necessary. The elasticity of scale (size) measurement can be utilized in the definition. When differential calculus is applied, all measurements are local, i.e., they measure what happens in the small neighbourhood of the measurement point. In this case, the elasticity of scale (size) measures the change in output in the small neighbourhood of the input space.

2.5 Duality between the production and cost function

According to the dual approach, all economically relevant information on production technology can be solved from a well defined cost function, if its definition is consistent with the well defined production function (MCFADDEN 1978a, p. 3–4, 19–20). The cost function has been expressed as the function of output and input prices, which makes the cost function an efficient tool for research in production and cost theory, and, in particular, for the economic applications.

According to equation (8), C(w,y) is the minimum cost for producing output y, which means that a cheaper way of producing output y does not exist. When the prices of inputs vary over all possible price vectors, the optimal derived demand varies over all possible $x_i(w,y)$, in which case the optimum points form a curve that resembles the isoquant, which forms the lower boundary for the set marked $V^*(y)$. $V^*(y)$ can be presented as follows:

$$V^*(y) = \{x: wx \geq C(w,y), \forall w > 0\}, \quad (15)$$

where the original input requirement set V(y) is included in the approximated input requirement set $V^*(y)$. $V^*(y)$ is always convex, independent of the shape of V(y). Due to this property, $V^*(y)$ corresponds to the quasi-concave production function. In the dual approach, the following connection is central:

$$V^*(y) = V(y). \quad (16)$$

If V(y) is convex and monotonic, $V^*(y)$ is identical with V(y). If V(y) is nonconvex or nonmonotonic, $V^*(y)$ can be represented as a convexified and monotonized version of V(y), so that $V^*(y)$ has the same cost function as V(y). This connection makes it possible to solve the optimal production technology, from the viewpoint of economic decision-making, directly from the cost function. The connection has been proved by DIEWERT (1971) and MCFADDEN (1978a).

The minimization of costs guarantees the generality of the theory, because $V^*(y)$ is always convex, and in the case of cost minimization it is equivalent to V(y). Consequently, the cost function of a dairy farm summarizes all economically relevant aspects of production technology (see DIEWERT 1982, p. 537–545, VARIAN 1992, p. 84).

2.6 Definition of elasticities of substitution from the cost function

2.6.1 Marginal rate of technical substitution

Agricultural economists have long been aware of the concept of the marginal rate of technical substitution (MRTS). In the 1820s, von Thünen started collecting data, which provided the first empirical evidence of the fact that an input could substitute for another maintaining a constant output (CHAMBERS 1988, p. 2). Since the 1960s, the interest in the study of the MRTS gained new depth, since the development of automatic data processing (ADP) made it possible to process more complex models by means of computers. Pioneering work in this sector was performed by HEADY (1963) and his colleagues. The MRTS indicates to what an extent the use of an input can be replaced by increasing the use of another input, when we move from one point to another on the isoquant. In the case of at least three inputs, the isoquants are (hyper)surfaces.

Isoquants are essential in the study of the MRTS. Isoquants describe the physical and tech-

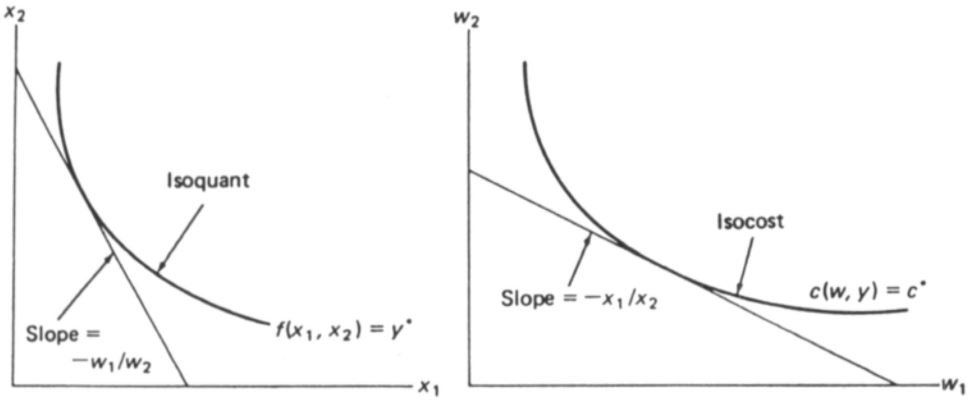

Fig. 2. Isoquant and isocost curves (VARIAN 1992, p. 89).

nical relationship between the inputs, when the output remains constant. Consequently, an isoquant is a curve or surface where every point represents a possible combination of inputs, at a given level of output. According to the production and cost theory, the use of inputs is assumed to be efficient, which means that the isoquant indicates the minimum quantities of inputs needed to produce a certain level of output. The shape of the isoquant may vary a great deal, depending on the substitution possibilities among inputs. Substitution between inputs is easier, the closer the shape of the isoquant is to linear.

2.6.2 Relationship between the isoquant and isocost curves

As was noted earlier, any economically relevant production technology can be described completely by starting from different concepts or functions, such as the production function (production technology of a dairy farm) and the cost function (economic behaviour of a milk producer). From the viewpoint of this study, it is expedient to present the dual relationship between these functions using the isoquant and isocost curves.

In economics a transformation function is often used to characterize the production possibility set. McFADDEN (1978a, p. 34–37) has proved the duality between the input distance function

$$F(x,y) = \text{Max}\ \{\lambda: (x/\lambda) \in V(y)\}, \tag{17}$$

which is a transformation function, and the cost function. The value of the input distance function is given by the ratio of the lenght of the input vector observed to the lenght of an input vector defined by the intersection of the given isoquant and the ray through the input vector observed. In other words, it measures the largest possible radial contraction of the input vector when the input vector is held at V(y). The input bundle is efficient in producing y when F(x,y) = 1. According to the duality, V(y) has an image set in the space of input prices, and this can be presented as follows:

$$\begin{aligned} R(y) &= \{w: wx \geq F(x,y), \forall x > 0\} \\ &= \{w: C(w,y) \geq 1\}. \end{aligned} \tag{18}$$

The set R(y) has been called the factor price requirement set. Its boundary forms the isocost. The duality between V(y) and R(y) can be presented as the following relationship (McFADDEN 1978a, p. 37).

$$wx \geq 1, \quad \forall\ w \in R(y) \text{ and } x \in V(y). \tag{19}$$

Since the cost function is concave, and thus quasiconcave, R(y) must be convex, and the isocost must be convex to the origin. Thus, the isocost curve describes the boundary {w: C(w,y) = 1} of the factor price requirement set. Figure 2 presents the boundaries of the sets V(y) and R(y), i.e. the isoquant and isocost curves for the same level of output y, and the slopes of the curves.

The slope of the isocost curve at w^* can be solved as follows:

$$\frac{\partial w_2}{\partial w_1} = -\frac{\frac{\partial C(w^*,y)}{\partial w_1}}{\frac{\partial C(w^*,y)}{\partial w_2}} = -\frac{x_1(w^*,y)}{x_2(w^*,y)}. \qquad (20)$$

The second stage of equation (20) results from Shephard's Lemma. According to the equation, the ratio of the respective marginal prices of inputs is minus the ratio of the optimal inputs. If (x_1^*,x_2^*) is the cost minimizing point on the isoquant at prices (w_1^*,w_2^*), then according to the first order conditions

$$\frac{\partial x_1}{\partial x_2} = -\frac{\frac{\partial f(x^*)}{\partial x_2}}{\frac{\partial f(x^*)}{\partial x_1}} = -\frac{w_2^*}{w_1^*}. \qquad (21)$$

There is a duality between equations (20) and (21). The ratio of the input prices can be obtained from the slope of the isoquant, and the ratio of the input quantities from the slope of the isocost curve. The slope of the isocost curve, according to equation (20) in Figure 2., is equal to $-x_1/x_2$. This relationship makes it possible to derive the slope of the isoquant and the relative use of inputs directly from the cost function, which makes it possible to derive the elasticities of substitution directly from the cost function.

An inverse relationship can be presented between the isoquant and isocost curves. The straight isocost line is the dual of the rectangular isoquant, and vice versa. The dual isocost curve of isoquant y', which is more curved than y", is flatter than the isocost curve of y", and vice versa. This relationship can be illustrated by choosing point (w_1,w_2) on the isocost curve, and then moving along the curve to point (w_1',w_2'), which differs clearly from point (w_1,w_2). If the slope of the isocost curve changes only little, the isocost curve is rather flat. Since the demand for inputs is obtained from the slope of the isocost curve, when costs are minimized, the demand for inputs remains almost unchanged. As a result, the isoquant must be strongly curved.

2.6.3 Elasticities of substitution

The concept of the elasticity of substitution was developed by Joan Robinson and John Hicks, without being aware of each other's work, in the 1930s (Helm 1987, p. 127). Developing the concept of elasticity of substitution was an important step forward in the marginal theory, because it combined the concepts of elasticity and substitution, which had earlier been presented separately in literature.

The pure number which is independent of the units of measurement was considered the ideal measurement for the elasticity of substitution. Since the 1930s, the various elasticities of substitution have been generated. Originally, the definitions of the various elasticities of substitution were mainly developed on the basis of the primal approach (see Appendix 4).

The duality between the production and cost functions makes it possible to determine the elasticities of substitution directly from the cost function. Implicitly, the elasticity of substitution was originally introduced to measure the relative change in the ratio of two inputs brought about by a relative change in their input price ratio, or marginal product ratio for a given level of output (cf. Appendix 4, equation 64). Hicks defined the elasticity of substitution for a 2-dimensional input vector as follows:

$$\sigma = \frac{\partial \ln (x_2/x_1)}{\partial \ln (w_1/w_2)}. \qquad (22)$$

Mundlak (1968, p. 225–231) generated the foundation for the definitions of the various elasticities of substitution into a general theory of derived demand for inputs, and examined the relationships between the various definitions for n-dimensional input vectors. He gave three definitions: one input one price; two inputs one price; and two inputs two prices measures.

The following presentation of the elasticities of substitution is mainly based on the publications of ALLEN (1950), MUNDLAK (1968), KOIZUMI (1976), MCFADDEN (1978b, p. 78–80), BALL and CHAMBERS (1982, p. 700), NADIRI (1982, p. 467–468), and CHAMBERS (1988, p. 95–97). On the basis of these publications, the properties of the elasticities of substitution obtained by means of the different measurements are evaluated and compared with each other. The discussion is in terms of the cost function under the assumptions of cost minimization, twice continuous differentiability of cost function, and that the cost minimizing derived demand functions for inputs x_i and x_j are available via Shephard's Lemma.

1. One input one price elasticities of substitution (OOES)

OOES can be referred to as the Allen framework. We start assuming a constant output, and that the vector of input prices, exept w_j, is constant. Writing equation (9) as an elasticity we get:

$$\frac{\partial \ln x_i(w,y)}{\partial \ln w_j} = e_{ij} = \frac{\partial x_i(w,y)}{\partial w_j}\frac{w_j}{x_i(w,y)}. \qquad (23)$$

Thus, all derived demand responses to input prices can be solved directly from the Hessian matrix of the cost function. Thus, a unit free measure was obtained for the derived demand elasticity. The measurement is not symmetric, because $e_{ij} \neq e_{ji}$. The symmetric version of OOES is the Allen partial elasticity of substitution, in which $\sigma_{ij} = \sigma_{ji}$. It can be shown that

$$\sigma_{ij} = \frac{cc_{ij}}{c_i c_j} = \frac{e_{ij}}{S_j(w,y)}, \qquad (24)$$

in which $c_i = \partial C(w,y)/\partial w_i$, $c_{ij} = \partial^2 C(w,y)/\partial w_i \partial w_j$, and $S_j = [w_j x_j / C(w,y)]$ (UZAWA 1962, BINSWANGER 1974, p. 378–379). Note, that as elasticities of cost function with respect to input prices we can write $\partial \ln C(w,y)/\partial \ln w_j = \partial C(w,y) w_j / \partial w_j C(w,y) = w_j x_j(w,y)/C(w,y) = S_j(w,y)$. $S_j(w,y)$ measures the cost share of the input x_j of the total cost.

Input x_i is called the Allen substitute for input x_j, if $\sigma_{ij} > 0$ and $e_{ij} > 0$. Correspondingly, input x_i is called the Allen complement for input x_j, if $\sigma_{ij} < 0$ and $e_{ij} < 0$. With respect to the sign, e_{ij} and e_{ji} are equivalent, even if $e_{ij} \neq e_{ji}$, which means that the classification of inputs into Allen substitutes and complements is not dependent on which one of the elasticities e_{ij} or e_{ji} is used in the classification.

If the increase in the price of input x_i increases (reduces) the use of input x_j and the output level remains constant, input x_i is a substitute (complement) for input x_j. Input's own price elasticity (e_{ii}) measures the percentage change in the use of input x_i, resulting from a percentage change in input's own price w_i. According to the concavity of the cost function, $e_{ii} \leq 0$, and according to the homogeneity of the derived demand for inputs $\sum_{i \neq j}^{N} e_{ij} = -e_{ii}$. Consequently, no input can be Allen's complement to all other inputs.

2. Two inputs one price elasticity of substitution (TOES)

It is possible that the price ratio changes when the price of only one of the prices change, keeping the other prices and output constant. This kind of substitution between inputs is measured by the TOES measurement. This measurement corresponds to the concept of Morishima partial elasticity of substitution. We let $S_i(w,y) = S_i$ and $S_j(w,y) = S_j$.

$$\begin{aligned}\sigma_{ij}^{M} &= \frac{\partial \ln [x_i(w,y)/x_j(w,y)]}{\partial \ln w_j} \\ &= S_j(\sigma_{ij} - \sigma_{jj}) = e_{ij} - e_{jj}\end{aligned} \qquad (25)$$

It is easy to see by using equation (69) from Appendix 4 and equation (24) that $\sigma_{ij}^{M} = e_{ij} - e_{jj}$. TOES measurement can be considered a more complete measurement for describing economic phenomena than OOES measurement, because it takes into account the change in the i,j input ratio when the price of input x_j changes. Inputs x_i and x_j are Morishima substitutes (complements), if $\sigma_{ij}^{M} > 0$ ($\sigma_{ij}^{M} < 0$). Inputs x_i and x_j are Morishima substitutes, if a rise in the price of input x_j causes a rise in the input ratio $x_i(w,y)/x_j(w,y)$.

If inputs are Allen substitutes, they are also

Morishima substitutes, but the opposite is not true. Morishima elasticity of substitution is not necessarily symmetric with respect to the sign, which means that the classification of inputs x_i and x_j into substitutes and complements depends on which input price changes. No input can be Morishima complement for all other inputs, as was also the case with Allen.

3. *Two inputs two prices elasticity of substitution (TTES)*

Finally, we consider the case where two input prices (w_i and w_j) change. We assume a constant output and the vector of input prices, exept w_i and w_j, is constant. The effect of the change in the price of two inputs on the substitution between inputs can be measured by the TTES measurement.

$$\sigma_{ij}^{s} = \frac{\partial \ln [x_i(w,y)/x_j(w,y)]}{\partial \ln (w_j/w_i)} \quad (26)$$

It is possible to impose a symmetry property for the Morishima elasticity of substitution. This can be done by taking the weighted average of Morishima elasticities of substitution σ_{ij}^{M} and σ_{ji}^{M}. The cost shares S_i and S_j are related to the definition of these Morishima elasticities of substitution in equation (25), so that $S_i/(S_i + S_j)$ and $S_j/(S_i + S_j)$ can be considered the logical weights when the weighted average for Morishima elasticity of substitution is determined (Koizumi 1976, p. 154). In this case TTES is

$$\begin{aligned} \sigma_{ij}^{s} &= \frac{S_i}{S_i + S_j}\sigma_{ij}^{M} + \frac{S_j}{S_i + S_j}\sigma_{ji}^{M} \\ &= \frac{S_i S_j}{S_i + S_j}(2\sigma_{ij} - \sigma_{ii} - \sigma_{jj}), \end{aligned} \quad (27)$$

which McFadden (1963, p. 76) called the shadow elasticity of substitution, because in this case costs are held constant, i.e. the elasticity is determined from the isocost curve. The shadow elasticity of substitution is a more complete measurement of the elasticity of substitution than OOES and TOES. Intuitively, it can be regarded as closest to the elasticity of substitution defined by Hicks, since it gives the percentage adjustment in input ratio to change in input price ratio. As has been noted, OOES and TTES are symmetric, i.e. $\sigma_{ij} = \sigma_{ji}$ and $\sigma_{ij}^{s} = \sigma_{ji}^{s}$.

In this chapter, various measurements for the elasticity of substitution have been discussed. It can be asked which is the most appropriate. It has not been possible to give an unambiguous answer to this question. Even if the different measurements of substitution do not always give equivalent elasticities in cases where there are more than two inputs, this does not mean that the measurements were wrong. It shows that there have been difficulties in defining a measurement with a single concept in cases where there are more than two inputs, which means that the substitution between inputs should be examined by means of different measurements for the elasticity of substitution.

2.7 Cost flexibility

The effect of output on the level of costs is measured by the cost flexibility measurement, which measures the ratio of marginal cost (MC) to average cost (AC). The cost flexibility corresponds to the measurement of the elasticity of scale (size) in the primal approach. The cost flexibility is presented as follows:

$$\begin{aligned} \eta(w,y) &= [\partial C(w,y)/\partial y]/[C(w,y)/y] \\ &= \partial \ln C(w,y)/\partial \ln y. \end{aligned} \quad (28)$$

The classical AC curve is assumed to be U-shaped as a function of output (Truett and Roberts 1973, p. 976). The U-shaped AC curve reaches its minimum at the point where the MC curve intersects it, i.e., the point where the cost flexibility is one. If the AC curve is U-shaped, the elasticity of size decreases as a function of output. In agriculture, in practice, the AC curve may deviate from the shape of the classical AC curve (Doll and Orazem 1984, p. 198–199).

In long-run studies it can be assumed that all costs of a dairy farm are variable. This means that increasing average costs seem unrealistic, because a milk producer can be assumed to be able to increase production by, for example, multiplying the existing production process. On the other hand, it can be assumed that some production inputs, (e.g., management of a dairy farm), in the long run, can be like a fixed input in character. In this case, it is expedient to assume that the AC curve is U-shaped. According to this, it is likely that both increasing and decreasing average costs may occur, and this is when the properties of the cost function are needed.

3 Short run in a long-run study

In most studies it has been assumed that the equilibrium states of the long-run optimization problem can be approximated directly from the data, and that all inputs are variable in the long run, and, therefore, they can be optimized at all observation points (e.g., RAY 1982, p. 492–493, GLASS and MCKILLOP 1990, p. 284–285). This thinking is based on comparative statics.

Long-run assumptions are not directly applicable to short run, so that the short run is examined separately. In the short run costs can be divided into different groups according to their fixity (CHAMBERS 1988, p. 100, FERNANDEZ-CORNEJO et al. 1992, p. 331). If changes occur in the prices of inputs or the demand for the product, the quantities of quasi-fixed inputs cannot be immediately adjusted to the optimal level, which means that long-run and short-run optimization may differ from each other.

In the short run all costs of milk production cannot be considered variable, but part of the costs are quasi-fixed in character, e.g., the cost of the cowshed. In the very short run it is not possible for a milk producer to increase the capacity of the cowshed, so that the use of variable inputs is optimized on the condition that the use of the cowshed remains unchanged. In the long run it is possible for a milk producer to increase the capacity, in which case the restrictions of the short run are removed.

Defining an unambiguous link in economic terms, between the short and long run has not been successful. Adjustment costs and asset fixity have aroused a lot of discussion and argument among agricultural economists (e.g., JOHNSON, G.L. 1982, JOHNSON, M.A. and PASOUR Jr. 1981, 1982, CHAMBERS and VASAVADA 1983, 1985, VASAVADA and CHAMBERS 1986, HSU and CHANG 1990).

3.1 Static examination

In the production and cost theory the problem of the short and long run has been approached by dividing the costs into groups on the basis of their fixity (e.g., CHAMBERS 1988, VARIAN 1992). In the traditional short-run production function study it is assumed that the input vector can be divided into the vectors of variable and fixed inputs (e.g., HEADY 1952, DEBERTIN 1986). In the short run V(y) is written as follows:

$$L(y,x'') = \{x': f(x',x'') \geq y\}, \tag{29}$$

where x'' is the maximum available quantity of fixed inputs used, and x' is the set of variable input vectors. The cost minimization problem of the short run can be presented as follows:

$$C(w',y,x'') = \min_{x' \geq 0}\{w'x': x' \in L(y,x'')\}, \tag{30}$$

in which w' is the vector of the variable input prices, L(y,x'') is a non-empty set, C(w',y,x'') satisfies the properties of the cost function, and is non-increasing in x''.

The cost function studies of the long run (the starting point in milk production, unless giving up production is planned) and the short run differ from each other, because in the short run fixed inputs do not always make it possible to minimize costs. However, by theory, variable costs are minimized for any choice of x", and the cost minimization problem can be written as follows:

$$C(w,y) = \min_{x''} C(w',y,x'') + w''x''. \qquad (31)$$

In equation (31) the problem of the long run is divided into two parts so that variable costs are minimized at the current quantity of fixed inputs, and after this a new quantity of fixed inputs is chosen. Thus the equation presents the effect of the fixity of inputs on a dairy farm. According to the first order condition,

$$\frac{\partial C(w',y,x'')}{\partial x''_j} + w''_j = 0, \quad j \in N'' \ (N'' \text{ is the set of inputs } x''), \qquad (32)$$

which means that in the long run fixed inputs are purchased to the extent that the reduction in the variable costs (the shadow price) is at equilibrium with the marginal cost, i.e., w_j''. According to the second order condition, it is required that the matrix with the elements

$$\frac{\partial^2 C(w',y,x'')}{\partial x''_i \, \partial x''_j}, \ i, j \in N'', \qquad (33)$$

is positive semidefinite. The function of the short-run variable costs is convex with respect to fixed inputs, so that the cost minimization of the long run is realized. The convexity of C(w',y,x") means that the shadow prices approach zero, when the use of fixed inputs increases towards the infinite, i.e., the greater the use of fixed inputs is, the smaller is the reduction in the short-run variable costs, when the use of fixed inputs is increased.

According to the envelope theorem, the long-run cost function is tangent to the short-run cost function from below (see BIRCHENHALL and GROUT 1984, p. 225–228, CHAMBERS 1988, p. 104). The short-run and long-run cost functions share the point in which the fixed input bundle minimizes costs. According to Shephard's Lemma,

$$x_i(w,y) = x_i(w,y,x''(w,y)), \qquad (34)$$

in which x"(w,y) is the solution to equation (31). According to Le Chatelier's Law, the long-run cost function is more concave than the short-run cost function, which means that long-run derived demand is more own price elastic than short-run derived demand, i.e.,

$$\frac{\partial x_i(w,y)}{\partial w_i} \le \frac{\partial x_i(w,y,x''(w,y))}{\partial w_i}. \qquad (35)$$

During different time periods, inputs can be divided into several groups on the basis of their fixity, so that this reasoning can be applied generally (CHAMBERS 1988, p. 106–107).

In empirical studies the short-run elasticities have been defined by deriving the demand equations of variable inputs with respect to prices of variable inputs by holding the fixed inputs constant (e.g., THIJSSEN 1992b, HELMING et al. 1993). Dynamic models make it possible to define the elasticities of the short run, intermediate run, and long run (ITO 1991, p. 11). Elasticities of the short run have been defined by holding the fixed inputs constant, those of the intermediate run by including an adjustment coefficient, and those of the long run by assuming that fixed inputs have been fully adjusted to the desired level of the use of inputs.

3.2 Dynamic examination

In the dynamic adjustment cost model no assumptions are made on the fixity of inputs, but the change in the quantity of use of quasi-fixed inputs is modelled as more expensive than the change in the quantity of variable inputs (VASAVADA and CHAMBERS 1986, ITO 1991, FERNANDEZ-CORNEJO et al. 1992). Thus, the adjustment cost is part of the theoretical model, in which it is assumed to be strictly convex, i.e., its marginal cost is assumed to be increasing (JORGENSON 1986, p. 1905, ITO 1991, p. 3). If the adjustment cost were assumed to be linear or strictly concave, delayed adjustment would not occur (ROTHSCHILDT 1971, p. 621, MACCINI 1987, p. 25).

The dynamic problem of a dairy farm is the minimization of the present value of future total costs. Cost minimization is subject to the production function and the increasing marginal cost of the adjustment cost. Adjustment costs are assumed to ensue from institutional factors, imperfect markets, and internal factors of firms. Internal adjustment costs are assumed to ensue from directing resources from production to investments, reorganization of production, as well as changing the level of knowledge and skills. Adjustment costs mean that a rapid increase of capital is more expensive than a slow increase. Without the adjustment cost the dynamic model becomes a static model.

According to Hsu and Chang (1990), the examination of the fixity of inputs should be combined with the adjustment cost model, in order to obtain a realistic approach for the examination of the fixity of inputs. The convexity of the adjustment cost in the neighbourhood of the origin does not guarantee the fixity of inputs, so that the popular quadratic adjustment cost function captures only part of the slowness of the adjustment of inputs.

The fixity of inputs is guaranteed by the discontinuity of the first derivative of the adjustment cost function. According to Hsu and Chang, this explains why the adjustment cost theory has had only little significance in the study of the fixity of inputs. According to them, testing the fixity of inputs by means of the traditional econometric techniques is bound to fail (see also Chambers and Vasavada 1983, p. 768, 1985, p. 139). The smoothness of the adjustment cost at the origin and the symmetry of the adjustment cost should be tested empirically. Only through this is it possible to obtain information on the fixity of inputs and the degree of fixity, as well as the investment decisions of the enterprise (Rothschildt 1971, p. 609, 621).

In the literature the adjustment cost is usually presented as differentiable everywhere and symmetric with respect to, for example, the change in capital input, which is probably not true (Hsu and Chang 1990, p. 305–307). According to empirical studies, no support has been found for the assumption that the adjustment cost is symmetric (e.g., Chang and Stefanou 1988, Pfann and Verspagen 1989, p. 368–370). According to Maccini (1987, p. 25), the foundations of the adjustment cost theory are weak. The problem is not the adjustment cost itself, but the assumption of the increasing marginal cost of the adjustment cost. According to Rothschildt (1971, p. 608), decreasing marginal costs are as likely and feasible as increasing adjustment costs.

However, the quadratic adjustment cost assumption has been popular in empirical time series models. Models in which this assumption has not been made have tended to have poor statistical properties (Hetemäki 1990, p. 15). According to Hetemäki, rejecting the non-quadratic adjustment cost models for this reason may have been based on erroneous statistical inference.

The studies presented above question the reliability and applicability of the traditional adjustment cost models. In milk production the labour input may in the short run be more fixed than the capital input, which means that the preconditions for constructing a dynamic demand model of inputs in this study are quite problematic. In adjustment cost models the labour input is usually assumed to be variable, and capital is considered quasi-fixed (Maccini 1987, p. 23). Debertin (1986, p. 285) notes that in a short-run examination tractors, machinery, full-time labour force, and land should be considered fixed inputs.

In the literature it remains unclear how long-run and short-run examinations should be combined. The error correction model (ECM) and information provided by cointegration have been offered as solutions to this problem (e.g., Hetemäki 1990, Engle and Granger 1991). According to advocates of this approach, in empirical studies the properties of time series do not receive enough attention (Hendry 1991).

ECM is based on the idea that, in the long run, equilibrium between the factors exists. Short run is seen as stochastic noise, which cannot be explained by economic theory. The ECM cannot answer the question of the mechanism in the economic theory that brings about the dynamics of the model. However, its assumptions are not unrealistic. In this study, the applicability of the ECM in the short-run dynamic modelling of milk production will be examined.

Granger's concept of integrated series refers to the stationarity properties of the time series. The time series x_t, t = 1,2,...,T is integrated of order d, denoted $x_t \sim I(d)$, if the time series $(1-L)^d x_t$ has a stationary representation after differencing d times (Virén 1992, p. 121). Cointegration can be presented as follows: the components of vector x_t are integrated of degree d,b ($x_t \sim I(d,b)$), if all components of x_t are of degree d and there is a vector a ($\neq 0$), so that $z_t = a'x_t \sim I(d-b)$, $b > 0$. Vector a is called the cointegration vector (Granger 1991, p. 72).

Intuitively this means that in the long run two or more series move in a parallel direction. Even if the series are not stationary, their linear combination is stationary. Thus, the series have a common stochastic trend. When the common trend is subtracted out, the difference between variables is stationary. The series can be considered a long-run "equilibrium" relationship. In this connection, equilibrium differs from the concept of the economic theory. In the literature on cointegration equilibrium is understood as an observed relationship that a set of variables has formed in the long run.

Cointegration is a necessary condition for the existence of the ECM. The formation of a long-run relationship between the series I(0) and I(1) is impossible, because series I(0) has a fixed average, whereas in the case of series I(1) the average moves towards the infinite. If the series are I(1) and they are cointegrated, according to Granger's representation theorem (Engle and Granger 1991, p. 86–87), an ECM exists. In the case of two series the ECM can be presented as follows:

$$\Delta y_t = \beta_0 - \gamma (y_{t-1} - \mu x_{t-1}) + \beta_1 \Delta x_t + \varepsilon_t, \qquad (36)$$

in which ε_t is an error term with mean zero, constant variance, and zero covariance. γ measures the extent of correction of errors by adjustments in y, μ measures the long-run equilibrium relationship between x and y, β_1 measures the short-run effect on y of changes in x, and Δy_t, Δx_t and $(y_{t-1} - \mu x_{t-1})$ are I(0). If $(y_{t-1} - \mu x_{t-1})$ is I(1), the error correction mechanism does not exist.

Implicitly, the ECM can be thought to operate so that the short-run shocks Δx_t feed Δy_t, and the long-run error $(y_{t-1} - \mu x_{t-1})$ attaches the long run into the model. If $\Delta x_t = 0$, $(y_{t-1} - \mu x_{t-1})$ determines the steady state in the long run. Thus, the ECM can be regarded as a description of a stochastic process, according to which the economy corrects the error in the equilibrium.

Granger's representation theorem provides the theoretical basis for the ECM. It makes it possible to model the short run dynamics for the derived demand model, provided that the variables in the cost function and the cost share equations are cointegrated (Hetemäki 1990, p. 25).

4 Earlier studies

In international studies of agricultural economics the dual approach was used to solve empirical problems quite soon after the flexible functional forms were developed (e.g., Binswanger 1974). The dual approach has rarely been applied in Finnish agricultural economic studies.

4.1 Finnish studies

Finnish studies in which the neoclassical production and cost theory has been applied, and in which the substitution between inputs and elasticities of substitution have been examined are dealt with in this study. The aim is to link the present study to earlier studies made in Finland. At the same time, it is reflected on what new information this study possibly brings to what is known at present.

The first study in the field of agricultural economics in Finland in which the elasticities of substitution were examined empirically was Hemilä's (1983) doctoral thesis. The main emphasis was in the examination of the technological change in

Finnish agriculture, but it also included an analysis of the substitution possibilities between inputs. In his study Hemilä used two inputs, labour and capital, so that he aggregated all inputs except the labour input into the capital input. The data consisted of cross section data collected from the bookkeeping farms from the years 1947/48, 1956/57, 1968, and 1979, which were normal years in terms of weather conditions. The CES production function was applied in the study. He observed that the elasticity of substitution was between 1.6 and 4.2. He concluded that on the basis of the elasticity of substitution estimates calculated in his study, no far-reaching conclusions can be drawn (HEMILÄ 1983, p. 211–212). The substitution of capital input for labour input was easier in the latter part of the research period than in the beginning.

YLÄTALO (1987, p. 69–71) touched on the substitution of the labour input through the capital input in agriculture. In his study the main emphasis was on examining the productivity and investments in agriculture. Ylätalo used the Cobb-Douglas production function, and the data used were aggregate time series data from the years 1961–1984. He examined the substitution between labour and capital by calculating the change percentages of each factor, and by putting the values into the following equation:

$$\Delta K = \Delta A + l\Delta B, \quad (37)$$

in which ΔK = change in the productivity of capital, %
ΔA = change in the total productivity, %
l = income share of labour input
ΔB = change in labour input/capital stock

Ylätalo used 0.7, 0.6, and 0.5, alternatively as the income shares of labour input. In equation (37) term $l\Delta B$ indicates the substitution effect. According to Ylätalo's research results, the substitution effect between labour and capital has remained almost the same. According to him, in terms of its absolute value, the substitution between labour and capital has been bigger than the change in the productivity of capital. Since the total productivity has grown at the same time, substituting capital for labour has been economically profitable.

LUMIAHO (1990, p. 58, 63–65) examined the elasticities of substitution by the same methods as Hemilä. He chose cross section data from the bookkeeping farms from the years 1979, 1982, 1984, and 1986. According to Lumiaho, analysing the elasticities of substitution is problematic, because some of the substitutions receive negative values. The elasticities of substitution determined by Lumiaho deviated from those determined by Hemilä with respect to their level, but they gave a similar result in the development of the substitution of the labour and capital input.

RYHÄNEN (1992) examined the effect of the change in relative prices of inputs and the technological development on the derived demand for inputs by means of the translog cost function. He used aggregate time series data from the years 1962–1989. Variables chosen for the cost function were: output, prices of capital, labour, purchased feed and purchased fertilizers, and a linear time trend to describe technological development.

The results show that the inputs used in agricultural production are for the most part substitutes for each other. The values of the elasticities of substitution are small, which means that by means of the existing production technology the substitution of inputs for other inputs is inelastic. The own price elasticities are also inelastic.

According to the research results, it seems that in Finnish agriculture there are advantages related to the farm size, which means that expanding agricultural enterprises should be allowed. Technical change in agriculture has been capital-using, and labour- and purchased feed-saving. Substituting the cheaper capital input for the expensive labour input has been profitable. In addition, through investments new technology has been obtained for production.

YLÄTALO (1987) and RYHÄNEN (1992) only had at their disposal data that was aggregate from the whole agricultural sector. The production and cost theory is based on decision-making of individual agricultural entrepreneurs, which means that the use of data consisting of information collected from individual farms would be theoretically on firmer ground than the use of aggregate data. Hemilä (1983) and Lumiaho (1990) used cross section data consisting of information collected from individual farms. In their studies solving the elasticities of substitution was restricted by the primal approach, as well as the restrictions on the substitution possibilities set by the production functions used (see e.g., Lau 1986, p. 1519).

