Journal of the Scientific Agricultural Society of Finland
Vol. 54: 165–223, 1982
Maataloustieteellinen Aikakauskirja

MEASURING TECHNOLOGICAL CHANGE IN AGRICULTURE

AN APPLICATION BASED ON THE CES PRODUCTION FUNCTION

Selostus: Teknologisen muutoksen mittaaminen maataloudessa
CES-tuotantofunktioon perustuva sovellutus

KALEVI HEMILÄ

Ministry of Agriculture and Forestry,
SF-00170 Helsinki 17, Finland

ACADEMIC DISSERTATION
TO BE PRESENTED, WITH THE PERMISSION OF THE FACULTY OF AGRICULTURE AND FORESTRY OF THE UNIVERSITY OF HELSINKI, FOR PUBLIC CRITICISM IN AUDITORIUM XII ON JANUARY 21, 1983, AT 12 O'CLOCK.

SUOMEN MAATALOUSTIETEELLINEN SEURA HELSINKI

Preface

Most of the present study was carried out while I was employed at the Agricultural Economics Research Institute. I wish to express my sincere gratitude to Professor MATIAS TORVELA, Head of the Institute, for his encouragement and for placing the facilities of the Institute at my disposal.

I owe a debt of gratitude to my teacher, Professor VILJO RYYNÄNEN, for the support he has given me in my work over a long period of time. His guidance and the interest with which he shared the numerous problems I faced in the course of my research work were crucial to the completing of this study.

My special thanks are also due to Professor RISTO IHAMUOTILA for his support, advice and our discussions, which have been of great benefit to me. He has also given me confidence and courage, without which I would not have been able to finish this study.

I also wish to thank Professor LAURI KETTUNEN, Head of the Marketing Research Department of the Institute, and other colleagues at the Institute who helped in different ways to bring this study to a conclusion.

Mrs. BIRGIT HAGGREN and Mrs. RITVA HEIKKILÄ helped me in translating the text. PHILIP MASON, B.Sc. and THE ENGLISH CENTRE revised the English text. Mr. JANNE PINOMAA provided substantial assistance in solving the computational problems. Special thanks also to Miss HELENA KOIVULA for typing the manuscript and Miss MERJA MANNINEN for drawing the numerous figures.

The support and encouragement of some of my closest friends have been very important to me. Therefore I wish to thank MATTI YLÄTALO and MIKKO SIITONEN.

This study was supported by grants from the KYÖSTI HAATAJA FOUNDATION and the FINNISH CULTURAL FOUNDATION. I am grateful to the Scientific Agricultural Society of Finland for including this study in their series of publications.

Finally, I wish to express my sincere thanks and gratitude to my wife for her interest and patience during my work.

Helsinki, November 1982 *Kalevi Hemilä*

CONTENTS

JOURNAL OF THE SCIENTIFIC AGRICULTURAL SOCIETY OF FINLAND
Maataloustieteellinen Aikakauskirja
Vol. 54: 165–223, 1982

Abstract. The purpose of this study is to analyse and measure the technological change that has occurred in agriculture. The study is primarily methodological with the focus on development of a method for measuring technological change and on testing this method.

The study is divided into a theoretical and an empirical part. The most common methods for measuring technological change are examined in the theoretical part of the study together with the concepts connected with a technological change and its characteristics. The empirical part tests the applicability of the measuring method based on the CES function for estimating the parameters of technological change in agriculture. To a great extent the parameter estimates calculated conform with what was anticipated.

Technological change will continue to be a very important source of productivity growth. By adapting to new technology our small farms can develop very fast in terms of structure and productivity. It appears that technological development will continue to proceed along the lines described in this study in the near future. Technological change can be expected to be capital-using and labour-saving. It will also have a considerable influence on increasing output, especially in cattle husbandry.

Introduction

The earliest developmental stage in agricultural production technology can be called the period of muscular labour. Agriculture based on muscular labour can be characterized in the following way. The majority of the population earns its living directly from agriculture. Production is largely non-specialized, and rural families produce foodstuffs and raw materials primarily to satisfy their own needs and to obtain the inputs required for further production. Tools – hoes, wooden ploughs and sleds – are made by agricultural producers themselves. The only source of power in agricultural production is human labour or animal power. The yield per unit area and per capita is low. Trade with other branches of the economy is restricted. Capital inputs are used very little (YUDELMAN et al. 1971, p. 136).

Some progress was made as early as the period of muscular work. SCHAEFER-KEHNERT (1961, p. 219) considers the introduction of draught animals, the wheel and plough in agricultural production the first step towards technological development. HAYAMI and RUTTAN (1971, p. 27) state that growth in agricultural production based on muscular work amounts to an average of one per cent annually over the long term. They use this statement to refute the argument that traditional agriculture is perfectly static. Changes and growth are merely very slow.

The industrial revolution, which began in the 18th century, led to the next stage in the development of the industrializing countries. The division of labour and specialization between the various fields of the economy followed industrial growth. This also meant that agriculture was offered an increasing amount of inputs of industrial origin. This is how mechanization began.

Although industrialization was rapid and the prices of industrially manufactured tools dropped, not all of them could be used in agriculture. According to SCHAEFER-KEHNERT (1961, p. 219), this was due to lack of suitable draught power. New machines were not of any significant help when animal power was used. Because of its heavy weight the steam engine was unsuitable for use on fields, though it was the basic machine in industry. It was not until the combustion engine was invented and mounted in a tractor that equipment produced by industry could be utilized by agriculture, thanks to sufficient draught power. Because the energy economy was in a crucial position when this change occurred, the new phase can also be called motorization.

The introduction of the tractor into agriculture caused a noticeable reduction in the need for labour. In the diminishing rural population, true, it is hard to distinguish between the effect of the decreasing need for agricultural workers and that of the growing demand for industrial labourers. Both of them acted and still act side by side and exert an effect in the same direction.

Increased productivity created by new technology has long been studied in economics. As early as the 1940s it was observed that an increase in capital input alone cannot explain the rise in labour productivity (e.g. TINBERGEN 1942, TINTNER 1944). However, economic theory was still, roughly speaking, based on the assumption that the main factor influencing the growth of labour productivity is growth in capital input.

The article by Moses Abramowitz in 1956, "Resource and Output Trends in the United States since 1870" (ABRAMOWITZ 1956) is considered an important step towards a detailed theoretical study and an empirical measurement of the factors that affect growth in productivity. There he proposed that the growth in output per unit of labour input is significantly greater than the growth in capital input he had measured. Abramowitz calls the "factor" that has – together with capital input – such an important effect on economic growth "the Residual". Abramowitz characterizes the problem in the following way: "Since we know little about the causes of the Residual, the indicated importance of this element may be taken to be some sort of measure of our ignorance about the causes of economic growth in the United States and some sort of indication of where we need to concentrate our attention".

After the publication of Abramowitz' article, empirical studies made by several researchers (e.g. SOLOW 1957, MASSELL 1960, KENDRICK 1961) have shown that in Western economies the growth in capital input is about half of the growth in labour productivity, or as low as only 10 % according to some researchers. Several studies found it surprising that greater attention had not been given to this "factor", which together with capital input, so strongly affects economic growth. Abramowitz' article started a new discussion about what this residual – as Abramowitz and several other researchers called it or technical change by SOLOW (1957) or technological change by DOMAR (1961) – includes and what the quantities of its components are.

During the past two decades literature on technological change has become comprehensive. Different methods have been developed to measure technological change and its components and to estimate its effects.

The purpose of this study is to analyse and measure the technological change that agriculture has undergone. The first part of the study is a fairly comprehensive review of the theory and terminology on technological change. In the framework of the theory, the empirical part of the study makes an effort to analyse the tehnological development of Finnish agriculture. Here it is examined mainly as a problem of measurement. A solution is sought through production functions. The main interest is focused on measuring the characteristics of technological change. The goal of the empirical part of the study is to develop a method based on a production function for measuring technological change and to test it in different kinds of agricultural enterprises using the results from bookkeeping farms.

1. Technological change

1.1. The concept

The New Encyclopedia (ANON 1974) defines the concepts technique and technology in the following way: "Technique is the practical utilization of theoretical knowledge in material production, the science of engineering; in a wider sense knowledge of and skill in using labour saving methods. Being a theoretical concept, technique approaches technology. Technology is a common name for sciences which deal with technical systems and methods; it is a doctrine of the methods by which raw materials are worked into processed goods". According to JANTSCH (1967, p. 15), technology means utilization of applied sciences; of natural, humanistic and social sciences. Technology includes the entire concept technique together with medicine, the science of agriculture and forestry, management science, etc.

"Technology is systematic knowledge and action, usually of industrial processes but applicable to any recurrent activity. Technology is closely related to science and to engineering. Science deals with man's understanding of the real world about him – the inherent properties of space, matter, energy and their interactions. Engineering is the application of objective knowledge to the creation of plans, designs, and means for achieving desired objectives. Technology deals with the tools and techniques for carrying out the plans" (ANON. 1966).

Technology is a wider concept than technique. Each production technology requires inputs appropriate to it. These inputs can then be utilized by means of several techniques (YUDELMAN 1971, p. 38–39). If technology is divided into land-saving and labour-saving technology (HEADY 1949, p. 296), technique is closer to labour-saving technology (UPTON 1976, p. 201).

In terms of production, technological change can be divided into introduction of new products, or product innovations, and into new production methods, which are called process innovations. Process innovations can be further divided into introduction of a new means of production and improvement of the properties of an older means of production (WILLER 1967, p. 28, UPTON 1976, p. 201).

UPTON (1976, p. 201) has defined process innovation as any adopted improvement in the method of production which reduces average costs per unit output at constant input prices. Alternatively, this implies an increase in the average productivity of at least one resource. This study deals mainly with process innovations. New products are not as significant for agriculture as they are for industrial production. Product innovations in agriculture largely represent changes in product quality.

Economics has presented several definitions of technological change which differ from each other only in that they focus on different aspects.

According to KENDRICK (1961), technological change can be defined as a change in total factor productivity. His starting point is shown in the equation

$$Q_0 = w_0L + r_0C,$$

where w_0 is the average wage at time zero and r_0 is the average return to capital at time zero. Changes in total factor productivity from time 0 to time 1 can be calculated by using constant weights and by calculating change as a function of changes in labour and capital in the following way:

$$\frac{Q_1}{Q_0} = A \left(w_0 \frac{L_1}{L_0} + r_0 \frac{C_1}{C_0}\right).$$

In this equation the coefficient A, which characterizes total factor productivity, represents technological change.

Abramowitz (1956) has also used an index based on total factor productivity as his starting point when calculating a factor which he calls residual and which corresponds to technological change. Presented mathematically, Abramowitz' residual is calculated in the following way:

$$\text{residual} = \frac{dQ}{Q} - a_0\frac{dL}{L} - b_0\frac{dC}{C},$$

where $\frac{dQ}{Q}$ = proportional change in output,

$\frac{dL}{L}$ = proportional change in labour,

$\frac{dC}{C}$ = proportional change in capital,

a_0 = labour's share of income in a base period,

b_0 = capital's share of income in a base period.

LEONTIEF (ref. DOMAR 1961, p. 709–710) in turn has defined technological change as a weighted average of the relative changes of all input coefficients (in accordance with the input-output method) between two points in time.

However, in economics generally and also in this study, technological change is defined as a shift in the production function. SOLOW (1957, p. 312) has described technological change ”as a shorthand expression for any kind of shift in the production function”. This definition is based on the idea that technology is ”embodied” in the production function and can be expressed in its terms.

Production function $Q = f(X_1, X_2,...,X_n)$, where Q = output, X_i = factor of production affecting output through production process ($i = 1, 2,...,n$), shows how production is carried out, i.e. the technology by means of which the production process operates.

The parameters of the production function indicate the technology of production. Technological change is only a change in these parameters. Thus defined, technological change is also a change in the productivity of one or more inputs. In this way technological change is also a shift in the production function (NIITAMO 1969, p. 1–2).

Presented in a slightly wider mathematical sense, the relation between inputs and output can be described as output vector (Q) through transformation of input vector (X):

$$Q = T(X).$$

T, which in system theory represents the so-called transformation operator, expresses the way in which vector X is transformed into vector Q. This vector indicates the technology by means of which the production process takes place (NIITAMO 1969, p. 11).

The shift in the production function has been called both technological change (e.g. DOMAR 1961, LAVE 1966, BROWN 1968, IHAMUOTILA 1971, UPTON 1976) and technical change (e.g. SOLOW 1957, ROUHIAINEN 1972, HEERTJE 1977). German literature in particular has used the term technical progress – technischer Fortschritt (e.g. WILLER 1967, FLECK 1973). HEERTJE (1977, p. 3) has stated that the term technical change may in its broadest sense mean a shift in production function. In this study, however, a shift in the production function is called technological change.

1.2. Characteristics of technological change

Technological change can be divided in several ways according to its characteristics. In this study, as in ROUHIAINEN's (1972) and NIITAMO's (1969) studies, the classification presented by BROWN (1968) is used.

1. *The efficiency of a technology* is changed when a given combination of inputs produces a quantitative change in output. The characteristic efficiency deals only with the relationship between inputs and output. It does not affect

the relationship between inputs. Neither is it connected with the relationship between the change of output and the change of inputs. Fig. 1 shows the simplest presentation of change in the efficiency of a technology:

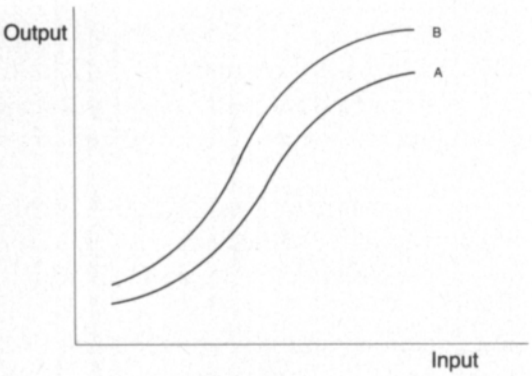

Fig. 1. Change in the efficiency of a technology.

When two technologies or production methods A and B (Fig. 1) require the same inputs, we can state that technology B is more efficient than technology A at all input quantities, because B lies "above" A.

2. *Technologically determined economies of scale.* Technological progress can alter the way in which inputs are transmitted into output in such a way that the production process formerly characterized, for example, by decreasing returns is now characterized, say, by constant returns, while the scale of operations of the firm remains unchanged. This characteristic of technology is presented graphically in Fig. 2.

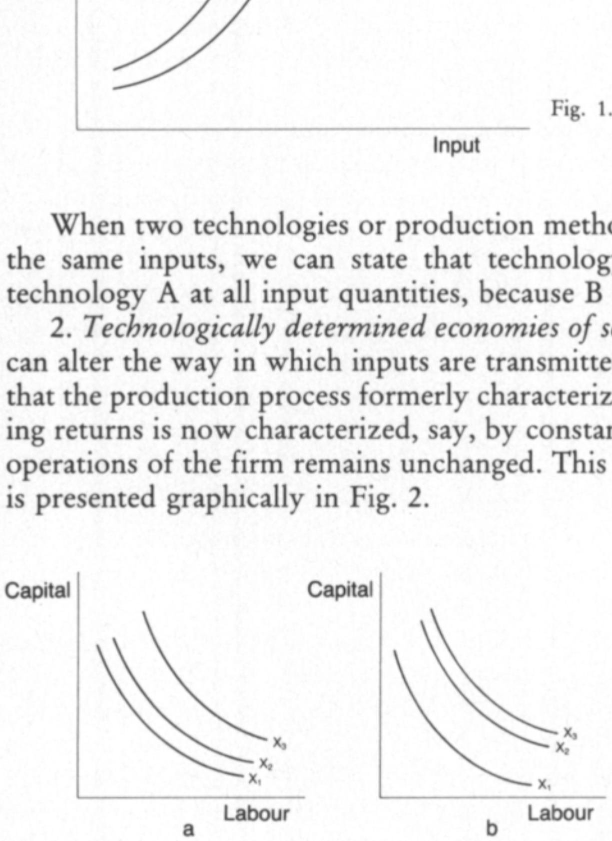

Fig. 2. A technologically determined change in the degree of returns to scale. Fig. a describes decreasing returns to scale and Fig. b describes increasing returns to scale.

Fig. 2_a describes decreasing returns to scale when output moves from X_1 to X_3 $[X_3 > X_2 > X_1, (X_3 - X_2) = (X_2 - X_1)]$. When output grows from X_1 to X_2, a smaller increase in labour and capital is required than when output is increased form X_2 to X_3. Examining Figure 2_b we can suppose that a technological change has occurred and a new configuration of isoquants indicates increasing returns to scale at the same input levels as in Fig. 2_a.

3. *The capital intensity of a technology* varies when the ratio (L:C) between the inputs changes as a result of a proportionally different change in the productivity of the inputs, i.e. the origin of the change is technical (NIITAMO 1969, p. 23):

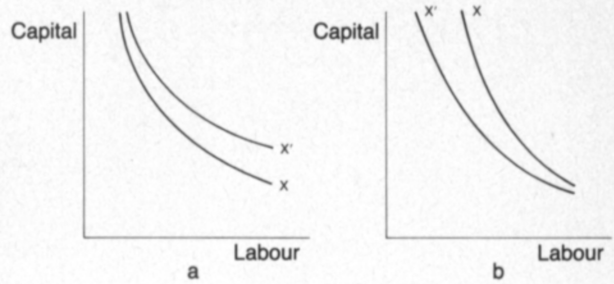

Fig. 3. Different capital intensities of a technology. The technologies represented by the X' isoquants are more capital intensive than those denoted by the X isoquants.

In Fig. 3, the technologies represented by the X' isoquants are more capital intensive than those denoted by the X isoquants. The marginal rate of substitution between capital and labour is smaller and the marginal product of capital compared with that of labour is higher in the X' technology than in the X technology. If a unit of labour is added to both production processes, a smaller amount of capital will have to be withdrawn from the X' process than from the X process.

4. *The ease with which capital is substituted for labour* changes when e.g. a certain effect of capital change on the quantity of production can be replaced by a different change in labour. This is closely linked with the declining marginal rate of substitution (c.f. Figs. 2 and 3) between labour and capital. A gradual substitution of capital for labour leads to a continuously changing rate of substitution. NIITAMO (1969, p. 13–14) has described this with parameters by means of the so-called elasticity of substitution. We come to this after first defining the marginal rate of substitution, R, which is in fact the ratio of marginal profitability of capital to that of labour. Hence,

$$R = \frac{\frac{dQ}{dC}}{\frac{dQ}{dL}},$$

where
Q = output,
C = capital and
L = labour.

After this, the elasticity of substitution (σ) can be defined in the following way:

$$\sigma = \frac{\frac{du}{u}}{\frac{dR}{R}}, \qquad \text{when } u = \frac{L}{C}.$$

The elasticity of substitution measures how fast the marginal rate of substitution changes when substitution is continued. The elasticity of substitution can take any value between zero and infinity, always being positive (BROWN 1968, p. 18). The larger the curvature of the isoquants, the smaller the elasticity of substitution. In Fig. 4_a the elasticity of substitution is zero and in Fig. 4_b it is infinite.

The so-called question of complementarity (NIITAMO 1969, p. 14) brings another problem into the discussion of the fourth characteristic of technological change. Here a certain type of capital requires only a certain type of

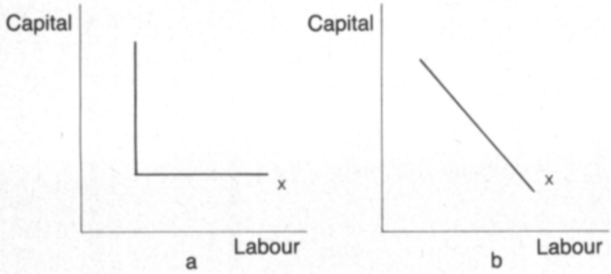

Fig. 4. Extreme values of the elasticity of substitution. In Fig. a the elasticity of substitution is zero and in Fig. b it is infinite.

labour. Inputs make each other complete. In agriculture this problem arises especially in tasks requiring great skill.

The four main characteristics of technological change have been presented above. Based on them, we can further define the "neutral" and "non-neutral" technological changes. A neutral technological change affects labour and capital in the same way (Fig. 5_a). A neutral change is caused either by a change in the efficiency of production or in the rate of returns. On the other hand, a non-neutral change affects the production function, i.e. it alters productivity relations and the rate of substitution in such a way that the process becomes for example more labour-saving (Fig. 5_b). A non-neutral technological change is caused by alterations in the intensity of capital and in the elasticity of substitution.

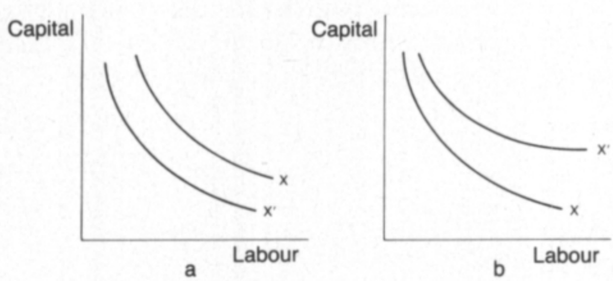

Fig. 5. A neutral (a) and a non-neutral (b) technological change.

2. How technological change occurs

2.1. Forms of technological change

A technological change can be either embodied or disembodied, according to its form (SOLOW 1962, p. 216). This division is based on the idea that the effects of technological changes are on the one hand tied to new capital inputs, and on the other hand a result of improvement in the technical relationships between known inputs. In order to be possible a technological change in the first category requires, introduction of new capital assets either in the form of increased net capital or replacement investment. Without investment to modernize machinery, improved technique merely represents an unused chance to achieve a higher productivity (SALTERS 1960, p. 63).

If a technological change tied to capital is examined together with the durability of capital inputs, more information is gained about this type of change. Short-term capital inputs, which are used during one production period, can be continuously applied with the latest know-how. With long-term capital inputs, which are used for several production periods, the problem of aging is crucial. Long-term means of production that are already laid in and designed for a certain function, such as machines and buildings, can only rarely be applied with the latest know-how, sometimes the application may not be successful at all.

A disembodied change which is independent of capital mainly raises the quality of labour and alters organization. Such changes provide a chance to increase production by the same inputs as before without requiring replacement investment. Promotion of vocational skills and experience from a continuous flow of a production process are the basis for this type of technological progress. Change independent of capital can only happen if the people in the production process have a higher level of technical know-how during period t + 1 than during period t (WILLER 1967, p. 33).

In the first years of research on technological change, SOLOW (1957) and several of his followers thought the effects of capital on the growth of productivity were insignificant and therefore did not require more thorough study. Later studies have, however, found that embodied and disembodied technological changes have to be examined simultaneously (INTRILLIGATOR 1965, p. 65–70). This is also implied if the term embodied is also used for labour (NIITAMO 1969, p. 16). Then technological change is embodied in the labour force, e.g. in the form of increased working skills. This type of technological change can be embodied simultaneously in both labour and capital. In this situation disembodied changes in technology are mainly organizational as for instance a more efficient use of an existing building, thanks to better planning, etc.

In the long run, technological progress independent of capital is not as efficient as progress dependent on capital. Improvements in the quality of the labour force and of the organization approach their limit values unless capital changes.

WILLER (1967, p. 23) has divided technological change into induced and autonomous change. An induced change is connected with economic factors and can be regarded as an endogenous variable in terms of production. Such economic factors include a) relative price changes of inputs in the long run, b) learning and experience from the production process and c) investments in trading and research (HEERTJE 1977, p. 174). An autonomous change is independent of economic factors and can be regarded as an exogenous variable. ARROW's (1962) analysis of the "learning-by-doing" phenomenon also led to the same classification. Arrow's starting point was the idea that a substantial part of technical development is not exogenous in view of the enterpreneur and the enterprise. It is instead created within the enterprise by the experience originating from its own production process.

In agriculture, technological changes can be classified in the following way: 1) biological, 2) mechanical and 3) organizational changes (HEADY

1949, p. 296–297, OTT 1959, p. 302, WILLER 1967, p. 116). Biological changes mean better plant varieties and animal breeds. Innovations in the manufacture and application of inputs to increase output, for example new fertilizers, feeds and concentrates, are also biological changes (WEINSCHENK and MEINHOLD 1969, p. 91). Biological changes have a physiological effect on total output. They raise the productivity of land or the yield per animal. Mechanical changes refer to machines and equipment which compensate capital for labour but do not alter the physiological output of plants and animals. Changes having both biological and mechanical effects are called biological-mechanical (HEADY 1949, p. 297). In general it can be stated that a biological technological change is usually a substitute for land and a mechanical technological change is a substitute for labour (WEBER 1973, p. 57).

In addition to biological and mechanical technological changes there are also organizational changes in agriculture. These changes are mainly connected with the form, structure and size of the enterprise, management and personal questions (SCHAEFER-KEHNERT 1961, p. 218). The agricultural enterpreneur plans the use of inputs in accordance with the goals he sets. Production and marketing of products have to be organized to carry out a production process. If the provisions for production and marketing change essentially, they have to be adapted to meet the new situation. The greater the applicability of new technological inputs in agriculture the higher are the demands on the farmer as manager and organizer of the enterprise.

As it is very hard to distinguish from other development, organizational change is usually not examined alone. In most research it is included in biological technology (e.g. WESTERMARCK 1973, p. 15, WEBER 1973, p. 57). In these cases the effects of technological change have been the starting point. On the basis of this, agricultural technology could be classified in the following way (HAYAMI and RUTTAN 1971, p. 44):

Agricultural technology
1. A substitute for labour
1.1. Mechanical technology
2. A substitute for land
2.1. Chemical technology
2.2. Biological technology

The effects of technological progress on production can be described as follows (WILLER 1967, p. 15):

a) Saving in the use of inputs
b) Increase in production volume
c) Diversification of product range
d) Improvement in product quality
e) Replacement of old products with new ones

Saving in the use of inputs is related to the tendency of technological progress to lower costs. A certain quantity of output is produced with less labour, land or capital, or the same amount of input creates a larger output. The inputs saved can remain as such or they can raise the volume of output in the original use. They can also be transferred to another branch of production, in which case they increase the volume of production of either completely new products or of those previously manufactured. In this way technological progress can lead to saving, widening of the production base and of the product range. Technological progress may also improve the quality of a product. Although technological changes are usually examined with regard to increased output, it must be noted that they can also reduce losses or insecurity and risk. These changes are ultimately reflected in the output as well.

2.2. Different trends in technological change

The period of technological change in agriculture has been described as the "age of substitutability" (WEINBERG 1978) for some time. New technologies have made it possible to replace scarce and expensive inputs with relatively more abundant and inexpensive ones. A new technology is not always a substitute for land or labour; it often acts as a catalyst in making substitutability between inputs easier. The scarcest input can be used at maximum efficiency and this results in the highest possible output (HAYAMI and RUTTAN 1971, p. 44).

Technological progress depends on the preconditions set by the economic and social circumstances of the country. Technological change has occurred in different ways in different countries. The differences between the technologies become obvious when the productivities of agriculture in different countries are compared (Figs. 6 and 7).