In this study the dual approach and flexible functional forms are used, and the data are collected from bookkeeping dairy farms. This should make it possible to define the elasticities of substitution more accurately than earlier, and provide a better theoretical foundation for the analysis. Time series data are formed from the information collected for this study, which is based on the idea of a representative dairy farm. The data set collected makes it possible to utilize a panel data set, too, for some dairy farms. The results from the panel data set will be compared with the results from the representative dairy farm data set.

4.2 Foreign studies

In the case of foreign studies, the examination is restricted to recent studies in which the dual approach has been applied and flexible functional forms have been used. Studies in which the derived demands and the elasticities of substitution in agriculture have been examined are dealt with in this study.

Cost function studies

Binswanger (1974) estimated the elasticities of input demand and elasticities of substitution in agriculture in the United States, utilizing the translog cost function. As data he used cross section data collected from different states from the years 1949, 1954, 1959, and 1964. He assumed the scale economies to be neutral, so that he excluded the output from his analysis. Technical change was assumed to be non-neutral. As variables for the cost function he chose the prices of five aggregate inputs (land, labour, machinery, fertilizers, and 'other inputs'), and he chose a linear time trend to describe the technical change.

According to the research results, the best substitutes were land and fertilizers. 'Other inputs' was a substitute for all inputs, except for land. Machinery was a substitute for both land and labour. A complementary relationship existed between labour and fertilizers, machinery and fertilizers, and land and 'other inputs'. Technical change was labour-saving and machinery-using. The derived demand for arable land was inelastic. The own price elasticities for other inputs was close to –1. The Cobb-Douglas form was not an appropriate production and cost function specification in this data.

Ray (1982) chose the translog cost function for the analysis of agricultural production in the United states. For data he chose aggregate time series data from the years 1939–1977. In the cost function he chose as variables the crop output and livestock output, as well as the prices of hired labour, capital, fertilizers, 'purchased feed, seeds, animals', and miscellaneous inputs (pesticides, detergents, electricity, telephone). According to Ray, this kind of multi-output and multi-input model is problematic, because the number of parameters to be estimated is quite large.

Ray's primary objective was to measure the elasticities of substitution between inputs. He assumed technical change to be Hicks neutral. The annual technical change was estimated at 1.8% (increase in productivity). The possible non-neutral technical change was excluded from the analysis, because he wanted to have only one measurement for the increase in productivity. He may also have excluded non-neutral technical change because of the problems related to model specification, as well as the rapid growth in the number of parameters to be estimated.

According to Ray, capital was a substitute for all other inputs. In addition to capital, fertilizers and 'purchased feed, seeds and animals' were substitutes for hired labour. The elasticity of substitution between hired labour and capital decreased, whereas, at the same time, it increased between hired labour and fertilizers, as well as hired labour and 'purchased feed, seeds and animals'. The own price elasticities for all the inputs were negative and less than one in their absolute value. The absolute value of the own price elasticity for hired labour was the highest. As a function of time, the absolute values of the own price elasticities for all inputs increased. This was likely to be caused by the increase in the use of purchased inputs compared with inputs produced on the farm. The non-homothetic technology indicated that the cost function is not separable.

The labour input of the farm family was excluded from Ray's data. Usually the labour of the farm family is priced according to the market prices (e.g., Binswanger 1974). According to Ray (1982, p. 497), this kind of pricing should not be used, because it does not take into account the demand for agricultural workers in the market and the management work included in the labour input of the farm family. According to him, the labour input of the farm family should be a separate input, and it should not be added to the hired labour.

Lopez (1980) examined the production structure and the derived demand for inputs in Canadian agriculture by means of a generalized Leontief cost function. As data he chose time series data from the years 1946–1977. In the cost function he chose as variables the output and prices of four aggregate inputs [labour (own and hired), capital (machinery, implements, farm vehicles, animals), 'land and structures', and aggregate intermediate inputs (fertilizers, seeds, feed, fuel, electricity)].

According to Lopez, the Leontief, Cobb-Douglas, and CES functional forms were not appropriate for the data. The constant returns to scale hypothesis was also rejected. It was surprising that the null hypothesis, neutral technical change, could not be rejected, even if technological progress has been important in Canadian agriculture, being labour-saving and capital-using. According to Lopez (1980, p. 43) this phenomenon reflects the fact that the increase in the demand for capital and the decrease in the demand for the labour input has been caused by changes in the relative prices, in which case the expansion path of a non-homothetic production function bends into a higher capital/labour ratio as the output increases, rather than into non-neutral technical change. This observation is supported by the fact that when the model was specified into a constant returns to scale model, the null hypothesis, neutral technical change, was rejected. The own price elasticities for inputs were inelastic –(0.280–0.897). The elasticities of substitution between all pairs of inputs were positive, but quite small. The highest degree of substitution occurred between labour and capital, and between capital and intermediate inputs.

Glass and McKillop (1990) examined the production structure of Irish agriculture by means of a generalized translog cost function. As data they chose aggregate time series data from the years 1953–1986. In the cost function they chose as variables the output and prices of four inputs (capital, 'feed and seeds', fertilizers, and labour). The objective of the study was to obtain econometric measures of substitution between inputs, elasticities of input demand, neutral and non-neutral technical change, and scale economies.

According to Glass and McKillop, labour is a substitute for capital, fertilizers and 'feed and seeds'. A complementary relationship exists between fertilizers and 'feed and seeds'. The own price elasticities for inputs were inelastic –(0.08–0.85). Technical change was labour-saving and fertilizer-using. It also seemed to be capital-using and 'feed and seeds'-using.

Glass and McKillop estimated the average annual technical change to be 1.33%. Technical change slowed down during the research period, and the average non-neutral technical change was negative. According to them, the result was probably caused by the fact that agricultural entrepreneurs assumed the demand for agricultural products to be higher than the realized demand and increased the capacity too much, so that the substitution of capital for labour input seems to have been inefficient.

Agriculture in Ireland is described by the diseconomies of scale. Technological development seems to have influenced the change in the farm size. According to GLASS and MCKILLOP (1990, p. 278), along with the progress of the technology, savings of costs are achieved in larger enterprises. The average annual increase in the total productivity was 2.0% (technical change 1.33%, scale economies –0.22%, and residual 0.89%). Finally, Glass and McKillop note that the increase in productivity has been hindered by the relatively small average farm size and by inefficient use of capital.

Profit function studies

HIGGINS (1986) derived a set of demand and output supply equations from the short-run translog profit function. From the estimated parameters he solved the own and cross price elasticities of the demand and supply. The cross section data included information from 1454 bookkeeping farms from the year 1982. In the profit function he chose as variables the prices of three outputs and four variable inputs, as well as quantities of five fixed inputs. Pig and poultry farms, as well as farms in which there were zero or negative profits were, excluded from the study.

Higgins' empirical result did not support the profit maximization assumption. According to him, this may have been caused by e.g., errors in the approximation and assumptions, problems in the measurement, as well as by the fact that the data could include farms that did not maximize profit (see also MCKAY et al. 1983, SHUMWAY 1983, WEAWER 1983, LOPEZ 1984). However, it should be noted that in Higgins' results only own price elasticity for crop output had the wrong sign, which automatically meant rejection of the assumption of convexity and, hence, the profit maximization hypothesis.

According to Higgins, milk output was the most price elastic. Decreases in the price of milk relative to other prices reduces milk production, whereas the effect of relative decreases in the prices of beef and mutton on meat production was a lot smaller. According to Higgins, a decrease in the price of industrial fodder had a greater impact on milk production than on meat production. He concludes that price policy directed to inputs and products is an efficient means of controlling production in milk production, but not in meat production.

TIFFIN (1991) constructed a theoretical model to describe how production decisions that can be realized in the short run are made on a farm. The model that was based on the theoretical profit function was applied empirically. Research data consisted of information from the years 1964/5–1983/4, which had been collected from farms in England and Wales, where 50–75% of the labour input was used for milk production. Information after 1984 was not included in the data, because this is when the quota system was introduced, and the output of milk became a fixed factor (exogenous).

The annual number of farms included in the study varied between 237 and 377 farms. Tiffin's model was based on the idea of a representative farm, which was arrived at by calculating the averages from the data separately for each year. As variables Tiffin chose the prices of crops, animals, and milk, as well as the prices of variable inputs (fertilizers, industrial fodder, labour), and as fixed inputs arable land, physical capital, animal capital, as well as the time trend to describe the change in technological factors.

Tiffin's empirical result did not support the profit maximization assumption. He considered the reliability of his results to be weak, so he made his conclusions at a general level. According to the results, on a dairy farm the variable factors change only little, when the prices change, holding the production technology constant. Tiffin points out that it is important to understand the long-run adjustment mechanisms of the production technology, by means of which milk producers operate during each period of time. According to him, the control of the output and input quantities, in order to change production that has been the objective of agricultural policy, is not a reasonable measure, unless the production technology of a dairy farm can be changed at the same time. Finally, he notes that in empirical studies there generally occurs a "trade-off" between theoretical exactness and statistical reliability.

Thijssen (1992b) examined supply response and input demand in milk production in the Netherlands using incomplete panel data. He used the quadratic profit function as the flexible functional form in the short-run examination. He applied Hausman's test for testing the estimates obtained by means of the fixed effects estimator and random effects estimator. According to the test, the random effect model is based on the wrong specification, so that he ended up using the fixed effects model. Thijssen had at his disposal information from the bookkeeping dairy farms from the years 1970–1982. The farms were followed usually for five years, so that the data became incomplete panel data. There were altogether 2,196 observations from 568 dairy farms.

As variables Thijssen chose the normalized price, for which he used the ratio of Törnqvist price index of the variable input and the Törnqvist price index of the output, as well as three fixed inputs (labour, capital, arable land). The aggregate variable input includes feed, fertilizers, seeds, pesticides, fuel, and the output includes milk and meat. He chose a linear trend to describe the technical change. Finally, he added a variable describing the weather index into the demand function for the variable input and to the output supply function.

The model estimated by Thijssen fulfilled statistically the assumptions set by the theory. The incomplete panel data made it possible that the intercept in the demand function for the variable input and the intercept in the output supply function vary over the dairy farms. The value of the intercept varied between farms, which shows that there are differences caused by the managerial abilities and the quality of land between farms. As the own price elasticity of the output Thijssen estimated 0.10, and as the price elasticity of the demand for the variable input –0.25. These elasticities are smaller than those arrived at in earlier studies based on the profit function. According to the results, the possibilities of the traditional agricultural and environmental policies, which are based on taxation and support, to influence the production quantities are small in the short run.

Helming et al. (1993) examined the production relationship between the short-run outputs and inputs from Thijssen's (1992a, b) data set before and after the introduction of the milk quota system was presented. They used the restricted quadratic profit function in their examination. The estimated model fulfilled the theoretical assumptions well. Price elasticities were smaller during the milk quotas than during the time prior to the quotas, but it should be noted that all short-run elasticities were inelastic. According to Helming et al. (1993, p. 358), the overcapacity of quasi-fixed inputs resulting from the milk quotas would influence milk production a great deal, if the quota system were abolished.

In the comparison between the research results presented above it must be taken into account that the studies differ from each other with respect to their assumptions, the model used, as well as the aggregation of the variables. Empirical analyses have for the most part been problem specific, which means that each research problem had the circumstances of the research period as its starting point. Consequently, the formulation of the problem, with its restrictions, in, for example, different countries and in different production lines has differed a great deal, as the preconditions for production have been different.

5 Theoretical model for the study

5.1 Choice of the cost function

The theory and the research problem impose requirements on the functional form to be chosen for this study. The functional form presented algebraically should fulfill all theoretical properties required of economic relationships, in order to make it possible to include the appropriate parameters into the model (LAU 1986, p. 1520). The theory of statistics does not provide any unambiguous guidelines for the choice of the functional form. Consequently, the researcher has to choose the functional form and the restrictions on the parameters set for the function to be estimated.

The theoretical discussion of the first part of the study provides the foundations for the empirical analysis. The theory receives particular emphasis in this study, because illogicality is excluded by means of theoretical analysis. By means of the empirical analysis, the values of the parameters are estimated, and the structure of the model is tested. Thus, the values of the parameters arrived at in the empirical analysis describe the economic behaviour of the decision-maker measured from milk production in practice.

The Cobb-Douglas production function, which included two inputs, can be considered the starting point for the development of advanced functional forms (COBB and DOUGLAS 1928). The properties of the Cobb-Douglas production function include constant returns to scale, neutral technical change, and a constant value, one, for the elasticity of substitution. The CES function, which allows the elasticity of substitution to have other values than one, can be considered the next step forward (ARROW et al. 1961). It is perfect in the case of two inputs, but its generalization to cases with three or more inputs involves too many restrictions on the substitution possibilities.

The development of flexible functional forms was a major improvement compared to the earlier functions (JORGENSON 1986, p. 1845). The translog functions (CHRISTENSEN et al. 1971, 1973) and the generalized Leontief functions (DIEWERT 1971) became the most widely used flexible functional forms. Flexible functional forms refer to functional forms with the second order approximation property (LAU 1986, p. 1540, CHAMBERS 1988, p. 164). Thus, the function includes an adequate number of parameters, so that the derived demands and the matrix of derived demand elasticities can be solved.

According to DIEWERT (1987, p. 693), the following properties must be taken into account in the choice of the functional form:

1. Flexibility: The functional form should be so flexible that the amount of free parameters required by the theory can be estimated.
2. Parsimony: Only the minimum amount of free parameters required for the flexibility property is used.
3. Linearity: The unknown parameters of the cost function should be solved linearly-in-parameters from the system of equations to be estimated.
4. Consistency: The functional form of the cost function should be consistent with properties 1–6 (see Chapter 2.3.4).

According to DIEWERT (1987, p. 693) the translog function fulfills the first three properties, but the fourth gives cause for critique, as in empirical analyses flexible functional forms have not fulfilled this condition at every point of the data. Locally flexible functional forms are well-behaved with respect to the fourth condition, but not necessarily at all points of the data. Since the econometric statistical conclusions are based on the behaviour of the model at all points, the lack of global properties restricts the usefulness of flexible functional forms.

The translog function is globally valid only when the strict conditions set on the parameters prevail, but locally it may be valid under relatively more relaxed restrictions. Even if the global theoretical consistency is not fulfilled, there still exists a set of input prices in which the theoretical consistency is satisfied, and this may be large enough for all practical purposes (LAU 1986, p. 1527–1539).

The lack of global properties has led to the development of new functional forms, in order to obtain globally better behaved functions. Despite these attempts, it has not been possible to develope a new generation of functional forms that behave as desired (e.g., HETEMÄKI 1990, p. 13).

On the basis of the previous discussion, the translog cost function is chosen for the estimation of the research model. The translog cost function is

$$\ln C(w,y) = \beta_0 + \sum_{i=1}^{N}\beta_i \ln w_i + \beta_y \ln y + \beta_T T + \tfrac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N}\beta_{ij}\ln w_i \ln w_j + \tfrac{1}{2}\beta_{yy}(\ln y)^2 + \tfrac{1}{2}\beta_{TT}(T)^2 + \sum_{i=1}^{N}\beta_{yi}\ln w_i \ln y + \sum_{i=1}^{N}\beta_{iT}\ln w_i T + \beta_{yT}\ln y T, \quad (38)$$

in which $\beta_{ij} = \beta_{ji}$, and T describes the technical change. By the properties of a cost function, the cost function (38) must be consistent with linear homogeneity in the prices of inputs. Therefore, the following restrictions have to be imposed on the parameters to be estimated:

$$\sum_{i=1}^{N}\beta_i = 1 \text{ and } \sum_{i=1}^{N}\beta_{yi} = \sum_{i=1}^{N}\beta_{ij} = \sum_{i=1}^{N}\beta_{ji} = \sum_{i=1}^{N}\beta_{iT} = 0. \quad (39)$$

By Shephard's Lemma the cost shares of inputs can be solved from equation (38). The cost shares of inputs can be presented as elasticities of the cost function with respect to prices of inputs (see JORGENSON 1986, p. 1885).

$$\frac{\partial \ln C(w,y)}{\partial \ln w_i} = \frac{\partial C(w,y)\, w_i}{\partial w_i C(w,y)} = \frac{w_i x_i(w,y)}{C(w,y)} = S_i(w,y), \quad (40)$$

so that the cost shares of inputs are

$$S_i(w,y) = \beta_i + \sum_{j=1}^{N}\beta_{ij}\ln w_j + \beta_{yi}\ln y + \beta_{Ti}T. \quad (41)$$

The cost shares of inputs are determined as the function of the input prices, output, and technical change. According to formula (41), the unknown parameters of the cost shares can be solved linearly-in-parameters from the system of equations to be estimated.

The approximation of the production technology is homothetic, if the cost function is separable with respect to output and the prices of inputs, i.e., if $\beta_{yi} = 0$ in all i. Homotheticity means that the cost minimizing input bundle is determined as a function of the prices of inputs and technical change so that the cost minimizing input bundle is independent of the level of output. A homothetic cost function is homogeneous, if cost flexibility is independent of output, i.e., $\beta_{yy} = 0$. When these restrictions apply, the degree of the homogeneity can be obtained from the coefficient β_y. If $\beta_y = 1$, the cost function is linearly homogenous, and production is described by constant returns to scale (JORGENSON 1986, p. 1892–1893).

The restrictions of the production and cost theory set into the model reduce the space of the parameters so that it is possible to find out the economic relations. In addition, it should be noted that the properties of flexible functional forms are local, which means that the interpretation of the results is also local.

5.2 Theoretical model

The theoretical framework of the study is illustrated in Figure 3. In the study it is assumed that milk production can be described by a production function, which has the properties presented in Appendix 1, and that a typical dairy farm operates in conditions restricted by the technical relationship between the inputs and output determined by the production function.

The production function can be presented as follows:

$$Y = f(K,L,M,H,T). \quad (42)$$

The total output Y, and the quantities of the capital items K, labour L, purchased feed M, and purchased fertilizers H used on a dairy farm, as well as the technical change T are included in the model.

In the study, it is assumed that the prices of inputs and products are determined exogenously, and that a dairy farm minimizes costs. Based on the duality, there exist a cost function which reflects the production technology. The cost function can be presented as follows:

$$c = g(W_K,W_L,W_M,W_H,Y,T), \quad (43)$$

in which c is the total cost of production, W_K, W_L, W_M, W_H are the prices of inputs, Y is the

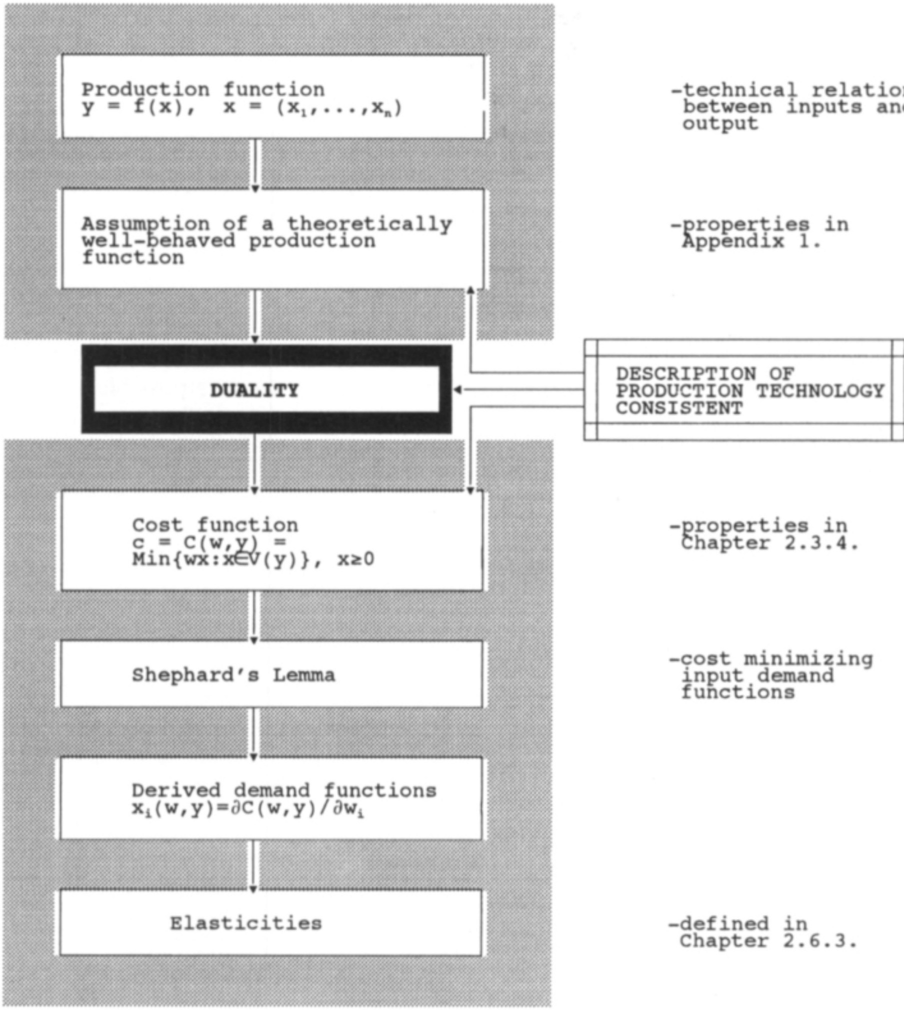

Fig. 3. Theoretical framework of the study.

total output, and T is a linear time trend, which describes the technical change.

The cost function is assumed to fulfill the properties presented in Chapter 2.3.4. After the choice of the functional form, the theoretical model of the study is as follows:

$$
\begin{aligned}
\ln C(w,y) = {} & \beta_0 + \beta_Y \ln Y + \beta_K \ln W_K + \beta_L \ln W_L \\
& + \beta_M \ln W_M + \beta_H \ln W_H + \beta_T T + \tfrac{1}{2}\beta_{TT}(T)^2 \\
& + \tfrac{1}{2}\beta_{YY}(\ln Y)^2 + \tfrac{1}{2}\beta_{KK}(\ln W_K)^2 \\
& + \beta_{KL}\ln W_K \ln W_L + \beta_{KM}\ln W_K \ln W_M \\
& + \beta_{KH}\ln W_K \ln W_H + \tfrac{1}{2}\beta_{LL}(\ln W_L)^2 \\
& + \beta_{LM}\ln W_L \ln W_M + \beta_{LH}\ln W_L \ln W_H \\
& + \tfrac{1}{2}\beta_{MM}(\ln W_M)^2 + \beta_{MH}\ln W_M \ln W_H \\
& + \tfrac{1}{2}\beta_{HH}(\ln W_H)^2 + \beta_{YK}\ln Y \ln W_K \\
& + \beta_{YL}\ln Y \ln W_L + \beta_{YM}\ln Y \ln W_M \\
& + \beta_{YH}\ln Y \ln W_H + \beta_{TY} T \ln Y + \beta_{TK} T \ln W_K \\
& + \beta_{TL} T \ln W_L + \beta_{TM} T \ln W_M + \beta_{TH} T \ln W_H,
\end{aligned} \tag{44}
$$

in which $\ln W_K$, $\ln W_L$, $\ln W_M$, $\ln W_H$ are the logarithms of the prices of capital items, labour, purchased feed, and purchased fertilizers, $\ln Y$ is the logarithm of the quantity of total output, and T is the time trend describing the technical change.

Technical change is described by coefficients β_{Ti}. Technical change is Hicks neutral, if $\beta_{Ti} = 0$ for all inputs x_i. Technical change is said to be input x_i-using (x_i-saving), if $\beta_{Ti} > 0$ (< 0) (NADIRI 1982, p. 444–445, 467).

Linear homogeneity in prices of input imposes the following restrictions on formula (44).

$$\begin{aligned}
&\beta_{KK} + \beta_{KL} + \beta_{KM} + \beta_{KH} = 0 \quad && \beta_K + \beta_L + \beta_M + \beta_H = 1 \\
&\beta_{LL} + \beta_{LK} + \beta_{LM} + \beta_{LH} = 0 && \beta_{TK} + \beta_{TL} + \beta_{TM} + \beta_{TH} = 0 \\
&\beta_{MM} + \beta_{MK} + \beta_{ML} + \beta_{MH} = 0 && \beta_{YK} + \beta_{YL} + \beta_{YM} + \beta_{YH} = 0 \\
&\beta_{HH} + \beta_{HK} + \beta_{HL} + \beta_{HM} = 0
\end{aligned} \tag{45}$$

Under these restrictions, the cost function allows for non-homotheticity and non-neutral technical change. It should be noted that the translog cost function cannot be made globally concave by imposing restrictions on the parameters.

According to CHRISTENSEN and GREENE (1976, p. 662), the simultaneous estimation of the equation system formed by the cost function and the cost share equations is an optimal procedure in order to solve for efficient parameters. Thus, in this study the cost shares of inputs from the translog cost function, are also solved. By Shephard's Lemma, we arrive at the following equations for the cost shares.

$$\begin{aligned}
S_K &= \beta_K + \beta_{KK}\ln W_K + \beta_{KL}\ln W_L + \beta_{KM}\ln W_M \\
&\quad + \beta_{KH}\ln W_H + \beta_{YK}\ln Y + \beta_{TK}T \\
S_L &= \beta_L + \beta_{LL}\ln W_L + \beta_{LK}\ln W_K + \beta_{LM}\ln W_M \\
&\quad + \beta_{LH}\ln W_H + \beta_{YL}\ln Y + \beta_{TL}T \\
S_M &= \beta_M + \beta_{MM}\ln W_M + \beta_{MK}\ln W_K + \beta_{ML}\ln W_L \\
&\quad + \beta_{MH}\ln W_H + \beta_{YM}\ln Y + \beta_{TM}T \\
S_H &= \beta_H + \beta_{HH}\ln W_H + \beta_{HK}\ln W_K + \beta_{HL}\ln W_L \\
&\quad + \beta_{HM}\ln W_M + \beta_{YH}\ln Y + \beta_{TH}T,
\end{aligned} \tag{46}$$

in which S_K, S_L, S_M, S_H are the cost shares of capital items, labour, purchased feed, and purchased fertilizers, respectively. The equations for the cost shares sum up into one, because their total must be equal to the total costs. The cost share equations have to fulfill the assumptions set by the production theory (45), as well as the symmetry assumption $\beta_{ij} = \beta_{ji}$.

It is implicitly assumed in the study that, as a group, capital items, labour, purchased feed, and purchased fertilizers are weakly separable from the inputs excluded from the study.

5.3 Research method

In econometrics it is crucial to estimate the relationships between the observed economic variables so that they can be quantified. In general, the relationships to be estimated are assumed to be stochastic. In practice, this means that the relationships between variables are specified so that they can be divided into a deterministic and stochastic part (LAU 1986, p. 1516).

The cost share equations and the cost function presented in the previous chapter form the deterministic part of the econometric model of this study. This is where the cost share equations and the cost function are presented as a function of the observed variables and the unknown parameters. In addition to the deterministic part, a stochastic part is added to the right-hand side of the equations. The cost function (44) and the cost share equations (46) form the equation system to be estimated.

Parametric restrictions are set between the equations of the equation system so that the assumptions set by the neoclassical production and cost theory are fulfilled. The symmetry assumption will be tested. The cost shares are the same amount as the total costs, which means that the equation system to be estimated is singular. The singularity of the equation system is avoided by taking away one cost share equation from the equation system, and by choosing an estimation procedure that estimates the parameters so that the values of the parameters estimated are not dependent on which equation is left out of the equation system. Taking away one cost share equation from the system does not reduce the information, because the parameters of the excluded cost share equation can be solved by means of the parametric restrictions.

According to PINDYCK and RUBINFELD (1991, p. 314), the choice of an appropriate estimation method depends on the use of the method, as well as the ability of the method to provide consistent and asymptotically efficient estimates. Methodologically the easiest way would be to estimate the translog cost function directly by means of the OLS procedure, but in this case the additional information included in the cost share equations would not be utilized. In addition to this problem, in OLS estimation the multicollinearity may cause problems in the estimation of an individual cost function (Christensen and Greene 1976, p. 662).

It has been noted that the direct application of the OLS and GLS procedures into equation systems usually leads to biased and nonconsistent parametric estimates (Mardia et al. 1979, p. 208). According to Monte Carlo simulations, the estimation methods for equation systems have given smaller variance to estimates than the estimation methods for individual equations. Therefore, instead of estimating equation by equation, an estimation method in which the whole equation system can be estimated simultaneously is chosen.

Modern statistical programs (see Hall 1993) make it possible to use GLS estimation, so that the advanced estimation methods can be taken advantage of in solving the equation system. Zellner's iterative estimation procedure is chosen for solving the research problem of this study (see Pindyck and Rubinfeld 1991, p. 326–327). The method is appropriate for estimating the equation system of the study, because the cost share equations form a system of seemingly unrelated equations (SUR). In these equations the cross-equation error terms of the cost share equations are correlated, and none of the cost share variables, acting as dependent variables, occurs on the right-hand side of equations to be estimated.

In iterative SUR estimation each equation is first estimated separately by means of the OLS procedure. The estimations provide the estimates for the error terms, from which the covariance matrix of the error terms is formed. After this, GLS estimation is used. In GLS estimation the error terms are estimated again, and the covariance matrix of error terms is updated. GLS iteration is continued until convergence is achieved ($\rho = 0.000001$).

In system estimation the correlation between residuals can be taken into account, which improves the efficiency of the estimation (e.g., Wonnacott and Wonnacott 1979, p. 503). System estimation also makes it possible to set the parameters of one equation to be estimated to be the same as the parameters of another equation or, other equations of the system.

According to Monte Carlo simulations made by Kmenta and Gilbert (1968, p. 1191–1192), by iterating Zellner's procedure, ML estimates (maximum likelihood) can be solved for the parameters. Determining the ML estimates makes it possible, for example, to test the homotheticity hypothesis by the likelihood ratio test. The determinants of the error covariance matrix estimated from an unrestricted and a restricted equation system are marked Ω_U and Ω_R, respectively. The likelihood ratio test is as follows (e.g., Spanos 1986, p. 299–303):

$$\lambda = (|\Omega_U| \,/\, |\Omega_R|)^{-T/2}, \tag{47}$$

in which T is the number of observations. The testing of the hypotheses is based on the test statistic, $-2\ln \lambda$, which has asymptotically a χ^2 distribution, with degrees of freedom equal to the number of restrictions imposed (Christensen et al. 1975, p. 378–389).

6 Agricultural production during the research period

The importance of agriculture for employment and in the gross domestic product of the national economy has decreased considerably since the beginning of the 1960s. In 1960, the share of agriculture in the GDP was 10.7% (Tilastollinen päätoimisto 1970, p. 287), and in 1991, it was 3.3% (Tilastokeskus 1993, p. 37). The decrease of the share of agriculture in the GDP means that the share of people earning their livelihood from agriculture has also decreased. During the same period of time, the share of the population employed in agriculture, out of the total active labour force, has fallen from 29.2% (Tilastollinen päätoimisto 1970, p. 36) to 7.1% (Tilastokeskus 1993, p. 106).

In the beginning of the 1960s, the number of agricultural enterprises started to decrease, and the average arable land area started to increase. Thus, the early part of the 1960s can be considered a turning point in the structural development of agriculture (MÄKINEN 1990, p. 101). The decrease in the number of farms can be seen, in particular, in the rapid decrease of the number of agricultural enterprises with less than 10 hectares arable land. At the same time, the number of agricultural enterprises with over 10 hectares arable land increased slightly. However, the increase in the average arable land area has been quite slow.

During the research period, Finnish agriculture became increasingly specialized. Farms no longer raise different species of animals, and they have specialized in either crop production or livestock production. At present, most agricultural enterprises engaged in livestock production raise only one species of animal. During the research period, it was also characteristic that the share of dairy farms decreased continuously, and the share of crop producing farms increased.

The development has been rapid in milk production. The number of dairy cattle has fallen from 240,000, at the beginning of the 1960s, to under 35,000 at present. Despite the rapid change, there are less than 10 cows on more than half of the dairy farms, which means that this development is likely to continue into the future (RYHÄNEN 1989, p. 51).

The trend in the yields of field crops has been increasing, but the total yields have varied a great deal because of the weather conditions (SILTANEN 1977, p. 5–8, KETTUNEN 1993, p. 12–15). The years 1976 and 1990 were exceptionally good, and in 1981 and 1987 the yields were exceptionally poor.

One of the most obvious features of the structural change in agriculture has been the rapid decrease in the labour force in agriculture. The decrease in the number of agricultural enterprises has not been nearly as drastic, so that the difference in the trends must at least partly be caused by the fact that the shift of the labour force from agriculture to other sectors has mainly concerned the assisting family members and hired labour (YLÄTALO 1987, p. 30). As the labour force in agriculture has decreased, the use of other inputs has increased clearly, except for agricultural land. The area of agricultural land increased slowly in the 1960s, but in the 1970s it started to decrease.

In addition to the changes in the structure and number of agricultural enterprises, significant changes have also occurred in the use of inputs and in investments. From 1960 to 1984, the use of production factors (e.g., purchased feed, purchased fertilizers) tripled, and the investments increased 1.5 times (YLÄTALO 1987, p. 34). The net capital stock increased steadily, resulting from the fact that depreciations were smaller than investments.

Total agricultural production has continued to grow, despite various measures to restrict production. At the beginning of the 1960s, the foundation of new agricultural enterprises was still supported with state funds. During the rapid changes in society in the 1960s and 1970s, agricultural enterprises decreased considerably. The overall development of the economy, which attracted a labour force, especially from small farms, is considered the most important individual factor behind the change. As a result, the structural development of agriculture was favourable in the early part of the 1970s.

Since the mid-1970s, the central objective of agricultural policy has been to reduce the overproduction of agriculture. Reducing overproduction has been difficult, despite the rapid decrease in the number of farmers, because production has at the same time become more productive, and the output and yield levels have increased. The measures to restrict production have slowed down the structural development of agriculture (YLÄTALO 1987, p. 41, RYHÄNEN 1989, p. 47, KOLA 1991, p. 112).

7 Data and variables

The theory of the first part of the study forms the basis for the empirical analysis. The empirical observation data consists of the total return of dairy farms, the prices of inputs, and the cost shares of inputs. The total return of dairy farms and the cost shares of inputs were collected from the bookkeeping farms. Four aggregate inputs were chosen for the study: labour (the farm family and hired labour), capital items (machinery, implements, buildings), purchased fertilizers, and purchased feed. Forestry, non-agricultural production, secondary incomes, and the private household of dairy farms were not included in the study. The data were collected from the entries of the accounting year, which were marked down in terms of flows, so that the output and the inputs used in producing the output are located during the same time period.