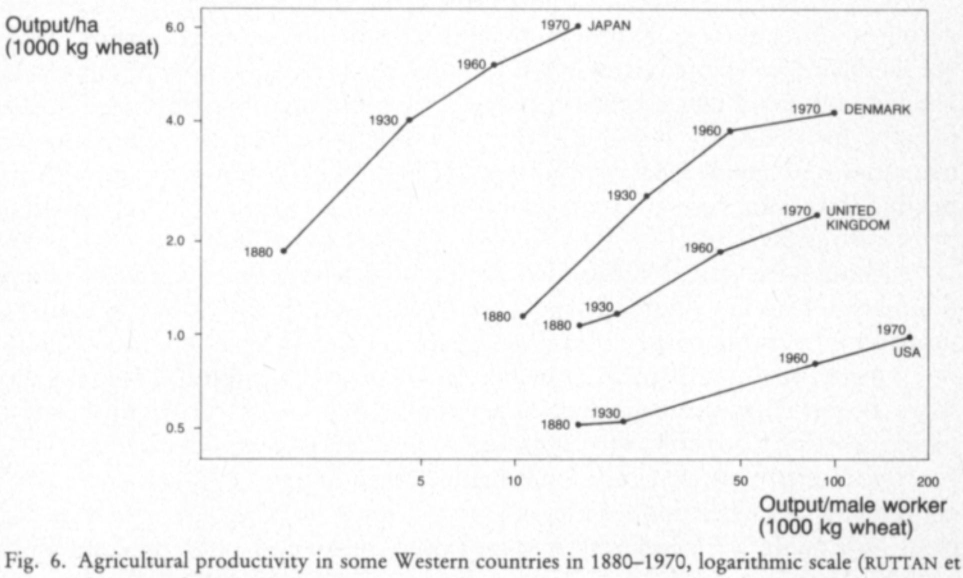

Fig. 6. Agricultural productivity in some Western countries in 1880–1970, logarithmic scale (RUTTAN et al. 1978, ref. WEINBERG 1978).

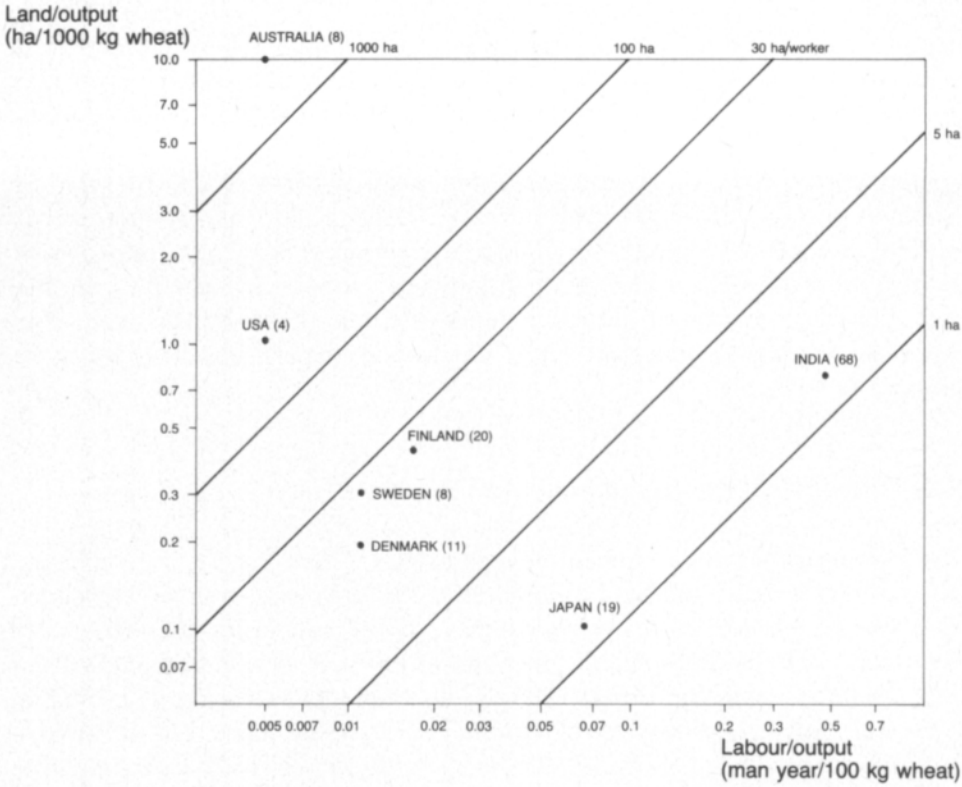

Fig. 7. International comparison of labour/output and land/output ratios in situations described by different land/labour ratios in 1970, log. scale (YAMADA and RUTTAN 1975).

In Fig. 7 the diagonal lines represent constant land/labour ratios and the numbers in parentheses are percentage ratios of agricultural workers to the total economically active population.

As illustrated in Figs. 6 and 7, the U.S.A. and Japan represent the extremes of technological progress in the so-called Western countries. They are therefore well suited to analysis. In Japan the inelastic supply of farm land has led to a rapid development of land-saving biological technology. In the U.S.A., on the other hand, a scarcity of labour has led to greater use of machines and mechanical technology. These opposite bases for growth in productivity can best be understood as dynamic adaptation to changing prices of inputs.

Although the cost of human labour has no doubt been a decisive factor in the mechanization of agriculture in the U.S.A., other effects of mechanization should also be stressed in this connection. According to SCHERTZ (1968, p. 3), mechanization helps to 1) accomplish tasks more carefully, 2) make the work faster, 3) create inputs not previously used and 4) accomplish tasks which were not possible with traditional production methods.

Inputs representing under mechanical technology, e.g. machines and equipment, are often indivisible and have a long working age. Their use is most profitable in larger enterprises, when fixed costs per product unit decrease. See Fig. 8.

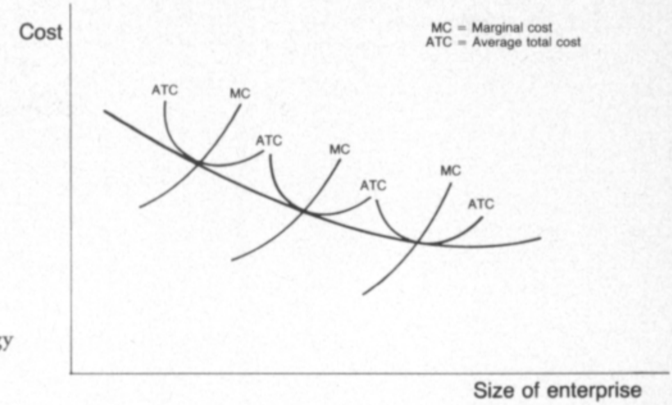

Fig. 8. Mechanical technology and size of enterprise.

Adapting mechanical technology to agriculture makes it possible to manage larger production units (cf. e.g. TORVELA and MÄKI 1974, p. 71). As a result, farms in the U.S.A. are very large on average.

In Japan the supply of land has been inelastic and the price of land has increased in relation to wages. It has not, therefore, been economically feasible to replace labour with machines. On the other hand, new potentials, which resulted from the steady fall in fertilizer prices in relation to the price of land, were utilized thanks to progress in biological technology. This led primarily to the improvement of plant varieties to give higher yields and make better use of fertilizers. The intensive increase in the amount of fertilizer used in Japan during the past few decades reflects not only farmers' adaptation to relatively lower fertilizer prices but is also a result of the development of new plant varieties by Japanese agricultural research. These varieties make better use of the increased amounts of fertilizers (HAYAMI and RUTTAN 1971, p. 159).

The effect of the prices for means of production on the progress and choice of a technology is shown in Fig. 9 in the case of fertilizers.

In both 1880 and 1960 farmers in the U.S.A. used less fertilizer than those in Japan (Fig. 9). However, in spite of the enormous differences in both physical and institutional resources, the relationhip between these variables has been almost identical in these two countries. When the price of fertilizers decreased in relation to other inputs, both Japanese and American researchers reacted by improving crop varieties to correspond better to reduced fertilizer prices. The Americans have always been some decades "behind" the Japanese in the process, because the price of land was lower in relation to that of fertilizers. This meant that yieldincreasing technology was valued less in the U.S.A. than in Japan.

It is possible to find the same process in cross section material pertaining to mechanical technology. Variations in tractor horsepower per worker are to a very large extent a result of the price of human labour in relation to the price of mechanical labour (Fig. 10). When wages increase in countries where there are small farms, such as Japan, it is possible to introduce mechanical technology within the limits set by the field area of the farm (YAMADA and RUTTAN 1975)

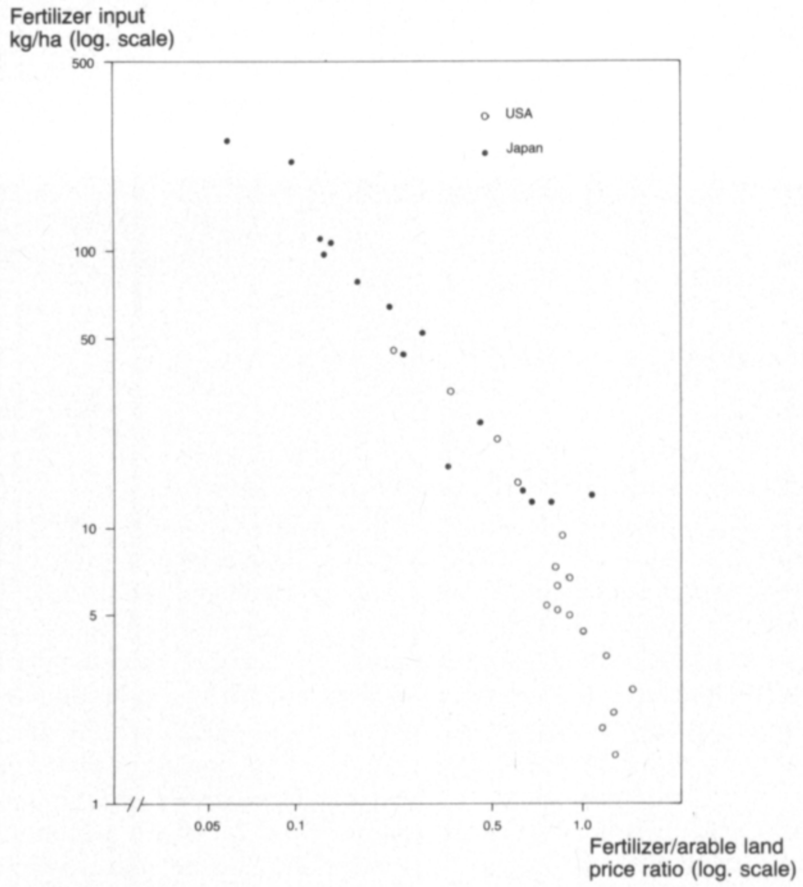

Fig. 9. Fertilizer input per arable land area (hectares) in relation to the price ratio between fertilizers and land in the U.S.A. and Japan in 1880–1960 (HAYAMI and RUTTAN 1971, p. 127).

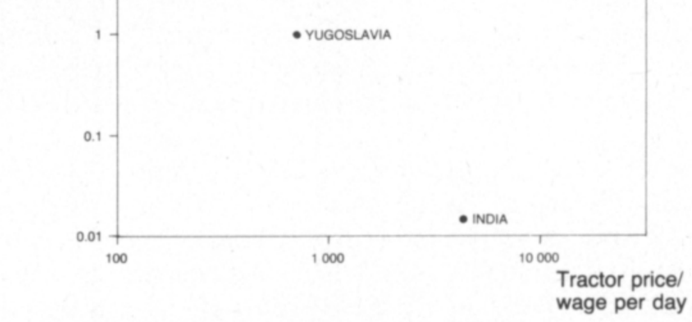

Fig. 10. Tractor horsepower per male worker in relation to the ratio between the prices of machines and human labour in 1970, log scale.

The increase in the price of fertilizers in relation to the price of land, or the rise in the price of labour in relation to the price of machines has caused changes in biological and mechanical technology. Thanks to cheaper and more profitable new technology, farmers have substituted fertilizers for land and machines for human labour. The technological differences and the different trends correspond to the special features of each country. Farmers, researchers and the agricultural industry and services, all influence technological development (YUDELMAN et al. 1971, p. 40).

It appears that during the past two decades as wages increased rapidly in Japan and land prices rose in the U.S.A., the models for technological change have approached each other in these two countries. Both seem to approach the European model of technological change, in which output per worker and per hectare increase at about the same speed.

2.3. The effect of technological change on the optimum level of production

To study the effect of technological change on the optimum level of production we can start from a simple example about technological improvement, such as that presented in Fig 11.

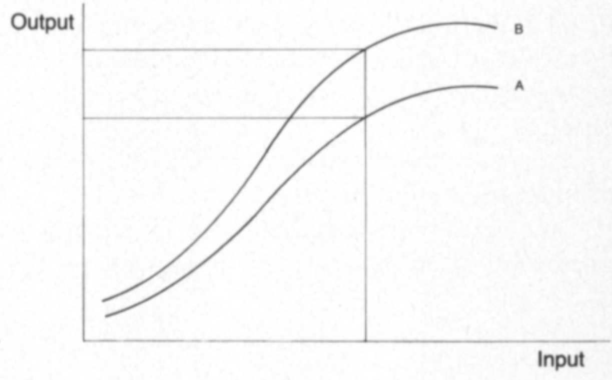

Fig. 11. Improvement in technology.

If the technologies or production methods A and B require the same inputs, then from the producer's point of view technology B is more profitable than technology A. Method B gives a higher level of output for each level of input.

The effect of a technological change on the optimum level of production depends upon the manner in which the change affects total output. If the technological change is such that marginal product for a given level of input increases, it is profitable to expand the quantity of the input used. For example in Fig. 12 the marginal product has been increased at each level of input by a technological change. Hence, as the value of the marginal product has grown as a result of technological change, it pays the producer to increase the amount of input X_1 used from 10 to 15 units.

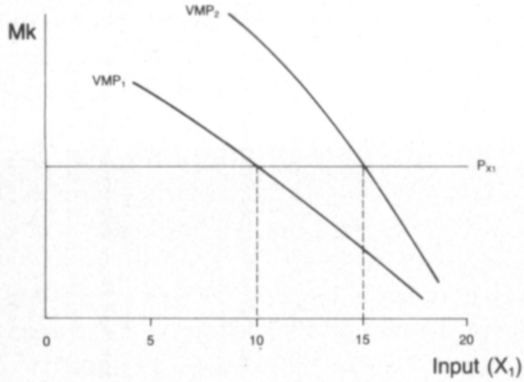

Fig. 12. Technological change and the maximization of net revenue.