The year 1965 was chosen as the beginning of the research period, because this is when the bookkeeping farms shifted from the accounting period beginning in July, to an accounting period starting from the beginning of the year. In the accounting year 1964–1965, a complete balancing of the accounts had not been made on all farms, so that the data of this period remained small. In addition, a so-called incomplete balancing of the accounts had been made for some of the farms. These changes made it impossible to obtain reliable data from the beginning of the 1960s.

In the course of time, certain changes have been made in the bookkeeping form, and the changes affecting the data of this study have to be dealt with. The accounting period 1965 forms the basis for the whole research period, so that the variables of this accounting period are presented in detail in Appendix 5. The changes made in the forms and a detailed account of the data until 1991, which is the last year included in the study, are also presented in Appendix 5. The number of bookkeeping farms has varied during the research period, farms have been left out, and new farms have joined the bookkeeping.

Two different sets of data were collected from the bookkeeping dairy farms:

A dairy farms (44), which were included in the study during the whole research period (in 1962 and 1989 the milk production of these farms accounted for a minimum of 50% of the total return of agriculture, which does not include direct subsidies), and

B dairy farms (168–364), on which the milk production of the year in question accounted for a minimum of 70% of the total return of agriculture, which does not include direct subsidies.

The idea of a "representative" dairy farm was applied to both data sets (cf. TIFFIN 1991, p. 397). The observations of representative A and B dairy farms were obtained by calculating separately the averages from the A and B dairy farm data sets for each year.

The data set collected from the A dairy farms forms a panel data set. The production and cost theory is based on the decision-making of an individual entrepreneur. This means that the use of panel data consisting of information collected from individual dairy farms are theoretically on firmer ground and makes the application of theory more reliable than the use of aggregate data. During the research period the development of ADP made it possible to solve the research problem with panel data. Thus, the A dairy farms data set will be used as the panel data set, too.

The following information was collected from the bookkeeping farms:

Returns: return of milk, livestock, crop and garden production, and other agricultural return.

Costs: purchased feed, purchased fertilizers, maintenance of buildings and implements, rents of machinery and implements, insurance (tractor and combine harvester), and the labour costs of agricultural enterprises performed by a hired labour force (wages and social security payments).

Consumption of labour: hours of labour of hired workers and the men, women, and children of the farm family currently working and investing in agriculture.

Investments: investments in machinery, implements and production buildings, as well as income from sales of machinery and implements.

The quantity of output

The quantity of output was determined from the total return of agriculture, which includes the return of livestock production, crop production, and garden production. The percentage share of livestock production of the total return of agriculture on a representative A dairy farm varied annually from 85.6% to 97.1%, the average being 93.3%, and on a representative B dairy farm between 92.0% and 97.9%, with an average of 96.1%.

The quantities of output had not been written down on the farms included in the study, so that the aggregate output quantity was determined as follows. The producer price and quantity series of milk and other livestock products were used for determining the aggregate quantity of output, because it was not possible to determine the price and output series for the products forming the latter part of the total return of agriculture on the basis of the data. Also, the share of the products forming the latter part of the total return of agriculture was small. The producer price series of beef was used as the price series of other livestock products, because the meat from animals removed from production forms the largest share of other livestock products. This also includes the animals supplied to other farms, but these could not be separated into a group of their own in the data.

On the basis of this, the aggregate quantity of output was determined so that the total return of agriculture was regarded as consisting of the return of milk and other livestock products. The total return of agriculture was divided into the returns of milk and other livestock products in proportion to their shares of the return ($\sum_{i=1}^{2} = 1$). By means of the producer price series of milk and beef, the produced quantity series of milk and other livestock products were calculated. The aggregate output quantity is calculated from the price and quantity series as a Divisia index (1985 = 1.0000),

$$\ln Q_t - \ln Q_{t-1} = \sum_{i=1}^{M} \tfrac{1}{2} (v_{it} + v_{it-1}) (\ln q_{it} - \ln q_{it-1}), \quad (48)$$

in which $q_1,...,q_n$ are output quantities and Q is the Divisia quantity index. It is obtained by cumulating over time a weighted sum of rates of change of the component quantities. The weights are the arithmetic average of the output shares, $v_{it} = (p_{it}q_{it}/\sum_{j=1}^{M} p_{jt}q_{jt})$, in each of the two periods for which the rate of change is calculated. $p_1,...,p_n$ are producer prices. The Divisia index is used in aggregation, because as an ideal index it was considered the best choice among the index numbers (see Hulten 1973, Diewert 1976, 1978, Ylätalo 1987, p. 18).

The use of the Divisia index for aggregation has been a general starting point in empirical demand studies (e.g., Ray 1982, Higgins 1986). When the Divisia index is used, linear homogeneity of this aggregate is assumed. The Divisia quantity indices for the representative A and B dairy farms are presented in Appendix 6.

Costs

Labour cost: Labour cost is arrived at by adding up the labour costs of agricultural enterprises performed by a hired labour force (wages and social security payments) and the costs of the labour of the farm family. The labour cost of the farm family is determined by multiplying the hours of labour by the unit wages of agricultural workers. The share of hired labour in the total costs of the farms included in the study was small. On the bookkeeping farms the pension payments (MYEL) were separated from other payments only after 1989, so they could not be included in the labour cost. Until 1990, the pension payments were determined according to the area ("MYEL" hectares), specified separately for each farm, and included the share of forests as well.

Cost of machinery, implements, and buildings: For determining the cost of machinery, implements, and buildings, information on the capital stock, investments, and depreciations of dairy farms is needed. In this study the depreciations for agricultural machinery and implements is determined by assuming that after 15 years of use, machinery and implements have 10% of their initial value left. The research results on the age and time of use of machinery were taken into account when determining the depreciations (e.g., Bolin 1971, p. 66, Juvonen 1982, p. 44, Kämäräinen 1988, p. 55–57).

When economic plans are made in business economics, shorter periods of time than the technical time of use are often used in order to make sure that the property shares are depreciated in full before they are no longer used. In this study, the times of use of machinery and implements are based on research results, which means that they can be considered more accurate than the times of use based on rough approximations. However, certain reservations have to be made, because it is very difficult to determine the exact time of use of long-run property shares.

The depreciation of production buildings is determined in the same way as that of agricultural machinery and implements, and the time of use is 40 years (see Vihavainen et al. 1980, Ylätalo and Pyykkönen 1991). The property series used in the study are formulated so that the amount of capital at the end of the period t is equal to K_t. The series is formulated as follows (Boyle 1981, p. 158):

$$K_t = I_t + (1-d)K_{t-1}, \qquad (49)$$

in which I_t = investments in period t
d = constant rate of capital depreciation

In order to define K_t, the depreciation rate of capital d must be known. According to the assumptions presented above, the depreciation rate is determined as follows:

$$(1-d)^V = 0.1, \qquad (50)$$

in which V is the years of use of capital, when there is 10% left of the initial value of the capital item. As a result of these assumptions and calculations, the depreciation rates for agricultural machinery, implements, and buildings are as follows:

machinery and implements	d = 0.1423
buildings	d = 0.0559

For practical reasons, in 1968, the bookkeeping farms started to use the same property values used in the tax system (MTTL 1970, p. 3). In this connection, an initial inventory of capital assets was made according to section 18 in the Act on the Taxation of Farm Income (MVL). In the initial inventory of the capital assets, the replacement cost of agricultural buildings, machinery, and implements corresponding to their economic use value deducted by the following value reductions for each year, from the year when the goods were purchased or built, until 1968, is used as the purchase cost of agricultural buildings, machinery, and implements (Verohallitus 1988, p. 107–108):

production buildings:	
made of wood	5.0 %
made of stone	4.0 %
machinery and implements	20.0 %

In the study, the values of the capital items at the end of 1967, determined in the initial inventory, are considered the starting point in formulating the capital series. The capital values at the end of 1964 for machinery, implements, and buildings were determined as follows:

machinery and implements

$$K_t = (K_{t+1} - I_{t+1})/(1-0.2)$$

buildings

$$K_t = (K_{t+1} - I_{t+1})/(1-0.045) \qquad (51)$$

The capital series for machinery and implements was determined by means of equations (49) and (50) with the values at the end of 1964 as the starting point. The value of the investment work of the farm family was added to the building investment series of the bookkeeping farms. The value of the investment work on a dairy farm was calculated in the same way as the cost of the agricultural labour of the farm family.

The cost of machinery, implements, and buildings is obtained by multiplying the value of the capital series each year by the sum of the depreciation rate and the real interest rate, and by then adding the repair costs and rent of machinery.

The real interest rate was defined as the effective yields on tax free government bonds, deducted by the rate of inflation calculated from the cost-of-living index. The bonds were considered an alternative to investments.

Cost of purchased fertilizers and purchased feed: Costs collected directly from bookkeeping farms are used as costs of purchased fertilizers and purchased industrial feed.

Cost shares

$S_i = c_i / \Sigma c_i$,
S_i = the cost share of input i
c_i = cost of the use of input i

Prices

In the base year 1985, all indices are normalized so that they receive the value 1.0000.

Labour: The price of the labour input of men and women was collected from the publications "Studies on the profitability of Finnish agriculture" by the Agricultural Economics Research Institute (AERI) for the years 1965–1991. The total average income of agricultural workers (FIM/h) in quarters of a year was used as the price of the labour input. Because of the change in the statistical basis in 1982, the price of the labour input for 1965–1981 was chained to correspond to the series of 1982–1991.

The use of labour in agriculture varies according to the season. According to the research results, grazing reduces the use of labour during the summer, but, at the same time, the cultivation of crops increases the use of labour on dairy farms. On the basis of earlier research results, it was concluded that in the first and fourth quarter of a year the use of labour on dairy farms is about 20%, and in the second and third quarters it is about 30% of the use of labour during the whole year (Ryynänen and Pölkki 1982, p. 83, Alastalo 1991, p. 43–46). These percentages were used as weights in formulating the annual labour input price series.

The quantities of labour input were collected from the hours of labour done by men, women, and children on the farms included in the research. In the profitability study of agriculture the work done by under fourteen-year-olds is estimated at 50% of the work done by men, so that the hours of labour of men and children were calculated by dividing the children's hours of labour by two, and adding this to the men's hours of labour. This was followed by the calculation of the Divisia price indices of the labour input, presented in Appendix 6.

Purchased fertilizers and purchased feed: price indices calculated in the AERI, presented in Appendix 6.

Price of capital: The price of capital W_k is equal to the user cost of capital. It is considered an appropriate definition for the price of the capital input, because it describes the cost shares related to the ownership of the capital input. According to Boyle (1981, p. 159), the price series of capital in question can be formulated as follows:

$$W_K = q(r + d), \tag{52}$$

in which q = cost index of capital in question
r = real interest rate
d = fixed depreciation rate

The user costs of capital were calculated as Divisia indices, which are presented in Appendix 6 (Note! when inflation is high, (r+d) can be negative). In 1973–1975, it was negative in the case of production buildings. Thus, Divisia indices cannot be calculated for the years 1973–1975, and for these years W_K was calculated as a weighted average of capital items with weights of 0.3 for production buildings and 0.7 for machinery and implements (average cost shares during the research period).

It would be logical for the study to include arable land as well. However, determining the price and quality of arable land on the farms included in the study was impossible. Also, there were considerable differences between different statistical sources in the development of the prices of arable land (Ylätalo and Pyykkönen 1991, p. 3–7). For example, changes in the land use, mechanization of agriculture, the change on the trade of arable land into sales of supplementary land, as well as periods of inflation during the research period have affected the price of arable land. No reliable research data was available, and, consequently, arable land had to be excluded from the study.

Thus, the assumption of weak separability is not completely valid for arable land. However, in empirical studies the assumption of weak separability has to be made, and it has assumed a so-called "State of Art" status in applied economic study (CHAMBERS 1988, p. 157).

The problems related to the determination of the price of arable land and the capital stock, as well as the reliability of the data available from different sources, are extensively covered in the publications of IHAMUOTILA and STANTON (1970, p. 10–28), RYYNÄNEN (1978, p. 77–85), IHAMUOTILA (1983, p. 9–37), and YLÄTALO and PYYKKÖNEN (1991, p. 3–7).

8 Results of the study

8.1 Descriptive statistics of the farms included in the study

The data consists of farms participating in the profitability research of Finnish agriculture. Bookkeeping is realized on a voluntary basis, which means that these farms cannot be regarded as representing all Finnish dairy farms. The average farm size in terms of both the number of dairy cows and the area is considerably larger than in the whole country on the average. In 1990, the average number of cows on dairy farms of group A was 14.3 and in group B 15.6, whereas on all dairy farms the average number of cows was 10.8. The level of output is also above the average on the bookkeeping farms. Since the bookkeeping is voluntary, the agricultural entrepreneurs participating in it are more active than usual.

Information from the bookkeeping data was used, because the assumptions related to the production theory are more likely to be fulfilled on the farms included in the study than in sample data. Bookkeeping farms include fewer farms that give up production, which distorts the picture of the production technology on farms that continue production, than on all Finnish farms. Changes in the prices, measures to regulate production, changes in the production conditions, and other factors affect the bookkeeping farms in the same way as other farms are affected. This means that from the viewpoint of solving the research problem, the data is as good as sample data. Also, using sample data was not possible, because sample data was not recorded.

The data consisted of two sets: by means of dairy farm group A, the distortions caused by the change of farms could be eliminated, so that the data describes the development of the production technology in the same farm group. In dairy farm group B, part of the farms and the number of farms varied annually, so that the data were collected to describe the development of the production technology in the whole sector. The decrease in the number of the weakest and smallest dairy farms in the data should describe the general development in the whole sector reasonably well. It can be assumed that the change in the production technology has been more rapid on dairy farms of group B than in group A.

The development of the production technology on farms included in the study should be seen as development on farms that continue milk production, which should describe the future development quite well. The development of the arable land area and the number of dairy cows on a representative dairy farm of group A and B for 1965–1991 is presented in Figures 4 and 5.

Figures 4 and 5 show that on dairy farms of group B the farm size has grown more rapidly than in group A, measured as both the number of dairy cows and the arable land area. The development is similar when measured as the quantity

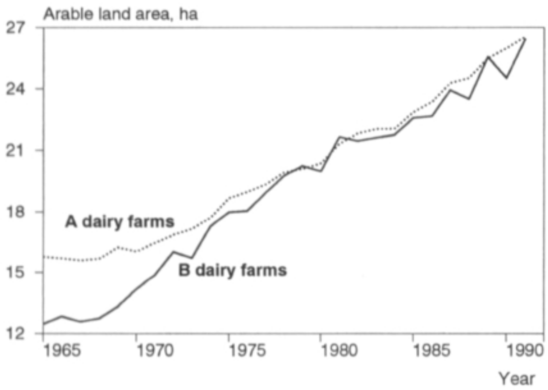

Fig. 4. Development of the arable land area on farms included in the study for 1965–1991.

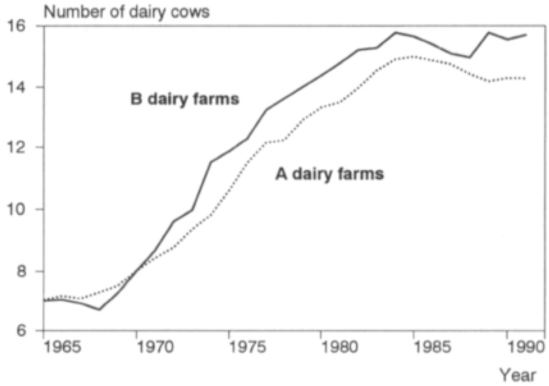

Fig. 5. Development of the number of dairy cows on farms included in the study for 1965–1991.

of output. The number of cows, arable land area, and their standard deviations every five years are presented in Tables 1a and 1b. The development of the output quantities, costs, and cost shares is presented in Appendix 6.

8.2 Representative dairy farm approach

8.2.1 Short run in a long-run study

Economic theory does not provide any unambiguous solution to the combination of short-run and long-run studies. As was noted in Chapter 3, this problem has aroused a lot of discussion both in economics in general and in agricultural economics. The adjustment cost model and the discontinuity of the first derivative function of the adjustment cost function linked to the fixity of inputs are difficult to combine into the same model, so that the study of the short-run adjustment by means of the traditional econometric techniques has been seen to be impossible. It is known that economic phenomena include an adjustment cost, but its theoretical foundations are not yet known accurately enough.

The error correction model has been offered as the solution to the combination of the short-run and long-run examination. The error correction model does not provide a solution to the problem of the economic theory, but it provides for the possibility to examine the linkage between the long-run equilibrium and the short-run dynamic development by means of empirical data. In the

Table 1a. Number of cows, arable land area, and their standard deviations on dairy farms of group A every five years.

	Cows	S.dev.	A.l.area	S.dev.
1965	7.04	2.43	15.77	6.83
1970	8.03	2.29	16.03	5.85
1975	10.62	3.87	18.69	7.31
1980	13.32	5.30	20.40	7.10
1985	15.02	5.10	22.88	8.02
1990	14.31	4.88	25.99	11.59

Table 1b. Number of cows, arable land area, and their standard deviations on dairy farms of group B every five years.

	Cows	S.dev.	A.l.area	S.dev.
1965	7.01	2.73	12.47	5.77
1970	8.04	3.38	14.19	6.29
1975	11.88	5.55	17.98	7.95
1980	14.41	7.04	20.02	10.40
1985	15.66	6.66	22.59	11.23
1990	15.57	5.89	24.53	10.96

following, it will be examined if the time series of the study are cointegrated, i.e., if it is possible to construct an error correction model to study the derived demand of inputs in milk production.

8.2.1.1 Autocorrelation functions

The autocorrelation function indicates the amount of correlation between the data points in the time series. In a stationary process the average, variance, and covariances are invariant with respect to time. The autocorrelation function can also be used for testing the stationarity of the time series (PINDYCK and RUBINFELD 1991, p. 449). If the value of the autocorrelation function does not decrease rapidly along with the increase in the lag, the result indicates nonstationarity.

On the basis of the autocorrelation functions, all the level terms of the time series of the study seemed nonstationary. This is, because the first autocorrelation coefficient is fairly high, and the coefficient decreases slowly when the lag is increased, but S_H and S_K seem to be questionable series. The autocorrelation functions of differenced series seem to be close to zero in the case of all other series, except for the ln W_L and ln C time series. The autocorrelation functions of the level terms and differenced time series are presented in Appendix 7.

According to the autocorrelation functions, the differencing of the series removes the nonstationarity from all series, except for the ln W_L and ln C series. From these series, second differences were taken, and the autocorrelation functions were calculated (see Appendix 7). According to the result, these series would seem to follow the I(2) process.

It is possible that the time series are cointegrated, if they are integrated of the same order, or if the higher order series are cointegrated with the order of the low order series. According to the autocorrelation functions, all series are not integrated of the same order.

8.2.1.2 DF- and ADF-tests

In a more accurate study of the order of integration, the Dickey-Fuller (DF) and Augmented Dickey-Fuller (ADF) tests are used. The following regressions are made in the tests (GRANGER 1991, p. 71):

$$\text{DF: } \Delta x_t = (\rho-1)x_{t-1} + \varepsilon_t, \tag{53}$$

$$\text{ADF: } \Delta x_t = (\rho-1)x_{t-1} + \sum_{j=1}^{p}\gamma_j\Delta x_{t-j} + \varepsilon_t, \tag{54}$$

in which Δ is $x_t - x_{t-1}$. In the DF- and ADF-tests the H_0 is that $\rho = 1$, in which case $x_t \sim I(1)$. The DF-test is used in the first order autoregressive case, and the ADF-test in the higher order autoregressive processes. Values defined by MACKINNON (1991, p. 267–275) are used as the critical values for cointegration.

To start with, the time series are examined by regressing each variable in the level form by their five lags. The estimated results are presented in Appendix 8. According to the results, the series seem to follow the AR(1) process, except for the ln W_H series. ADF-series is thus used only for ln W_H series, because otherwise the test becomes overparametrized in the AR(1) series (HETEMÄKI 1990, p. 35). Theoretically the ADF regression should include an adequate number of lagged first differences to make sure that the error term of the ADF regression would be white noise. In an empirical study this objective may be difficult to achieve, if the process has an ARMA representation, because the corresponding AR process usually has an infinite number of terms.

The DF- and ADF-tests were made with the intercept and the trend terms, because economic time series involve a trend component. On the basis of the results, all series seem to be I(1), except for ln W_L, ln W_M, and ln W_H series, which seem to be I(2) series, but ln W_H may be an I(3) series. On dairy farms of group A ln C and S_L series, and on dairy farms of group B S_M series are I(1) series at the 10% significance level, but they are I(2) series at the 1% significance level. The results of the DF- and ADF-tests are presented in Tables 2a and 2b.

The results from the autocorrelation functions are parallel to the results of the DF- and ADF-tests. In both cases ln W_L looks like an I(2) series, and ln C possibly like an I(2) series. The I(2) series according to the DF- and ADF-tests,

Table 2a. DF- and ADF-tests on dairy farms of group A.

Serie	Levels	1. diff.	2. diff.	3. diff.
ln W_K	–2.199	–4.265		
ln W_L	–0.120	–2.381	–5.685	
ln W_M	–0.895	–2.525	–4.591	
ln W_H	–3.220	–2.777	–3.385	–5.422
ln Y	–0.867	–4.921		
ln C	0.121	–3.437	–7.030	
S_K	–1.837	–4.199		
S_L	–1.604	–3.322	–5.618	
S_M	–0.865	–4.164		
S_H	–1.875	–5.422		

Table 2b. DF- and ADF-tests on dairy farms of group B.

Serie	Levels	1. diff.	2. diff.	3. diff.
ln W_K	–2.197	–4.275		
ln W_L	–0.050	–2.140	–5.179	
ln W_M	–0.895	–2.525	–4.591	
ln W_H	–3.220	–2.777	–3.385	–5.422
ln Y	–0.598	–4.701		
ln C	0.332	–3.821		
S_K	–1.803	–4.422		
S_L	–1.590	–5.067		
S_M	–0.909	–3.531	–5.470	
S_H	–1.011	–5.334		

Table 3. Mackinnon's critical values of cointegration for Tables 2a and 2b.

C.value	Levels	1. diff.	2. diff.	3. diff.
1 %	–4.374	–4.394	–4.417	–4.442
5 %	–3.603	–3.612	–3.622	–3.633
10 %	–3.237	–3.242	–3.247	–3.254

ln W_M and ln W_H, received the highest values of the autocorrelation function when differenced once, after the ln W_L series.

According to the theory, cointegration is possible if the variables are integrated of the same order. It is possible that a valid cointegration relationship exists between series of different orders, if the higher order series are cointegrated with the lower order series (HETEMÄKI 1990, p. 39). According to the results, ln W_L, ln W_M, and ln W_H are I(2) series, but if a cointegration vector, which is I(1), exists between them, the combination of these series and all I(1) series may form a valid cointegration relationship.

Therefore, it will be examined with yet another cointegration test if the first differences of the prices of labour, purchased feed, and purchased fertilizers (ln W_L, ln W_M, and ln W_H) are cointegrated. The test is made as an Engle-Granger cointegration test, in which one series at a time is regressed by the other series (ENGLE and GRANGER 1991). The test is based on testing the stationarity of the error term. If the error term is stationary, the variables are cointegrated. In the first stage of the test the cointegration regression between once differenced variables is estimated. In the second stage the stationarity of the obtained error term is tested by the DF-test. The results are presented in the following arrangement (A:=dairy farms of group A and B:=dairy farms of group B).

	Dependent	Independent	Independent	DF t value
A:	ln W_L	ln W_M	ln W_H	–2.841
A:	ln W_M	ln W_L	ln W_H	–3.571
A:	ln W_H	ln W_L	ln W_M	–2.526
B:	ln W_L	ln W_M	ln W_H	–2.755
B:	ln W_M	ln W_L	ln W_H	–3.572
B:	ln W_H	ln W_L	ln W_M	–2.553

Mackinnon's critical values:
1% –5.486 5% –4.621 10% –4.210

In addition, in the second stage of the cointegration test the ADF-test was performed on those error terms of the cointegration regressions in which the dependent variable of the cointegration regression on dairy farms of group A was ln W_L and ln W_M, and in group B ln W_M, because the autoregressive process of these error terms seemed a higher process than the AR(1) process (see Appendix 8). According to the ADF-test, the DF t values were –2.364 (A: ln W_L), –2.800 (A: ln W_M) and –2.783 (B: ln W_M), when Mackinnon's critical values at the 10% significance level were between –4.2 and –4.3.

According to the cointegration tests, I(2) series are not cointegrated, which means that they cannot form a cointegration relationship with the I(1) series and, consequently, an error correction model cannot be constructed to study the derived demand of inputs in milk production.

8.2.2 Empirical models and hypothesis tests

An empirical investigation is carried out on the basis of the theoretical model. In order to solve the research problem, alternative model specifications made possible by the production and cost theory were estimated from the empirical data, and the parameter restrictions set in the theoretical examination were tested. The parameters of the models were estimated from the equation system, consisting of the cost function (44) and the cost share equations (46), on which restrictions according to the production and cost theory were set between the equations. The restrictions were released according to each test situation. The symmetry assumption could not be tested from this equation system because of the lack of the degrees of freedom, so that they were tested from the equation system of the cost share equations (46).

The dependent cost shares sum up into one, i.e., the cost share equations form a singular equation system. As a result, the covariance matrix of the error terms of the cost share equations is singular. The singularity problem was solved by leaving out one cost share equation in the estimation (fertilizer input). The parameters of the equation left out were calculated from the parameter restrictions, and their t values by replacing the cost share equation of purchased feed by the cost share equation of fertilizers. The following models made possible by the production technology were estimated from the equation system of the cost function and the cost share equations:

1. non-homothetic function – non-neutral technical change (NH-NN)
2. homothetic function – non-neutral technical change (H-NN)
3. homogenous function – non-neutral technical change (HG-NN)
4. non-homothetic function – neutral technical change (NH-N)
5. constant return to scale – non-neutral technical change (C-NN)

The models derived in the theoretical part of the study and the parameter restrictions set for them are tested by means of the empirical data. If statistical tests reject the models derived from the theory and the theoretical parameter restrictions, the theory and the models derived from the theory become questionable. In empirical study "theory" is also used to refer to the functional form and the estimation technique chosen, as well as to the economic theory on which the model to be estimated is based (Tiffin 1991, p. 398).

The model specifications and parameter restrictions according to the production and cost theory were tested by the likelihood ratio test. The first row in Table 4 gives the χ^2 test value for H_0 hypothesis, for example, supporting the symmetry assumption (SYM) $\beta_{ij} = \beta_{ji}$ in all $i \neq j$, against the alternative H_1 hypothesis of no symmetry. The calculated χ^2 values of the symmetry assumption on farms of group A was 9.09, and in group B 2.12, which are smaller than the critical values at the 1% and 5% significance level. Therefore, the H_0 hypothesis on the symmetry of the Hessian matrix is not rejected. The alternative model specifications made possible by the production and cost theory were tested with the symmetry assumption in force.

The H_0 hypotheses of the homotheticity and homogeneity of the production technology, neutral technical change, and constant returns to scale are rejected at the 1% significance level. According to the likelihood ratio test, the structure of the cost function cannot be simplified from the general model (NH-NN), so that in the following, a cost function that is consistent with a non-homothetic production process and describes non-neutral technical change is used.

The specification of the cost function to de-

Table 4. Critical values of χ^2 test in testing H_0 hypotheses.

H_0-hypothesis	Solved value		Degrees of freedom	Critical value	
	A farms	B farms		1%	5%
SYM	9.09	2.12	6	16.81	12.59
H-NN	24.96	36.81	5	15.09	11.07
HG-NN	25.00	36.92	6	16.81	12.59
NH-N	16.58	26.17	4	13.28	9.47
C-NN	53.83	71.76	7	18.48	14.07

Table 5a. Estimated parameters solved from the equation system of the cost function and the cost share equations on dairy farms of group A (p values in parenthesis).

β_{KK}	0.1321 (0.000)	β_{KL}	–0.0455 (0.000)	β_{KM}	–0.0772 (0.000)	β_{KH}	–0.0094 (0.230)
β_{LL}	0.0204 (0.399)	β_{LM}	0.0326 (0.157)	β_{LH}	–0.0075 (0.631)	β_{MM}	0.0187 (0.545)
β_{MH}	0.0259 (0.140)	β_{HH}	–0.0090 (0.612)	β_0	1.5757 (0.169)	β_K	0.1119 (0.005)
β_L	0.3827 (0.000)	β_M	0.3398 (0.000)	β_H	0.1656 (0.002)	β_Y	4.5892 (0.073)
β_{YY}	5.0288 (0.062)	β_{YK}	–0.1019 (0.008)	β_{YL}	–0.1445 (0.007)	β_{YM}	0.1742 (0.004)
β_{YH}	0.0722 (0.001)	β_T	–0.1380 (0.182)	β_{TT}	0.0061 (0.191)	β_{TY}	–0.2103 (0.079)
β_{TK}	0.0056 (0.004)	β_{TL}	0.0034 (0.103)	β_{TM}	–0.0056 (0.020)	β_{TH}	–0.0034 (0.028)
γ_{K+}	0.0100 (0.032)	γ_{K-}	–0.0159 (0.002)	γ_{L+}	0.0271 (0.032)	γ_{L-}	–0.0210 (0.002)
γ_{M+}	–0.0275 (0.000)	γ_{M-}	0.0319 (0.000)	γ_{H+}	–0.0096 (0.017)	γ_{H-}	0.0050 (0.174)
γ_{KI}	0.0743 (0.000)	γ_{LI}	0.0251 (0.129)	γ_{MI}	–0.0805 (0.000)	γ_{HI}	–0.0189 (0.111)
γ_{CI}	0.5711 (0.069)						

scribe non-homothetic production technology and non-neutral technical change means that changes in the prices of inputs and the level of output affect significantly economies of scale (size) and technical development. The result of the likelihood ratio test is supported by the fact that the parameters β_{Yi} and β_{Ti}, presented in Tables 5a and 5b, are all statistically significant, except for β_{TL} on A dairy farms, and β_{TL} and β_{TH} in group B. The values of the parameters estimated from the NH-NN model and their asymptotic p values (in parentheses) are presented in Tables 5a and 5b.

In addition to the relative prices, change in output, and technical change, the weather conditions also have an effect on the derived demand for inputs in milk production. The weather conditions affect directly the yields of silage, hay, pasture and feed grain, as well as the quality of the crops. Thus, the weather conditions must be estimated in the model as a dummy variable. Dum-

Table 5b. Estimated parameters solved from the equation system of the cost function and the cost share equations on dairy farms of group B (p values in parenthesis).

β_{KK}	0.1350	β_{KL}	–0.0451	β_{KM}	–0.0729	β_{KH}	–0.0170
	(0.000)		(0.000)		(0.000)		(0.011)
β_{LL}	0.0943	β_{LM}	–0.0404	β_{LH}	–0.0088	β_{MM}	0.1105
	(0.001)		(0.120)		(0.434)		(0.036)
β_{MH}	0.0028	β_{HH}	0.0231	β_0	–0.8462	β_K	0.1007
	(0.833)		(0.051)		(0.189)		(0.005)
β_L	0.4453	β_M	0.3377	β_H	0.1163	β_Y	–0.4611
	(0.000)		(0.000)		(0.001)		(0.624)
β_{YY}	–0.5333	β_{YK}	–0.0810	β_{YL}	–0.1265	β_{YM}	0.1802
	(0.490)		(0.000)		(0.000)		(0.000)
β_{YH}	0.0273	β_T	0.0804	β_{TT}	–0.0037	β_{TY}	0.0307
	(0.046)		(0.188)		(0.197)		(0.489)
β_{TK}	0.0059	β_{TL}	0.0002	β_{TM}	–0.0051	β_{TH}	–0.0010
	(0.000)		(0.876)		(0.001)		(0.283)
γ_{K+}	0.0098	γ_{K-}	–0.0170	γ_{L+}	0.0230	γ_{L-}	–0.0118
	(0.048)		(0.002)		(0.000)		(0.017)
γ_{M+}	–0.0170	γ_{M-}	0.0278	γ_{H+}	–0.0158	γ_{H-}	0.0010
	(0.012)		(0.000)		(0.000)		(0.695)
γ_{KI}	0.1046	γ_{LI}	–0.0218	γ_{MI}	–0.0576	γ_{HI}	–0.0252
	(0.000)		(0.125)		(0.008)		(0.007)
γ_{CI}	0.0451						
	(0.088)						

my variables refer to either-or situations. Thus, something either happened or did not happen. According to INTRILIGATOR (1978, p. 58–61), dummy variables can encompass qualitative variables and qualitative shifts over time or space (e.g., war or peace time). A dummy variable receives only two values (0,1), of which one means one possibility, and the other the other possibility.

In this study the weather conditions were included in the cost share equations as dummy variables by formulating two distinct dummy variables: 1) an exceptionally good year and the year following it were marked by one and other years by zeros, 2) an exceptionally poor year and the year following it were marked by one, and other years by zeros. It was important to include the weather conditions because almost all of the weather dummy variables of the cost share functions of the capital item, purchased feed, and purchased fertilizers were statistically significant at the 5% significance level. A dummy variable was also used for the period of high inflation from 1973–1975 (> 15%). In this study, it is assumed that dummy variables affect the intercepts of the estimated functions. The values of the dummy variables γ_{i+} (good years), γ_{i-} (poor years), and γ_{iI} (period of high inflation) are presented in the lower part of Tables 5a and 5b.

8.2.2.1 Regression statistics and tests

The validity of the model depends on the overall fit of the estimated system, the significance of the coefficients, and whether the estimated cost function satisfies the theoretical assumptions (WEAVER 1983, p. 51). The overall fit of the estimated NH-NN models is good, when the measurement is made using the R^2 and F values. When measured by the corrected R^2 (R^2_K), the goodness-of-fit of the cost functions on A farms are 0.994 and on B farms 0.997 (F values: 220.1 and 358.2), and the goodness-of-fit of the cost share equations vary between 0.871 and 0.959 (F values vary between 22.9–77.1). The use of the cor-

Table 6a. Goodness-of-fit, F values, and significance of the cost function (C) and the cost share equations (S_i), and the standard error of the regression (SER) on farms of group A.

Function	R^2	R^2_K	F value	Significance	SER
C	0.999	0.994	220.1	0.000	0.077
S_K	0.972	0.959	77.1	0.000	0.010
S_L	0.938	0.911	34.2	0.000	0.013
S_M	0.910	0.871	22.9	0.000	0.013

Table 6b. Goodness-of-fit, F values, and significance of the cost function (C) and the cost share equations (S_i), and the standard error of the regression (SER) on farms of group B.