It is possible, on the other hand, for a technological change to increase the total product for some input levels but not to increase the marginal product on these levels. The marginal product of 20 inputs, for example, might be the same for both production methods. However, the total production may be larger with the new method than with the previous one. In this situation the value of the marginal product remains equal for both production methods, and the level of input at which the marginal product equals price is unchanged. Although it is profitable to increase production, it does not pay to increase the quantity of the input used (BISHOP and TOUISSAINT 1958, p. 52).

The producer will not approve of a technological change unless he expects its introduction to lead to a reduction in costs per unit at the output at which he expects to operate. Since most innovations involve extra expenditure, total costs often grow at lower levels of output as a result of a technological change.

A typical cost situation facing the producer planning a change in a production method is presented in Fig. 13.

TC_1 represents the total cost in relation to output when the original method is used (Fig. 13). TC_2 represents the total cost curve after the

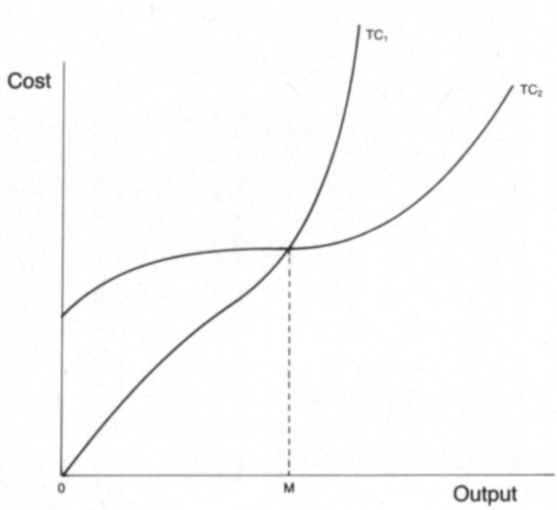

Fig. 13. Effects of a technological change on production costs.

technological change, when a new production method is used. The total cost of a new technology exceeds the total cost of the old method until a level of production OM is obtained. At higher levels of output the new method is more profitable.

The optimum level of inputs is defined by the marginal product and marginal cost as based on the production function. The effect of a technological change on the optimum use of inputs depends on the quality of the change. A neutral technological change does not affect the form of the production function. In other words, the curve as such moves upwards when MP and MC also remain constant (Fig. 14). A neutral technological change, therefore, does not affect the optimum use of the inputs. A non-neutral technological change, on the other hand, alters the shape of the production function. The value of MP changes simultaneously. After the change, the optimum intensity will be either at the upper or the lower level depending on the point where the condition MP = MC is valid.

Technological change can also occur in production that manufactures an input. This change usually lowers the price of the final product. Fig. 14 will be studied below. There the optimum intensity of X_i is X_{i0}. We assume that the price of input X_i has dropped as a result of the technological progress mentioned. The marginal cost (MC) then decreases to value MC' (Fig. 14), which corresponds to marginal product MP' of equal quantity. The intensity level of input X_i has thus risen to X_{il}. There has been a simultaneous increase in production.

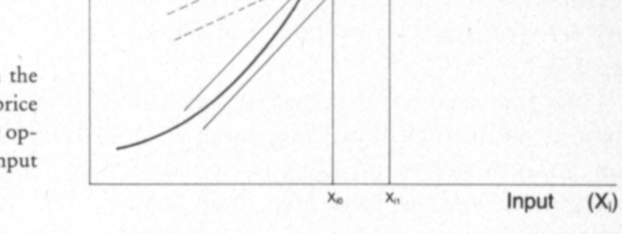

Fig. 14. The effect of the change in the ratio between the input price and the final product on the optimum intensity level of input X_i.

3. Measurement of technological change

3.1. Different lines of measuring

In measuring a technological change we are interested in the overall effects of the change and especially in determining its characteristic features and in assessing the effect of each of them. The methods for measuring technological change can be divided into two main classes: methods based on production function and those based on index figures (HEERTJE 1977, p. 193, ROUHIAINEN 1972, p. 15). In the methods based on production function, either the transfers of the production function are measured or else a correction required by a technological change is made in the building of the production function. When examining the change in terms of index figures, the technological change is measured by means of indices of inputs and output. The division of measuring methods into these main types is not entirely unambiguous. Measuring methods based on indices are often used in studies on production functions. In principle production function approach is only a mathematical description of measuring method based on indices.

3.1.1. Measuring methods based on a production function

When studying measurement of a technological change with regard to the construction of a production function, we start with the following equation

$Q = f(L, C, A)$, where L = labour,
C = capital and
A = the part which cannot be explained by the variables L and C, or the residual.

Measuring methods based on production function can be divided into traditional and "service-flow" methods (NIITAMO 1969, p. 4).

Traditional measuring methods are aimed at measuring transfers of the function by adding to the model those variables that are supposed to explain a technological change. This method is based on the fact that technological change is included in the residual. It must be emphasized in this connection that the residual or the unexplainable part may, in addition to the technological change, include: 1) measuring or aggregation errors, 2) errors in the estimation of parameters, 3) errors in the hypothesis of the function and 4) errors caused by exclusion of one or more variables (ROUHIAINEN 1972, p. 15).

In the traditional measuring methods, certain substitute delineators for labour and capital input are approved and the residual is divided each time in an analytically interesting or suitable way. In such cases the inputs are measured without regard to their quality. This is the same as assuming the homogeneity of the inputs (IHAMUOTILA 1971, p. 69).

NIITAMO (1969, p. 4) presents the "instrumental model" as a more advanced way of traditional measuring:

$$Q = f(L, C, H, V, \ldots, X, e).$$

Labour and capital inputs are measured in some ordinary physical units, and the part which cannot be explained by these variables will be analysed and divided into those factors affecting the quantity of output that the decision-maker can use when he wants to alter production. Among such factors are variables describing effects of change in education and of modernization in machinery.

In the "service-flow" methods, output is always the sum of the inputs used. Qualitative changes in, say, workers and machines should then be reflected as a corresponding change in the labour or capital input concerned. The inputs used are then measured in productivity units. In the service-flow method the residual is regarded entirely as an error in measuring which, in principle, can be made infinitely small. If the inputs are corrected carefully, no errors occur in the measuring and aggregating of inputs, the estimating method and the functional form are correct and all the variables are included, there should be no residual at all. The service-flow method allows only constant returns to scale, because in this method the correction due to technological change has been made through input variables and a corresponding quantity of change is reflected in the output (NIITAMO 1969, p. 5). In contrast, increasing and decreasing returns to scale are possible with traditional measuring methods.

The greatest problem in the use of service-flow methods is how to measure the input quality. It is hard to define a unit of productivity for many inputs that would be unambiguous and would allow combining of qualitative changes with labour and capital inputs.

In measuring methods based on production function the basic problem can be presented as in Fig. 15.

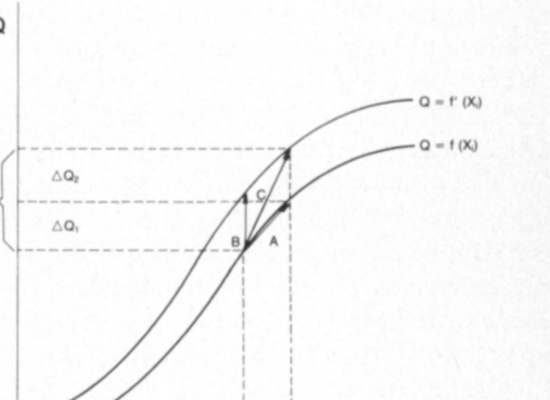

Fig. 15. Effect of technological change on production function.

Fig. 15 shows that the quantity of output can in principle change in two ways. The change may occur along the production function (A), which requires an increase in inputs $X_{i0} - X_{i1}$, or as a transfer of the production function (B). In practice (C) is probably the most common. Here the rate of input use increases and we also move to an "upper" production function.

When a production function is estimated from data, estimates are obtained for the parameters of the function. These estimates are constants. This means that they indicate the state in which the production technology exists but they say nothing about change in it.

The problem behind the measurement of a technological change is thus how the increased output should be divided – and how it can be divided – between the increase in the use of inputs and technological progress. In Fig. 15 the problem is how ΔQ can be divided between the components ΔQ_1 and ΔQ_2.

3.1.2. Measuring methods based on indices

A technological change can also be measured by different kinds of productivity indices. Such indices are either partial or total depending on whether the increase in output is calculated for one or for all inputs (HEERTJE 1977, p. 193).

Output per unit of labour is a common measure of partial productivity. This partial index is not, however, a good measure of technological change, because it does not take into consideration substitution of the inputs caused by changes in relative prices. Because the price of labour has also increased in relation to the price of capital in agriculture, the productivity of labour gives the technological change too high a value. This rate also rises faster than technological change does in reality (ROUHIAINEN 1972, p. 19).

The index based on total productivity is calculated from the relation between the output index and the indices of all inputs. The total index is calculated either from arithmetic or geometric averages. When arithmetic values are used, the output is divided by the weighted sum of the input indices, whereas the geometric values are presented in logarithmic form (HEERTJE 1977, p. 193). When indices based on total productivity are used, all changes in output are explained by technological change.

The greatest problem in the measuring method based on total productivity is how the inputs and outputs should be aggregated. Because changes in the relative prices should not distort the index derived for total productivity, price changes should be eliminated. To solve this problem Laspeyres or Paasche indices or versions of these, such as Fisher's and Edgeworth's indices, are normally used (IHAMUOTILA 1971, p. 20, FLECK 1973, p. 89–91).

In the Laspeyres index,

$$Q_{0i} = \frac{\Sigma p_0 q_i}{\Sigma p_0 q_0},$$

where Q = index of gross output,
p = price of a single product,
q = quantity of a single product,
0 = base year,
i = year studied,

the prices from the base year are used throughout the research period. The base year can be any year within the period studied (IHAMUOTILA 1971, p. 16).

In the Paasche index,

$$Q_{0i} = \frac{\Sigma p_i q_i}{\Sigma p_i q_0},$$

the prices for each period to be compared are used both in the period under study and in the base period. There are very great restrictions when these indices are used to derive accurate estimates for the trend in total output or for the sum of all inputs. When using the Laspeyres index RUTTAN (1954, p. 15) assumed that the enterprise works in a balanced state during the whole research period, the production function shows constant returns to scale, both the price ratios between the inputs and those between the products remain constant and the technological change is neutral. The same assumptions must also be made when the Paasche index is used. Assumptions of this kind are unrealistic in practice.

The Laspeyres and Paasche indices define the limits of the ”right” index (ROUHIAINEN 1972, p. 20). Therefore various calculation methods have been developed in which attempts have been made to correct the defects of these basic methods. The approach, however, is of the same kind.

Fisher’s index is the geometric average of the Laspeyres and Paasche indices (IHAMUOTILA 1971, p. 20). Neither can the effects of changing prices be totally eliminated in this index. The same applies to Edgeworth’s index,

$$Q_{0i} = \frac{\Sigma q_i \ \frac{1}{2}(p_0 + p_i)}{\Sigma q_0 \ \frac{1}{2}(p_0 + p_i)},$$

where the average prices for the base year and for the comparison year are used as weights (FLECK 1973, p. 91).

3.2. Some methods for measuring technological change

3.2.1. Arithmetic and geometric indices

Abramowitz’ arithmetic (ABRAMOWITZ 1956) and Solow’s geometric index (SOLOW 1957) can be considered the basic methods for measuring technological change. Both are typical measuring methods based on productivity indices. In the former method the prices of inputs, and in the latter the elasticities of output in relation to the corresponding inputs, are used as weights. Because of these differences in weights, the character of the indices is also different. In the arithmetic index relative prices have to remain constant, and in the geometric index relative shares of returns must be kept constant (LAVE 1966, p. 12–13).

The arithmetic index was already studied in connection with the definition of technological change in Chapter 1.1. (p. 174). The equation for the arithmetic index is (LAVE 1966, p. 7):

$$\frac{Q_1}{Q_0} = A\,(w_0 \frac{L_1}{L_0} + r_0 \frac{C_1}{C_0}),$$

where Q = output,
L = labour input,
C = capital input,
A = technological change,
0 = base year,
1 = year studied,
w = average wages and
r = average return on capital.

The arithmetic index is quite simple in this form, and therefore it has been used very often, either as such or applied, in the experimental measurement of technological change (e.g. LAVE 1966, KENDRICK 1961).

The geometric index applied by SOLOW (1957) studies dependences based on aggregate production function where labour and capital are variables and technological change is a parameter. Solow supposed that the function is homogenous and linear, that the market is in perfect competition and that the technological change is neutral. The function type examined by Solow is

$$Q = A(t)\, f(C, L).$$

The term A(t) describes technological change, which is a function of time. We can derive the formula below for the calculation of the geometric index (LAVE 1966, p. 11):

$$\frac{\Delta A}{A} = \frac{\Delta x}{x} - W_C \frac{\Delta k}{k},$$

where x = Q/L,
k = C/L,
Δ = change in a term between two periods and
W_C = elasticity of output with respect to capital.

According to this formula, technological change is equal to the change in output not accounted for by changes in labour and capital (LAVE 1966, p. 11).

3.2.2. Production functions

The measuring methods based on production functions should be divided into macro- and microeconomic approaches. In the microeconomic production functions, the latest and most developed technology is generally the starting point (HEADY and DILLON 1961). These functions are used mainly when studying the reasons leading to the development of a technology (HEERTJE 1977, p. 192). Macroeconomic production functions are used in examining the average efficiency of production. Technological progress can then also be negative (LAVE 1966, p. 19).

3.2.2.1. The Cobb-Douglas function

The formula for the Cobb-Douglas production function for two inputs is (HEADY and DILLON 1961, p. 75):

$Q = a L^{\alpha} C^{\beta}$,

where Q = output,
L = labour,
C = capital,
a, α and β = parameters.

The exponents α and β are the corresponding elasticities of production (HEERTJE 1977, p. 126):

$$\alpha = \frac{\frac{dQ}{Q}}{\frac{dL}{L}}, \qquad \beta = \frac{\frac{dQ}{Q}}{\frac{dC}{C}}.$$

Technological changes cause changes in the parameters of the production function. In the Cobb-Douglas production function the changes in each parameter (a, α, β) describe a different kind of technological progress (BROWN 1968, p. 39). The change in the efficiency of a technology is reflected only in the term a, as a neutral technological change. A change in the degree of returns to scale is reflected in the variations of the sum $\alpha + \beta$.

A change in the sum of the parameters α and β indicates the degree of returns to scale in the following way:

$\alpha + \beta = 1$, there are constant returns to scale. When labour and capital are increased by x % (ceteris paribus), output will also rise by x %.

$\alpha + \beta > 1$, there are economies of scale. When labour and capital are both increased by x % (ceteris paribus), the returns will rise by more than x %. The returns will rise by yx %, when $\alpha + \beta = y$ (NIITAMO 1969, p. 12).

$\alpha + \beta < 1$, there are diseconomies of scale.

Changes in the capital intensity of a technology are seen in the ratio α/β. The fourth property of technological change, the rate of substitutability of inputs, cannot be derived from the Cobb-Douglas function, because in this function the elasticity of substitution is 1 with all the combinations of inputs and rates of capital intensity (BROWN 1968, p. 39).

The worst deficiency of the Cobb-Douglas function is that it cannot show any changes in the elasticities of substitution and generally does not permit any alternative other than that of complete substitutability (NIITAMO 1969, p. 19). BROWN (1968, p. 38) mentions the following variants of the Cobb-Douglas function in which the variations of elasticities have been taken into account to some extent:

$$Q = L^{\alpha} C^{1-\alpha} e^{\beta L}$$

$$Q = a L^{\alpha} C^{\beta} \exp(\gamma \log L \log C)$$

$$Q = a L^{\alpha} C^{\beta} e^{\gamma C} e^{\beta L}.$$

3.2.2.2. The CES function

CES stands for "constant elasticity of substitution production function". This function provides new scope for estimation of technological progress.

The Cobb-Douglas function presented above and the Leontief function are special cases of the CES function. In all three functions the elasticity of substitution is assumed to be constant. The difference is that in the CES function elasticity can derive any value between zero and infinity without any other forehand restrictions, whereas in the Cobb-Douglas function the elasticity has been prescribed to be one and in the Leontief function zero (FLECK 1973, p. 165).

In designing the formula for the CES function, ARROW et al. (1961) supposed that first, it is a homogeneous first degree function, and second, there is perfect competition both on the product and on the input market. In its basic formula the CES function can be presented in the following way (HEERTJE 1977, p. 127):

$$Q = \gamma\,[\delta C^{-\varrho} + (1-\delta)\,L^{-\varrho}]^{-\frac{v}{\varrho}}$$
$$\gamma > 0$$
$$0 \leq \delta \leq 1$$
$$\varrho \geq -1$$
$$v \geq 0.$$

The parameter γ in the production function denotes the efficiency of a technology. A proportional change in this parameter causes a proportional change of equal size in the output when all other factors are kept constant. The parameter v shows the degree of returns to scale in the function, i.e. the production function is a homogeneous function of the v:th degree. Thus a neutral technological change is reflected as changes in the efficiency parameter γ and in the degree of returns to scale v (NIITAMO 1969, p. 42).

A non-neutral technological change is associated with variations in δ, the capital intensity parameter, and ϱ, the substitution parameter. The elasticity of substitution is derived from the substitution parameter through the following transformation:

$$\sigma = \frac{1}{1+\varrho}\,.$$

The maximum level of the elasticity of substitution infinity makes the minimum of the parameter $\varrho = -1$. An elasticity of substitution greater than 1 makes the limits of $-1 \leq \varrho \leq 0$. When $\varrho = 0$ we have a Cobb-Douglas function because the elasticity of substitution (σ) is then = 1. When $\varrho = \infty$ and $\sigma = 0$, we have the Leontief function mentioned above.

Although the CES function is more general than the Cobb-Douglas function, it still does not permit solution of all the problems encountered in studying technological change functionally.

There are many problems with the CES function which restrict its use (BROWN 1968, p. 59). First, it is difficult to generalize the CES function to more than two factors of production. Estimation of the parameters usually requires restrictive hypotheses (UZAWA 1962, p. 291–299).

The second restriction deals with the elasticity of substitution. This parameter is the basis for the "superiority" of the CES function, because it is allowed to get its value separately in each case, in accordance with inputs and outputs, and without advance restrictions. It also restricts the use of the function because the estimation of the elasticity of substitution is a very difficult task both theoretically and empirically.

The third restriction deals with the parameter v. Changes in the degree of returns to scale, which appear as changes in the parameter v, can be caused by both technological changes and changes in the degree of activity with constant technology. According to BROWN (1968. p. 60), these effects cannot be separated from each other without restrictive hypotheses. In the interpretation of the parameter v special caution must be taken to avoid too far-reaching conclusions.

The greatest problem in the use of the CES function is, however, in the fitting the function into the data. There are particularly great difficulties in the measurement of the capital input. The estimation of the parameters of the CES function does not succeed without restrictive hypotheses.

3.3. Practical applications of the measurement of technological change – previous studies

TINBERGEN (1942, p. 511–549) added a trend term to the Cobb-Douglas function to express neutral technological change. Beginning his study with the 3/4 and 1/4 elasticities of production, Tinbergen estimated this trend for 1870–1914 from data on the United Kingdom, the U.S.A., Germany and France. This research represents a major step forward in the development of the methods for measuring technological change. The method has, however, encountered strong criticism, especially because it studies the elasticities of production and their sum a priori.

SOLOW (1957, p. 312–320) made the following assumptions when examining technological change: there are "constant returns to scale", technological change is neutral, there is a macroeconomic production function and the theory of marginal productivity is valid in this situation. Solow's material deals with the private sector of the U.S.A., excluding agriculture, in the years 1909–1949. The data are best suited to an analysis with a Cobb-Douglas production function. The arithmetic index calculated by Solow for technological change grows by one per cent annually during the first half of the study period and by two per cent during the second half. These results mean that about 90 % of the total growth in labour productivity during this forty-year period is caused by technological change and only 10 % results from capital formation. MASSELL (1960, p. 182–188) came up with practically the same results for the industrial sector of the U.S.A. from 1919–1955. ARCHIBALD (1964) also carried out a corresponding study on Greek industry from 1951–1961. McLEAN (1973) applied the same research method to agriculture in Victoria, Australia.

Similar research by Solow, Massell and others has encountered strong criticism. It has been directed mainly at the statistical data and the research method used. The hypothesis about neutral technological change which is not embodied in capital inputs, constant returns to scale and the restriction of research to the case where elasticity of substitution is 1 have also been strongly criticized. The critics have emphasized that a rise in productivity caused by technological change can also result from learning, better education and improved social and organizational conditions (HOGAN 1958, RESEK 1963).

ABRAMOWITZ (1956), KENDRICK (1961) and DENISON (1962) used a method based on the "Abramowitz' residual" when measuring technological change. This method is based on the fact that when the effect of labour and capital are eliminated from the change in productivity, the effect of other factors, of technological change, can be seen. There are, however, great defects in this method owing to simplification. First, when it is assumed that the entire residual consists of technological change, the change receives too high a value. Another source of error in this method is that the relations between the inputs affecting one another have been oversimplified.

BROWN and POPKIN (1962) made a distinction between neutral and non-neutral technological change. Although they use a Cobb-Douglas function they do not assume constant returns to scale. With a statistical method they examine neutral technological change during three different periods between the years 1890 and 1958. The research deals with the private sector in the U.S.A., excluding agriculture. Production figures for each period can be explained by labour and capital inputs, neutral technological change and the degree of returns to scale. As indicated by the following figures, the parameters of the Cobb-Douglas function vary between the periods under study. This is caused by non-neutral technological change:

	Elasticity of production in relation to labour α	Elasticity of production in relation to capital β	$\alpha+\beta$
1890–1918	0.97	0.49	1.46
1919–1937	0.43	0.60	1.03
1938–1958	0.51	0.53	1.04

The greatest defect in the method of Brown and Popkin is that it uses a production function in which the elasticity of substitution between the various inputs is always 1. SALONEN (1981) has also used the Cobb-Douglas function in measuring technical change in Finland.

ARROW et al. (1961) estimated the elasticity of substitution between the inputs at 0.57 in their study based on the same data which Solow used in his research mentioned above (SOLOW 1957). The annual growth of productivity was estimated to be 1.8 % and technological change was supposed to be neutral. In the additional research work based on a cross section of data, the elasticity of substitution varies between 0.72 and 1.01 depending on the sector under study.

According to the indices of KENDRICK and SATO (1963), the annual neutral technological change in the U.S.A. was 2.1 % between 1919 and 1960, when the elasticity of substitution in the CES function was 0.58. BROWN and de CANI (1963) have estimated the neutral technological change, the rates of returns to scale and the values of the elasticity of substitution during three periods: 1890–1918, 1919–1937 and 1938–1958.

David and van de Klundert have attempted to explain the growth of production in the private sector of the U.S.A. between 1899 and 1960 by means of a CES production function and operating with non-neutral technological change. They found the annual technological change to be 1.85 % on average, which is more labour-saving than neutral (DAVID and van de KLUNDERT 1965).

REVANKAR (1971) has rejected the supposition about constant elasticity of substitution. He has made some studies on the so-called VES function. VES stands for "variable elasticity of substitution production function". SIMULA (1979) has done some comparisons between Cobb-Douglas, CES and VES functions. He has measured productivity and technological changes in Finnish forest industry.

The empirical research reviewed above has been based on the hypothesis that technological change is not embodied in new capital inputs. In spite of this simplification there are great difficulties in interpreting the results. The worst problems are the definition of the production function, the consideration of the rate of use of inputs and of the changes in the rate of returns to scale, and the division of technological change into a neutral and a non-neutral component. There will be still more problems if it is assumed that technological change is embodied in new capital inputs. The growth of the capital input must then be divided into a quantitative and a qualitative factor.

Many economists prefer omission of the hypothesis of embodied technological change. DENISON (1964) believes that the significance of technological change embodied in capital depends essentially on the age structure of the capital inputs to be used. YOU (1976) also supports this view. Even before Denison, ARROW (1962) developed a theory from the "learning by doing" hypothesis, which is based on the assumption that as a production process ages, machines specialize in that particular production line, labour input becomes correspondingly more skillful etc. Thus accumulated experience and specialization reflect technological progress, which Arrow regards as an internal factor in an enterprise or in a production sector.

SOLOW (1962) suggested that technological change is embodied in investments for each year. Investments made in a particular year include the technological improvements developed in previous years. So technological progress can be measured indirectly in terms of accumulating investments. SOLOW (1962) realizes that macroeconomic empirical data can be explained equally well by both types of technological change.

In his detailed study, JORGENSON (1966) comes to the conclusion that it is not possible to distinguish between models of embodied and disembodied technological change on the basis of empirical data.

SOLOW (1960) has calculated that embodied technological change raises production by 2.5 % annually when disembodied technological change is not considered separately.

SOLOW (1960, 1962) has assumed a shifting production function. GRILICHES (1963) examines a fixed production function and tries to explain the changes in production with changes in the quality and quantity of inputs and with scale effects. In this case the "Abramowitz' residual" is the sum of the errors made in measuring. Griliches succeeded quite well in explaining the development of agricultural production in the U.S.A. in 1940–1960 with these factors. He therefore concludes that technological change is embodied in both labour and capital – not only in the former, as assumed by Denison but also in the latter, as assumed by Solow.

NELSON (1964) makes a clear distinction between quantitative and qualitative changes in capital. He further divides the qualitative changes into qualitative changes and changes in the age structure of capital inputs. He also presents a parameter for the qualitative improvement of labour resulting e.g. from better trading and education. Nelson's most important conclusion is that it is wrong to assume that the various factors which influence total productivity are independent of each other. Changes in labour and capital inputs and scale effects should be seen as phenomena which influence each other. If technological change is regarded as an endogenous process, the growth rate cannot be estimated by regression analysis when these quantities are supposed to be constant.

INTRILLIGATOR (1965) has designed a model which includes both forms of technological change. His conclusion deals with the U.S.A. from 1929–1958 and states that the best results are achieved when both embodied and disembodied technological changes are studied simultaneously. They increase production by 4 % and 1.67 % per annum, respectively. SZAKOLCZAI and STAHL (1969) have further developed this work and rejected constant returns to scale. PHELPS and PHELPS (1966) have likewise included both forms of technological change in their econometric studies.

JORGENSON's and GRILICHES' (1967) work, in which growth of production is almost totally explained with inputs, is almost the complete opposite of those empirical studies in which "Abramowitz' residual", regarded as a result of a technological change, has a significant position. Jorgenson and Griliches corrected the errors made in aggregation and noted the changes in the rate of capital use. They estimated that 96.7 % of the growth of production in the U.S.A. in 1945–1965 can be explained with growth in inputs. This interesting conclusion results to a great extent from the fact that labour and capital are measured in relation to their ability to produce. Capital, which, as a result of disembodied technological change, has a double effect on production at moment t compared with moment t–1, is calculated in double quantity. This way "technological change" is narrowed because of the effects of capital and labour changes.