Function	R^2	R^2_K	F value	Significance	SER
C	0.999	0.997	358.2	0.000	0.064
S_K	0.969	0.956	71.4	0.000	0.013
S_L	0.961	0.944	55.6	0.000	0.009
S_M	0.941	0.914	35.7	0.000	0.012

rected R^2 in examining the goodness-of-fit of the model is desirable, because when a corrected R^2 is used, the improving effect of the number of dependent variables on R^2 is eliminated (PINDYCK and RUBINFELD 1991, pp. 76–79). According to Pindyck and Rubinfeld, the standard error of the regression (SER) in relation to the average of the dependent variable should not exceed 15%. In the cost function and the cost share equations this ratio varies between 1.8% and 7.6%. The goodness-of-fit measures, F values, and SER of the cost function and the cost share equations are presented in Tables 6a and 6b.

In evaluating the estimated model, the statistical significance of the estimated parameters, i.e., the significant deviation from zero, is generally used. The number of statistically significant parameters on dairy farms of group A is 23 (18), and on dairy farms of group B 26 (20) of the possible total of 41 parameters at the 5 (1) % significance level. Of the parameters related to the elasticities of substitution and own price elasticities (marked in equation (38) by β_{ij}) on A farms three (β_{KK} (1%), β_{KL} (1%) and β_{KM} (1%)) and on B farms six (β_{KK} (1%), β_{KL} (1%), β_{KM} (1%), β_{KH} (5%), β_{LL} (1%) and β_{MM} (5%)) out of ten deviated statistically from zero.

The statistical significance criterion of parameters is appropriate for evaluating the parameters of 'ad hoc' models, in which the statistical significance of parameters is used as justification for including them in the model. In theoretically derived models, like the model of this study, the inclusion of the parameters into the model is justified by the theory, which is considered a more powerful justification than the statistical significance of 'ad hoc' parameters (TIFFIN 1991, p. 399).

The number of statistically significant parameters may usually give some indication of the degree of reliability of the results provided by the measurements derived from the model. It should be noted, however, that in this model, which is based on the idea of estimating the parameters that are first and second order logarithmic derivatives of the cost function evaluated at the approximation point, no prior expectations about their sign are set by the production and cost theory (see WEAVER 1983, p. 51).

According to the results, the weather conditions influenced the demand for inputs on dairy farms in a significant way. This result can be regarded as correct, because the shortage of feed resulting from poor crops is satisfied by means of purchased feed and, correspondingly, in good years the need for purchased feed decreases. This means that at the same input prices the cost shares of inputs are not the same in good and poor years.

The H_0 hypothesis, the error term of the explained equations includes a first order positive autocorrelation, was tested by the Durbin-Watson test. The critical values of the DW-test in the case of 27 observations and five independent variables (PINDYCK and RUBINFELD 1991, p. 568) and the DW-values of the estimated functions are presented in Table 7.

According to PINDYCK and RUBINFELD (1991, p. 144–145), in time series the independent vari-

Table 7. Critical values and estimated values of the DW-test.

	Critical values		Est. DW-value	
Function	d_l	d_u	A farms	B farms
C	1.01	1.86	1.30	1.16
S_K	1.01	1.86	1.55	1.29
S_L	1.01	1.86	1.20	1.67
S_M	1.01	1.86	1.34	1.35

ables are likely to be autocorrelated, in which case the use of the d_l value may be the more significant one of the two values. In connection with the testing of the time series properties of the independent variables, it was observed that they include an AR(1) process, and in one case an AR(2) process. The DW-test values of the estimated functions remain between the critical values, which means that the H_0 hypothesis can be neither accepted nor rejected. If d_l is considered the limit of the test, the H_0 hypothesis can be rejected.

When the covariance matrix of the error terms is singular, the significant autocorrelation of the error terms causes the estimated parameters to become dependent on which cost share equation is left out of the system to be estimated (Berndt and Savin 1975). When the cost share equation to be left out was varied, no changes were observed to occur in the values of the parameters, so that in this respect the possible autocorrelation of the error terms does not hinder the estimation and interpretation of the parameters. As a summary of the general examination, it can be noted that the models are at least satisfactory.

8.2.2.2 Empirical models and the theoretical assumptions

The cost function estimated empirically is well behaved, if it is consistent with a theoretically well defined cost function. In a well behaved cost function, the cost shares, cost flexibility, and technical change are homogenous of degree zero with respect to input prices. In addition, a well behaved cost function satisfies the conditions of monotonicity and concavity. Also, the cost shares must sum up into one, and the Hessian matrix of the second partial derivatives of the cost function must be a symmetric matrix, according to Young's Theorem.

According to the production and cost theory, the cost shares and cost flexibility should be non-negative. Parametric restrictions that make sure the non-negativity of the cost shares and cost flexibility cannot be set in advance to the translog cost function without losing the flexibility of the cost function. Instead, restrictions that imply monotonicity of the cost shares wherever they are non-negative are considered (Jorgenson 1986, p. 1858). The matrix of the cost shares derived from the translog cost function (β_{ij}+SS'-diag[S]), in which diag[S] is the diagonal matrix with S_i's on the diagonal, must be negative semidefinite (Lau 1986, p. 1543). The negative semidefiniteness of the matrix ensures that the cost function is concave as a function of input prices when the cost shares are non-negative.

The symmetry assumption was tested from the cost share equations, and it was accepted in both farm groups. On dairy farms of groups A and B the estimated cost shares were positive at all observation points. On B farms the cost flexibility was positive at all observation points, but on A farms 14 out of 26 observations were negative. According to Ball and Chambers (1982, p. 706), it is possible that the cost flexibility and technical change are confounded when equation (38) is estimated, in which case it is doubtful whether the cost flexibility estimated from equation (38) can be interpreted appropriately.

According to Diamond et al. (1978, p. 147), reliable cost flexibility cannot be defined from time series data, rather cross section data is needed. In spite of this, equations like (38) are frequently used in empirical studies to solve the cost flexibility from time series data (e.g., Ray 1982, Glass and McKillop 1990).

In empirical studies in economics, restrictive assumptions are also generally made on, for example, the neutrality of cost flexibility, in which case the output has not been included in equation

(38) (e.g., BINSWANGER 1974), or constant returns to scale (e.g., BERNDT and WOOD 1975). If the cost function of the dairy farms of groups A and B is restricted by the homogeneity assumption (HG-NN), the cost flexibility on A farms is 0.33 and on B farms 0.39. When the cost function to be estimated is defined as homogenous, explaining the variation of costs by input prices and technical change only may lead to an incorrect interpretation, if cost variation is partly caused by variation in the factors of cost flexibility, too. The technical change and cost flexibility are dealt with in more detail in a chapter of their own.

A necessary condition for the concavity of the cost function as a function of input prices is that all own price elasticities are negative. A necessary and sufficient condition on concavity is that the Hessian matrix formed from the parameters estimated from the cost function is negative semidefinite. The sign of the own price elasticity of labour, purchased feed, and purchased fertilizers is at all observation points in accordance with the theory. The sign of the own price elasticity of capital items is in accordance with the theory, except during the years of exceptionally high inflation 1973–1975, and in 1980, when the inflation was also high, so that the necessary condition on concavity is not satisfied in these years. In other years the Hessian matrix formed from the parameters estimated from the cost function on dairy farms of group A is negative semidefinite. In group B the Hessian matrix is negative semidefinite in 1978 and 1983–1991, and in other years it is indefinite.

A possible reason for the deviation of the model from the assumption for 1973–1975 and 1980 is the rapid and drastic change in the relative prices caused by inflation. The indefiniteness of the Hessian matrix of B dairy farms for 1965–1977 and 1979–1982 may be caused partly by the great annual variation in the number of farms included in the study during this period of time (Appendix 8). According to the research results, during rapid and drastic changes it is not possible to adjust the production of dairy farms immediately in a way the changes would require.

However, it should be noted that a situation in which the concavity assumption is not satisfied is not uncommon in empirical study (see e.g., GLASS and MCKILLOP 1990, p. 276, CHAMBERS and POPE 1994, p. 110). According to WALES (1977, p. 191), slight deviations from the assumptions of concavity and monotonicity do not necessarily weaken the assumption of cost minimization or the reliability of the estimated parameters.

8.2.2.3 Empirical models for the post energy crisis period

At the beginning of the research period there was a powerful economic shock, the energy crisis, which greatly affected the preconditions for action of the national economy and private enterprises, such as dairy farms. In addition, there was extensive annual variation in the data for the first part of the study on dairy farms of group B. Thus, it is also necessary to examine the economic activity of dairy farms during a less dramatic period in order to provide more uniform data.

Models are estimated for the period after the energy crisis, 1976–1991. The time span is so short that the cost function cannot be estimated due to the lack of the degrees of freedom, so that the models are estimated from the cost share equations. Flexible functional forms and the dual approach make it possible to estimate the elasticities of substitution without the cost function. It is not possible to solve the cost flexibility and the technical change from the cost share equations.

The calculated χ^2 value of the symmetry assumption on farms of group A was 12.85, and in group B 4.97, which are smaller than 16.81, the critical value at the 1% significance level. Therefore, the H_0 hypothesis on the symmetry of the Hessian matrix is not rejected. The cost share equation system (46) is estimated holding the parameter restrictions (45) in force. The values of the parameters estimated from the cost share equations, and their asymptotic p values in parenthesis, are presented in Tables 8a and 8b.

The estimated models of cost share equation systems fit the data well, when the measurement is made using the R^2 and F values. The corrected

Table 8a. The estimated parameters of the cost share equation system on dairy farms of group A for 1976–1991 (p values in parenthesis).

β_{KK}	0.1060 (0.000)	β_{KL}	–0.0256 (0.014)	β_{KM}	–0.1029 (0.000)	β_{KH}	0.0225 (0.041)
β_{LL}	0.0584 (0.015)	β_{LM}	0.0158 (0.424)	β_{LH}	–0.0486 (0.011)	β_{MM}	0.0609 (0.073)
β_{MH}	0.0262 (0.225)	β_{HH}	–0.0001 (0.998)	β_{K}	0.1650 (0.000)	β_{L}	0.3559 (0.000)
β_{M}	0.3128 (0.000)	β_{H}	0.1663 (0.014)	β_{YK}	0.0387 (0.314)	β_{YL}	–0.2394 (0.002)
β_{YM}	0.1387 (0.096)	β_{YH}	0.0620 (0.371)	β_{TK}	0.0031 (0.046)	β_{TL}	0.0044 (0.072)
β_{TM}	–0.0044 (0.134)	β_{TH}	–0.0031 (0.245)				
γ_{K+}	0.0144 (0.001)	γ_{K-}	–0.0095 (0.004)	γ_{L+}	0.0148 (0.002)	γ_{L-}	–0.0174 (0.000)
γ_{M+}	–0.0251 (0.002)	γ_{M-}	0.0237 (0.001)	γ_{H+}	–0.0041 (0.403)	γ_{H-}	0.0032 (0.442)

Table 8b. The estimated parameters of the cost share equation system on dairy farms of group B for 1976–1991 (p values in parenthesis).

β_{KK}	0.0991 (0.000)	β_{KL}	–0.0366 (0.004)	β_{KM}	–0.0658 (0.001)	β_{KH}	0.0033 (0.653)
β_{LL}	0.0892 (0.001)	β_{LM}	–0.0243 (0.226)	β_{LH}	–0.0283 (0.037)	β_{MM}	0.1021 (0.005)
β_{MH}	–0.0120 (0.364)	β_{HH}	0.0370 (0.019)	β_{K}	0.0991 (0.004)	β_{L}	0.4278 (0.000)
β_{M}	0.3854 (0.000)	β_{H}	0.0877 (0.014)	β_{YK}	–0.0168 (0.621)	β_{YL}	–0.1697 (0.003)
β_{YM}	0.2062 (0.005)	β_{YH}	–0.0197 (0.540)	β_{TK}	0.0058 (0.001)	β_{TL}	0.0010 (0.547)
β_{TM}	–0.0074 (0.006)	β_{TH}	0.0006 (0.671)				
γ_{K+}	0.0116 (0.005)	γ_{K-}	–0.0118 (0.003)	γ_{L+}	0.0196 (0.001)	γ_{L-}	–0.0132 (0.004)
γ_{M+}	–0.0176 (0.007)	γ_{M-}	0.0279 (0.000)	γ_{H+}	–0.0136 (0.001)	γ_{H-}	–0.0029 (0.272)

R^2 of the cost share equations varies between 0.862 and 0.976 (F value varies between 14.4 and 89.7). In the cost share equations the standard error of the regression in relation to the average of the dependent variable varied between 1.3% and 4.4%. The goodness-of-fit measures, F values, and SER of the cost share equations are presented in Tables 9a and 9b.

The number of statistically significant parameters on dairy farms of group A is 18 (12), and in group B 22 (19) out of a possible total of 30 parameters at the 5 (1) % significance level. Of the parameters related to the elasticities of substitution and own price elasticities, on A farms six (β_{KK} (1%), β_{KL} (5%), β_{KM} (1%), β_{KH} (5%), β_{LL} (5%), and β_{LH} (5%)); and on B farms seven (β_{KK}

Table 9a. Goodness-of-fit, F values, and significance, as well as the standard error of the regression (SER) of the cost share equations (S_i) on dairy farms of group A.

Function	R^2	R^2_K	F value	Significance	SER
S_K	0.987	0.976	89.7	0.000	0.023
S_L	0.954	0.914	23.7	0.000	0.013
S_M	0.927	0.862	14.4	0.000	0.044

Table 9b. Goodness-of-fit, F values, and significance, as well as the standard error of the regression (SER) of the cost share equations (S_i) on dairy farms of group B.

Function	R^2	R^2_K	F value	Significance	SER
S_K	0.986	0.973	78.8	0.000	0.029
S_L	0.954	0.913	23.6	0.000	0.014
S_M	0.930	0.869	15.2	0.000	0.040

(1%), β_{KL} (1%), β_{KM} (1%), β_{LL} (1%), β_{LH} (5%), β_{HH} (1%), and β_{MM} (5%)) out of ten deviated statistically from zero.

According to the results, the weather conditions affect the demand for inputs in a significant way, so that at the same input prices the cost shares vary due to good and poor years. The results obtained from the post energy crisis period is consistent with the results of the whole research period.

Table 10 presents the critical values of the DW-test in the case of 16 observations and five independent variables (Pindyck and Rubinfeld 1991, p. 568), as well as the estimated values when the H_0 hypothesis, the error term of the explained equations includes a first order positive autocorrelation, is tested. The area between d_l and d_u values is wide, due to the small number of observations. The number of observations cannot be increased, because the data are available only as annual data. The DW values of the estimated functions remain between the critical values in two out of three functions, which means that the H_0 hypothesis cannot be accepted or rejected. When the cost share equation to be left out was varied, no changes were observed in the values of the parameters. As a summary of the general examination, it can be noted that the models are at least satisfactory.

The cost share equation system estimated empirically is well-behaved, if it is consistent with the theoretical assumptions. Homogeneity of degree zero with respect to input prices was ensured by means of parameter restrictions. In addition, it was ensured that the cost shares sum up to one, and the Hessian matrix is a symmetric matrix according to Young's Theorem.

Table 10. Critical values of the DW-test and values estimated from the cost share functions.

	Critical values		Est. DW value	
Function	d_l	d_u	A farms	B farms
S_K	0.62	2.15	2.62	2.06
S_L	0.62	2.15	1.78	2.95
S_M	0.62	2.15	1.90	2.07

According to the production and cost theory, the cost shares should be non-negative. Parameter restrictions that guarantee the non-negativity of the cost shares cannot be set in advance in the cost share equations solved from the translog cost function without losing the flexibility of the cost function. The matrix of the cost shares derived from the translog cost function (β_{ij} + SS'-diag[S]) should be negative semidefinite. The negative semidefiniteness of the matrix makes sure that the cost function is concave, as a function of input prices when the cost shares are non-negative.

The cost shares estimated from dairy farms of groups A and B are positive at all observation points. The sign of the own price elasticity of the inputs included in the model is in accordance with the theory, so that the necessary condition for the concavity of the cost function with respect to input prices is satisfied at all observation points. The Hessian matrix of the parameters estimated on dairy farms of group A is negative semidefinite, except in 1976 and 1980. On dairy farms of group B the Hessian matrix is negative semidefinite in all years included in the research, so that the concavity of the cost function with respect to input prices is realized at all observation points. On the basis of the result, milk producers seem to behave according to the cost minimization assumption. The deviation of the model of the dairy farms of group A from the assumption in 1976 and 1980 may partly be caused by the rapid and powerful economic shocks in the 1970s, as well as the inflation shock of 1980.

8.2.3 Elasticities of substitution

In the theoretical part of the study it was presented analytically that there may be differences between the values (measurements) of substitution defined in different ways. Because of these possible differences, the elasticities of substitutions should be solved from the data by means of several measurements for the elasticity of substitution. In this study the derived demand elasticities, Allen and Morishima partial elasticities of substitution, and shadow elasticities of substitution are solved from the data. In the study the elasticities of substitution are solved from a system of four inputs: capital items K, labour L, purchased feed M, and purchased fertilizers H.

8.2.3.1 Allen partial elasticities of substitution and derived demand elasticities

The determination of Allen partial elasticities of substitution and derived demand elasticities is based on both the estimated parameters presented in Tables 5a, 5b, 8a, and 8b and the estimated values of the cost shares solved by means of Shephard's Lemma. The economic information included in parameters β_{ii} and β_{ij} in the tables cannot be seen directly from their values, so that elasticity formulas for the translog cost function have been derived for the calculation of the elasticities of substitution. Allen partial elasticities of substitution can be calculated from the translog cost function by the following formulas:

$$\sigma_{ij} = \frac{\beta_{ij}}{S_i S_j} + 1 \tag{55}$$

$$\sigma_{ii} = \frac{\beta_{ii}}{S_i^2} - \frac{1}{S_i} + 1 \tag{56}$$

These elasticity formulas have been derived by BINSWANGER (1974). According to formula (24), the Allen partial elasticity of substitution is equal to the derived demand elasticity divided by the cost share. The derived demand elasticities can be determined from formula (24), and these are presented in Tables 11a–11d. The first column in the tables gives the value of e_{Kj}, the second the value of e_{Lj}, and so forth. The elasticities have been solved from the values of the parameters presented in the elasticity formulas and the averages of the cost shares. The results of the tables can be interpreted, ceteris paribus, as the average demand behaviour of the research period when the price in question changes. Tables 11a–11d present the derived demand elasticities, because these are more informative than Allen partial elasticities of substitution.

The elasticities of substitution are positive (negative), if inputs are substitutes (complements) of each other. These relationships are easier to examine from Allen partial elasticities of substitution than from derived demand elasticities, because Allen partial elasticities of substitution are symmetric. All inputs seem to be Allen substitutes with each other, except the capital items and purchased feed. On dairy farms of group A, in the data for the post energy crisis period, the Allen partial elasticity of substitution of labour and purchased fertilizers was also negative. In all examinations the relationship of complementarity was found between only one pair of inputs, so that when relative prices change in milk production, it is possible to substitute cheaper inputs for an input that becomes more expensive, at least to some extent.

According to the cross price elasticity e_{ij}, the inputs are for the most part substitutes with each other, as should be the case according to Allen partial elasticities of substitution. It can be seen in Tables 11a–11d that the cross price elasticities are not symmetric. The asymmetry can be interpreted so that, for example, the demand for la-

Table 11a. Derived demand elasticities on dairy farms of group A.

	K	L	M	H
K	–0.150	0.114	–0.189	0.107
	(0.040)	(0.020)	(0.054)	(0.081)
L	0.281	–0.456	0.670	0.424
	(0.040)	(0.048)	(0.105)	(0.165)
M	–0.181	0.261	–0.709	0.467
	(0.056)	(0.045)	(0.157)	(0.179)
H	0.050	0.081	0.228	–0.998
	(0.037)	(0.031)	(0.034)	(0.185)

Standard errors in parentheses: s.e.(e_{ij}) = s.e.(β_{ij})/S_i

Table 11b. Derived demand elasticities on dairy farms of group B.

	K	L	M	H
K	–0.110	0.103	–0.144	0.013
	(0.053)	(0.018)	(0.065)	(0.064)
L	0.264	–0.313	0.309	0.403
	(0.051)	(0.045)	(0.115)	(0.118)
M	–0.160	0.134	–0.272	0.245
	(0.028)	(0.050)	(0.153)	(0.140)
H	0.006	0.076	0.107	–0.661
	(0.012)	(0.022)	(0.061)	(0.117)

Table 11c. Derived demand elasticities for post energy crisis period on dairy farms of group A.

	K	L	M	H
K	–0.281	0.155	–0.283	0.444
	(0.035)	(0.017)	(0.048)	(0.099)
L	0.364	–0.393	0.563	–0.024
	(0.039)	(0.040)	(0.082)	(0.157)
M	–0.286	0.242	–0.500	0.486
	(0.053)	(0.040)	(0.130)	(0.212)
H	0.203	–0.004	0.220	–0.906
	(0.044)	(0.031)	(0.087)	(0.317)

Table 11d. Derived demand elasticities for post energy crisis period on dairy farms of group B.

	K	L	M	H
K	–0.303	0.122	–0.081	0.234
	(0.044)	(0.019)	(0.057)	(0.075)
L	0.288	–0.339	0.368	0.171
	(0.046)	(0.037)	(0.079)	(0.121)
M	–0.095	0.183	–0.330	0.106
	(0.067)	(0.039)	(0.114)	(0.133)
H	0.110	0.034	0.043	–0.512
	(0.035)	(0.024)	(0.053)	(0.134)

bour increases when the price of capital items rises less than the demand for capital items when the price of labour rises. According to the results, the use of capital items is more sensitive to a change in the price of labour than the use of labour to a change in the price of capital items, which means that the substitution of labour for capital items is very inelastic.

The cross price elasticity between labour and capital items is inelastic in the other direction, too, and the elasticity varies between 0.264 and 0.364. Similarly, the cross price elasticities between capital items and purchased fertilizers and, labour and purchased fertilizers are, on the average, very inelastic, so that the substitution of these inputs with each other is very difficult. On the average, the cross price elasticities are more elastic between labour and purchased feed, and between purchased fertilizers and purchased feed. The elasticities vary between 0.134 and 0.670, and between 0.043 and 0.486, respectively, which shows that there is inelasticity between these inputs, too, and thus their substitutability with each other is weak.

The signs of the own price elasticities (e_{ii}) of all inputs in Tables 11a–11d are in accordance with the theory. The demand for capital items was the most inelastic; the elasticity varied between –0.110 and –0.303. The demand for labour was almost as inelastic, so that a change of 1% in the own price of these inputs caused a change of only less than 0.5% in the use of these inputs. The demand for purchased fertilizers is the most elastic; the elasticity varies between –0.512 and –0.998. According to the results, a price change of 1% leads to, on the average, a change of clearly under 1% in the demand for the input in question, when all other factors are held constant.

Table 12a. Morishima partial elasticities of substitution on dairy farms of group A.

	K	L	M	H
K	–	0.265	–0.039	0.257
L	0.737	–	1.126	0.881
M	0.528	0.970	–	1.176
H	1.048	1.079	1.226	–

Table 12b. Morishima partial elasticities of substitution on dairy farms of group B.

	K	L	M	H
K	–	0.213	–0.034	0.123
L	0.577	–	0.623	0.716
M	0.112	0.406	–	0.518
H	0.667	0.737	0.768	–

Table 12c. Morishima partial elasticities of substitution for the post energy crisis period on dairy farms of group A.

	K	L	M	H
K	–	0.436	–0.001	0.725
L	0.757	–	0.955	0.369
M	0.214	0.742	–	0.986
H	1.110	0.901	1.126	–

Table 12d. Morishima partial elasticities of substitution for the post energy crisis period on dairy farms of group B.

	K	L	M	H
K	–	0.426	0.223	0.538
L	0.628	–	0.707	0.510
M	0.235	0.513	–	0.436
H	0.622	0.546	0.555	–

8.2.3.2 Morishima partial elasticities of substitution

The Allen partial elasticity of substitution and the derived demand elasticity measure solely the adjustment of a single input to a change in the price of a single input. Instead, the Morishima partial elasticity of substitution measures how the i,j input ratio responds to a change in w_j (see formula 25). Morishima partial elasticities of substitution are presented in Tables 12a–12d. The first column gives the value of σ^M_{Kj}, the second the value of σ^M_{Lj}, and so forth. It can be seen in the tables that, like the derived demand elasticity, the Morishima partial elasticity of substitution is also asymmetric. According to the Morishima partial elasticity of substitution, the inputs seem to be substitutes with each other, except capital items and purchased feed on dairy farms of groups A and B when the price of capital items changes.

Due to the asymmetry, the interpretation of the Morishima partial elasticity of substitution differs from the interpretation of the Allen partial elasticity of substitution. According to the Allen partial elasticity of substitution, capital items and purchased feed are complements with each other, so that an increase in the price of purchased feed reduces the use of capital items. According to the Morishima partial elasticity of substitution (σ^M_{KM}), when the price of purchased feed rises, capital items and purchased feed are substitutes with each other, which can be explained through the increase in the ratio of capital items and purchased feed. The increase in the ratio of capital items and purchased feed can be explained by the fact that, in percentages, the use of purchased feed decreases more than the use of capital items.

On the whole, the opposite signs of Allen and Morishima partial elasticities of substitution between capital items and purchased feed, when the price of purchased feed rises, is interpreted so that, when the price of purchased feed rises, the use of capital items is reduced, but, at the same time, the use of purchased feed is also reduced according to the production and cost theory (concavity). As can be seen in Tables 11a–11d, the use of capital items and purchased feed is reduced so that the K/M ratio increases. Correspondingly, according to σ^M_{MK}, when the price of capital items increases, the K/M ratio increases so that the rise in the price of capital items causes a smaller reduction in the use of capital items

Table 13a. Shadow elasticities of substitution on dairy farms of group A in the lower triangle, and on dairy farms of group B in the upper triangle.

	K	L	M	H
K	–	0.316	–0.035	0.490
L	0.401	–	0.472	0.734
M	0.251	1.013	–	0.692
H	0.796	1.047	1.210	–

Table 13b. Shadow elasticities of substitution for the post energy crisis period on dairy farms of group A in the lower triangle, and on dairy farms of group B in the upper triangle.

	K	L	M	H
K	–	0.486	0.228	0.595
L	0.532	–	0.577	0.540
M	0.105	0.807	–	0.521
H	0.989	0.815	1.082	–

than in the use purchased feed. This means that, when the price of capital items rises, capital items and purchased feed are complements according to the Morishima partial elasticity of substitution.

According to Tables 12a, 12b, and 12c, on dairy farms of groups A and B σ^{M}_{KM} and σ^{M}_{MK} have opposite signs. Thus, on these farms capital items and purchased feed are substitutes (complements) according to the Morishima partial elasticity of substitution, when the price of purchased feed (capital) increases. According to the result, the demand for purchased feed is more sensitive to changes in the price than the demand for capital items, in the case of changes with respect to the prices of both inputs w_K or w_L.

According to the Morishima partial elasticity of substitution, the elasticities of substitution between inputs are more elastic than the derived demand elasticity. Similarly, there is less complementarity between inputs with the Morishima partial elasticity of substitution than with the derived demand elasticity.

Morishima partial elasticities of substitution related to capital items show complementarity or inelastic substitution between capital items and other inputs everywhere in the data, except on dairy farms of group A between capital items and purchased fertilizers, when the price of purchased fertilizers changes. The elastic substitution between capital items and purhased fertilizers in group A, when the price of purchased fertilizers changes, is quite surprising. In all other cases, the results show complementarity or inelasticity between capital items and other inputs. Note, that in group B they are in all cases inelastic.

On dairy farms of group B Morishima partial elasticities of substitution show inelastic substitution between other inputs (L, M and H); the elasticity varies between 0.406 and 0.768. In group A Morishima partial elasticities of substitution between these inputs are, on the average, more elastic than in group B; the elasticity varies between 0.369 and 1.226.

8.2.3.3 Shadow elasticities of substitution

The shadow elasticity of substitution measures the change in the ratio of the use of two inputs in percentages, when the relative prices of these inputs change in percentages. The shadow elasticities of substitution are presented in Tables 13a and 13b. According to the results presented in the tables, all inputs seem to be substitutes with each other according to the shadow elasticity of substitution, except that a complementary relationship seems to exist between capital items and purchased feed on dairy farms of group B for the model of the whole research period.

Determining the shadow elasticity of substitution differs from determining the other elasticities of substitution in that the shadow elasticity of substitution is determined from the isocost curve, in which case costs are held constant. In addition, it should be noted that in all other measurements of the elasticity of substitution used in this study the change in the price of only one input is taken into account. Theoretically, the shadow elasticity of substitution can be considered an elasticity of substitution of a longer run than the derived demand elasticity. This conclusion is based on the fact that the inputs excluded from the examination of shadow elasticities of substitution can be purchased freely at fixed prices.

According to the shadow elasticity of substitution, on dairy farms of group B the elasticities of substitution between inputs are inelastic; the elasticity varies between, –0.035 and 0.734. On dairy farms of group A the shadow elasticities of substitution are more elastic than in group B. The shadow elasticities of substitution between capital items and other inputs are, on the average inelastic on dairy farms of group A, too; the elasticity varies between 0.105 and 0.989. The shadow elasticities of substitution between other inputs (L, M and H) on dairy farms of group A are relatively elastic; the elasticity varies between 0.807 and 1.210.

When shadow elasticities of substitution are compared to the derived demand elasticities it is observed that in the so-called long run the use of inputs is more elastic than in the short run, which is in accordance with the law of Le Chatelier.

8.2.3.4 Summary of the elasticities of substitution

The elasticities of substitution presented above have been solved from the values of the parameters presented in the elasticity formulas, and the averages of the cost shares. The values of the elasticities of substitution at five year intervals are presented in Appendix 9. The year 1976 was chosen, instead of 1975, because it is the first year of the empirical model for the post energy crisis period. Thus it is possible to compare the elasticities of substitution estimated from the whole research period and the post energy crisis period with each other.

The different elasticities of substitution calculated above give similar information on the substitution between inputs. The elasticities of substitution calculated empirically supported the theoretical conception that in milk production inputs are at least to some extent substitutes with each other. Complementarity was observed mainly between capital items and purchased feed. In the years of high inflation 1973–1975, and in 1980, there was complementarity in the elasticities between capital items and other inputs. This is likely to be caused by the fact that on dairy farms production cannot be adjusted according to rapid changes in the relative prices.

An average development trend during the research period was that the inelasticity of production decreased slightly up to the mid-1970s, and after that the elasticity increased so that at the beginning and end of the research period the elasticities of substitution and own price elasticities of inputs were almost equal (see Appendix 9). The elasticities of substitution estimated from the post energy crisis data give similar information, i.e., on the average, the elasticity of production increased slightly in the post energy crisis period. It should be noted, however, that the changes in the elasticity have been very small, and for the most part the production has been relatively inelastic.

When the elasticities of substitution and own price elasticities on dairy farms of groups A and B are compared with each other from Tables 11a–11d, 12a–12d, and 13a–13b, it can be seen that on dairy farms of group B the elasticities are more inelastic in 56 cases, and on farms of group A in 12 cases. The comparison included the derived demand elasticity, the Morishima partial elasticity of substitution, and the shadow elasticity of substitution for both the whole research period and the post energy crisis period (the total of 68). Dairy farms of group B are more strongly specialized in milk production than of group A, which probably explains the greater inelasticity of the production in group B. In general, the elasticity of production seems to decrease as a result of specialization.

The relatively small values of the elasticity of substitution solved in the study mean that with the existing production technology the substitution of inputs for other inputs has been quite inelastic. This is illustrated in Figure 6.

Figure 6 describes an efficiently used combination of inputs by which an output determined in advance is produced. The isoquant presented in the figure is strongly curved. With this kind of production technology, for example, an increase

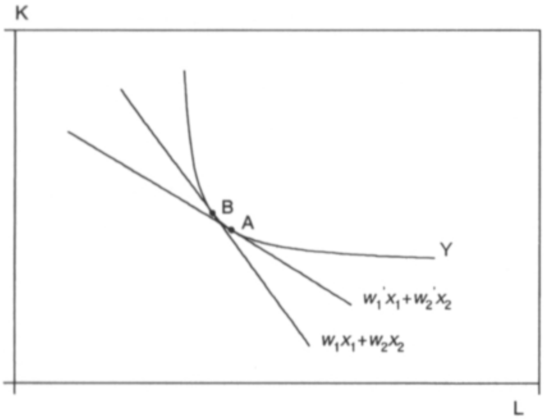

Fig. 6. Isoquant of the labour and capital inputs.

in the price of labour in relation to the price of capital items causes only a small change in the relative use of labour and capital items. This is illustrated in Figure 6 by the shift from point A to point B.

According to the elasticities solved in the study, substitution between inputs with the existing production technology seems inelastic. Inelastic elasticities of substitution and own price elasticities mean that, with the production technology in question, changes in the prices of inputs have little effect on their demand. Thus, the effect of input taxes (e.g., environmental taxes) on the demand for inputs is small, so that, by their possible introduction, costs are mainly increased, and the farm income of the milk producer is reduced.

The results of this study do not support the traditionally used assumption on the applicability of Cobb-Douglas and CES functional forms in the modelling of the production technology of milk production. The elasticities of substitution seem to deviate from one, so that the Cobb-Douglas functional form assumption cannot be accepted. As the elasticities of substitution seem to vary between different inputs, CES functional form assumption cannot be accepted, either. On the basis of this, Cobb-Douglas and CES functional forms are not appropriate for modelling milk production in Finland.

8.2.4 Technical change and cost flexibility

Cost flexibility and technical change seem to be interrelated, so that they are dealt with together. A change in the scale of production is usually understood as global. Traditionally the economies of scale have been interpreted from the advantage or disadvantage related to the size of the enterprise. In this study the economies of scale (size) are local, and they are presented according to the cost flexibility concept.

The technical change measures to what extent the changes in the total productivity have been caused by the increased efficiency of the production. The total productivity is measured as the ratio between the output quantity and the amount of inputs used. Thus, technical change measures the part of growth in production that does not result from an increase in the use of inputs. Technical change usually occurs on dairy farms when new production technology is introduced, and also through an increase in crop yields and the milk output level, as a result of progress in livestock and plant breeding. Technical change can be described by the shift of the isoquant in the input space.

Temporally, technical change is usually seen in two different ways. It can be short-term development, in which case the effect of measures on the current production is taken into account. Alternatively, structural technical change also takes into account the long-term effects, which are realized only through reorganization of production.

An example of a structural technical change in milk production is the introduction of milking machines that replace milking by hand, which is labour intensive. This investment increases the production capacity of a dairy farm, which is realized through future outputs.

The estimated parameters indicate that technical change in milk production is not Hicks neutral. The H_0 hypothesis on neutral technical change was rejected by the likelihood ratio test. The estimated parameters describing technical change β_{Ti} have been presented in Tables 5a and 5b, as well as 8a and 8b. Figure 7 illustrates the technical change in milk production in Finland.

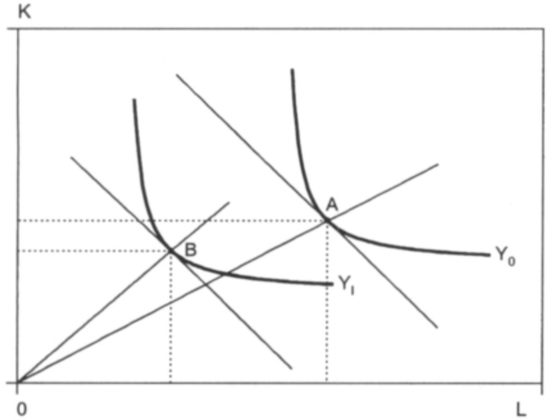

Fig. 7. Non-neutral Hicks technical change.

Table 14. Estimated β_{Ti} and β_{Yi} parameters from NH-NN, NH-N, and H-NN dairy farm models.

Model	β_{YK}	β_{YL}	β_{YM}	β_{YH}
A:NH-NN	–0.1019	–0.1445	0.1742	0.0721
B:NH-NN	–0.0810	–0.1265	0.1802	0.0273
A: NH-N	0.0019	–0.1035	0.0722	0.0294
B: NH-N	0.0113	–0.1246	0.1038	0.0095
	β_{TK}	β_{TL}	β_{TM}	β_{TH}
A: NH-NN	0.0056	0.0034	–0.0056	–0.0034
B: NH-NN	0.0059	0.0002	–0.0051	–0.0010
A: H-NN	0.0010	–0.0023	0.0007	0.0006
B: H-NN	0.0021	–0.0030	0.0003	0.0006

In Figure 7, along with the technical change, the isoquant Y_0 shifts in the input space to position Y_1. When the relative prices of inputs and output remain constant, the ratio of the use of inputs moves as a result of the technical change from OA to OB, which causes the share of the use of one input to increase, and the share of the other input to decrease.

Rejecting the Hicks neutral technical change means that, as a result of technical change the isoquant moves along the expansion path of the enterprise towards the origin so that the cost shares of inputs change simultaneously. In all estimated models technical change in milk production has been capital items-using. The parameters describing technical change estimated from different models give a different picture of labour-, purchased feed-, and purchased fertilizer-saving or -using technical change.

It is obvious that the problem in estimating the cost function (38) is with the small number of degrees of freedom, and thus the possible multicollinearity. This means that the identification and indication of the effects of parameters β_{TY}, β_{YY}, β_{TT}, β_{Ti}, and β_{Yi} separately is difficult, even impossible. β_{Yi} parameters describe the effects of the farm size on the relative cost shares of inputs. If the biases related to the farm size are positive (negative), the cost share of the corresponding input increases (decreases) as the output level changes.

The capital items-using technical change turned out to be as assumed. The technical change describing the use of labour, purchased feed, and purchased fertilizers varies according to the specification of the model, so that they are examined separately. It is likely that technical change and increasing the farm size are interrelated, so that it is impossible to separate their effects from each other.

The purchased feed- and purchased fertilizer-saving technical change estimated from the NH-NN models seems somewhat surprising. Self-sufficiency in feed has been an objective in Finnish milk production. The production technology of milk production has been developed so that it is suitable for the production of own feed on dairy farms, and thus the purchased feed-saving technical change appears logical. The purchased fertilizer-saving technical change may be caused by the increased accuracy in fertilization resulting from technical change, and the more efficient use of manure.

To study the linkages between technical change and the farm size, parameters β_{Ti} and β_{Yi} estimated from models NH-N and H-NN are also examined. The parameters are presented in Table 14. When the model is specified as homothetic, technical change can be examined separately from the output quantity. However, in this case a model that was rejected by the likelihood ratio test is examined. Technical change according to the H-

NN model is capital items-, purchased feed-, and purchased fertilizer-using and labour-saving. According to the NH-N model, increasing the output quantities greatly increases the cost share of purchased feed, whereas the cost share of capital items and fertilizers increases only slightly, and a strong reduction occurs in the cost share of labour.

When parameters describing technical change estimated from NH-NN and H-NN models are compared, it is observed that the signs of the parameters related to labour, purchased feed, and purchased fertilizers change places with each other. The same phenomenon can be observed in the case of capital, when parameter β_{YK} estimated from NH-NN and NH-N models is examined. This phenomenon has also been observed by Lopez (1980, p. 43) in his study on the production structure in Canadian agriculture and the derived demand for inputs. According to β_{Yi} parameters in NH-NN models, the cost shares of capital items and labour decrease, and those of purchased feed and purchased fertilizers increase when the farm size grows.

On the basis of this examination, technical change and increasing the farm size are interrelated, so that parameters β_{Ti} and β_{Yi} should be interpreted together. However, the joint interpretation of parameters β_{Ti} and β_{Yi} does not mean that the original model could be simplified, because the simplified models were rejected by the likelihood ratio test.

According to the estimated results, parameter β_{TK} is positive in all models, which means that technical change in milk production has been capital items-using. The signs of parameters β_{TL}, β_{TM}, and β_{TH} change in the restricted models (NH-N and H-NN). It seems that in milk production technical change is linked to the farm size, which is a logical result. According to Lund and Hill (1979, p. 146–148), changes in the efficiency may have a similar effect on costs as does the increase in the farm size.

Technical change, such as the introduction of milking machines, mechanical manure disposal, new machine chains for feed crops, etc., has made it possible to increase the size of dairy farms. According to the estimated parameters, it seems that, as a result of the increase in the farm size and technical change, other inputs have been substituted for the labour input.

The interpretation of technical change in an empirical study is also difficult, because it has not been possible to develop an unequivocal measurement for it. In examining technical change, strongly simplified variables must be used, for example, the linear time trend. In addition, in empirical studies there are problems in separating the effects of technical change and the farm size from each other, because part of the technical change is realized through investments and inputs, and part through working methods and improved know-how.

In this study it was logical to link the examination of technical change to the cost function study in order to be able to utilize calculation in terms of derivatives. It is also possible to examine the technical change (productivity) by utilizing the index theory directly. According to Chambers (1988, p. 203–249), neither of the possible approaches is perfect, and it is not clear which is preferable.

According to the research results, in the research period the average cost flexibility on dairy farms of group A was 0.06, and on farms of group B 0.20. On dairy farms of group A half of the observations of cost flexibility were negative, which is not acceptable theoretically. When the cost flexibility was solved from the HG-NN model, it was 0.33 on farms of group A, and 0.39 on farms of group B.

On the basis of the results, an increase of 1% in output (ceteris paribus) increases costs by under 0.4%, so that increasing the size of dairy farms should be allowed. The estimated, relatively high economies of scale (size) are likely to be partly caused by structural technical change, which causes calculatory economies of scale (size) in econometric time series analyses (cf. Lehto 1991, p. 15).

The economies of scale (size) may also indicate inefficient use of the production capacity. Since milk production is restricted very strongly, there is unused production capacity on dairy farms, which cannot be utilized efficiently in the production. In addition, the estimated economies of scale (size) also indicate that it is necessary to maintain production capacity for short peak seasons in the production to be able to meet the quality requirements of the products during these periods (timeliness cost).

To summarize the economies of scale (size), it can be noted that the size of dairy farms should increase so that the existing advantages could be utilized. In particular, the underutilization of the production capacity resulting from the increase in the yield level of field crops and the average milk output should be replaced rapidly by, at least, a full degree of use of the existing capacity.

The possible multicollinearity hidden in the cost function (38), as well as the fact that the farm size and technical change are interrelated have an effect on the estimated values of the parameters related to the economies of scale (size) and technical change. Thus, the parameters related to the technical change and economies of scale (size) and their interpretations should be taken with caution. In addition, parameters related to economies of scale (size) estimated from time series data are less reliable than parameters estimated from cross section or panel data sets.

8.3 Dairy farm level approach

The data set collected from the A dairy farms makes it possible to utilize panel data and its properties. The panel data set possesses many advantages over time series or cross sectional data sets when enlarging the number of data points, and making possible more detailed analysis of economic problems (HSIAO 1986, p. 1–2).

In this study the panel data set is used since the neoclassical production and cost theory is based on the farm level argument. So having panel data makes the application of the theory more reliable. On the other hand, the panel data set is used to confirm and specify the results obtained from the analysis of the representative dairy farm data set because the time series used was nonstationary but not cointegrated and, therefore, ECM cannot be applied. Thus, in time series analyses there was the possibility of spurious regression.

In this study the panel data set gives new information about the variation of output, costs, and cost shares across farms. However, farm level prices have not been recorded. Thus, the sample over the research period contains only 27 observations of the prices. In other words, prices differ over the years but not across the farms. This restricts the potential advantages provided by the analysis of panel data. On the other hand, the panel data set is more effective in studying the size economies and technical change than is the representative dairy farm data set.

8.3.1 Estimation procedure for panel data set

In the equations, the intercept may vary over the dairy farms. The model was assumed to be a fixed effect model and the intercepts were treated as fixed parameters. When the indicator (dummy) variables are used, the inference is conditional on the individuals in the sample. The indicator model is appropriate because the sample of dairy farms cannot be regarded as a random sample from some larger population (see JUDGE et al. 1988, p. 489). According to THIJSSEN (1992, p. 220), the intercepts reflect quality differences in the inputs between farms and consist mainly of managerial differences and differences in the quality of land. The fixed effect model can be written in a general form as follows (JUDGE et al. 1988, p. 469):

$$y_{it} = \sum_{j=1}^{R} \delta_{1j} D_{jt} + \sum_{k=2}^{K} \beta_k x_{kit} + \varepsilon_{it}, \quad i = 1,2,\ldots,R,\ t = 1,2,\ldots,T \tag{57}$$

where y_{it} is the dependent variable, x_{kit} are the explanatory variables, ε_{it} are assumed to independent and identically distributed random variables with mean zero and variance σ_ε^2, R is a number of farms, T is a number of time-series observations, β is the K vector of parameters, δ_{1j} is the fixed effect of farm i, and D_{jt} are indicator variables and assume values 0 or 1; $D_{jt} = 1$ if $j = i$, and $D_{jt} = 0$ if $j \neq i$.

Equation (57) cannot be estimated, because the model becomes too large for the computer packages available. According to JUDGE et al. (1988, p. 471–472), the model can be solved by transforming the observations on each dairy farm so that they are in terms of the deviation from the mean for that dairy farm. This can be expressed as follows:

$$y_{it}-\bar{y}_i = \sum_{k=2}^{K} \beta_k(x_{kit}-\bar{x}_{ki}) + \varepsilon_{it}-\bar{\varepsilon}_i, \tag{58}$$

where $\bar{y}_i = 1/T\sum_{t=1}^{T} y_{it}$, $\bar{x}_i = 1/T\sum_{t=1}^{T} x_{kit}$, $\bar{\varepsilon}_i = 1/T\sum_{t=1}^{T}\varepsilon_{it}$. Both equations (57) and (58) give the same residual vector, but the estimated standard errors of the coefficients need to be corrected by multiplying them by $[(R\times T-K)/(R\times T-R-K)]^{1/2}$. In examining the goodness-of-fit of the model, the R^2 from equation (58) also needs to be corrected.

The F-test is applied to test the fixed effect model against the model of all dairy farms having the same intercept (see JUDGE et al., p. 475–476)

$$F = \frac{(SSE_r - SSE_u)/(R-1)}{SSE_r/(R\times T - R - K)}, \tag{59}$$

where SSE_r is the sum of squared residuals obtained from the estimation of the equation in which all dairy farms have the same intercept. SSE_u is the sum of squared residuals obtained from equation (58). According to the F-test, the H_0 hypothesis that all the fixed effects are equal is rejected. For the model of the whole research period F-test values for S_K, S_L, S_M, and C were 16.66, 61.27, 66.31, and 24.66, respectively. For the post energy crisis model F-test values for S_K, S_L, and S_M were 16.23, 67.15, and 58.85, respectively. The critical F-test value at the 1% significance level for (43,1135), (43,1122), and (43,653) degrees of freedom is about 1.7.

The two models, for the whole research period and for the post energy crisis period, are estimated using the A dairy farm data set, as in the case of representative dairy farm models above. Because the cost share equations form a system of seemingly unrelated equations, SUR is an appropriate estimation technique.

8.3.2 Empirical models and hypothesis tests

The calculated χ^2 value of the symmetry assumption for the whole research period model is 12.90, and for the post energy crisis period model 14.53. These values are smaller than 16.81, the critical value at the 1% significance level, therefore, the H_0 hypothesis on the symmetry of the Hessian matrix is not rejected. The system of equations are estimated according to equation (58), holding the parametric restrictions (45) in force. The values of parameters estimated from the equation systems are presented in Appendix 10. The parameter values related to the elasticities of sub-

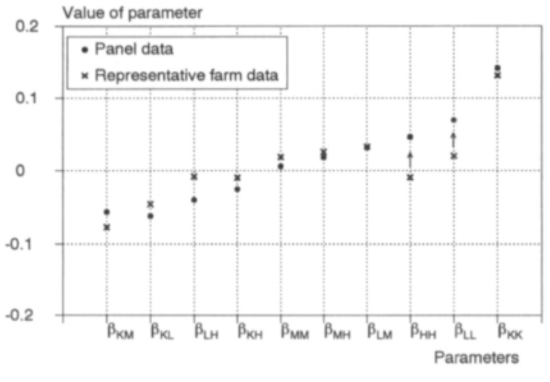

Fig. 8a. The parameters related to the elasticities of substitution and own price elasticities for the whole research period.

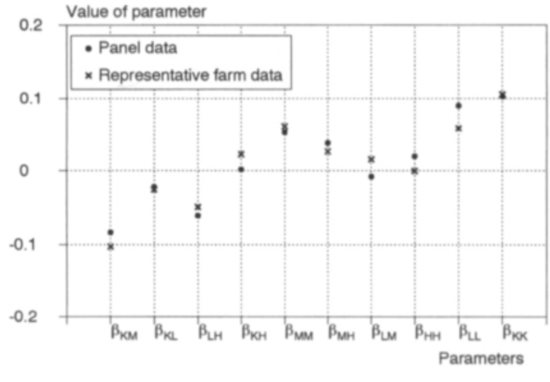

Fig. 8b. The parameters related to the elasticities of substitution and own price elasticities for the post energy crisis period.

stitution and own price elasticities are compared with the parameter values solved from the representative dairy farm data set in Figures 8a and 8b.

The parameter values estimated from the panel data set differ only slightly from the parameter values obtained from the representative dairy farm, except for β_{HH}, β_{LL}, and β_{LH} in the whole research period model (arrows in Figures show the largest differences). The economic information included in parameters β_{ii} and β_{ij} cannot be seen directly from their values, so the possible differences in the elasticities of substitution will be examined later in Chapter 8.3.3.

The estimated models fit the data satisfactorily, when the evaluation is made using the R^2 values. The calculated R^2 values for the whole research period model for S_K, S_L, S_M, and C are 55.60, 72.58, 73.24, and 98.62, respectively; and for the post energy crisis period model for S_K, S_L, and S_M are 59.55, 82.25, and 80.49, respectively.

The number of statistically significant parameters in the whole research period model is 28 (24) out of a possible total of 41 parameters at the 5 (1) % significance level, and in the post energy crisis period model 16 (13) out of a possible total of 26 parameters. Of the parameters related to the elasticities of substitution and own price elasticities, in the whole research period model seven (β_{KK} (1%), β_{KL} (1%), β_{KM} (1%), β_{KH} (1%), β_{LL} (1%), β_{LH} (1%), and β_{HH} (1%)); and in the post energy crisis period model five (β_{KK} (1%), β_{KM} (1%), β_{LL} (1%), β_{LH} (1%), and β_{MH} (1%)) out of ten deviated statistically from zero.

The cost shares estimated from the whole research period model and from the post energy crisis period model are not positive at all sample points, 12 out of a total of 4752 cost shares in the whole research period and 17 out of a total of 2816 cost shares on the post energy crisis period are negative. Thus, monotonicity is not satisfied at these observations. The sign of the own price elasticity of the inputs included in the model is in accordance with the theory, evaluated at the sample mean. But they do not have the correct sign at all sample points, 434 out of a total of 4752 own price elasticities in the whole research period model and 164 out of 2816 own price elasticities in the post energy crisis period model are positive.

On the basis of this result, some of the milk producers do not seem to behave according to the cost minimization assumption, but in the majority of cases the own price elasticities are negative as assumed. The deviation of the models from the assumptions may partly be caused by the rapid and powerful economic shocks during the research period, as well as the risk and uncertainty in milk production. The weather conditions seem to affect the demand for inputs in a significant way, so that at the same input prices the cost shares vary depending on good and poor years. The results obtained from the panel data set is parallel with the results obtained from the representative dairy farm data set, except for the parameters β_{HH} and β_{LL} that differ from the whole research period representative dairy farm parameters.

8.3.3 Elasticities of substitution

In this study the panel data set gives a more reliable picture of the effects of the price variables than does the representative dairy farm data set, although the price variations across farms have not been recorded. Furthermore, using the panel data set increases the reliability of the parameters related to output changes. Thus, if there is multicollinearity between price series and output series in the representative dairy farm data set, analysis of panel data gives more reliable information about the effects of the price variables (VARTIA 1994).

The cross price and own price elasticities solved from the panel data set are quite similar to the elasticities solved from the representative dairy farm data set, except the own price elasticity for purchased fertilizers and the cross price elasticity for labour and purchased fertilizers when the price of labour changes, which are more inelastic. It seems that there is multicollinearity between purchased fertilizers, output and technological development in the representative dairy farm data set.

Otherwise, the results obtained from the panel data set are interpreted the same as are the results

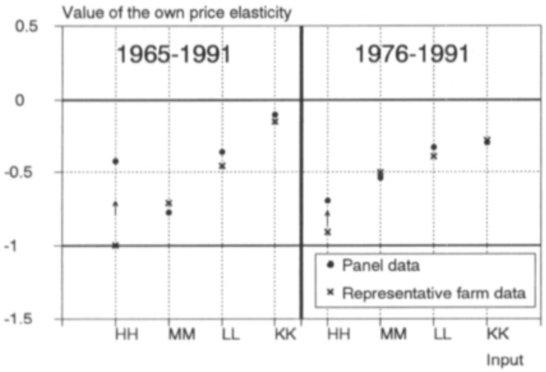

Fig. 9a. Own price elasticities in the whole research period and in the post energy crisis period.

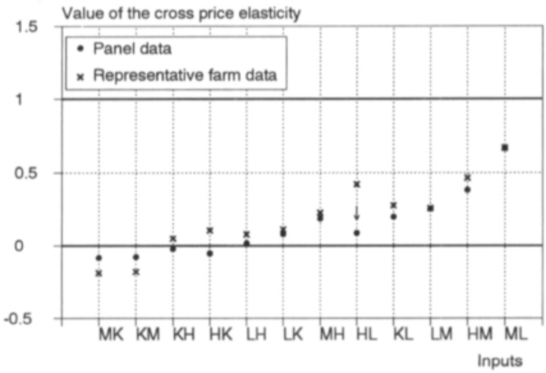

Fig. 9b. Cross price elasticities in the whole research period.

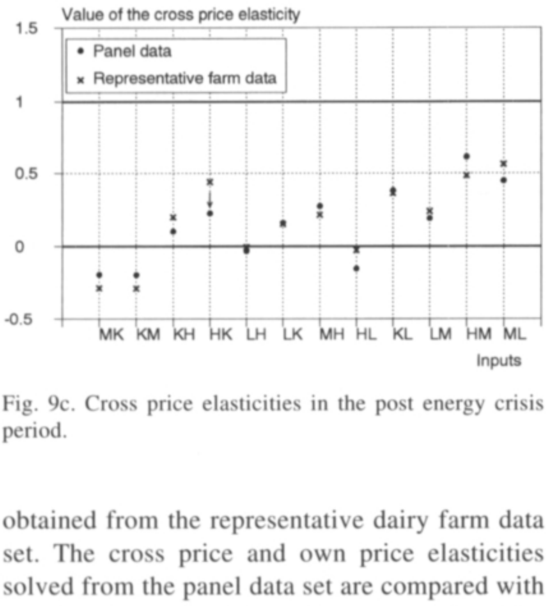

Fig. 9c. Cross price elasticities in the post energy crisis period.

obtained from the representative dairy farm data set. The cross price and own price elasticities solved from the panel data set are compared with the elasticities solved from the representative dairy farm data set in Figures 9a–9c. The cross price and own price elasticities are presented in Appendix 11.

The Morishima partial elasticities of substitution and shadow elasticities of substitution solved from the panel data set differ only slightly from the elasticities solved from the representative dairy farm data set, except the elasticities related to purchased fertilizers which are, on average, much more inelastic than those solved from the representative dairy farm data set, particularly in the whole research period model. One reason for this surprisingly large difference in the substitution possibilities related to purchased fertilizers in the whole research period model may be caused by the possible multicollinearity hidden in the time series data, as mentioned before.

Otherwise, the results are interpreted the same as the results of the representative dairy farm, but the elasticities are, on average, more inelastic. The Morishima partial elasticities of substitution and shadow elasticities of substitution are compared with the elasticities solved from the representative dairy farm data set in Figures 10a–10c. The Morishima partial elasticities of substitution and shadow elasticities of substitution are presented in Appendix 11.

The different elasticities of substitution calculated above from the panel data set give similar information on the substitution possibilities between inputs. The elasticities of substitution solved empirically support the theoretical conception that, in milk production, inputs are at least, to some extent, substitutes with each other. When the elasticities of substitution and own price elasticities solved from the panel data set and representative dairy farm data set are compared with each other, it can be seen that the elasticities solved from the panel data set are more inelastic in 46 cases, and from the representative dairy farm data set in 22 cases. The comparison included the derived demand elasticity, Morishima partial elasticity of substitution, and shadow elasticity of substitution.

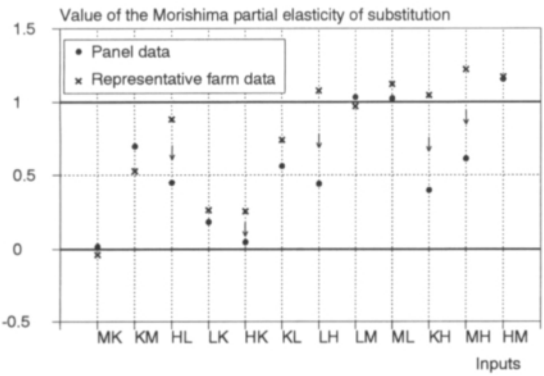

Fig. 10a. Morishima partial elasticities of substitution in the whole research period.

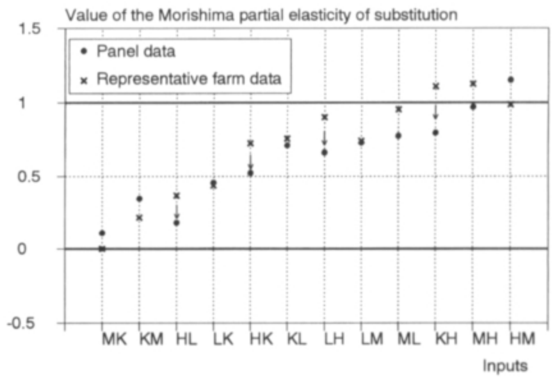

Fig. 10b. Morishima partial elasticities of substitution in the post energy crisis period.

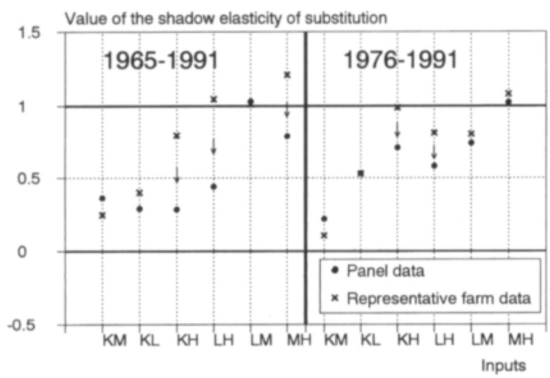

Fig. 10c. Shadow elasticities of substitution in the whole research period and post energy crisis period.

According to the elasticities solved from the panel data set, substitution between inputs with the existing production technology seems more inelastic than in the case of the representative dairy farm; in particular elasticities related to purchased fertilizers. On the other hand, the differences in results between the panel data set and the representative dairy farm data set are mainly small, and there is no systematic twist.

8.3.4 Technical change and cost flexibility

Cost flexibility and technical change are interrelated in the models solved from the representative dairy farm data set. The panel data set possesses large amounts of new information concerning output variation across farms. New information of cost and cost shares are obtained, too. Thus, the panel data set provides more reliable results concerning the cost flexibility, and more effectively separates the effects of the farm size economies and technical change from each other, as compared to the representative dairy farm data set (Vartia 1994).

In this study, the panel data set does not give a more reliable picture of the effects of technical change than does the representative dairy farm data set, because there are no farm specific measures for technical change. In other words, the linear time trend is the same for every farm in a certain year. If multicollinearity existed between the time trend and output series in the representative dairy farm data set, it would be possible to get more reliable information about the effects of technical change from the panel data set, too.

The estimated parameters indicate that technical change in milk production is not Hicks neutral. The H_0 hypothesis on neutral technical change is rejected by the likelihood ratio test. The calculated χ^2 value of the neutral technical change assumption is 19.34, which is larger than 13.28, the critical value at the 1% significance level. The estimated parameters describing technical change β_{Ti} are presented in Appendix 10.

Technical change in milk production seems to be purchased feed-saving and other inputs-using. Self-sufficiency in feed has been an objective in

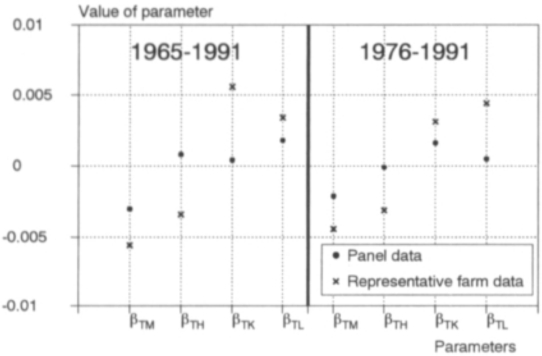

Fig. 11. The parameters of technical change solved from the panel data set and representative dairy farm data set.

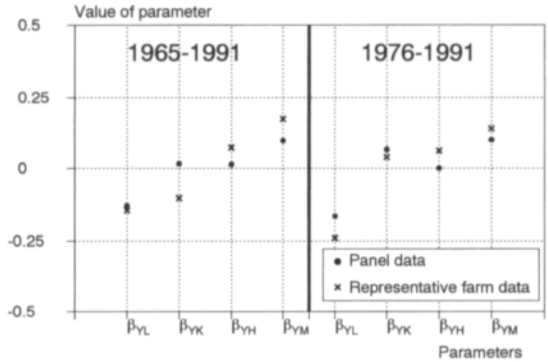

Fig. 12. The parameters of size economies solved from the panel data set and representative dairy farm data set.

Finnish milk production, and thus, the purchased feed-saving technical change appears logical. The average annual rate of technical change for the whole research period is 1.30, and it is increasing of the level of technology. On the basis of the result, the technological development has had a positive contribution to the dairy farms.

The use of the panel data set makes it possible to obtain much more reliable information concerning the size economies than does the use of the representative dairy farm data set. The H_0 hypotheses of the homotheticity and homogeneity of the production technology, and constant returns to scale are rejected by the likelihood ratio test at the 1% significance level. The calculated χ^2 value of the homotheticity is 301.30, which is very much larger than 15.09, the critical value at the 1% significance level. According to the likelihood ratio test, the structure of the cost function cannot be simplified from the general model (NH-NN).

According to the results, in the research period the average cost flexibility solved from the panel data set is 0.58, and it is increasing of the level of output. All of the observations are positive, and thus in accordance with the theory. For a comparison, the cost flexibility solved from the representative dairy farm data set was 0.06, and half of the observations were negative, which is not acceptable theoretically. On the basis of the results obtained from the panel data set, an increase of 1% in output increases costs about 0.6%, so that increasing the size of dairy farms should be allowed. The empirical result on milk producer behaviour under increasing returns to size is consistent with the theoretical assumption made earlier in the theoretical part of the study.

Biases of scale, β_{Yi} parameters in Appendix 10, describe the effects of economies of size for the relative distribution of costs among inputs. When the biases related to the farm size is positive (negative), the cost share of the corresponding input increases (decreases) with a change in the level of output. The cost shares of labour decrease, and those of other inputs increase when the farm size grows. Thus, the cost flexibility increases with the prices of purchased feed, capital items, and purchased fertilizers, and decreases with the price of labour. For a comparison, the β_{YK} solved from the representative dairy farm data differed from the result solved from the panel data set.

It can be assumed that small dairy farms differ from other farms regarding the variable lny. It is examined using rough indicator variables, such as 1 × lny for the small farms and zero for the other farms. The estimated parameters which are connected to these variables do not deviate statistically from zero by the t-test. On the basis of the result, the coefficient of lny for the small farms does not differ from the coefficient for the other farms.

To complete the discussion of technical change and cost flexibility, β_{Yi} and β_{Ti} parameters solved from the panel data set and representative dairy farm data set are compared in Figures 11 and 12.

From Figures 11 and 12 we can see that the parameters differ greatly from each other. The multicollinearity hidden in the cost function of the representative dairy farm (38) has an effect on the estimated values of the parameters β_{Yi}, β_{Ti}, β_{YY}, β_{TT}, β_{TY}, β_T, and β_Y. Thus, these parameters and their interpretations should be viewed with caution when the parameters are solved from the representative dairy farm data set.

9 Examination of the results and conclusions

The study was initiated because of the need for new information on the input substitution and technological development in Finnish agriculture. There has been very little research on the effects of the changes in relative prices and technical change on the production technology of dairy farms, so that the study was considered necessary. The dual approach of the neoclassical production and cost theory was chosen for the examination of the elasticities of substitution between inputs and the technical change on dairy farms. The flexible translog cost function and cost share equations derived from it were utilized to solve the empirical research problem. The cost function study was chosen, because it made it possible to examine the production of farms operating in the area of decreasing average costs.

Data collected from dairy farms participating in the profitability research of Finnish agriculture, for the years 1965–1991, were used in the study. For this study, two sets of data were collected: dairy farms of group A (44), which were included during the whole research period, and dairy farms of group B (168–364), the number of which varied annually. Models were estimated separately for the post energy crisis period 1976–1991. The data were well suited for the study, because the data consists of dairy farms practicing active entrepreneurship.

The idea of a representative dairy farm was applied in both data sets. The dairy farms of group A form a panel data set. The applications of the theory are more reliable with the panel data set than with the representative dairy farm data set because the panel data set consists of information from individual dairy farms. Thus, the results obtained from the panel data set are theoretically more reliable than the results obtained from the aggregate data set. During the research period the development of ADP made it possible to solve the research problem with panel data. Thus, the data set from dairy farms of group A was also used as a panel data set.

The potential of dairy farms to influence the price of milk and the inputs needed to produce it is very limited, which means that the adjustment to the changes in the prices of inputs is realized mainly by changing the production technology, if possible. The own price elasticities and the elasticities of substitution, as well as the technical change indicate the possibilities to adjust the production to the new price relations. Therefore, it is important for milk producers to be aware of the elasticities, but, in particular, it is important for the agricultural policy makers, because they need to know the effects of the decisions on the economy of the enterprises.

In this study, the elasticities of substitution between the capital items, labour, purchased feed, and purchased fertilizers were solved. The inputs were classified as substitutes or complements on the basis of the estimated elasticities of substitution. According to the Allen partial elasticities of substitution, the inputs are, for the most part, substitutes with each other. In all cases, the capital items and purchased feed were complements. In some parts of the data, complementarity between the labour and purchased fertilizers, and capital items and purchased fertilizers was observed.

According to the Morishima partial elasticity of substitution and shadow elasticities of substitution, the inputs are substitutes with each other, except that complementarity was observed between the capital items and purchased feed. According to the elasticities of substitution, the substitution between inputs is mostly inelastic, i.e., it is quite difficult to substitute an input for another.

The demand for the capital items was the most inelastic when measured by the own price elasticity. The demand for the labour was almost as inelastic. According to Marttila (1991, p. 72), the capital tied to agriculture is very fixed in Finland, which means that its substitution by other production factors is inelastic.

When the elasticities of substitution and own price elasticities on representative dairy farms of groups A and B were compared with each other, the elasticities are on average more inelastic on dairy farms of group B than on dairy farms of group A. Dairy farms of group B are more strongly specialized in milk production than dairy farms of group A, which may explain the greater inelasticity of the production in group B. In general, substitution possibilities on dairy farms seem to decrease as a result of specialization.

The elasticities solved from the panel data set are quite similar to the elasticities solved from the representative dairy farm data set. Thus, results support each other. However, the elasticities related to purchased fertilizers are on average much more inelastic than those obtained from the representative dairy farm, particularly with the whole research period model. One reason for this may be the multicollinearity hidden in the time series data. Differences in the other elasticities solved from the panel data set and the representative dairy farm data set are mainly minor and there is no systematic twist.

The results obtained from the panel data set are more reliable than the results obtained from the representative dairy farm data set, because the use of panel data increased the information about variation of output, costs, and cost shares across dairy farms. Thus, if there is multicollinearity between the series in the representative dairy farm data set, the analysis of panel data gives the means to correct information obtained from the time series data.

The inelastic elasticities of substitution and own price elasticities mean that, with the existing production technology, the changes in the prices and/or relative prices of inputs have little effect on their demand. Consequently, it is not possible to regulate the demand for inputs in a flexible way by, for example, taxation. Thus, taxation measures are mainly visible in the farm income of the milk producer. The possibilities of traditional agricultural policies and environmental policies to have an influence on the level of demand of the inputs of production, in Finnish agriculture, with levies and/or subsidies are small.