This approach gives a better result about exogenous technological change, but it also lends itself to criticism, which can be made on the measurement of any qualitative process. In empirical research it is more common to study endogenous factors that explain technological change. SHESHINSKI's research (1967) is one example which tests Arrow's model of learning. Sheshinski realized that labour productivity is greatly affected by investments, which are a measure of additional experience achieved. However, he forms this argument from Arrow's theory and states that technological change as embodied in capital had been ignored. Also CHEN (1976) has attempted to test the significance of the endogenous component in technological change.

There are many ways in which the qualitative changes in the labour variable have been considered. NIITAMO (1958) has used the proportion of those who have finished secondary school in the potential labour force as a measure of technological change.

In agricultural research technological change has usually been measured indirectly with various indicators or substituting variables.

IHAMUOTILA (1971, p. 71) has explained technological change with two separate individual variables. One describes the prevailing stage of technology including the applicable production techniques each year as well as the current knowledge about input – output ratios. In other words it shows the general opportunities that agricultural production can utilize each year. This variable, is at the least, partially external because the innovations available for agriculture do not originate only in agriculture but are also – and obviously primarily – caused by the increase of human knowledge in general. The other variable represents the conditions which must exist within agriculture before use of the available innovations and knowledge can be made. So this variable, which represents farmers' current know-how, reflects internal development in agriculture. These two variables have been constructed in the following way: a simple time factor has been used as an estimate of technological change for the first technology variable. The other variable depicting technological change is partly based on the theory of accumulating investments presented above. In this study, however, investments have been restricted to cover only the capital items which most clearly reflect technological progress. Furthermore, it has been thought that technological change is reflected in the quantity of human labour which has been saved thanks to the investments. To estimate this, the real stock of accumulated investments each year is given in relation to labour input in agriculture at present.

In agricultural research methods for measuring technological change based on simple indicators start from the basic features of the farms, mostly from the inputs used. The aim is to distinguish farms using different technologies from each other.

WEBER (1973) deals with inputs on the basis of their price. Weber has used the cost of fertilizers as an indicator for biological technology, as have HAYAMI and RUTTAN (1971). Weber gives proof of the justification for this method by calculating the correlation between the use of fertilizers and the use of all chemical inputs (fertilizers, herbicides, etc). The comparison covering the period 1959–1969 shows a clear positive correlation, +0.96. The prices included were deflated with the wholesale price index (WEBER 1973, p. 58).

HAYAMI and RUTTAN (1971) used the number of tractor horsepower per worker as an indicator of mechanical technology. This clearly indicated the relationship between human and mechanical labour. Weber also tested this method on conditions in West Germany from 1950–1969. He compared the number of tractor horsepower with the prices of electricity, fuels and lubricants, tractors and agricultural machines, all deflated by the wholesale price index, and derived a positive correlation, +0.95 (WEBER 1973, p. 58). On the basis of these results Weber argues that the use of fertilizers and the number of tractor horsepower per agricultural worker can be used without risk to indicate the relationship between biological and mechanical technologies in other European countries as well.

TORVELA (1966, 1971) calculates the ratios of different inputs from their price ratios. He also follows the trend of the share of human labour in operating costs. He states that in 1968 the share of human labour in the operating costs of the bookkeeping farms in southern Finland was on average 33.7 %. The share of human labour on farms smaller than 10 hectares was 1180 marks/ha and on farms larger than 50 hectares 332 marks/ha. As a percentage of operating costs the figures are 46.6 % and 25.4 % respectively (TORVELA 1971, p. 42). Torvela further states that the cost of labour is remarkably high on farms practising intensive animal husbandry. Its share in operating costs also increases as a farm decreases in size, because it is hard to rationalize production on small farms to the same extent as on larger ones (TORVELA 1971, p. 60).

4. The method and statistical data used for empirical research

4.1. The method of empirical research

The goal of the empirical part of this study is to measure technological change and its characteristics in different kinds of agricultural enterprises. The research method used is based on the CES production function, which has been chosen mainly because the parameters of the CES function reflect the various characteristics of technological change. This function does not restrict the size of the elasticity of substitution. It is defined purely by statistical data.

The method used in this study is based on a cross section data. Some years in the research period are chosen for closer study, and the CES function will be applied to their data. The parameters estimated from the cross section data will then show the state of the technology in that particular year. Technological change can be measured and described by comparing the estimates for parameters of various years with each other. As agricultural production fluctuates greatly from year to year, mainly because of climatic conditions, special attention must be given to the choice of the research period and the research years.

4.2. Estimation of the parameters of the CES function

The logarithmic alteration of the CES function is in the following form:

$$\log Q = \log \gamma - \nu/\varrho \log [\delta C^{-\varrho} + (1-\delta) L^{-\varrho}],$$

where
Q = output,
C = capital,
L = labour,
γ = the efficiency parameter of the technology,
δ = a parameter indicating the capital intensity of the technology,
ν = a parameter indicating the degree of returns to scale and
$\varrho = -[1-(1/\sigma)]$ = substitution parameter, σ = elasticity of substitution.

The problem is how to derive estimates for the parameters γ, δ, σ and ν by using data on output, labour and capital. A simple least squares procedure cannot be applied directly, because the term $\log [\delta C^{-\varrho} + (1-\delta) L^{-\varrho}]$ contains the parameters δ and ϱ, which must also be estimated. Therefore a side relation will be chosen by means of which parameters δ and ϱ will be estimated separately. The estimates thus derived will be placed in the equation given above. The equation can then be solved by the method of least squares (BROWN 1968, p. 128).

Researchers have used many alternatives in the estimation of parameters δ and ϱ. Usually the side relations have been based on marginal product, marginal rate of substitution or expansion path (BROWN and de CANI 1963, McKINNON 1962, BROWN 1968). The basic idea here seems to be that it must be possible to solve the side relation by the method of least squares. When this method is applied it is assumed that the error is normally distributed (VASAMA and VARTIA 1972, p. 396).

In this study the side relation is formed in the following way: when production occurs at the optimum level, the marginal rate of substitution between the inputs is equal to the inverse number of the price ratio of these factors. When production shifts from one level of output – from the curve of equal output – to another, the optimum points will form an expansion path which simultaneously describes both the combination of minimum costs and the optimal intensity of production (KEHRBERG and REISCH 1969, p. 51). The connection between the expansion path and the price ratio of inputs in the case of CES production function can be presented as follows (FLECK 1973, p. 146, BROWN 1968, p. 169):

$$\frac{w}{r} = \frac{1-\delta}{\delta} \left(\frac{C}{L}\right)^{1/\sigma},$$

where
w/r = "the price ratio" between labour and capital,
C = capital input,
L = labour input,
σ = elasticity of substitution and
δ = a parameter indicating the capital intensity of the technology.

Because the cost of capital (r), however, is very difficult to estimate, the above equation will be multiplied by L/C. Then the prices of inputs will also be replaced by corresponding "shares of income". When $\varrho = (1/\sigma) - 1$ is set in the equation at the same time, the side relation has the following form

$$\frac{wL}{rC} = \frac{1-\delta}{\delta} \left(\frac{C}{L}\right)^{\varrho}.$$

To make use of the method of least squares in the estimation of the parameters, the logarithmic alteration of the equation is applied in the calculation

$$\log (wL/rC) = \log (\frac{1-\delta}{\delta}) + \varrho \log (C/L)$$

or shorter

$$\log y = \log b + m \log X,$$

where
$$y = wL/rC$$
$$b = (1-\delta)/\delta$$
$$m = \varrho$$
$$X = C/L.$$

4.3. Statistical data

4.3.1. General

The data in this study comes from the bookkeeping farms within the agricultural profitability survey. This study deals only with the farms which have participated in the profitability survey for the whole research period.

The research pertains to the period 1947–1979. This period includes the changes that took place when more advanced machines and implements and more advanced technology in general were gradually substituted for manual labour and horses (in the 1940s). The years 1947/48, 1956/57, 1968 and 1979 have been chosen for this study. These years were chosen primarily for the following reasons:

1. These years describe different stages of mechanization. During the fiscal year 1947/48 agricultural production was mainly based on the use of horses. In the fiscal year 1956/57 mechanization had just begun, and 1968 and 1979 are representative of subsequent stages of agricultural production technology.
2. The research years were chosen to represent roughly average weather conditions. At the same time, however, it was kept in mind that the intervals between the research years would be approximately the same, i.e. 8–12 years.
3. When calculating the results for 1947/48 and 1968 the values of different capital items have been raised to correspond with current market values. Although this kind of correction was not made in the second half of the 1950s nor in the 1970s, 1956/57 and 1979 have been included in order to permit examination of the whole research period.

The material for this study is derived from the bookkeeping farms which have participated in the profitability survey during all the years studied. There are in all 78 such farms. They are divided into different branches of production as follows:

	1947/48	1956/57	1968	1979
Farms specialized in animal husbandry				
1. Cattle farms I (over 80 %)[1)]	–	9	16	31
2. Cattle farms II (over 60 %)[1)]	2	39	29	6
3. Pig farms (over 35 %)[1)]	3	1	4	8
4. Other animal husbandry farms	73	25	14	6
Farms specialized in crop production				
5. Grain farms (over 45 %)[1)]	–	–	13	24
6. Other crop production farms	–	4	2	3
	78	78	78	78

[1)] The share of the main product in gross return

The trend towards specialization in Finnish agricultural production is evident in these distributions. In the fiscal year 1947/48 almost all the farms studied were in a group of farms engaged in varied production and designated "other animal husbandry farms". In 1979 most research farms were specialized in dairying, pig production or in the production of grain.

There are 49 research farms from southern Finland, 13 from central Finland, 7 from southern Ostrobotnia and 9 from northern Finland.

4.3.2. Selection of variables

4.3.2.1. Output

In the production function the dependent variable is output. This is the physical quantity of the products produced in a fixed production unit during a given period of time (NIITAMO 1958, p. 42). Because the number of different products cannot be added up directly, the quantities produced have to be made commensurable. Monetary values have thus been assigned to the products.

The gross return from agriculture has been chosen to describe the output. In order to determine the total effects of mechanical technology gross return is calculated per farm. The enlargement of farm size during the research period is reflected as a corresponding increase in capital input. In the bookkeeping statistics gross return has been calculated per hectare.

The gross return figures describing total output are converted to a constant price level. The fiscal year 1968 was chosen as the base year. Gross return is converted to the price level of the base year in the following way:

$$X_{0i} = \Sigma\, p_0 q_i,$$

where X_{0i} = gross return of the year i at the price level for the base year,
0 = base year,
i = comparable year,
p = price of a single product and
q = quantity of a single product.

For the most important products it was possible to use either the farm price or the average producer price to present the total output at the price level for the base year. The values of the output amounts for which it has not been possible to calculate a unit price were converted to the basic price level by means of the producer price index for agriculture.

The table below shows the trend in gross return from the farms studied by region on average at the 1968 price level:

	Gross return in 1968 prices, 1000 marks/farm				
	Southern Finland	Central Finland	Southern Ostro-bothnia	Northern Finland	Average
1947/48	32	19	15	11	26
1956/57	37	24	19	18	31
1968	51	29	27	30	43
1979	81	55	49	43	70

As shown above, the volume of total output increased 2.7-fold during the research period. The increase in volume has been fastest after 1968.

4.3.2.2. Labour and capital inputs

When choosing substitutes for labour and capital inputs, the starting point can be either input flow or stock quantities (NIITAMO 1958, p. 48–53). The starting point implies that both variables have to be described in similar grounds. If capital input is described with a substitute for capital stock, labour input should also be described by a variable representing the potential labour force. A variable of this kind could, for example, be the population in working age (NIITAMO 1958, p. 51).

In this study both labour and capital inputs are described as input flows. The justification for this is that many changes of short duration, for example business fluctuations and crop failures then affect both variables. On the other hand, it can be shown that technology is so closely connected with investments and reforms in agriculture that the fixed substitutes for capital input calculated from capital stock are not sufficiently illustrative when technological change is examined (c.f. Solow 1962). The use of input flow quantities, however, makes great demands on the data examined.

Labour input

In labour input, an attempt has been made to take into consideration all the work accomplished in agriculture. The starting point is labour input expressed in working hours performed by both the farm family and the hired labour force. Labour and capital inputs are made commensurable by expressing both in marks at the price level for the base year (1968).

Labour input for the year i is calculated in the following way:

$$L_i = \frac{H_i}{H_p} (T_p),$$

where L_i = labour input in marks in the year i,
H_i = working hours in the year i,
H_p = working hours in the base year and
T_p = labour income in the base year.

Wages per hour are calculated on similar basis as in the profitability survey. The hourly wages of the hired labour force used in the profitability survey have been calculated directly on the basis of the wages paid. The value of the work performed by the farm family itself is calculated in the bookkeeping statistics according to the average wages per hour paid to hired farm workers.

A farm family's wages per hour in particular are rather low. In some studies the farm family's labour is rated according to higher wages per hour than those in the bookkeeping statistics. In this study, however, the basis in calculation of the data used has not been changed. This can be justified by the fact that if the wages per hour had been changed, the relation between labour and capital income should also have been corrected at the same time. On the other hand, the farm family's real wages per hour are also proved to be rather low on the average on the bookkeeping farms.

By region labour input calculated at the 1968 price level has developed on the farms in this study on the average in the following way:

	Labour input in 1968 prices, marks/farm				
	Southern Finland	Central Finland	Southern Ostro-bothnia	Northern Finland	Average
1947/48	34 200	24 400	20 800	19 400	29 600
1956/57	23 200	17 400	14 400	13 500	20 300
1968	15 400	12 400	9 700	10 900	13 800
1979	9 300	10 400	8 000	9 900	9 500

The average labour input per farm has fallen to about one third during the research period. Differences by regions are rather large: in the 1940s and 1950s labour input on the farms in the bookkeeping region of southern Finland has been distinctly greater than that in the other regions studied.

Capital input

Capital input can be measured by using either capital stock or the actual utilization of productive capital as the base. Because working hours are used to describe labour input, capital should also be measured as capital actually used. Therefore capital should be measured as a kind of capital flow

(NIITAMO 1958, p. 51).