The elasticities of substitution estimated in the study were nearly similar to those estimated in other countries where substitution between inputs also dominated. Lopez (1980) found a relationship of substitution between all inputs. Binswanger (1974) found a relationship of complementarity between the labour input and fertilizers, machinery and fertilizers, and arable land and other inputs. According to Ray (1982), miscellaneous inputs (e.g., cleaners, electricity) are complements for the labour input, fertilizers, and feed. According to Glass and McKillop (1990), the aggregate input consisting of feed and seeds was a complement for fertilizers and the capital input. Differences between the research results are probably caused, in part, by the different conditions and production technology in different countries. Comparison of the research results was difficult, because they differed from each other in terms of the estimated model and the aggregation of inputs.

The elasticities estimated in other countries were also relatively inelastic. Binswanger's results differed from the other research results with respect to the elasticity of the elasticities of substitution, which is probably caused by the fact that Binswanger's data dates from an earlier period of time (1949–1964) than the data of the other studies. At that time production was not as specialized as later, so that the possibilities for flexibility were greater than at present.

Technical change on dairy farms has increased the use of capital. The technical change describing the use of the labour, purchased feed, and purchased fertilizers solved from the representative dairy farms data set varied according to the model specification. Technical change solved from the panel data has been purchased feed-saving and other inputs-using. Self-sufficiency in feed has been an objective, and thus the purchased feed-saving technical change appears logical.

The average annual rate of technical change for the whole research period has been 1.3%, and it has been increasing of the level of technology. On the basis of this result, the technological development has had a positive contribution to the dairy farms.

In the long run, profitability is the driving force of production. In the short run, liquidity may restrict production. Maintaining the profitability and continuity of production requires that the dairy farm keeps up with the technical development. Without utilizing the technical development, a milk producer cannot compete with other entrepreneurs in the same field or in other fields in the long run, but the production becomes unprofitable and must be discontinued. According to the results, new technology should be utilized in increasing the farm size. In the EU system, however, increasing the farm size may be difficult because of the weakening profitability (LATUKKA et al. 1994).

Increasing the output quantities and substituting the relatively cheaper capital items for the more expensive labour has been profitable. Investments have brought new technology to dairy farms. YLÄTALO (1987, p. 84) came to the same conclusion. He noted that, at the level of agriculture as a whole, the arguments of too high investments in agriculture were not true.

As a result of technical development, the introduction of new machine and production chains has made it possible to increase the size of dairy farms. The size of the farms included in this study increased considerably, but compared to, for example, Sweden and Denmark, Finnish dairy farms are still very small. In the research period the output of dairy farms of group A increased over 2.5 times, whereas the use of labour input decreased by about 20%. On dairy farms of group B output grew over 3.5 times, but because of the strong growth in output the decrease in the use of the labour input remained below 5%.

According to the results, there are advantages related to the size (scale) of the enterprise in milk production. On the basis of the results obtained from the panel data set, an increase of 1.0% in output increases costs about 0.6%. So the unit costs decrease as production is expanded and thus, increasing the size of dairy farms should be allowed. When the farm size grows, the cost shares of labour decrease, and those of other inputs increase.

In milk production it has not been possible to utilize the economies of size (scale) in full during the last two decades, because the main focus in agricultural policy has been in abolishing the overproduction of milk, and developing production has remained in the background.

In the representative dairy farm data set technical change and farm size are confounded, and there is multicollinearity between them and purchased fertilizers, which made it impossible to separate their effects clearly from each other. The panel data set made it possible to obtain more reliable information concerning technical change and size economies than did the representative dairy farm data set. The increasing returns to size assumption made in the theoretical part of the study is consistent with empirical results.

In developing the production of dairy farms it is essential that they are allowed to grow. This means that the number of dairy farms will decrease. RYYNÄNEN (1972, p. 11) brought this forward very clearly: the growth of an enterprise and an entrepreneur is not possible, unless the society provides conditions that favour change. Finnish society faces a time in which it has to promote the growth of the farm size in a more determinate way than earlier. The gap between the farm size required for development and the prevailing farm size may otherwise become too wide. According to the results, this prognosis seems to have come true.

Measures to restrict production at the farm level (mandatory fallowing, production quotas) have increased the unit costs, because the production capacity of the farm has not been fully utilized. Also, these measures restrict the production to the area where the unit costs decrease most strongly when the farm size increases (cf. HEIKKILÄ 1987). According to RYYNÄNEN and PYYKKÖNEN (1988), costs can be lowered and the profitability of the production can be secured only by increasing the farm size and the efficiency of the use of production factors.

In Finland the farm size is determined by more than just economic factors. STANTON (1978, p. 727) notes that the size of agricultural enterprises must be seen as a political issue. According to him, agricultural production has a special role compared with other sectors. This was/is the prevailing view in Finland, too.

When examining the current situation, it should be kept in mind that the objectives of agricultural policy also include objectives that do not belong to agriculture. A special feature in Finnish policy was the settlement after the wars, which increased the number of farms and decreased the average farm size considerably. Through the settlement, the "social problem" was transferred to the agricultural sector and agricultural policy, which led to the splitting up of dairy farms, and thus to the small farm size.

According to the research results, milk producers seem to have operated rationally. By means of the growth of the farm size and the new production technology they have been able to increase output, so it has not been necessary to increase the use of the labour input, the price of which has increased the most. Milk producers seem to have operated principally in an economical way. Thus, milk producers have operated according to the theoretical assumptions within the framework provided by the legislation. In times of powerful economic shocks it has not been possible to adjust the production of dairy farms in an optimal way, which can be considered a logical result because of the inelastic substitution of inputs.

In 104 cases out of 108 the signs of the own price elasticities of inputs in the representative dairy farm models for the whole research period were in accordance with the theory. In times of powerful economic shocks, the years 1973–1976 and 1980, the sign of the own price elasticity of the derived demand for the capital input deviated from the assumption. In the post energy crisis period representative dairy farm models all own price elasticities were in accordance with the theory.

According to the negative semidefiniteness of the Hessian matrix and the estimated positive cost shares, the theoretical concavity and monotonicity assumptions were realized in all post energy crisis period representative dairy farm models at all observation points, except on dairy farms of group A in 1976 and 1980. In the representative dairy farm models for the whole research period the concavity assumption was not realized in times of powerful economic shocks. On representative dairy farms of group B the deviation of the negative semidefiniteness of the Hessian matrix at the beginning of the research period may also have been caused by the great variation in the number of farms included in the research.

The cost shares estimated from the the panel data set for the whole research period and for the post energy crisis period are not positive at all sample points, 12 out of a total of 4752 cost shares in the whole research period and 17 out of a total 2816 cost shares in the post energy crisis period are negative. Thus, monotonicity is not satisfied at these observations. The sign of the own price elasticity of the inputs included in the model is in accordance with the theory, evaluated at the sample mean. But, they do not have the correct sign at all sample points, 434 out of a total of 4752 own price elasticities in the whole research period model and 164 out of a total of 2816 own price elasticities in the post energy crisis period model are positive.

Even if milk producers were aware of the marginal rate of technical substitution and price relations between inputs and would strive to operate in an optimal way, this cannot always be observed from ex-post data, because the situations examined ex-ante and ex-post differ from each other. Milk producers make ex-ante decisions, but research is based on ex-post data, which means that observations deviating from optimum behaviour are possible because of risk and uncertainty. This can be seen in the effects of the powerful economic shocks during the research period, to which milk producers could not adjust themselves immediately. Thus, on the basis of ex-post observations it cannot be concluded that milk producers would behave irrationally, although the data includes some observations that deviate from the optimum behaviour (cf. Singh 1987, p. 444–445).

The empirical research results should be viewed cautiously. The research data and research methods do not allow experimental research, and thus repetition is not possible. In spite of the possible defects in the existing data, the bookkeeping data was the best possible data for solving the empirical problem of the study.

In interpreting the results obtained from the representative dairy farm data set it should be kept in mind that time series data is deficient for determining the advantages and disadvantages related to the size (scale) of the enterprise. On the other hand, the panel data set used in the study possessed a large amount of new information concerning output, costs, and cost shares variation across farms. Thus, the panel data set provided more reliable results concerning the size (scale) economies, and made it possible to separate the effects of the farm size economies and technical change from each other.

In recent years the production and cost theory, as well as the research methods, have developed rapidly, but in spite of this, simplification of the research problem is still necessary in empirical studies. Alternatively, one would have to abandon the empirical approach. In this study, it was essential to obtain an empirical answer to the research problem. Theoretical study alone does not give quantitative information needed in policy making.

In empirical analyses the estimated function is necessarily an approximation of the real cost function. Also, the number of variables included in the analysis must be restricted, because the data and the research methods do not allow for examination of large groups of variables simultaneously. In this study, too, the estimated cost function is an approximation of the real cost function. Aggregate price indices of inputs and the aggregate output were used in the estimation. The problems related to the number of variables in milk production can be illustrated by, for example, several kinds of feed (e.g., protein feed, energy feed, minerals, vitamins). Various kinds of machines are also used on dairy farms, so that obtaining and using detailed data is impossible with the current knowledge and data.

In this study the demand for the capital items, labour, purchased fertilizers, and purchased feed was assumed to be weakly separable. In practice, it cannot be assumed, a priori, that this restriction would be completely true. The choice of the combination of purchased feed, for example, may depend on the choice of the combination of capital items. The assumption on the separability of inputs had to be made, even if it could not be tested, because it makes the theory and the empirical research methods compatible with each other. The assumption of separability is needed, because in empirical studies it must be solved, a priori, which individual inputs are connected to which aggregate input, and thus it has assumed a "State of Art" position in applied economic study (Chambers 1988, p. 157).

The fact that the adjustment to new price relations has been assumed to occur without adjustment costs may also have influenced the research results. On the other hand, in economics it has not been succeeded to solve the dependency between the adjustment costs and the fixity of inputs, so that the use of a dynamic approach involves a theoretical problem. The small number of observations (a year) is problematic, because the estimation methods are based on asymptotic properties, and thus the results may include a small sample bias.

To improve the reliability of the empirical results it would be essential to obtain better research data. The price indices used in this study are the same for all dairy farms for one year.

Thus, regional differences in prices are treated in the same way as quality differences. If the dairy farm level prices would be available, it would be possible to distinguish more inputs than in this study. On the other hand, by using different price indices, it is possible that these indices become endogenous variables.

Improving the quality of the data would be important, but the requirements set for an adequate amount of data should also be kept in mind. Developing the statistical methods would also improve the reliability of the results.

10 Summary

In this study, the effect of the change in the relative prices of inputs and the technical change of production on the derived demand for inputs of dairy farms was examined. The dual approach of the neoclassical production and cost theory is used in the study. Based on the theory, it is assumed that the production function describes the technical relationship that transforms inputs into output, dairy farms aim at minimizing costs, and the prices of inputs and products are determined exogenously.

To solve the empirical research problem, an equation system in which parameter restrictions according to the neoclassical production and cost theory were set between the equations. The system of equations was constructed from the cost function and the cost share equations. The translog cost function was chosen as the cost function to be estimated. The equation system consisting of the translog cost function and the cost share equations was estimated by Zellner's iterative estimation method. On the basis of the likelihood ratio test, the cost function had to be specified as non-homothetic, and it also had to be possible to estimate non-neutral technical change from it.

On the basis of the research results, the inputs used in milk production are for the most part substitutes with each other. The values of the elasticities of substitution are small, so that, with the existing production technology, the substitution of inputs for other inputs is inelastic. The own price elasticities of the derived demand for inputs were also inelastic. This means that, the possibilities of traditional agricultural policies and environmental policies to have an influence on the level of demand of inputs of production, in Finnish agriculture, with levies and/or subsidies are small. Thus, changes in the prices of inputs will affect mostly the farm income of the milk producer.

Technical change on dairy farms has increased the use of capital. According to the results, technical change and the farm size were interrelated in time series data, in representative dairy farm data, which made it impossible to separate their effects clearly from each other. Technical change solved from the panel data has been purchased feed-saving and other inputs using. Self-sufficiency in feed has been an objective, and thus the purchased feed-saving technical change appears logical. The panel data set made it possible to obtain more reliable information concerning technical change and size economies than did the representative dairy farm data set.

The average annual rate of technical change for the whole research period has been 1.3%, and it has been increasing of the level of technology. On the basis of this result, technological development has been advantageous to dairy farms.

The new production chains resulting from technical change have made it possible to increase the size of dairy farms. Maintaining the profitability and continuity of dairy farms requires that they keep up with the technical development. Substituting the cheaper capital input for the more expensive labour input has been a profitable measure, in particular, as new technology has been introduced to production through investments.

According to the results, there are advantages related to the size economies in milk production.

In milk production it has not been possible to utilize the economies of size in full during the last two decades, because the main focus in agricultural policy has been in abolishing the overproduction, and developing production has remained in the background. On the basis of the results obtained from the panel data set, a 1.0% increase in output increases costs about 0.6%. So, unit costs decrease as production is expanded. Therefore, increasing the size of dairy farms should be allowed that the advantages related to economies of size can be utilized.

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SELOSTUS

Tuotantopanosten substituutio sekä tekninen kehitys Suomen maitotiloilla vuosina 1965–1991

Empiirinen sovellutus kirjanpitoa pitäville maitotiloille

Matti Ryhänen

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Tutkimuksen tausta ja tavoitteet

Suomen maataloustuotanto on muuttunut nopeasti 1960-luvun alusta lähtien. Maatalouden muutokset ovat kytkeytyneet läheisesti kansantalouden kehitykseen. Taloudellisen kasvun ja elintason kohoamisen myötä syntyneet työpaikat ovat houkutelleet työvoimaa etenkin pientiloilta. Kehityksen mukana maaseudun väestö on vähentynyt yli puolella miljoonalla henkilöllä. Samanaikaisesti maitotilojen lukumäärä on laskenut 240 000 tilasta nykyiseen alle 35 000 tilaan.

Maitotilojen nopea väheneminen ei ole poistanut maidon ylituotantoa. Vaikean ylituotannon vuoksi maidontuotantoa on rajoitettu voimakkaasti, jonka seurauksena maitotilojen aktiivinen kehittäminen on jäänyt vähälle huomiolle. Tulevaisuudessa tarve maitotilojen kehittämiseen näyttää kasvavan. Tällöin tarvitaan uutta tietoa tuotantopanosten substituutiomahdollisuuksista (tuotantopanosten välisestä korvattavuudesta) sekä maitotilojen teknisestä kehityksestä. Tuotantopanosten substituutiomahdollisuuksien tunteminen ei ole oleellista pelkästään maidontuottajille, joiden mahdollisuudet vaikuttaa tuotantopanosten ja tuotteiden hintoihin ovat vähäiset, vaan se on erityisen tärkeää poliittisille päättäjille, joiden tulisi tuntea kehittämistoimenpiteiden yritystaloudelliset vaikutukset.

Tutkimuksen tavoitteena on selvittää, kuinka maidontuottaja reagoi ja muuttaa tuotantopanosten käyttöä niiden suhteellisten hintojen muuttuessa. Maidontuottajat eivät voi siirtää suhteellisten panoshintojen muutosta tuotteittensa hintoihin, koska ne on sovittu etukäteen maataloustuloneuvotteluissa, joten sopeutuminen tuotantopanosten hintojen suhteellisiin muutoksiin tapahtuu pääosin maitotilan tuotantoteknologiaa muuttamalla, siinä mitassa kuin se vain on mahdollista.

Tutkimuksen keskeisenä tavoitteena on selvittää tuotantopanosten kysynnän substituutio- ja oman hinnan joustojen arvot. Tuotantopanosten välisten substituutiomahdollisuuksien tutkiminen suomalaisilla maitotiloilla on ollut vähäistä. Maitotiloja kehitettäessä ja maidontuotantoa ohjattaessa tuotantopanosten keskinäisten suhteiden ja substituutiomahdollisuuksien tunteminen on oleellista. Ilman yritystaloudellista tietoa kehittämis- ja ohjaustoimenpiteet voivat olla ristiriidassa asetettujen tavoitteiden kanssa.

Lisäksi tavoitteena on tutkia, kuinka tekninen kehitys on vaikuttanut yksittäisten tuotantopanosten kysyntään sekä minkä tuotantopanosten kysyntä on lisääntynyt ja minkä vähentynyt teknisen kehityksen myötä.

Tutkimuksen teoreettinen kehys

Tässä tutkimuksessa hyödynnetään neoklassista tuotanto- ja kustannusteoriaa. Tutkimus pohjautuu pitkän aikajänteen tarkasteluun, jolloin kaikki kustannukset oletetaan muuttuviksi kustannuksiksi. Tuotanto- ja kustannusteorian mukaisesti oletetaan, että maitotilalle on olemassa tuotantofunktio, joka täyttää hyvin käyttäytyvän tuotantofunktion ominaisuudet. Koska maidontuotantoa on rajoitettu maassamme vuodesta 1970 lähtien ja koska maitotilat eivät toimi täydellisen kilpailun oloissa tuotemarkkinoillaan, niiden taloudellista käyttäytymistä kuvataan tuotantokustannusten minimointiongelmana.

Tutkimusongelman ratkaisemiseen käytetään duaalilähestymistapaa. Teorian mukaan oletetaan, että tuotantofunktio kuvaa tuotantopanosten ja tuotoksen välisen yhteyden, maitotilat toimivat kustannusten minimoijina ja että tuotantopanosten ja tuotteiden hinnat määräytyvät eksogeenisesti. Duaalilähestymistapa ja kustannusfunktion käyttö mahdollistavat tutkimusongelman ratkaisemisen.

Aineisto ja tutkimusmenetelmät

Tutkimusaineistona käytetään Suomen maatalouden kannattavuustutkimukseen osallistuvilta maitotiloilta kerättyjä tietoja vuosilta 1965–1991. Tutkimusta varten kerättiin kaksi aineistoa: A-maitotilat (44 kpl), jotka ovat mukana koko tutkimusaikajänteen ja B-maitotilat (168–364 kpl), joiden määrä vaihtelee vuosittain. Energiakriisin jälkeiselle ajalle 1976–1991 estimoidaan mallit erikseen.

Empiirinen havaintoaineisto koostuu maitotilojen kokonaistuotosta, kustannuksista, tuotantopanosten hinnoista sekä tuotantopanosten kustannusosuuksista. Tutkimukseen valittiin neljä aggregoitua tuotantopanosta; työ (maidontuottajaperheen ja palkkaväen työ), pääoma (koneet, kalusto, laitteet ja rakennukset), ostolannoite ja ostoväkirehu. Maitotilojen metsätalous, muu tuotantotoiminta, sivuansiotalous ja yksityistalous eivät kuuluneet tutkimuksen piiriin. Aineisto kerättiin kirjanpitotilojen tilivuoden tapahtumista, jotka on merkitty muistiin virtasuureina siten, että tuotos ja sen tuottamiseen käytetyt tuotantopanokset sattuvat samalle ajanjaksolle.

Tutkimusjakson aluksi valittiin vuosi 1965, koska tällöin kirjanpitotiloilla siirryttiin kesä-heinäkuun vaihteen tilikaudesta vuoden alusta alkavaan tilikauteen. Tilivuonna 1964–1965 kaikille tiloille ei ole laadittu täydellistä tilinpäätöstä, joten tilikauden aineisto on jäänyt pieneksi. Luotettavan aineiston saanti vuotta 1965 edeltävältä aikajänteeltä ei ollut mahdollista.

"Edustava" maitotila periaatetta sovelletaan molempiin tutkimusaineistoihin. A- ja B-maitotiloja kuvaavan edustavan tilan havainnot saadaan laskemalla A- ja B-maitotila -aineistoista keskiarvot kullekin vuodelle erikseen.

A-maitotila -aineisto kerätään paneeliaineistoksi, koska tietoja halutaan erityisesti yritystasolta. Tuotanto- ja kustannusteoria perustuu yksittäisten yrittäjien päätöksentekoon, joten paneeliaineiston käyttö on teoreettisesti vahvemmalla pohjalla kuin "edustava" maitotila -aineiston käyttö.

Tutkimusongelman ratkaisemiseksi kustannusfunktiosta ja kustannusosuusyhtälöistä muodostetaan yhtälösysteemi, jossa yhtälöiden välille asetetaan tuotanto- ja kustannusteorian mukaiset parametrirajoitukset. Symmetrisyysoletus testataan. Malli saadaan estimoitavaan muotoon approksimoimalla joustavamuotoisella translogfunktiolla kustannusfunktiota ja kustannusosuusyhtälöitä.

Yhtälöryhmän singulaarisuus vältetään poistamalla yksi kustannusosuusyhtälö yhtälösysteemistä sekä valitsemalla estimointiproseduuri, joka estimoi parametrit siten, että estimoitujen parametrien arvot eivät riipu siitä, mikä kustannusosuusyhtälöistä pudotetaan yhtälösysteemistä. Poistetun kustannusosuusyhtälön parametrit ratkaistaan parametrirajoitusten avulla.

Yhtälösysteemi estimoidaan Zellnerin iteratiivisella estimointimenetelmällä. Se sopii hyvin tutkimuksen yhtälösysteemin estimointiin, koska kustannusosuusyhtälöt muodostavat SUR-yhtälösysteemin (system of seemingly unrelated equations), jossa kustannusosuusyhtälöiden virhetermit ovat keskenään korreloituneita sekä siksi, että yhtälöiden oikealla puolella olevat muuttujat ovat eksogeenisia. SUR-estimointitekniikkaa käytetään sekä "edustava" maitotila -aineistoon että paneeliaineistoon.

Estimoiduista parametri- ja kustannusosuusarvoista ratkaistaan pääoma-, työ-, ostorehu- ja ostolannoitepanosten väliset substituutiojoustot Allenin osittaissubstituutiojouston, Morishiman osittaissubstituutiojouston ja varjosubstituutiojouston mittareilla sekä näiden tuotantopanosten ristijoustot ja oman hinnan joustot.

Tutkimustulokset

Tutkimustulosten mukaan maidontuotannossa tuotantopanokset ovat pääosin substituutteja keskenään. Substituutiojoustojen arvot ovat suhteellisen pieniä ja tuotantopanosten johdetun kysynnän oman hinnan joustot ovat myös itseisarvoltaan pieniä, joten vallitsevalla tuotantoteknologialla tuotantopanosten korvaaminen toisilla tuotantopanoksilla on joustamatonta. Tämä merkitsee sitä, että perinteisen maatalouspolitiikan ja ympäristöpolitiikan mahdollisuudet vaikuttaa maitotilojen tuotantopanosten kysyntään tuotantopanosten hintoihin liittyvien verojen ja/tai tukien avulla ovat vähäiset.

Allenin osittaissubstituutiojouston mittarilla mitattuna tuotantopanokset ovat pääosin substituutteja keskenään. Kaikissa tutkimusaineistoissa pääoma- ja ostorehupanos ovat komplementtejä (tuotantopanosten välillä täydennyssuhde). Osassa tutkimusaineistoja havaitaan komplementaarisuutta myös työ- ja ostolannoitepanoksen sekä pääoma- ja ostolannoitepanoksen välillä. Morishiman osittaissubstituutiojouston ja varjosubstituutiojouston mittareilla mitattuna tuotantopanokset ovat pääosin substituutteja keskenään. Pääoma- ja ostorehupanoksen välillä havaitaan myös komplementaarisuutta.

Verrattaessa "edustavalle" A- ja B-maitotilalle estimoituja substituutio- ja oman hinnan joustoja havaitaan, että B-maitotilojen joustot ovat keskimäärin jäykempiä kuin A-maitotilojen. B-maitotilat ovat erikoistuneet A-maitotiloja voimakkaammin maidontuotantoon, mikä selittänee joustojen eroja.

Paneeliaineistosta ratkaistut joustot antavat samanlaista informaatiota kuin "edustava" maitotila -aineistosta ratkaistut joustot muutoin paitsi ostolannoitepanokseen liittyvien joustojen osalta, jotka ovat keskimäärin huomattavasti jäykempiä kuin "edustava" maitotila -aineistosta ratkaistut joustot. Syynä tähän näyttäisi olevan aikasarjoihin kätkeytyvä multikollineaarisuusongelma, jota voidaan korjata hankkimalla lisää aineistoa.

Paneeliaineistosta saatavat tulokset ovat luotettavampia kuin edustava maitotila -aineistosta saatavat tulokset, koska paneeliaineiston käyttö lisää informaatiota tiloittaisten tuotosten, kustannusten ja kustannusosuuksien vaihtelusta. Jos "edustava" maitotila-aineistoon liittyy multikollineaarisuusongelma, paneeliaineisto mahdollistaa aikasarja-aineistosta saatavan informaation korjaamisen.

Tutkimuksessa estimoituja substituutiojoustoja verrattaessa muissa maissa estimoituihin substituutiojoustoihin havaitaan niissä huomattavaa samankaltaisuutta. Kaikissa läpikäydyissä tutkimuksissa tuotantopanosten välillä substituutiosuhde on vallitsevana. Muissa maissa estimoidut joustot ovat myös suhteellisen jäykkiä.

Tekninen kehitys maitotiloilla on ollut pääoman käyttöä lisäävää. Työ-, ostorehu- ja ostolannoitepanoksen käyttöä kuvaava tekninen kehitys vaihtelee "edustava" maitotila -aineistossa mallin spesifioinnin mukaan. Tulosten mukaan "edustava" maitotila -aineistossa tekninen kehitys ja yrityskoko kietoutuvat toisiinsa, joten niiden vaikutusten erottaminen toisistaan on mahdotonta. Paneeliaineistosta ratkaistu tekninen kehitys on ostorehujen käyttöä säästävää ja muita tuotantopanoksia käyttävää. Suomalaisessa maidontuotannossa on pyritty rehuomavaraisuuteen, joten ostorehujen käyttöä säästävä tekninen kehitys on looginen tulos. Maidontuotannon tuotantoteknologiaa ei voida kuvata neutraalilla teknisellä kehityksellä. Vuosittainen tekninen kehitys maidontuotannossa tutkimusaikajänteellä on ollut keskimäärin 1.3 prosenttia.

Tutkimustulosten mukaan maidontuotannossa on yrityskokoon liittyviä etuja. Tulosten mukaan tuotoksen nostaminen prosentilla lisää kustannuksia 0.6 prosenttia, joten yksikkökustannukset alenevat tuotantoa laajennettaessa. Tulosten mukaan maidontuotannossa olevia yrityskokoon liittyviä etuja ei ole täysin voitu hyödyntää, koska maatalouspolitiikan pääpaino on ollut ylituotannon vähentämiseen tähtäävässä ohjaamisessa, jolloin tuotannon kehittäminen on jäänyt taka-alalle. Yrityskoon kasvaessa työpanoksen kustannusosuus pienenee ja muiden tuotantopanosten kustannusosuus vastaavasti kasvaa.

Maitotilojen tuotannon kehittämiselle on välttämätöntä, että niille annetaan kasvun mahdollisuus. Tämä merkitsee samalla maitotilojen lukumäärän vähenemistä. Tilakohtaiset tuotannonrajoitukset (kesannointivelvoite, tuotantokiintiö) ovat lisänneet yksikkökustannuksia, koska maitotiloilla oleva tuotantokapasiteetti on jäänyt vajaakäyttöön. Lisäksi tuotannonrajoitukset rajaavat useimmilla tiloilla yrityskoon alueelle, jossa yksikkökustannukset alenevat voimakkaasti yrityskoon kasvaessa. Mahdollisessa EU-jäsenyydessä yrityskoon kasvattaminen voi olla vaikeaa heikkenevän kannattavuuden vuoksi.

Tutkimus poikkeaa keskeisesti aiemmista panoskysyntätutkimuksista, koska tutkimuksessa verrataan "edustava" maitotila -tarkastelun tulosten ja paneeliaineiston analyysistä saatavien tulosten eroja sekä selvitetään, missä määrin paneeliaineisto varmentaa tai mahdollisesti kumoaa "edustava" maitotila -tarkastelun tulokset.

Suoritettujen estimointien perusteella paneeliaineisto tukee ja tarkentaa "edustava" maitotila -aineistoista estimoituja tuloksia. Estimoitujen substituutioparametrien erot ovat yleensä pieniä eikä niissä ole systemaattista vääntöä. Vain ostolannoitteisiin liittyvät substituutiojoustot ovat systemaattisesti jäykempiä paneeliaineistosta ratkaistuna kuin "edustava" maitotila -aineistosta ratkaistuna.

Properties of production possibility set T

The production possibility set T contains all technically feasible combinations of (x,y). In empirical study the observations are a set of observations collected from R dairy farms. Thus, it is possible to have only some points of (x,y), but not a whole convex set in applied study in production analysis. Therefore, to determine the production possibility set on the basis of these points requires the following restrictions on T (CHAMBERS 1988, p. 252, JACOBSEN and PAULSEN 1991, p. 5–8):

1. T is nonempty;
2. T is a closed set;
3. T is a convex set;
4. if $(x,y) \in T$, $x' \geq x$, then $(x',y) \in T$;
5. if $(x,y) \in T$, $y' \leq y$, then $(x,y') \in T$;
6. for every finite x, T is bounded from above; and
7. $(0,0) \in T$, but $(0,y) \notin T$, if $y > 0$.

In the literature on agricultural economics these restrictions are generally accepted. There also exists a weak disposability concept of properties 4 and 5, when there is a possibility that some inputs may have an adverse effect on output, if they are used in too high proportion (e.g., BYRNES et al. 1987, p. 369–373). It is assumed in this study that milk producers do not accept negative marginal products, so that the concept of weak disposability will not be needed.

According to property 1 of the production possibility set, there has to be at least one point where drawing conclusions from the production technology would be possible. Property 2 is purely a technical restriction that the optimum solution should exist. According to property 2, all of the boundary points of T belong to T. Property 3 implies that for any two technically feasible input-output combinations in set T, the line segment connecting these two points lies entirely in T and is also technically feasible.

Properties 4 and 5 rule out negative marginal product, i.e., overutilization of some input(s) to the point where output falls, is ruled out. Thus, marginal product is equal or greater than zero. According to property 4, if an input bundle can produce a given output bundle, a larger input bundle can also produce that output bundle. According to property 5, if an input bundle can produce a given output bundle, it can also produce all smaller output bundles, e.g., zero output is possible.

According to property 6, T is bounded from above. This implies that there is some limit that can be produced. In other words, for a given input bundle it is impossible to produce an infinite amount of output. So a limit must exist. Property 7 is a "no free lunch" property. The origin belongs to T, because producing zero output is always possible, but it is not possible to produce anything if there is no input.

The production technology described above is quite abstract. Thus, it is illustrated by Figure I.

Let us assume that we have a data set collected randomly from two dairy farms; $A = (x^1,y^1) \in T$ and $B = (x^2,y^2) \in T$, which describe input-output combinations from these dairy farms. In Figure I, illustration of production technology is started using property 4 to the point A. According to property 4, y^1 can be produced using x^1. It can also be produced using more input, for example x^3 (point C). This means that if a farmer can milk 20 cows during a day, two farmers can milk these 20 cows during a day, too. According to this property, we can draw the horizontal line from point A via point C to the right. According to property 5, x^1 can produce y^1, but the same amount of x^1 can also produce less output, for example, zero output is possible. This means that if a farmer can milk 20 cows during a day, it is possible that he/she can milk 10 cows during a day, too. Then we can draw the vertical line between points x^1 and A. We can continue with point B the same way as we did with point A.

We can see in Figure I that there is a hole between points A and B. Thus, we use property 3. If the production possibility frontier is concave, the frontier and the set under it form a convex set. Convex combinations are weighted averages which sum up to one. So we can draw the conclusion that with two known points, $A = (x^1,y^1) \in T$ and $B = (x^2,y^2) \in T$, so that θ $(0 \leq \theta \leq 1)$, we will be able to find points (for example D) where $D = (x,y) = (1-\theta)(x^1,y^1) + \theta(x^2,y^2) \in T$. So we can draw a line between points A and B because all convex combinations belong to the production possibility set T. By using the free disposability of inputs and outputs on this line we can fill the whole convex hole.

The production possibility set in Figure I illustrates the production technology of these two dairy farms. In the literature it is said that T forms a free disposal convex hull with respect to the collected data set. In Figure I the boundary of the production possibility set describes a traditional production function because it is defined as the locus of the technically efficient input-output combinations.

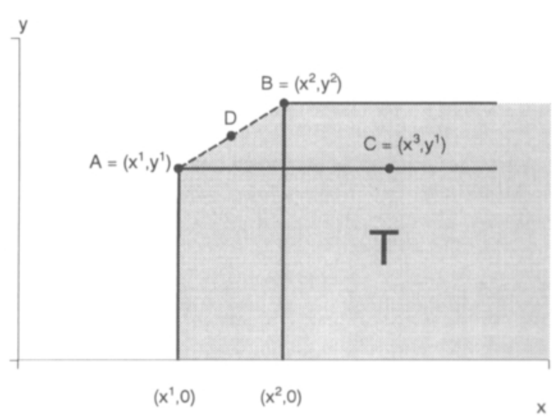


Fig. I. Production possibility set T.

Properties of the production function

The assumption that the production function of a dairy farm yields the maximum obtainable output from a given input vector does not provide a sufficient basis for economic analysis. Thus, it is necessary to use further restrictions on the production function (e.g., CHAMBERS 1988, p. 8–14):

1a. if $x' \geq x$, then $f(x') \geq f(x)$, monotonicity;
1b. if $x' > x$, then $f(x') > f(x)$, strict monotonicity;
2a. $V(y) = \{x{:}f(x) \geq y\}$ is a convex set, quasi-concavity;
2b. $f(\lambda x_1 + (1-\lambda)x_2) \geq \lambda f(x_1) + (1-\lambda)f(x_2)$, $0 \geq \lambda \geq 1$, concavity;
3a. $f(0_n) = 0$, null vector;
3b. $f(x_1,\ldots,x_{i-1}, 0, x_{i+1},\ldots,x_n) = 0$, $\forall x_i$;
4. $V(y)$ is closed and nonempty, $y > 0$;
5. $f(x)$ is finite, nonnegative, real valued, and single valued $\forall x$ which are nonnegative and finite; and
6. $f(x)$ is everywhere twice continuously differentiable.

These properties do not represent the set of hypotheses to be maintained universally, but these properties are generally agreed to characterize the real world and economic behaviour of a farm. They represent a catalog of assumptions that are useful and necessary in the presentation of the production and cost theory.

According to property 1, all marginal products are nonnegative or additional units of any input cannot decrease the level of output. Property 2a implies that $V(y)$ is convex. Convexity of $V(y)$ implies that, if x_1 and x_2 can produce y, then any weighted average of these input bundles can do this, too; or $x' = \lambda x_1 + (1-\lambda)x_2$ is an interior point of $V(y)$. $V(y)$ is a (strictly) convex set if $f(x)$ is (strictly) quasi-concave. $f(x)$ is quasi-concave, if upper contour sets are convex for all y. Property 2b is a mathematical representation of the law of diminishing marginal productivity. It means that when $f(x)$ is twice continuously differentiable the Hessian matrix of $f(x)$ is negative semidefinite.

Property 3a means that production of a strictly positive output without the use of scarce resources is ruled out. It is physically possible to produce output without economically scarce resources. Such instances are omitted here because they do not represent an economic problem. Property 3b is more restrictive than 3a. It states that the production of output without all essential inputs is impossible. In the real world the production is partly contradictory with properties 3a and 3b. For example, the use of fertilizers increases the yield, but is not essential to achieve some level of output. Property 3 means that $V(y)$ does not intersect the axis.

Property 4 is a technical assumption. It means that it is always possible to produce positive output, and it rules out the possibility of holes in the boundary of $V(y)$. So it is used to guarantee the existence of a well-defined constrained optimum. Property 5 is self-explanatory. Property 6 is necessary since it makes possible the use of differential calculus in the analysis.

Profit function

The profit function in conditions of pure competition can be presented as:

$$\Pi(p,w) = \text{Max}\ \{py - wx : (y,x) \in T\},\ \ x \geq 0,\ y \geq 0 \quad (60)$$

$$= \text{Max}\ \{pf(x) - wx\},\ \ x \geq 0 \quad (61)$$

This profit function is derived from the production function so that the constraint f(x) = y is binding, since the farmer aims at maximizing profit for any given level of output. Thus, f(x) is substituted for y, and a constrained problem is turned to an unconstrained one.

As an alternative, it is possible to leave the revenue part as a function of y, and present the cost part as a function of y. The latter part of the function is the cost function, since it is related to the optimal level of cost to output. Thus, the profit function can be written as:

$$\Pi(p,w) = \text{Max}\ \{py - C(w,y)\},\ y \geq 0 \quad (62)$$

According to the discussion above, the profit function can be derived directly from the cost function.

Definitions of various elasticities of substitution

According to HEADY (1952, p. 144–145), an elasticity of substitution between two inputs can be defined as an elasticity of production. Thus, the elasticity of substitution is equal to the percentage change in the use of x_1 divided by the percentage change in the use of x_2.

$$E_{sh} = (\Delta x_1/x_1)/(\Delta x_2/x_2)\,. \tag{63}$$

This measure failed to determine the slope of the isoquant map. Thus, the elasticity of substitution defined by HICKS (1963) became a more generally accepted definition (DEDERTIN 1986, p. 197). Its mathematical definition is more complicated, but the interpretation of the solved values relative to the shape of the isoquant map is clear. The elasticity of substitution defined by Hicks is given by:

$$E_s = \frac{\partial(x_2/x_1)}{\partial(f_1/f_2)}\,\frac{f_1/f_2}{x_2/x_1} = \frac{\partial \ln(x_2/x_1)}{\partial \ln(f_1/f_2)}, \tag{64}$$

in which $y = f(x_1,x_2)$ is fixed, and $f_1 = \partial y/\partial x_1$ and $f_2 = \partial y/\partial x_2$ are marginal products of inputs x_1 and x_2. The elasticity of substitution E_s between two inputs is defined as the elasticity of the ratio of the inputs with respect to the marginal rate of technical substitution between them. Intuitively, E_s tells how the ratio of inputs changes as the slope of isoquant changes. For example, if a small change in slope causes a large change in the input ratio, the E_s gets a large value. The first order conditions for cost minimization say that the $\partial\ln(f_1/f_2)$ equals the $\partial\ln(w_1/w_2)$ which gives another familiar definition.

Elasticity of substitution can be solved directly on the basis of first and second derivatives of the production function in two inputs case (HENDERSON and QUANDT 1971, p. 62):

$$\sigma_{12} = \frac{f_1 f_2 (f_1 x_1 + f_2 x_2)}{x_1 x_2 (2 f_{12} f_1 f_2 - f_1^2 f_{22} - f_2^2 f_{11})}, \tag{65}$$

in which $f_{11} = \partial^2 y/\partial x_1^2$;
$f_{22} = \partial^2 y/\partial x_2^2$; and
$f_{12} = f_{21} = \partial^2 y/\partial x_1 \partial x_2$ (Young's theorem)

Equation (65) makes it possible to calculate the elasticity of substitution at a certain point on an isoquant for a twice continuously differentiable production function. Equation (65) can be written in matrix notation as:

$$\sigma_{12} = \frac{x_1 f_1 + x_2 f_2}{x_1 x_2}\,\frac{F_{12}}{F}, \tag{66}$$

in which F is the bordered Hessian determinant and F_{12} is the cofactor. The measures above are directly applicable only for two input cases. They are equivalent measurements, except for Heady's measurement.

In the case that the production function has three or more inputs, a number of alternative definitions for elasticity of substitution have been developed. For example, in a three-input case it is possible to derive three separate isoquants when holding one of them in turn constant. This makes it possible to generalize the equation (64). According to CHAMBERS (1988, p. 33), this short-run elasticity is called direct elasticity of substitution. It measures the degree of substitutability between inputs x_i and x_j while all x_k $(k \neq i, k \neq j)$ are fixed.

The Allen partial elasticity of substitution (σ_{ij}) is a generalization for n inputs and it can be calculated using a generalization of equation (66)(ALLEN 1950, p. 503–505):

$$\sigma_{ij} = \frac{\sum_{k=1}^{n} x_k f_k}{x_i x_j}\,\frac{F_{ij}}{F} = \frac{\sum_{k=1}^{n} x_k f_k}{x_i x_j}\,(f^{-1})_{ij}\,, \tag{67}$$

in which $(f^{-1})_{ij}$ is the ijth element of f^{-1} (f is bordered Hessian from the equation (3)). Inputs are complements if the elasticity of substitution is negative, and substitutes if the elasticity is positive. σ_{12} and σ_{ij}, in the case of a two-input production function, are equivalent.

The Morishima partial elasticity of substitution (σ^M_{ij}) is another generalization given by (KOIZUMI 1976, p. 152):

$$\sigma^M_{ij} = \frac{f_j}{x_i}\frac{F_{ij}}{F} - \frac{f_j}{x_j}\frac{F_{jj}}{F}\,. \tag{68}$$

All other marginal rate of technical substitutions are intact. According to equations (67) and (68), there is a connection between Allen and Morishima partial elastisities of substitution (KOIZUMI 1976, p. 153):

$$\sigma_{ij}^{M} = \frac{f_j x_j}{\sum_{k=1}^{n} f_k x_k} (\sigma_{ij} - \sigma_{jj}) \ . \tag{69}$$

According to equation (69), the Morishima elasticity of substitution is asymmetric since $\sigma_{ij}^{M} \neq \sigma_{ji}^{M}$. It is possible that Allen complements can be Morishima substitutes. On the other hand, if inputs are Allen substitutes, they are also Morishima substitutes.

Sources of data

The data was collected from the bookkeeping dairy farms for 1965–1991. The data from 1965–1975 was collected manually from the original bookkeeping forms, and from 1976–1991 mainly directly from the databases recorded at the Agricultural Economics Research Institute (AERI), and the rest by hand from the original bookkeeping forms. The manually collected observations were recorded by the DBASE program. The SURVO program was used for checking and preliminary processing of the data.

Accounting year 1965

Returns were collected from the Gross Return Form of Agriculture, which means that they indicate the return of the financial year in question in FIM (the change in the storage, consumption of the private household, and other transfers affecting the return have been taken into account). The costs were collected from the Production Expenses in Agriculture Form, so that they are the costs of the production of the financial year (change in the storage, account receivables, etc., have been taken into account). Insurance payments (tractor and the combine harvester) were collected from the Cash Receipts and Cash Expenses Form. The use of labour of the farm family in current work and investment work in agriculture, the costs of the current work done by hired labour, and its use of labour in current work and investment work were collected from the Labour Costs Form. Maintenance costs do not include the costs of maintenance work done by hired labour or the farm family, because they are included in the costs of current work in agriculture. Since residential buildings were included in the property of agriculture, the repair costs had been included in the costs of agriculture. Investments were collected from the Agricultural Assets and Liabilities Form, and own timber as well as the costs of hired labour are also included in them. The sales of machinery and implements were collected from the Implements Form. The arable land areas of farms were collected from the Gross Return Form, and the average number of cows from the Livestock Form. If the average number of cows was not reported, the arithmetic average of the number of cows at the beginning and the end of the year was marked as the average number of cows in the research data.

Accounting year 1966

Residential buildings were separated from agriculture as a property group of their own. The repairs were no longer included in the expenditure of agriculture or the use of labour in current work. The repair costs of tractors and combine harvesters were not specified in the Production Expenses in Agriculture Form, but in the Cash Receipts and Cash Expenses Form. Only the insurances of tractors and combine harvesters could be specified. Other insurances are reported as unspecified in the group 'Other Expenditure of Agriculture'.

Accounting year 1967

No changes compared to the previous year.

Accounting year 1968

The values of machinery, implements, and buildings in taxation started to be used as the bookkeeping values of machinery, implements, and production buildings. In this connection, an initial inventory of the capital assets according to section 18 in the Act on the Taxation of Farm Income (MVL) was made, so that from this year the capital values of buildings, machinery, and implements were included in the data. In addition to the insurance of tractors, combine harvesters and cars, it was again possible to separate other insurances, but their contents were not specified. The rents of machinery and implements were unspecified, as was the case in the earlier years, too. The rent incomes from residential buildings were included in the total returns, and correspondingly, the costs ensuing from the residential buildings in the production expenses in agriculture, and the repair work of residential buildings in the current work of agriculture. In building investments residential buildings are still classified as a group of their own. Due to the lack of the Gross Return Form from the Southern Ostrobothnia and Northern Finland, the returns had to be collected from the Cash Receipts and Cash Expenses Form, which means that it was not possible to determine the cash value of deliveries in kind and the changes in the storage.

Accounting years 1969–1975

No changes compared to the previous year.

Accounting years 1976–1988

Since 1976 the information were mainly obtained from the databases recorded at the Agricultural Economics Research Institute. The insurance payments for hired labour and the number of cows remained to be collected by hand. Pension payments were not specified.

Accounting years 1989–1991

All necessary data was obtained from the databases recorded at the Agricultural Economics Research Institute.

Appendix of other data sources

Variable	Source
Effective yield on bonds, % p.a.	Statistics of the Bank of Finland
Inflation percentage	Central Statistical Office (Rise of cost-of-living index from December till December)
Price of labour input	Central Statistical Office as wages of agricultural workers FIM/h in 1982–1991
Wage and salary index, Agriculture	Central Statistical Office
Prices of purchased fertilizers and industrial feed	Indices calculated at the AERI
Machinery and implement cost index and the cost index for agricultural buildings	Indices calculated at the AERI
Producer price of milk	Statistics of the AERI
Producer price of beef	Statistics of the AERI

Data appendix

Dairy farms of group A (a representative dairy farm).

obs	$\ln W_K$	$\ln W_L$	$\ln W_M$	$\ln W_H$	$\ln Y$	$\ln C$
1965	−1.635320	−2.595923	−1.832582	−1.771957	−0.839075	−2.566017
1966	−1.857451	−2.491835	−1.801810	−1.737271	−0.876974	−2.561434
1967	−1.990625	−2.408590	−1.714798	−1.703749	−0.834273	−2.519051
1968	−1.848647	−2.318186	−1.639897	−1.604450	−0.908248	−2.361094
1969	−1.620246	−2.251559	−1.624552	−1.604450	−0.806898	−2.243486
1970	−1.660784	−2.135716	−1.619488	−1.604450	−0.774401	−2.179138
1971	−2.037839	−2.004661	−1.594549	−1.604450	−0.693727	−2.100142
1972	−1.889218	−1.838027	−1.565421	−1.570217	−0.656777	−1.978605
1973	−3.036138	−1.569146	−1.427116	−1.482805	−0.655659	−1.858169
1974	−2.938785	−1.353297	−1.224175	−1.301953	−0.569303	−1.545567
1975	−2.590400	−1.095878	−1.038458	−1.044124	−0.466857	−1.337809
1976	−1.226525	−0.936305	−0.879477	−0.791863	−0.349955	−1.081269
1977	−1.043755	−0.818255	−0.681219	−0.606969	−0.310623	−0.942027
1978	−0.672365	−0.720518	−0.701179	−0.556870	−0.273542	−0.779730
1979	−0.833605	−0.607443	−0.705220	−0.531028	−0.207959	−0.696274
1980	−1.121778	−0.504032	−0.621757	−0.441611	−0.168454	−0.605048
1981	−0.601827	−0.389620	−0.421594	−0.236989	−0.150102	−0.419304
1982	−0.472679	−0.275477	−0.298406	−0.175545	−0.098782	−0.271756
1983	−0.308674	−0.224244	−0.164875	−0.154317	−0.047396	−0.208894
1984	−0.089433	−0.108476	−0.048140	−0.076881	−0.020693	−0.109827
1985	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
1986	0.033686	0.064832	−0.020203	0.005982	−0.007387	0.061505
1987	0.022720	0.132194	0.020783	−0.133531	0.008553	0.103969
1988	−0.143132	0.195550	0.048790	−0.215672	−0.017502	0.116172
1989	−0.063132	0.305785	0.089841	−0.199671	0.077368	0.195841
1990	0.188453	0.386228	0.145830	−0.121038	0.103576	0.266342
1991	0.311110	0.491484	0.186480	0.099845	0.096355	0.338459

Dairy farms of group B (a representative dairy farm).

obs	$\ln W_K$	$\ln W_L$	$\ln W_M$	$\ln W_H$	$\ln Y$	$\ln C$
1965	−1.597954	−2.589348	−1.832582	−1.771957	−1.137623	−2.756070
1966	−1.822631	−2.496328	−1.801810	−1.737271	−1.116756	−2.748029
1967	−1.957720	−2.398336	−1.714798	−1.703749	−1.115565	−2.713158
1968	−1.815663	−2.314789	−1.639897	−1.604450	−1.187312	−2.576233
1969	−1.580608	−2.251065	−1.624552	−1.604450	−1.037583	−2.444437
1970	−1.623993	−2.138546	−1.619488	−1.604450	−0.908124	−2.336763
1971	−2.021626	−1.989513	−1.594549	−1.604450	−0.797619	−2.239817
1972	−1.869375	−1.829835	−1.565421	−1.570217	−0.681792	−2.034147
1973	−3.036138	−1.568166	−1.427116	−1.482805	−0.642606	−1.904534
1974	−2.938785	−1.349851	−1.224175	−1.301953	−0.533958	−1.611721
1975	−2.590401	−1.100797	−1.038458	−1.044124	−0.485970	−1.382024
1976	−1.207446	−0.928576	−0.879477	−0.791863	−0.353665	−1.110938
1977	−1.029403	−0.817808	−0.681219	−0.606969	−0.305683	−0.973674
1978	−0.668513	−0.711319	−0.701179	−0.556870	−0.239184	−0.807640
1979	−0.823438	−0.601383	−0.705220	−0.531028	−0.194190	−0.710845
1980	−1.102711	−0.497694	−0.621757	−0.441611	−0.140458	−0.638220
1981	−0.594551	−0.390161	−0.421594	−0.236989	−0.114457	−0.424095
1982	−0.467000	−0.276017	−0.298406	−0.175545	−0.072022	−0.271466
1983	−0.304516	−0.212055	−0.164875	−0.154317	−0.030428	−0.205892
1984	−0.088700	−0.112173	−0.048140	−0.076881	−0.015743	−0.098354
1985	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
1986	0.033947	0.064223	−0.020203	0.005982	−0.006602	0.044843
1987	0.023003	0.133201	0.020783	−0.133531	−0.011142	0.083095
1988	−0.145014	0.204099	0.048790	−0.215672	−0.026899	0.103065
1989	−0.064496	0.309908	0.089841	−0.199671	0.118441	0.210227
1990	0.187574	0.382845	0.145830	−0.121038	0.125275	0.269486
1991	0.310290	0.488684	0.186480	0.099845	0.126271	0.342104

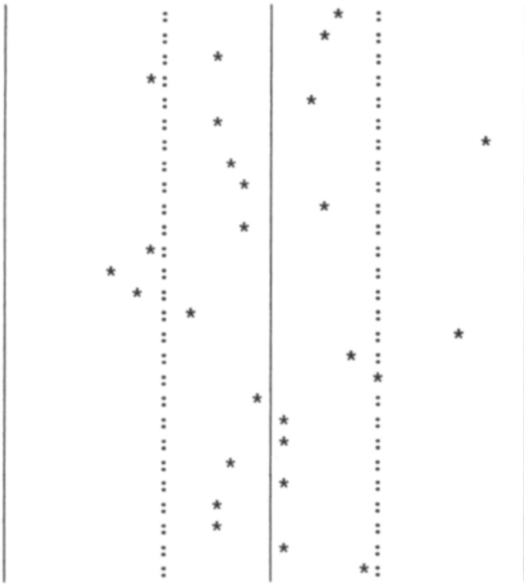
Dummy variables

obs	D_+	D_-	D_i	obs	D_+	D_-	D_i
1965	0	0	0	1980	0	0	0
1966	0	0	0	1981	0	1	0
1967	0	0	0	1982	0	1	0
1968	0	0	0	1983	0	0	0
1969	0	0	0	1984	0	0	0
1970	0	0	0	1985	0	0	0
1971	0	0	0	1986	0	0	0
1972	0	0	0	1987	0	1	0
1973	0	0	1	1988	0	1	0
1974	0	0	1	1989	0	0	0
1975	0	0	1	1990	1	0	0
1976	1	0	0	1991	1	0	0
1977	1	0	0				
1978	0	0	0				
1979	0	0	0				

D_+ = a dummy variable for an exceptionally good year
D_- = a dummy variable for an exceptionally poor year
D_i = a dummy variable for the period of high inflation (> 15 %)

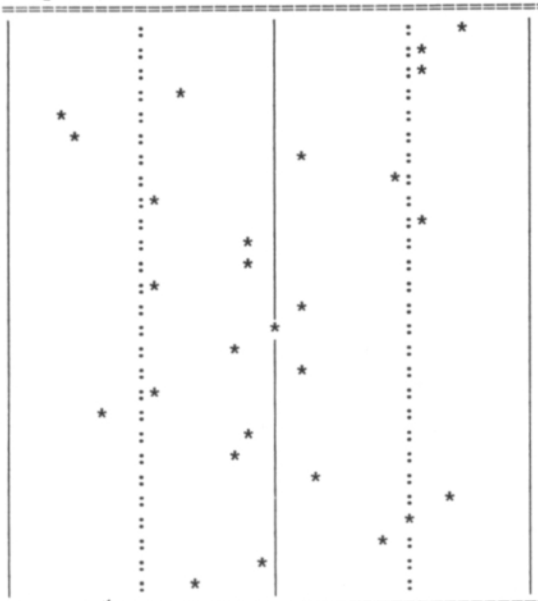
Cost shares and cost (actual, fitted, residual, and residual plot)
Dairy farms of group A (a representative dairy farm).

S_K Residual Plot



obs	RESIDUAL	ACTUAL	FITTED
1965	0.00668	0.26997	0.26329
1966	0.00457	0.24059	0.23602
1967	-0.00434	0.20456	0.20890
1968	-0.01080	0.21920	0.23000
1969	0.00411	0.25538	0.25127
1970	-0.00480	0.23778	0.24258
1971	0.01962	0.20194	0.18232
1972	-0.00372	0.18995	0.19367
1973	-0.00280	0.09545	0.09826
1974	0.00543	0.08621	0.08077
1975	-0.00263	0.09089	0.09352
1976	-0.01101	0.17020	0.18122
1977	-0.01443	0.17015	0.18458
1978	-0.01184	0.21027	0.22211
1979	-0.00717	0.18753	0.19470
1980	0.01712	0.16339	0.14627
1981	0.00759	0.18779	0.18020
1982	0.00997	0.19237	0.18239
1983	-0.00097	0.20658	0.20755
1984	0.00128	0.22569	0.22442
1985	0.00101	0.23140	0.23039
1986	-0.00339	0.23639	0.23979
1987	0.00145	0.22295	0.22150
1988	-0.00528	0.19834	0.20362
1989	-0.00485	0.21290	0.21776
1990	0.00163	0.25687	0.25524
1991	0.00893	0.27674	0.26782

S_L Residual Plot



obs	RESIDUAL	ACTUAL	FITTED
1965	0.01757	0.49989	0.48232
1966	0.01355	0.51771	0.50416
1967	0.01360	0.52534	0.51173
1968	-0.00948	0.51341	0.52290
1969	-0.02033	0.48280	0.50313
1970	-0.01966	0.48654	0.50620
1971	0.00222	0.52081	0.51859
1972	0.01195	0.52593	0.51398
1973	-0.01120	0.59260	0.60380
1974	0.01354	0.61349	0.59996
1975	-0.00234	0.57974	0.58207
1976	-0.00276	0.51237	0.51513
1977	-0.01133	0.50069	0.51201
1978	0.00231	0.46932	0.46701
1979	0.00062	0.47087	0.47025
1980	-0.00413	0.48107	0.48520
1981	0.00303	0.45166	0.44863
1982	-0.01131	0.43332	0.44463
1983	-0.01600	0.44337	0.45937
1984	-0.00215	0.45237	0.45452
1985	-0.00375	0.45032	0.45407
1986	0.00335	0.46097	0.45762
1987	0.01685	0.45884	0.44200
1988	0.01222	0.47174	0.45953
1989	0.01019	0.48022	0.47004
1990	-0.00137	0.48682	0.48820
1991	-0.00705	0.48182	0.48887

S_M — Residual Plot

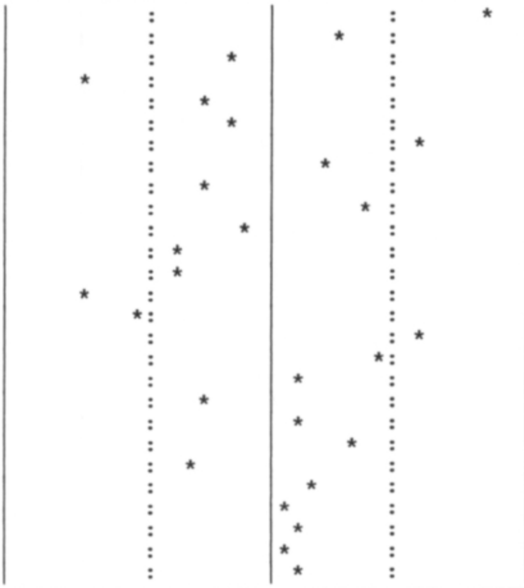
obs	RESIDUAL	ACTUAL	FITTED
1965	-0.01287	0.13654	0.14940
1966	-0.01545	0.14372	0.15917
1967	-0.00162	0.17483	0.17645
1968	0.01774	0.17161	0.15387
1969	0.01334	0.16405	0.15070
1970	0.01807	0.17578	0.15772
1971	-0.02497	0.17500	0.19998
1972	-0.00869	0.18747	0.19615
1973	-0.00069	0.21166	0.21235
1974	-0.00590	0.22384	0.22974
1975	0.00659	0.24018	0.23359
1976	0.00486	0.21554	0.21068
1977	0.01761	0.22773	0.21012
1978	0.01111	0.22504	0.21392
1979	0.00459	0.24103	0.23643
1980	-0.00812	0.25905	0.26717
1981	0.00171	0.27094	0.26923
1982	-0.00329	0.26688	0.27017
1983	0.00925	0.24288	0.23363
1984	0.00388	0.22755	0.22366
1985	-0.00462	0.21653	0.22114
1986	-0.00963	0.20387	0.21350
1987	-0.01726	0.22544	0.24271
1988	-0.00240	0.24338	0.24578
1989	0.00571	0.22907	0.22337
1990	0.00044	0.18145	0.18101
1991	9.9E-05	0.17465	0.17455

lnC — Residual Plot

obs	RESIDUAL	ACTUAL	FITTED
1965	0.06312	-2.56602	-2.62913
1966	0.02470	-2.56143	-2.58614
1967	-0.00557	-2.51905	-2.51349
1968	-0.03014	-2.36109	-2.33095
1969	-0.01034	-2.24349	-2.23315
1970	-0.03466	-2.17914	-2.14447
1971	0.03197	-2.10014	-2.13211
1972	-0.00166	-1.97860	-1.97695
1973	-0.04271	-1.85817	-1.81545
1974	0.04858	-1.54557	-1.59415
1975	-0.00587	-1.33781	-1.33194
1976	-0.02341	-1.08127	-1.05785
1977	-0.06012	-0.94203	-0.88191
1978	-0.03658	-0.77973	-0.74315
1979	-0.00346	-0.69627	-0.69282
1980	0.04305	-0.60505	-0.64809
1981	0.01241	-0.41930	-0.43172
1982	0.02927	-0.27176	-0.30102
1983	-0.01392	-0.20889	-0.19497
1984	-0.05048	-0.10983	-0.05935
1985	-0.02627	0.00000	0.02627
1986	0.00882	0.06151	0.05268
1987	0.02573	0.10397	0.07824
1988	0.03500	0.11617	0.08117
1989	0.04895	0.19584	0.14689
1990	0.00723	0.26634	0.25911
1991	-0.03464	0.33846	0.37309

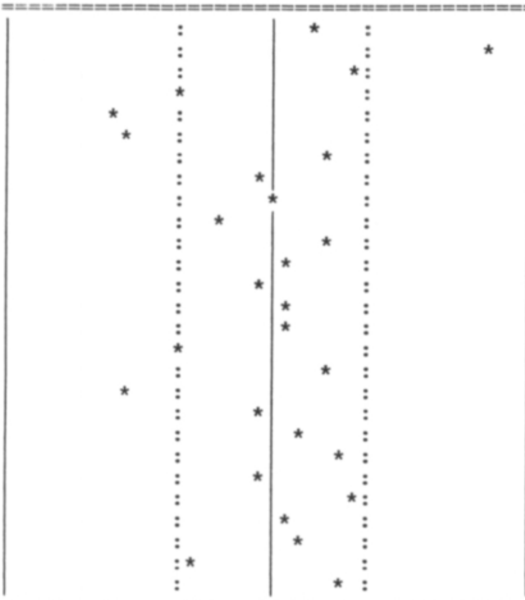
Cost shares (actual, fitted, residual, and residual plot)
Dairy farms of group B (a representative dairy farm).

S_K Residual Plot



obs	RESIDUAL	ACTUAL	FITTED
1965	0.01847	0.28201	0.26354
1966	0.00622	0.23657	0.23035
1967	-0.00340	0.20315	0.20655
1968	-0.01570	0.21081	0.22651
1969	-0.00568	0.24233	0.24801
1970	-0.00293	0.22917	0.23210
1971	0.01302	0.17980	0.16678
1972	0.00428	0.17821	0.17393
1973	-0.00602	0.09425	0.10027
1974	0.00816	0.09093	0.08277
1975	-0.00215	0.10050	0.10265
1976	-0.00857	0.15764	0.16621
1977	-0.00838	0.16127	0.16965
1978	-0.01612	0.18870	0.20482
1979	-0.01169	0.16934	0.18103
1980	0.01314	0.14569	0.13255
1981	0.00882	0.17384	0.16502
1982	0.00185	0.17137	0.16951
1983	-0.00558	0.19241	0.19799
1984	0.00228	0.21977	0.21749
1985	0.00645	0.23065	0.22420
1986	-0.00658	0.22709	0.23367
1987	0.00342	0.22112	0.21770
1988	0.00098	0.19929	0.19832
1989	0.00228	0.21454	0.21226
1990	0.00143	0.25422	0.25278
1991	0.00268	0.26634	0.26367

S_L Residual Plot



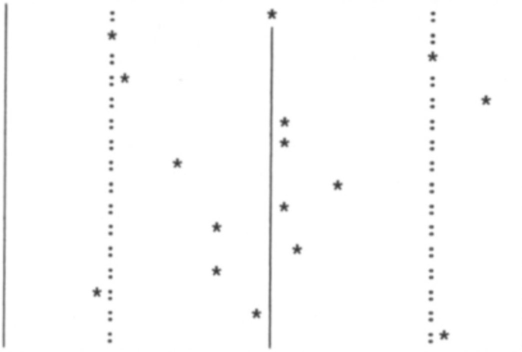
obs	RESIDUAL	ACTUAL	FITTED
1965	0.00358	0.51042	0.50685
1966	0.01942	0.54115	0.52174
1967	0.00703	0.54031	0.53328
1968	-0.00842	0.53167	0.54009
1969	-0.01418	0.50191	0.51609
1970	-0.01305	0.49919	0.51224
1971	0.00538	0.53481	0.52942
1972	-0.00091	0.52073	0.52164
1973	8.6E-05	0.56612	0.56603
1974	-0.00520	0.55366	0.55886
1975	0.00512	0.55606	0.55095
1976	0.00160	0.52591	0.52431
1977	-0.00088	0.51030	0.51118
1978	0.00063	0.47472	0.47409
1979	0.00067	0.48653	0.48586
1980	-0.00853	0.48893	0.49746
1981	0.00504	0.46493	0.45989
1982	-0.01304	0.44113	0.45418
1983	-0.00158	0.45238	0.45396
1984	0.00208	0.44863	0.44655
1985	0.00557	0.45424	0.44867
1986	-0.00117	0.45379	0.45496
1987	0.00755	0.45806	0.45051
1988	0.00120	0.46773	0.46653
1989	0.00214	0.46676	0.46461
1990	-0.00708	0.47233	0.47941
1991	0.00573	0.48603	0.48031

S_M	Residual Plot	obs	RESIDUAL	ACTUAL	FITTED
		1965	-0.01235	0.12884	0.14119
		1966	-0.01844	0.13752	0.15596
		1967	-0.00049	0.16616	0.16665
		1968	0.01919	0.16261	0.14342
		1969	0.01549	0.16274	0.14725
		1970	0.00921	0.17384	0.16464
		1971	-0.02032	0.18485	0.20517
		1972	-0.00442	0.20226	0.20668
		1973	0.00109	0.24219	0.24110
		1974	0.00279	0.26537	0.26257
		1975	-0.00388	0.24799	0.25187
		1976	0.00258	0.22422	0.22164
		1977	0.00266	0.23279	0.23013
		1978	0.01205	0.23334	0.22128
		1979	0.01062	0.24138	0.23076
		1980	0.00248	0.26345	0.26097
		1981	-0.00527	0.26433	0.26960
		1982	0.01134	0.28334	0.27200
		1983	0.00487	0.25184	0.24697
		1984	-0.00311	0.23472	0.23783
		1985	-0.01485	0.21523	0.23008
		1986	-0.00271	0.21377	0.21648
		1987	-0.01423	0.22625	0.24047
		1988	0.00615	0.25092	0.24477
		1989	0.00364	0.23612	0.23249
		1990	0.00317	0.19985	0.19668
		1991	-0.00670	0.17693	0.18363

lnC	Residual Plot	obs	RESIDUAL	ACTUAL	FITTED
		1965	0.05515	-2.75607	-2.81122
		1966	0.01685	-2.74803	-2.76487
		1967	-0.02388	-2.71316	-2.68928
		1968	0.01216	-2.57623	-2.58839
		1969	-0.03051	-2.44444	-2.41393
		1970	-0.03985	-2.33676	-2.29691
		1971	-0.00439	-2.23982	-2.23542
		1972	0.02705	-2.03415	-2.06120
		1973	-0.01211	-1.90453	-1.89243
		1974	0.02054	-1.61172	-1.63226
		1975	-0.00843	-1.38202	-1.37359
		1976	-0.00925	-1.11094	-1.10169
		1977	-0.05117	-0.97367	-0.92251
		1978	-0.03206	-0.80764	-0.77558
		1979	0.01571	-0.71084	-0.72655
		1980	0.02859	-0.63822	-0.66681
		1981	0.02145	-0.42409	-0.44554
		1982	0.04291	-0.27147	-0.31437
		1983	-0.00303	-0.20589	-0.20286
		1984	-0.03096	-0.09835	-0.06740
		1985	-0.02841	0.00000	0.02841
		1986	-0.01628	0.04484	0.06113
		1987	0.00064	0.08309	0.08245
		1988	0.03769	0.10306	0.06537
		1989	0.03997	0.21023	0.17026
		1990	-0.00280	0.26949	0.27229
		1991	-0.02425	0.34210	0.36636

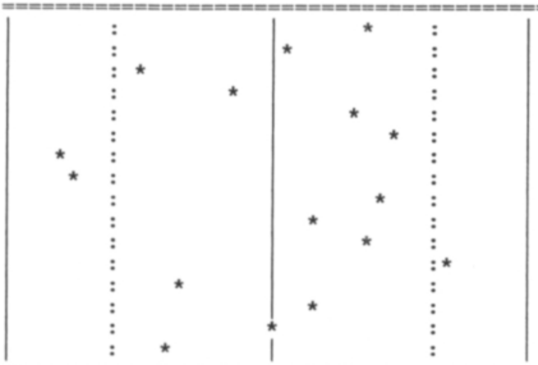
Cost shares (actual, fitted, residual, and residual plot)
Dairy farms of group A for 1976–1991 (a representative dairy farm).