Since total output is calculated as gross return, all the capital used in agriculture to produce this total output is included when capital input is calculated. Thus the value of total output also includes the value of raw materials and all purchased goods used. Total output is examined in relation to the total input volume. This aspect of examination can be illustrated by the following production function (GULBRANDSEN and LINDBECK 1969, p. 178):

$$Q = TK,$$

where Q = output,
T = parameter describing technology and
$K = P_D D + P_A A + P_L L + P_C C$,
where D = inputs bought from outside the enterprise,
A = depreciation and maintenance of real capital,
L = quantity of labour input,
C = quantity of capital input (interest) and
P = price of input.

Since this study uses only labour and capital inputs as explaining variables, capital input includes all the other inputs within the production function mentioned above, except labour input.

The sum of the cost of fertilizers and that of machines and implements at the 1968 price level has been used as a series describing capital input. The indices of the cost of fertilizers, machines and implements calculated at the Agricultural Economics Research Institute (ANON. 1975) are used as the price index. They have been extended when necessary to cover the whole research period (SUOMELA 1958, p. 73, PERNU 1957).

Capital input has changed during the period examined in the following way:

	Capital input in 1968 prices, marks/farm				
	Southern Finland	Central Finland	Southern Ostrobothnia	Northern Finland	Average
1947/48	4 400	2 100	1 600	1 100	3 300
1956/57	5 500	2 800	1 900	1 800	3 900
1968	11 300	7 400	6 200	5 800	9 600
1979	14 400	12 600	6 800	9 400	12 900

The volume of the cost of fertilizers, machines and implements has grown almost fourfold on average during the research period.

4.3.2.3. Compensation paid to labour and capital – the income shares of labour and capital

The side relation resulted in a solution where the relation between the income shares of labour and capital is defined as a function of labour and capital inputs,

$$\frac{wL}{rC} = \frac{1-\delta}{\delta} \left(\frac{C}{L}\right)^{\varrho},$$

where wL = cost of labour × quantity of labour input = income share of labour and
rC = cost of capital × quantity of capital input = income share of capital.

In the side relation, the ratio between labour income and capital income is the dependent variable. This makes it possible to include these income shares in current prices because the effect of the price development can be eliminated by using this ratio.

Labour income is calculated by totalling the farm family's salary claim and the wages paid to the hired workers. Capital income is composed of the value of purchased goods, interest claim, depreciation and maintenance of capital items.

The ratio between the income shares on the farms studied during the research period has changed as follows:

	Labour income/capital income				
	Southern Finland	Central Finland	Southern Ostro-bothnia	Northern Finland	Average
1947/48	1.25	1.42	1.86	1.97	1.42
1956/57	0.90	1.03	1.05	1.08	0.95
1968	0.58	0.58	0.58	0.64	0.59
1979	0.42	0.56	0.78	0.75	0.51

The ratio decreased very quickly until 1968. In two regions the ratio is even greater in 1979 than in 1968. Since 1968, following the normal bookkeeping procedure, the value of single capital groups has not changed, except through depreciation, unless purchases or sales were made. Because no inflationary corrections have been made, the depreciations and interests for 1979 remain distinctly smaller than the corresponding costs calculated according to the real values. This problem will be examined more closely when the results are analyzed.

5. Results

5.1. General

In this study the parameters of technological change will be estimated in the two stages described in Chapter 4.2. Firstly, the constant term log b and the coefficient of regression m will be solved from the side relation (c.f. p.

202) with the method of least squares, with which the estimates of the income share parameter (δ) and the elasticity of substitution (σ) can also be solved. The income share parameter will be estimated from the equation

$\delta = \frac{1}{1+b}$ · The transformation of the elasticity of substitution is again ϱ = m and the elasticity of substitution $\sigma = \frac{1}{1+\varrho}$ ·

The second stage of the analysis will solve parameters γ and ν, which indicate the efficiency of technology and the degree of returns to scale.

In analysing the results it has to be taken into special consideration that the parameter estimates describe the changes which have taken place in technology. Thus the parameter estimates do not give a very reliable picture of the level of the characteristics of the technology involved during the research year concerned. The variables used have been chosen to describe the technological development as reliably as possible.

5.2. Results of the first stage of the analysis

The results of the first stage are presented in Table 1. The table gives the estimates of the income distribution parameter (the share of capital in the compensation paid to the factors of production), the elasticity of substitution and the index series describing their development. The table also gives the regression coefficient and its standard error and the t-value calculated to the regression coefficient. The squared multiple correlation coefficients (R^2) for each equation are also shown in the table.

The results of the first stage of the analysis are presented by region and line of production. When calculating the results by region the research farms were divided into two groups, southern Finland and "the rest of Finland". Southern Finland includes 49 farms in the bookkeeping region of southern Finland. "The rest of Finland" covers the farms in the bookkeeping regions of central Finland, southern Ostrobothnia and northern Finland. There are 29 of these farms in this study.

Classified according to the line of production, the research farms were divided into three groups: cattle husbandry farms I, grain farms and farms engaged in mixed production. The first group consists of the farms specialized in cattle husbandry that receive more than 80 per cent of their gross return from cattle. Most of them are dairy farms. Grain farms are research farms on which crop cultivation accounts for more than one half of their gross return and where grain output accounts for at least 45 per cent of their gross return. The third group is composed of farms with diversified production. According to the classification used in the bookkeeping operations (see p. 203) this group consists of the so-called other animal husbandry farms and other crop production farms.

Evaluation of the parameter estimates is hindered considerably by the fact that the bookkeeping information for 1979 cannot be compared as such with that of the other research years. In 1968 the property values of the bookkeep-

Table 1. The results of the first stage of the analysis.

Group of farms	Number of farms	Year	Income share parameter (share of capital) δ	index	Regression coefficient m and its standard error		t-value for m	Substitution elasticity σ	index	R^2
All	78	1947/48	0.714	100.0	−0.485	±0.04	−12.74	1.943	100.0	0.681
research		1956/57	0.726	101.7	−0.455	±0.03	−15.97	1.833	94.3	0.770
farms		1968	0.739	103.5	−0.656	±0.04	−17.53	2.907	149.6	0.802
		1979a	0.677	94.8	−0.754	±0.06	−11.64	4.059	208.9	0.659
		b	0.744	104.2	−0.693	±0.05	−13.71	3.584	184.5	0.704
Southern	49	1947/48	0.696	100.0	−0.428	±0.05	− 9.31	1.747	100.0	0.648
Finland		1956/57	0.736	105.7	−0.465	±0.03	−13.76	1.867	106.9	0.801
		1968	0.745	107.0	−0.684	±0.04	−15.99	3.169	181.4	0.841
		1979a	0.699	100.4	−0.697	±0.08	− 8.29	3.302	189.0	0.604
		b	0.750	107.8	−0.695	±0.07	− 9.95	3.284	188.0	0.671
The rest	29	1947/48	0.704	100.0	−0.496	±0.07	− 7.36	1.985	100.0	0.667
of		1956/57	0.678	96.3	−0.367	±0.05	− 6.83	1.579	79.5	0.633
Finland		1968	0.726	103.1	−0.586	±0.07	− 7.97	2.415	121.7	0.702
		1979a	0.641	91.1	−0.746	±0.09	− 8.17	3.929	197.9	0.744
		b	0.737	104.7	−0.711	±0.07	−10.16	3.864	194.7	0.784
Cattle	–	1947/48	(0.714)	100.0	–	–	–	(1.943)	100.0	–
husbandry	9	1956/57	0.705	98.7	−0.386	±0.04	− 9.60	1.629	83.8	0.469
farms I	16	1968	0.726	101.7	−0.617	±0.07	− 8.97	2.613	134.4	0.781
	31	1979a	0.664	93.0	−0.795	±0.06	−13.18	4.888	251.6	0.845
		b	0.736	103.1	−0.684	±0.06	−11.36	4.206	216.5	0.788
Grain	–	1947/48	(0.714)	100.0	–	–	–	(1.943)	100.0	–
farms	–	1956/57	–	–	–	–	–	–	–	–
	13	1968	0.744	104.2	−0.571	±0.04	−10.86	3.104	159.8	0.736
	24	1979a	0.674	94.4	−0.743	±0.06	−12.30	3.888	200.1	0.801
		b	0.751	105.2	−0.664	±0.07	− 9.49	3.164	162.8	0.726
Mixed	73	1947/48	0.713	100.0	−0.488	±0.04	−12.24	1.950	100.0	0.678
production	29	1956/57	0.744	104.3	−0.538	±0.04	−13.48	2.166	111.1	0.845
farms	16	1968	0.745	104.5	−0.720	±0.07	−10.31	3.566	182.9	0.842
	9	1979a	0.698	97.9	−0.819	±0.09	− 9.14	5.531	283.6	0.700
		b	0.743	104.2	−0.736	±0.10	− 7.30	3.806	195.2	0.640

ing farms have been estimated at current values. Since 1968 the property values have been defined according to taxation values. As our present taxation system does not allow any inflationary adjustment in property values, the taxation values of buildings in particular, but also those of the machines and implements of the present bookkeeping farms, are distinctly smaller than the actual current values. That is why the property values of the research farms for 1979 are too low compared with the corresponding values for 1968. The bookkeeping results for 1979 have been corrected in order to make them correspond better to the results calculated for the other years.

In the 1950s the values of different capital items have been raised to correspond to current market values in 1951. Even though adjustments of this kind have not been made since that in the 1950s, the bookkeeping results for 1956/57 have been utilized as such in the analysis.

In Table 1 the results for 1979 have been presented in two different forms. The first results, a, have been calculated according to the original bookkeeping information. In alternative b the buildings, machines and implements were estimated at actual current values. When calculating the adjusted property values, the starting point has been the property values for 1968 on each farm. After that the property values for 1979 were calculated by means of investment accumulations. In principle, the machines have been calculated with the investment accumulations of eleven years and the buildings with those of twenty-five years. Therefore depreciation has been 1/11 and 1/25 of the annual property values respectively. Changes at the price level have been made by means of price indices calculated at the Agricultural Economics Research Inctitute.

5.2.1. The elasticity of substitution

The estimate of the elasticity of substitution must be interpreted in a slightly different way according to the type of farm being examined. The elasticity of substitution calculated for all the farms studied describes differences between different farms and also those between different lines of production, and changes in the relationship between labour and capital. In this case the line of production may also change if substitution is continued far enough. When a more homogeneous group of farms is considered, e.g. farms specialized in grain production, the elasticity of substitution describes the relationship between labour and capital inside this group. This is a problem when comparing the results.

In 1947/48 there were no farms specialized in cattle husbandry or grain production within the study. Therefore the parameter estimates were calculated only by regions and for the group of farms engaged in mixed production (Table 1). The estimates for the elasticity of substitution are between 1.747 and 1.985 for the first research year. The parameters estimated deviate only a little from each other. When the deviation of the regression coefficient from zero was tested, which simultaneously tests whether the estimate of the elasticity of substitution deviates from one, significant values were achieved in all cases.

In 1956/57 the elasticity of substitution could be estimated for all the farm types under examination, with the exception of the grain farms. The estimates calculated are between 1.579 and 2.166. The largest estimate was calculated from the mixed production farms and the smallest from the group of the rest of Finland. Differences, however, remain rather small. Development which has occurred since the first research year can primarily be seen by region. The standard errors in the regression coefficient still remain rather small and, according to the t-values, the results are quite reliable.

By 1968 specialization in production has already advanced so far that it is no longer reasonable to compare the results calculated from the different lines of production with those calculated by regions. The estimate of the elasticity of substitution calculated for all the farms is 2.907. The estimate has grown by about 59 per cent since 1956/57 and by about 49 per cent since the first research year. In the groups according to lines of production the values of the parameter are between 2.332 and 3.566.

The results for the last research year have been presented in two different forms. The estimates of the elasticity of substitution calculated from the original bookkeeping values (a) are unrealistically high. Determination of the value of property based on taxation values leads to the consequence of capital "being cheap" in relation to labour, and thus the substitution between labour and capital is accelerated. Corrected alternative b gives distinctly smaller estimates of the elasticity of substitution.

The results for 1979 show the difference between the results calculated by regions and the estimates of the elasticity of substitution calculated from the group of farms engaged in one line of production. When the value of the elasticity of substitution for all the farms was calculated to be 3.584 in alternative b, the corresponding value for the cattle farms was 4.206 and on the grain farms 3.164. For all the farms concerned, the line of production may also change when the substitution between labour and capital is altered. However, the estimated value of the cattle farms remains larger than that of all the farms.

The estimates of the elasticity of substitution calculated from the cross section materials can be interpreted to describe the ease of substitution for the point in time covered by the statistical material used in the calculations. This interpretation makes it easier to examine the estimates of the elasticity of substitution presented in Table 1. According to the results, the substitution between labour and capital has become easier throughout the research period. By line of production, substitution was easiest in 1968 on grain farms and farms engaged in varied production. These estimates have grown very little since then. On cattle farms the estimate of the elasticity of substitution has grown very quickly over the whole research period, especially since 1968.

The estimates of the elasticity of substitution give rather an interesting and, when examined theoretically, comprehensive picture of the change and trend in this parameter. Estimating the magnitude of the elasticity of substitution is, however, a very difficult problem. The estimates calculated in this study are between 1.579 and 4.206. In those contexts where the factors of production being substituted are of some significance, one of the following assumptions concerning the size of the elasticity of substitution is very often made. Firstly the factors of production can be complete substitutes for each other, in which case the elasticity of substitution is infinite. The other possibility is that the factors of production are not interchangeable, as the elasticity of substitution is zero. This is assumed in the Leontief production function. In the Cobb-Douglas function the elasticity is assumed to be one. In general, it can only be verified that the elasticity of substitution is positive in all factor combinations which are of interest in terms of economic theory.