S_K Residual Plot



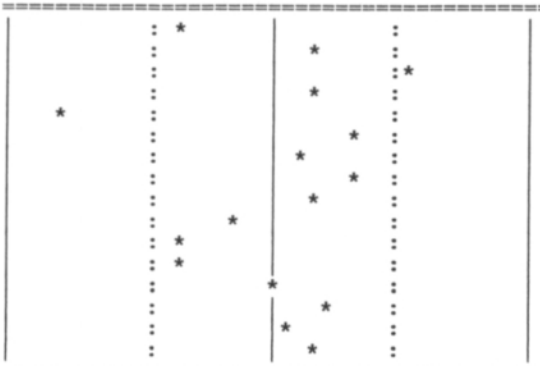
obs	RESIDUAL	ACTUAL	FITTED
1976	3.2E-06	0.17020	0.17020
1977	-0.00482	0.17015	0.17497
1978	0.00505	0.21027	0.20522
1979	-0.00438	0.18753	0.19191
1980	0.00656	0.16339	0.15683
1981	0.00044	0.18779	0.18735
1982	0.00042	0.19237	0.19195
1983	-0.00281	0.20658	0.20939
1984	0.00213	0.22569	0.22357
1985	0.00041	0.23140	0.23099
1986	-0.00157	0.23639	0.23797
1987	0.00098	0.22295	0.22197
1988	-0.00184	0.19834	0.20018
1989	-0.00538	0.21290	0.21829
1990	-0.00055	0.25687	0.25742
1991	0.00537	0.27674	0.27138

S_L Residual Plot



obs	RESIDUAL	ACTUAL	FITTED
1976	0.00355	0.51237	0.50882
1977	0.00049	0.50069	0.50019
1978	-0.00506	0.46932	0.47438
1979	-0.00165	0.47087	0.47252
1980	0.00320	0.48107	0.47788
1981	0.00466	0.45166	0.44700
1982	-0.00815	0.43332	0.44146
1983	-0.00759	0.44337	0.45096
1984	0.00415	0.45237	0.44822
1985	0.00156	0.45032	0.44876
1986	0.00371	0.46097	0.45726
1987	0.00681	0.45884	0.45203
1988	-0.00333	0.47174	0.47507
1989	0.00168	0.48022	0.47854
1990	9.7E-06	0.48682	0.48681
1991	-0.00406	0.48182	0.48587

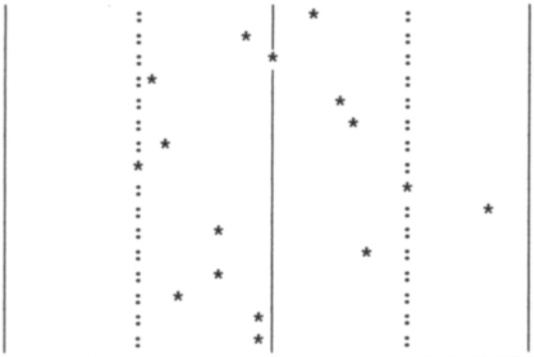
S_M Residual Plot



obs	RESIDUAL	ACTUAL	FITTED
1976	-0.00780	0.21554	0.22334
1977	0.00336	0.22773	0.22436
1978	0.01140	0.22504	0.21364
1979	0.00389	0.24103	0.23714
1980	-0.01787	0.25905	0.27692
1981	0.00637	0.27094	0.26457
1982	0.00197	0.26688	0.26491
1983	0.00628	0.24288	0.23659
1984	0.00325	0.22755	0.22430
1985	-0.00369	0.21653	0.22022
1986	-0.00741	0.20387	0.21128
1987	-0.00834	0.22544	0.23378
1988	-7.5E-06	0.24338	0.24338
1989	0.00417	0.22907	0.22491
1990	0.00157	0.18145	0.17988
1991	0.00287	0.17465	0.17178

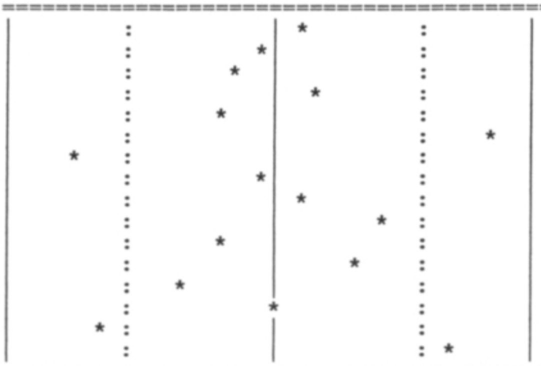
Cost shares (actual, fitted, residual, and residual plot)
Dairy farms of group B for 1976–1991 (a representative dairy farm).

S_K Residual Plot



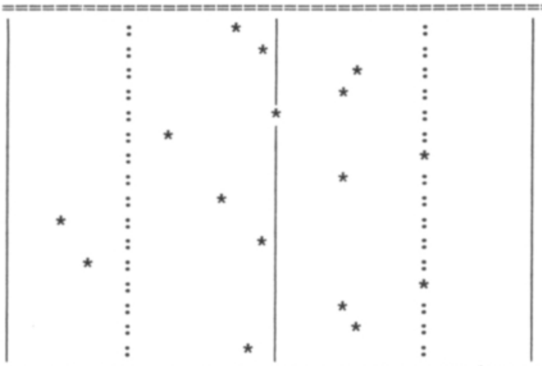
obs	RESIDUAL	ACTUAL	FITTED
1976	0.00157	0.15764	0.15607
1977	-0.00097	0.16127	0.16224
1978	-3.3E-05	0.18870	0.18873
1979	-0.00543	0.16934	0.17477
1980	0.00266	0.14569	0.14303
1981	0.00327	0.17384	0.17057
1982	-0.00488	0.17137	0.17624
1983	-0.00577	0.19241	0.19817
1984	0.00571	0.21977	0.21405
1985	0.00927	0.23065	0.22138
1986	-0.00259	0.22709	0.22967
1987	0.00408	0.22112	0.21704
1988	-0.00247	0.19929	0.20177
1989	-0.00383	0.21454	0.21837
1990	-0.00029	0.25422	0.25451
1991	-0.00031	0.26634	0.26666

S_L Residual Plot



obs	RESIDUAL	ACTUAL	FITTED
1976	0.00099	0.52591	0.52492
1977	-0.00082	0.51030	0.51112
1978	-0.00184	0.47472	0.47657
1979	0.00173	0.48653	0.48480
1980	-0.00269	0.48893	0.49162
1981	0.00958	0.46493	0.45535
1982	-0.00882	0.44113	0.44996
1983	-0.00066	0.45238	0.45305
1984	0.00107	0.44863	0.44756
1985	0.00492	0.45424	0.44932
1986	-0.00249	0.45379	0.45627
1987	0.00370	0.45806	0.45436
1988	-0.00445	0.46773	0.47218
1989	-3.6E-05	0.46676	0.46679
1990	-0.00766	0.47233	0.47999
1991	0.00748	0.48603	0.47855

S_M Residual Plot



obs	RESIDUAL	ACTUAL	FITTED
1976	-0.00302	0.22422	0.22724
1977	-0.00052	0.23279	0.23331
1978	0.00515	0.23334	0.22819
1979	0.00455	0.24138	0.23683
1980	-0.00031	0.26345	0.26376
1981	-0.00714	0.26433	0.27147
1982	0.00988	0.28334	0.27346
1983	0.00397	0.25184	0.24787
1984	-0.00310	0.23472	0.23782
1985	-0.01382	0.21523	0.22905
1986	-0.00055	0.21377	0.21432
1987	-0.01246	0.22625	0.23871
1988	0.00972	0.25092	0.24119
1989	0.00412	0.23612	0.23200
1990	0.00504	0.19985	0.19481
1991	-0.00150	0.17693	0.17843

Autocorrelation functions of the level series

Dairy farms of group A

Series	Lags				
ln W_K	0.871	0.721	0.566	0.476	0.407
ln W_L	0.903	0.802	0.696	0.589	0.476
ln W_M	0.914	0.817	0.719	0.620	0.515
ln W_H	0.913	0.824	0.730	0.638	0.533
ln Y	0.869	0.717	0.559	0.469	0.400
ln C	0.914	0.818	0.714	0.611	0.503
S_K	0.699	0.376	0.141	0.046	–0.019
S_L	0.841	0.581	0.339	0.161	0.066
S_M	0.787	0.534	0.413	0.353	0.289
S_H	0.509	0.181	0.072	–0.089	–0.167

Dairy farms of group B

Series	Lags				
ln W_K	0.869	0.717	0.559	0.469	0.400
ln W_L	0.903	0.802	0.697	0.589	0.476
ln W_M	0.914	0.817	0.719	0.620	0.515
ln W_H	0.913	0.824	0.730	0.638	0.533
ln Y	0.908	0.804	0.687	0.563	0.446
ln C	0.914	0.818	0.713	0.607	0.497
S_K	0.709	0.433	0.243	0.153	0.063
S_L	0.862	0.726	0.551	0.443	0.338
S_M	0.787	0.528	0.371	0.280	0.206
S_H	0.657	0.351	0.191	–0.028	–0.179

Autocorrelation functions of the first differences

Dairy farms of group A

Series	Lags				
ln W_K	0.095	0.065	–0.383	–0.190	–0.120
ln W_L	0.696	0.521	0.225	–0.032	–0.134
ln W_M	0.521	0.095	–0.148	–0.276	–0.374
ln W_H	0.603	0.147	–0.115	–0.146	–0.090
ln Y	0.093	0.069	–0.386	–0.184	–0.124
ln C	0.482	0.298	0.131	0.133	–0.008
S_K	0.173	0.008	–0.316	–0.221	–0.163
S_L	0.319	–0.068	–0.208	–0.267	–0.244
S_M	0.254	–0.093	–0.236	–0.136	0.047
S_H	–0.131	–0.279	0.192	–0.033	–0.168

Dairy farms of group B

Series	Lags				
ln W_K	0.093	0.069	–0.386	–0.184	–0.124
ln W_L	0.738	0.545	0.272	–0.005	–0.153
ln W_M	0.521	0.095	–0.148	–0.276	–0.374
ln W_H	0.603	0.147	–0.115	–0.146	–0.090
ln Y	0.151	0.142	–0.009	0.035	0.096
ln C	0.476	0.383	0.237	0.191	0.001
S_K	0.167	0.018	–0.250	–0.185	–0.094
S_L	–0.075	0.136	–0.242	0.013	–0.089
S_M	0.364	–0.081	–0.287	–0.188	–0.011
S_H	0.084	–0.057	0.231	0.130	–0.111

Autocorrelation functions of the second differences

Dairy farms of group A

Series	Lags				
ln W_L	–0.230	0.214	–0.087	–0.240	0.005
ln C	–0.325	0.090	–0.215	0.072	–0.131

Dairy farms of group B

Series	Lags				
ln W_L	–0.143	0.158	–0.016	–0.221	–0.126
ln C	–0.440	0.159	–0.139	0.141	–0.184

Autoregressive processes of dairy farm series
(p-values in parenthesis)

Dairy farms of group A

Series	Intercept	AR(1)	AR(2)	AR(3)	AR(4)	AR(5)
ln W_K	3.199	1.036	0.069	–0.497	0.234	0.133
	(0.88)	(0.00)	(0.85)	(0.15)	(0.52)	(0.62)
ln W_L	2.175	1.350	–0.052	–0.441	–0.140	0.255
	(0.07)	(0.00)	(0.90)	(0.26)	(0.73)	(0.24)
ln W_M	1.993	1.585	–0.778	0.095	–0.140	0.104
	(0.51)	(0.00)	(0.90)	(0.26)	(0.73)	(0.24)
ln W_H	1.063	2.019	–1.628	0.653	–0.122	0.052
	(0.59)	(0.00)	(0.01)	(0.32)	(0.83)	(0.84)
ln Y	0.370	0.992	–0.054	–0.092	0.239	–0.143
	(0.37)	(0.00)	(0.86)	(0.73)	(0.42)	(0.48)
ln C	1.235	1.371	–0.265	–0.311	0.338	–0.161
	(0.47)	(0.00)	(0.52)	(0.43)	(0.41)	(0.49)
S_K	0.192	0.952	–0.009	–0.427	0.093	0.039
	(0.00)	(0.00)	(0.98)	(0.20)	(0.79)	(0.81)
S_L	0.493	1.199	–0.421	0.057	–0.118	0.090
	(0.00)	(0.00)	(0.29)	(0.89)	(0.76)	(0.72)
S_M	0.227	1.064	–0.343	–0.264	0.161	0.097
	(0.00)	(0.00)	(0.40)	(0.51)	(0.68)	(0.71)
S_H	0.092	0.789	–0.227	0.306	–0.250	–0.047
	(0.00)	(0.01)	(0.50)	(0.39)	(0.47)	(0.89)

Dairy farms of group B

Series	Intercept	AR(1)	AR(2)	AR(3)	AR(4)	AR(5)
ln W_K	2.729	1.036	0.071	–0.504	0.242	0.126
	(0.87)	(0.00)	(0.84)	(0.15)	(0.50)	(0.63)
ln W_L	2.105	1.377	–0.089	–0.406	–0.183	0.272
	(0.05)	(0.00)	(0.82)	(0.32)	(0.65)	(0.19)
ln W_M	1.993	1.585	–0.778	0.095	–0.140	0.104
	(0.51)	(0.00)	(0.90)	(0.26)	(0.73)	(0.24)
ln W_H	1.063	2.019	–1.628	0.653	–0.122	0.052
	(0.59)	(0.00)	(0.01)	(0.32)	(0.83)	(0.84)
ln Y	0.289	0.573	0.276	–0.083	0.052	0.047
	(0.04)	(0.03)	(0.27)	(0.73)	(0.85)	(0.78)
ln C	0.946	1.153	0.009	–0.243	0.182	–0.138
	(0.42)	(0.00)	(0.98)	(0.52)	(0.64)	(0.55)
S_K	0.184	0.964	0.012	–0.347	0.019	0.072
	(0.00)	(0.00)	(0.97)	(0.31)	(0.96)	(0.76)
S_L	0.490	0.851	0.227	–0.292	0.098	–0.029
	(0.00)	(0.00)	(0.49)	(0.36)	(0.76)	(0.90)
S_M	0.234	1.152	–0.489	–0.206	0.153	0.077
	(0.00)	(0.00)	(0.21)	(0.60)	(0.68)	(0.74)
S_H	0.094	0.940	–0.156	0.298	–0.242	–0.257
	(0.00)	(0.00)	(0.66)	(0.40)	(0.55)	(0.37)

Autoregressive processes of the dairy farms residuals
(p-values in parenthesis)

Dairy farms of group A and B

Series	Intercept	AR(1)	AR(2)	AR(3)	AR(4)	AR(5)
A: ε_L	0.004	0.316	0.210	–0.003	–0.311	–0.056
	(0.69)	(0.24)	(0.42)	(0.99)	(0.24)	(0.82)
A: ε_M	0.003	0.220	–0.333	–0.074	–0.268	–0.179
	(0.68)	(0.43)	(0.24)	(0.80)	(0.34)	(0.52)
A: ε_H	–0.002	0.508	–0.227	–0.227	–0.175	0.051
	(0.90)	(0.11)	(0.50)	(0.48)	(0.58)	(0.89)
B: ε_L	0.005	0.333	0.160	0.026	–0.227	–0.162
	(0.63)	(0.21)	(0.54)	(0.92)	(0.39)	(0.51)
B: ε_M	0.003	0.219	–0.324	–0.073	–0.264	–0.181
	(0.71)	(0.45)	(0.26)	(0.80)	(0.35)	(0.52)
B: ε_H	–0.002	0.527	–0.254	–0.237	–0.139	0.018
	(0.89)	(0.10)	(0.45)	(0.46)	(0.66)	(0.96)

The number of dairy farms of group B in research period

1965	228	1966	243	1967	187	1968	335	1969	262
1970	181	1971	168	1972	192	1973	190	1974	188
1975	211	1976	270	1977	256	1978	300	1979	314
1980	304	1981	332	1982	322	1983	364	1984	349
1985	346	1986	321	1987	362	1988	324	1989	305
1990	303	1991	338						

ALLEN PARTIAL ELASTICITIES OF SUBSTITUTION

Dairy farms of group A.

	KK	LL	MM	HH
1965	–0.89291	–0.98550	–4.85716	–9.34119
1970	–0.87798	–0.89578	–4.58997	–10.7246
1976	–0.49661	–0.86427	–3.32599	–10.7974
1981	–0.48219	–1.12751	–2.45678	–9.67576
1986	–0.87341	–1.08767	–3.27433	–11.3585
1991	–0.89257	–0.96006	–4.11636	–15.4469

Dairy farms of group A for 1976–1991.

	KK	LL	MM	HH
1976	–1.21762	–0.73976	–2.25706	–9.24222
1981	–1.31880	–0.94486	–1.91004	–8.89364
1986	–1.33111	–0.90763	–2.36934	–9.69690
1991	–1.24611	–0.81078	–2.75842	–13.0914

Dairy farms of group B.

	KK	LL	MM	HH
1965	–0.84994	–0.60582	–0.53923	–7.37109
1970	–0.80145	–0.59275	–0.99709	–7.21351
1976	–0.12775	–0.56417	–1.26230	–7.40683
1981	–0.10037	–0.72848	–1.18884	–6.41507
1986	–0.80608	–0.74232	–1.26132	–6.98701
1991	–0.84999	–0.67315	–1.16856	–8.42997

Dairy farms of group B for 1976–1991.

	KK	LL	MM	HH
1976	–1.33945	–0.58133	–1.42373	–5.49331
1981	–1.45699	–0.76591	–1.29845	–5.22339
1986	–1.47560	–0.76322	–1.44349	–5.29820
1991	–1.35662	–0.70015	–1.39803	–5.73572

Dairy farms of group A.

	KL	KM	KH	LM	LH	MH
1965	0.641845	–0.96301	0.661033	1.452616	0.850707	2.653373
1970	0.629606	–1.01820	0.586883	1.408514	0.840269	2.758616
1976	0.512788	–1.02245	0.443851	1.300521	0.842143	2.324046
1981	0.437403	–0.59158	0.489917	1.270025	0.834693	1.944933
1986	0.585519	–0.50826	0.561388	1.333820	0.814566	2.363460
1991	0.652620	–0.65175	0.491184	1.382210	0.775098	3.160796

Dairy farms of group A for 1976–1991.

	KL	KM	KH	LM	LH	MH
1976	0.704391	–1.70674	2.355852	1.139440	0.020957	2.199986
1981	0.694311	–1.07576	2.189818	1.133989	–0.07651	1.978508
1986	0.764736	–1.04640	2.012773	1.164020	–0.13779	2.324789
1991	0.805847	–1.20710	2.169895	1.189857	–0.41058	3.146461

Dairy farms of group B.

	KL	KM	KH	LM	LH	MH
1965	0.662031	–0.96032	0.272171	0.435922	0.803640	1.224446
1970	0.620288	–0.90883	0.197187	0.521355	0.811256	1.186980
1976	0.481967	–0.98003	–0.16165	0.652635	0.808925	1.143922
1981	0.405144	–0.63954	0.025733	0.674427	0.818608	1.098522
1986	0.575355	–0.44197	0.235103	0.590144	0.796160	1.136404
1991	0.643532	–0.50651	0.111440	0.542325	0.746905	1.210788

Dairy farms of group B for 1976–1991.

	KL	KM	KH	LM	LH	MH
1976	0.553123	–0.85448	1.227613	0.796533	0.412520	0.423127
1981	0.528641	–0.42037	1.186262	0.803662	0.394308	0.568128
1986	0.650639	–0.33616	1.142312	0.751809	0.378136	0.437226
1991	0.713110	–0.38229	1.160100	0.715766	0.225550	0.117058

OWN PRICE ELASTICITIES

Dairy farms of group A.

	KK	LL	MM	HH
1965	–0.23509	–0.47532	–0.72566	–0.98073
1970	–0.21298	–0.45344	–0.72393	–1.00275
1976	–0.08999	–0.44521	–0.70072	–1.00383
1981	–0.08689	–0.50583	–0.66143	–0.98634
1986	–0.20943	–0.49774	–0.69907	–1.01193
1991	–0.23905	–0.46934	–0.71851	–1.06213

Dairy farms of group A for 1976–1991.

	KK	LL	MM	HH
1976	–0.20723	–0.37640	–0.50409	–0.90241
1981	–0.24707	–0.42235	–0.50533	–0.89896
1986	–0.31676	–0.41502	–0.50059	–0.90656
1991	–0.33817	–0.39393	–0.47384	–0.92910

Dairy farms of group B.

	KK	LL	MM	HH
1965	–0.22399	–0.30706	–0.07613	–0.65175
1970	–0.18601	–0.30363	–0.16416	–0.65657
1976	–0.02123	–0.29580	–0.27977	–0.65061
1981	–0.01656	–0.33502	–0.32051	–0.67672
1986	–0.18835	–0.33772	–0.27305	–0.66299
1991	–0.22411	–0.32332	–0.21458	–0.61024

Dairy farms of group B for 1976–1991.

	KK	LL	MM	HH
1976	–0.20904	–0.30515	–0.32353	–0.50412
1981	–0.24851	–0.34876	–0.35249	–0.53597
1986	–0.33890	–0.34823	–0.30936	–0.52844
1991	–0.36175	–0.33505	–0.24945	–0.43797

CROSS PRICE ELASTICITIES

Dairy farms of group A.

	KL	LK	KM	MK	KH	HK
1965	0.309574	0.168991	–0.14387	–0.25355	0.069401	0.174043
1970	0.318706	0.152729	–0.16059	–0.24699	0.054873	0.142366
1976	0.264152	0.092927	–0.21541	–0.18528	0.041264	0.080434
1981	0.196232	0.078820	–0.15927	–0.10660	0.049942	0.088283
1986	0.267945	0.140401	–0.10851	–0.12187	0.050014	0.134615
1991	0.319046	0.174784	–0.11376	–0.17455	0.033773	0.131548

	LM	ML	LH	HL	MH	HM
1965	0.217020	0.700625	0.089315	0.410313	0.278577	0.396414
1970	0.222150	0.712989	0.078565	0.425344	0.257930	0.435088
1976	0.273993	0.669937	0.078294	0.433813	0.216066	0.489630
1981	0.341928	0.569771	0.085088	0.374468	0.198266	0.523634
1986	0.284770	0.610382	0.072569	0.372761	0.210560	0.504598
1991	0.241264	0.675721	0.053295	0.378922	0.217336	0.551716

Dairy farms of group A for 1976–1991.

	KL	LK	KM	MK	KH	HK
1976	0.358408	0.119887	–0.38118	–0.29048	0.230025	0.400966
1981	0.310357	0.130079	–0.28461	–0.20154	0.221346	0.410262
1986	0.349683	0.181984	–0.22108	–0.24901	0.188174	0.478979
1991	0.391537	0.218691	–0.20735	–0.32758	0.153997	0.588866

	LM	ML	LH	HL	MH	HM
1976	0.254482	0.579770	0.002046	0.010663	0.214806	0.491344
1981	0.300019	0.506893	–0.00773	–0.03420	0.199987	0.523454
1986	0.245934	0.532260	–0.01288	–0.06300	0.217344	0.491181
1991	0.204393	0.578115	–0.02913	–0.19949	0.223304	0.540499

Dairy farms of group B.

	KL	LK	KM	MK	KH	HK
1965	0.335550	0.174471	–0.13558	–0.25308	0.024065	0.071728
1970	0.317736	0.143969	–0.14963	–0.21094	0.017948	0.045767
1976	0.252700	0.080107	–0.21721	–0.16289	–0.01419	–0.02686
1981	0.186321	0.066856	–0.17242	–0.10553	0.002714	0.004246
1986	0.261763	0.134443	–0.09567	–0.10327	0.022309	0.054936
1991	0.309095	0.169680	–0.09301	–0.13355	0.008067	0.029383

	LM	ML	LH	HL	MH	HM
1965	0.061547	0.220947	0.071057	0.407325	0.108265	0.172879
1970	0.085835	0.267058	0.073840	0.415557	0.108038	0.195424
1976	0.144650	0.342183	0.071056	0.424127	0.100482	0.253538
1981	0.181825	0.310162	0.086354	0.376469	0.115883	0.296161
1986	0.127754	0.268491	0.075547	0.362221	0.107833	0.246008
1991	0.099587	0.260484	0.054068	0.358746	0.087648	0.222337

Dairy farms of group B for 1976–1991.

	KL	LK	KM	MK	KH	HK
1976	0.290345	0.086326	–0.19417	–0.13335	0.112658	0.191593
1981	0.240716	0.090170	–0.11411	–0.07170	0.121722	0.202340
1986	0.296867	0.149432	–0.07204	–0.07720	0.113934	0.262354
1991	0.341259	0.190158	–0.06821	–0.10194	0.088585	0.309352

	LM	ML	LH	HL	MH	HM
1976	0.181004	0.418116	0.037857	0.216540	0.038830	0.096151
1981	0.218170	0.365947	0.040460	0.179548	0.058295	0.154229
1986	0.161127	0.343028	0.037715	0.172532	0.043608	0.093706
1991	0.127714	0.342530	0.017223	0.107937	0.008938	0.020886

MORISHIMA PARTIAL ELASTICITIES OF SUBSTITUTION

Dairy farms of group A.

	KL	LK	KM	MK	KH	HK
1965	0.784903	0.404087	0.581786	–0.01845	1.050134	0.409139
1970	0.772153	0.365710	0.563339	–0.03401	1.057630	0.355347
1976	0.709368	0.182924	0.485310	–0.09529	1.045100	0.170432
1981	0.702070	0.165712	0.502166	–0.01971	1.036289	0.175175
1986	0.765687	0.349838	0.590555	0.087558	1.061945	0.344051
1991	0.788392	0.413835	0.604748	0.064497	1.095903	0.370599

	LM	ML	LH	HL	MH	HM
1965	0.942681	1.175954	1.070048	0.885641	1.259310	1.122074
1970	0.946081	1.166436	1.081321	0.878790	1.260687	1.159020
1976	0.974715	1.115153	1.082129	0.879029	1.219902	1.190351
1981	1.003367	1.075609	1.071435	0.880306	1.184613	1.185073
1986	0.983842	1.108125	1.084501	0.870504	1.222492	1.203670
1991	0.959777	1.145067	1.115425	0.848268	1.279466	1.270229

Dairy farms of group A for 1976–1991.

	KL	LK	KM	MK	KH	HK
1976	0.734817	0.327126	0.122909	–0.08324	1.132436	0.608205
1981	0.732713	0.377157	0.220723	0.045533	1.120316	0.657341
1986	0.764710	0.498748	0.279509	0.067750	1.094737	0.795744
1991	0.785474	0.556862	0.266486	0.010588	1.083097	0.927038

	LM	ML	LH	HL	MH	HM
1976	0.758576	0.956178	0.904457	0.387072	1.117217	0.995438
1981	0.805359	0.929249	0.891235	0.388152	1.098957	1.028793
1986	0.746529	0.947287	0.893680	0.352017	1.123908	0.991776
1991	0.678235	0.972053	0.899961	0.194447	1.152404	1.014341

Dairy farms of group B.

	KL	LK	KM	MK	KH	HK
1965	0.642614	0.398466	–0.05945	–0.02908	0.675817	0.295723
1970	0.621368	0.329986	0.014531	–0.02492	0.674521	0.231784
1976	0.548500	0.101341	0.062561	–0.14165	0.636416	–0.00563
1981	0.521343	0.083421	0.148090	–0.08897	0.679440	0.020810
1986	0.599493	0.322800	0.177373	0.085080	0.685307	0.243293
1991	0.632416	0.393798	0.121571	0.090563	0.618312	0.253501

	LM	ML	LH	HL	MH	HM
1965	0.137682	0.528010	0.722809	0.714388	0.760017	0.249013
1970	0.249998	0.570690	0.730414	0.719189	0.764612	0.359586
1976	0.424426	0.637983	0.721672	0.719928	0.751098	0.533315
1981	0.502336	0.645184	0.763081	0.711491	0.792609	0.616673
1986	0.400806	0.606221	0.738545	0.699950	0.770831	0.519061
1991	0.314170	0.583805	0.664314	0.682067	0.697894	0.436920

Dairy farms of group B for 1976–1991.

	KL	LK	KM	MK	KH	HK
1976	0.595498	0.295374	0.129356	0.075688	0.616779	0.400641
1981	0.589477	0.338689	0.238372	0.176815	0.657695	0.450859
1986	0.645103	0.488334	0.237321	0.261694	0.642377	0.601257
1991	0.676316	0.551916	0.181238	0.259814	0.526565	0.671110

	LM	ML	LH	HL	MH	HM
1976	0.504534	0.723269	0.541978	0.521693	0.542952	0.419681
1981	0.570662	0.714708	0.576432	0.528309	0.594268	0.506722
1986	0.470496	0.691264	0.566158	0.520768	0.572052	0.403075
1991	0.377166	0.677588	0.455202	0.442994	0.446918	0.270338

SHADOW ELASTICITIES OF SUBSTITUTION

Dairy farms of group A.

	KL	KM	KH	LM	LH	MH
1965	0.538561	0.364489	0.867398	0.997849	1.037082	1.202671
1970	0.497384	0.327978	0.862249	0.998428	1.049744	1.222848
1976	0.319927	0.173186	0.748525	1.015480	1.051078	1.210854
1981	0.319413	0.189536	0.725160	1.030461	1.036047	1.184740
1986	0.492819	0.353643	0.867476	1.023379	1.049629	1.216950
1991	0.546404	0.391576	0.947731	1.008528	1.082483	1.276855

Dairy farms of group A for 1976–1991.

	KL	KM	KH	LM	LH	MH
1976	0.429316	0.005911	0.941330	0.818853	0.821158	1.080173
1981	0.482168	0.118161	0.958067	0.851422	0.798453	1.079561
1986	0.589784	0.179920	1.010405	0.809975	0.801733	1.083376
1991	0.638791	0.167293	1.050746	0.754981	0.810042	1.112040

Dairy farms of group B.

	KL	KM	KH	LM	LH	MH
1965	0.481986	–0.04886	0.580329	0.222723	0.721558	0.563236
1970	0.420844	–0.00184	0.549806	0.328001	0.728720	0.620415
1976	0.208973	–0.05414	0.414421	0.487879	0.721422	0.689284
1981	0.199063	0.001037	0.422596	0.555129	0.753455	0.743129
1986	0.416689	0.132989	0.557651	0.467034	0.731885	0.694104
1991	0.478365	0.108842	0.539729	0.388745	0.666639	0.624103

Dairy farms of group B for 1976–1991.

	KL	KM	KH	LM	LH	MH
1976	0.364157	0.097540	0.536748	0.570618	0.538960	0.507490
1981	0.407031	0.200568	0.580005	0.624464	0.567582	0.570254
1986	0.540824	0.249086	0.629927	0.541053	0.558016	0.518388
1991	0.596430	0.212738	0.558742	0.458758	0.453523	0.393998

Estimated parameters solved from the equation system of the cost function and the cost share equations on dairy farms of group A from the panel data set (t values in parenthesis).

β_{KK}	0.1423 (16.48)	β_{KL}	–0.0614 (6.657)	β_{KM}	–0.0562 (5.247)	β_{KH}	–0.0247 (4.837)
β_{LL}	0.0689 (3.862)	β_{LM}	0.0320 (1.792)	β_{LH}	–0.0395 (3.906)	β_{MM}	0.0059 (0.235)
β_{MH}	0.0182 (1.682)	β_{HH}	0.0460 (4.771)	β_0	–	β_K	0.1818 (5.739)
β_L	0.5527 (10.12)	β_M	0.3953 (6.169)	β_H	–0.1299 (2.327)	β_Y	0.5519 (10.47)
β_{YY}	0.0125 (0.268)	β_{YK}	0.0166 (2.418)	β_{YL}	–0.1283 (16.41)	β_{YM}	0.0973 (13.68)
β_{YH}	0.0143 (3.877)	β_T	0.0063 (1.323)	β_{TT}	–0.0013 (4.571)	β_{TY}	0.0011 (0.366)
β_{TK}	0.0004 (0.841)	β_{TL}	0.0018 (2.117)	β_{TM}	–0.0030 (3.765)	β_{TH}	0.0008 (1.712)
γ_{K+}	0.0068 (1.345)	γ_{K-}	–0.0132 (2.588)	γ_{L+}	0.0188 (3.342)	γ_{L-}	–0.0158 (2.814)
γ_{M+}	–0.0187 (3.752)	γ_{M-}	0.0268 (5.356)	γ_{H+}	–0.0069 (2.676)	γ_{H-}	0.0022 (0.869)
γ_{KI}	0.1134 (7.946)	γ_{LI}	–0.0231 (1.557)	γ_{MI}	–0.0570 (3.696)	γ_{HI}	–0.0333 (4.417)
γ_{CI}	0.0102 (0.264)						

Estimated parameters of the cost share equation system on dairy farms of group A from the panel data set for the post energy crisis period (t values in parenthesis).

β_{KK}	0.1029 (7.884)	β_{KL}	–0.0216 (1.691)	β_{KM}	–0.0834 (6.032)	β_{KH}	0.0021 (0.283)
β_{LL}	0.0901 (3.901)	β_{LM}	–0.0080 (0.344)	β_{LH}	–0.0605 (5.220)	β_{MM}	0.0530 (1.664)
β_{MH}	0.0383 (2.721)	β_{HH}	0.0201 (1.655)	β_K	–	β_L	–
β_M	–	β_H	–	β_{YK}	0.0656 (5.258)	β_{YL}	–0.1648 (12.18)
β_{YM}	0.0990 (7.911)	β_{YH}	0.0001 (0.020)	β_{TK}	0.0016 (2.298)	β_{TL}	0.0005 (0.571)
β_{TM}	–0.0021 (2.166)	β_{TH}	–0.0001 (0.136)				
γ_{K+}	0.0106 (2.329)	γ_{K-}	–0.0086 (1.895)	γ_{L+}	0.0164 (3.306)	γ_{L-}	–0.0175 (3.588)
γ_{M+}	–0.0196 (4.269)	γ_{M-}	0.0246 (5.418)	γ_{H+}	–0.0073 (2.958)	γ_{H-}	0.0015 (0.632)

Derived demand elasticities on dairy farms of group A from the panel data set for the whole research period.

	K	L	M	H
K	–0.100	0.083	–0.082	–0.053
L	0.203	–0.360	0.667	0.091
M	–0.078	0.260	–0.774	0.386
H	–0.025	0.017	0.189	–0.424

Derived demand elasticities on dairy farms of group A from the panel data set for the post energy crisis period.

	K	L	M	H
K	–0.296	0.163	–0.190	0.229
L	0.383	–0.328	0.450	–0.149
M	–0.192	0.194	–0.538	0.613
H	0.105	–0.029	0.278	–0.693

Morishima partial elasticities of substitution on dairy farms of group A from the panel data set for the whole research period.

	K	L	M	H
K	–	0.183	0.019	0.047
L	0.563	–	1.026	0.451
M	0.696	1.033	–	1.160
H	0.399	0.441	0.613	–

Morishima partial elasticities of substitution on dairy farms of group A from the panel data set for the post energy crisis period.

	K	L	M	H
K	–	0.459	0.107	0.525
L	0.711	–	0.777	0.179
M	0.345	0.731	–	1.151
H	0.799	0.664	0.971	–

Shadow elasticities of substitution on dairy farms of group A from the panel data set for the whole research period in the lower triangle, and for the post energy crisis period in the upper triangle.

	K	L	M	H
K	–	0.534	0.225	0.713
L	0.293	–	0.745	0.585
M	0.364	1.031	–	1.027
H	0.287	0.443	0.792	–