Different statistical collection and treatment methods and the use of different input concepts reduce the comparability of the elasticities of substitution, as well as that of the other statistical symbols. As to the comparability of the elasticities, it is of great significance whether the elasticities have been calculated from periodical or cross section materials, because they produce different types of parameters. The choice of the period examined is also significant because the values of the elasticities of substitution are very sensitive to incidental variations.

As to the absolute level of the elasticity of substitution, no far-reaching conclusions can be drawn on the basis of this study. The quantity of the parameter depends in general on the choice of variables and the research method used. On the other hand, this study provides a rather graphic and reliable picture of the development of the elasticity of substitution, which is interesting with respect to measurement of technological change.

5.2.2. The income share parameter and the capital intensity

An income share parameter that could be interpreted unambiguously can be estimated from the side relation used in this study. The income share parameter is not a direct component of technological change and it does not, as such, describe the trend in technological change. The development of this parameter, however, describes the changes of the proportional income shares, which gives interesting information on the effects of technological change at enterprise level. The parameter is unambiguous within the limits of the statistical material used in the estimation.

The capital share of the compensation paid to the factors of production was 69.6–71.4 per cent during the first research year. The capital share was smallest in southern Finland (Table 1).

In 1956/57 the capital share had increased in all the farm groups, except "the rest of Finland" when compared with that of the first research year. The parameter estimate for the rest of Finland is smaller than in the first research year, i.e. 68 per cent. The capital share on the other farm groups was some 71–74 per cent. In 1968 the capital share had still grown being about 73–75 per cent.

The estimates of the income share parameter for the last research year are very interesting. According to alternative a, the capital share of the compensation paid to the factors of production would be 64–70 per cent, depending on the farm group examined. The capital share would be smaller in most farm groups than in any previous research year. This shows very clearly how the result to be calculated changes when the property values are determined according to their taxation values. The use of the taxation values instead of the actual current values results in undervaluation of capital as a factor of production.

The corrected alternatives for 1979 change the capital share significantly. In alternative b, which corresponds to the results of the other research years, the capital share is 73.6–75.1 per cent. The capital share is smallest on the cattle farms and biggest on the grain farms.

According to the results presented in the foregoing, the share of capital income has increased at the expense of labour income. Over the entire research period the share of capital in the compensation paid to the factors of

Table 2. The relation of capital input to labour input at 1968 prices.

Farm group	Research years 1947/48	1956/57	1968	1979
Southern Finland	0.13	0.24	0.73	1.85
Central Finland	0.09	0.16	0.63	1.29
Southern Ostrobothnia	0.08	0.13	0.69	1.09
Northern Finland	0.05	0.14	0.55	0.88
All research farms	0.11	0.19	0.69	1.59
Cattle husbandry farms I	–	0.14	0.50	0.94
Grain farms	–	–	1.29	2.68
(Pig farms	–	0.13	0.95	1.05)
Mixed production farms	0.13	0.25	0.75	1.41

production has increased by 3.1–7.8 per cent. This is the extent to which technological change has changed the proportional income shares. We can see that technological change has had only a small effect on income distribution.

The capital intensity can be calculated very simply without the original side relation. After the inputs were first made commensurable, the relationship between capital and labour inputs describes capital intensity and its development. In Table 2 the average relationship between capital and labour inputs is presented by research region and line of production. On the basis of Table 2 capital input grew rapidly compared with labour input in all the farm groups. The farms in southern Finland are distinctly more capital intensive than those elsewhere in the country. This can be explained primarily by the fact that grain production is more capital intensive than the other lines of production and most grain farms are situated in the research region of southern Finland.

5.3. Results of the second stage of the analysis

The results of the second stage of the analysis are presented in Tables 3 and 4. In Table 3 the same division by region and line of production is used as in Table 1 when the results of the first stage of the analysis are calculated (p. 209). Table 3 presents the estimates of the efficiency parameter and the degree of returns to scale and the index series describing their development, the standard error and t-value of the regression coefficient (σ/ϱ) and the R^2-values describing the intensity of the indicators of labour and capital inputs to explain the output within the CES function.

Because the results of the second stage of the analysis remain to some extent indeterminate by the division according to region and line of production, Table 4 presents the research results more concisely in two different farm size classes, farms of less than 20 hectares and those of more than 50 hectares of arable land.

In Table 3 the results for 1979 have been calculated on the basis of the current capital values. The results correspond to alternative b in the first stage of the analysis (c.f. p. 209).

Table 3. The results of the second stage of the analysis.

Group of farms	Number of farms	Year	Efficiency parameter γ	index	Degree of returns to scale v	index	Standard error of the regression coefficient, v/ϱ	t-value for v/ϱ	R^2
All	78	1947/48	10.003	100.0	0.877	100.0	±0.12	14.800	0.742
research		1956/57	26.136	261.3	0.796	90.8	±0.08	20.729	0.850
farms		1968	8.823	88.2	0.910	103.8	±0.09	14.974	0.747
		1979	10.430	104.3	0.954	108.8	±0.08	16.526	0.811
Southern	49	1947/48	12.315	100.0	0.758	100.0	±0.16	11.189	0.727
Finland		1956/57	26.114	212.1	0.798	105.3	±0.12	14.871	0.825
		1968	2.007	16.3	1.121	147.9	±0.08	20.398	0.899
		1979	3.685	29.9	1.006	132.7	±0.10	14.710	0.863
The rest	29	1947/48	8.046	100.0	0.777	100.0	±0.23	6.695	0.624
of		1956/57	3.448	42.9	0.943	121.4	±0.14	18.372	0.804
Finland		1968	4.356	54.1	0.864	111.2	±0.17	8.574	0.687
		1979	14.035	174.4	0.840	108.1	±0.21	5.426	0.483
Cattle	–	1947/48	–	–	–	–	–	–	–
husbandry	9	1956/57	2.342	100.0	0.884	100.0	±0.22	10.407	0.764
farms I	16	1968	4.969	212.2	0.955	108.0	±0.17	9.113	0.750
	31	1979	6.740	287.8	0.980	110.9	±0.08	8.879	0.840
Grain	–	1947/48	–	–	–	–	–	–	–
farms	–	1956/57	–	–	–	–	–	–	–
	13	1968	2.658	100.0	1.038	100.0	±0.10	15.313	0.861
	24	1979	2.932	110.3	1.020	98.3	±0.06	24.853	0.925
Mixed	73	1947/48	10.320	100.0	0.868	100.0	±0.12	14.847	0.731
production	29	1956/57	14.363	139.2	0.684	78.8	±0.09	14.116	0.664
farms	16	1968	8.154	79.0	0.852	98.2	±0.11	10.764	0.784
	9	1979	1.322	12.8	1.118	128.8	±0.09	16.847	0.846

Table 4. The results in different farm size classes.

Farm size class, arable land ha	Region	Year	Number of farms	First stage Distributional parameter δ	Substitution elasticity σ	Second stage Efficiency parameter γ	Degree of returns to scale v	R^2
Under	Southern	1947/48	20	0.610	1.474	0.996	1.135	0.783
20 ha	Finland	1956/57	19	0.709	1.704	2.160	1.104	0.880
		1968	16	0.731	2.726	2.626	1.044	0.861
		1979a	13	0.724	2.989	2.430	1.068	0.804
		b	13	0.748	2.846	3.064	1.006	0.886
Over	Southern	1947/48	10	0.693	1.596	2.843	1.032	0.911
50 ha	Finland	1956/57	5	0.706	1.661	6.032	0.970	0.942
		1968	6	0.762	2.219	10.243	0.928	0.960
		1979a	8	0.718	3.313	4.412	0.954	0.936
		b	8	0.768	2.423	12.690	0.920	0.984

5.3.1. Technologically determined returns to scale

The parameter estimates of the degree of returns to scale calculated for all the farms in this study are very indeterminate (Table 3). As the farms are from different regions and represent different branches of production and farm size classes, the variables used in this study to describe labour and capital inputs do not give so exact a picture of the business economic activities of the enterprises that is accurate enough for the degree of returns to scale to be defined in a precise and unambiguous way. The estimates of the degree of returns to scale calculated for all the farms are between 0.796 and 0.954 in the different research years. The last research year gave the biggest value and 1956/57 the smallest one.

Calculating the degree of returns to scale by region gives more interesting results (Table 3). On the farms of southern Finland the estimate of returns to scale is 0.758 for the first research year. During the second research year the value of the estimate increased to 0.798. In 1968 the value of the degree of returns to scale increased up to 1.121. In 1979 the estimate decreased to 1.006. The parameter estimates calculated for the region comprising the rest of Finland were from 0.777 to 0.943.

In the results calculated by line of production, the degree of returns to scale is larger than one on the farms specialized in grain production. On the cattle husbandry farms the estimate grows steadily from 0.884 to 0.980. On the farms engaged in mixed production, the value of the degree of returns to scale varies between 0.684 and 1.118.

In the results according to farm size (Table 4), the values of the degree of returns to scale decrease on the small farms, i.e. those under 20 ha, from 1.135 to 1.006. On the large farms, i.e. over 50 ha, the estimates decrease from 1.032 to 0.920.

5.3.2. The efficiency parameter

Given the inputs, the elasticity of substitution and the degree of returns to scale, the efficiency parameter is a kind of coefficient of change between inputs and output. In theory the more efficient the production the larger the efficiency parameter. As the agricultural production process varies greatly depending on the line of production and the farm size, the values of the efficiency parameter calculated for different types of farm groups cannot be compared with each other. Instead, it is possible to compare the parameter estimates for different years within the same strictly limited farm group. In any case, the efficiency parameter must be interpreted with caution because it is very sensitive to any changes in the material used. The values of the efficiency parameter of this study are also partly contrary to what was anticipated.

The values of the efficiency parameter calculated from all the research farms are very indeterminate. The values of the parameter are between 8.823 and 26.136. This wide dispersion is primarily caused by the rapid change in our production structure. The strange behaviour of the efficiency parameter is caused primarily by the specialization that agricultural production in our country has undergone. This can also be seen in the results from the region of southern Finland. As production is very specialized and grain production has to a great extent replaced animal husbandry, the efficiency parameter has been reduced from 26.114 in 1956/57 to 2.007 in 1968.

In the results calculated by line of production the values of the efficiency parameter are partly those anticipated. This is chiefly due to the limited farm groups. On the cattle husbandry farms the efficiency parameter increased from 2.342 in 1956/57 to 6.740 in 1979. On grain farms the growth of the parameter was about 10 % between 1968 and the final research year. On the mixed production farms the parameter decreased surprisingly.

The efficiency parameter has the expected values in the results shown in Table 4, which are calculated by farm size classes. During the research period the efficiency parameter increased slightly more than threefold on farms of less than 20 hectares and about 4.5-fold on farms of more than 50 hectares. Defining the efficiency parameter unambiguously involves a division of research farms into narrow classes strictly limited by both farm size class and line of production. In this respect the efficiency parameter is distinctly more sensitive to the changes in the dispersion and other fundamental aspects of the data than the other characteristics of the technological change examined in this study.

6. Conclusions from the effects of technological change on the development of agricultural production

In Finland agricultural production is generally carried out in small units and mainly by members of the farm family itself, who are often numerous when one takes into account the size of the farm. In Finnish agriculture new technology has had to adapt to the prevailing restrictions and it has also initiated new trends in the structural development of agriculture. As the market for agricultural products has not been able to expand as rapidly as the productivity increases caused by a new technology would imply, it has been necessary to adapt the use of inputs in agricultural production in accordance with technological development. For the entire economy this has resulted in a rapid decrease in the agricultural labour force and strong pressure to reduce total arable field area. For the private farm enterprise, however, it has achieved the aim for rationalizing production and increasing farm size.

The method used in this study is based on cross section data. Certain years in the research period are chosen for closer study, and the CES function is applied to their data. Technological change is measured by comparing the estimates for parameters of various years with each other. Cross section data is used instead of time series for two main reasons. Firstly processing the bookkeeping data for cross section analysis is much easier than for time series. Secondly it was very interesting to see what kind of results cross section analysis would produce. As agricultural production fluctuates greatly from year to year and technological change is like a trend in time, research method based on time series would obviously have given more reliable and exact results. If this research had been based on time series data the results would describe various technological epochs and changes between these periods. Various fluctuations were levelled. After all the parameter estimates calculated in this study give an interesting picture of technological change.

Although the data used in this study do not represent a random sample of our farms, we can draw some general conclusions from the effects of technological change on the development of agricultural production in Finland.

Non-neutral technological changes are reflected as variations in the income share and the elasticity of substitution parameters. According to the results of this study, the changes in the income share parameter indicate a capital-using technological change. The rises in the elasticity of substitution are also indications of capital-using changes as capital grows more rapidly than labour. Thus non-neutral technological change has been labour-saving and capital-using.

The effect of a non-neutral technological change on output is also indicated. A non-neutral change has a positive effect on the growth of output. Because the growth of capital exceeds the growth of labour, we can say with certainty that the increase in the capital intensity characteristic, capital share of income, and the upward shift in the elasticity of substitution have increased the rate of growth in output. The data used in this study are not comprehensive enough for a detailed evaluation of the exact effects of a non-neutral change on output.

Neutral technological progress is reflected as changes in the efficiency parameter and in the returns to scale parameter. Increases in these parameters increase output while not affecting the marginal rate of substitution. The efficiency parameter proved to be very sensitive to heterogenity in the data. After all, it was shown that the efficiency parameter grew very quickly in the limited farm groups where this parameter was estimated successfully. This means that changes in the efficiency parameter increased output.

Another parameter change which does not affect the marginal rate of substitution of capital for labour was v , which represents technological returns to scale. This parameter determines the degree of returns to scale but does not indicate how much of any change in output is attributable to the exploitation of economies of scale. The latter requires a knowledge of the volume of capital and labour actually employed. So economies or diseconomies of scale can also occur because of variations in the scale of the operations of the firm. If we attribute a change in v to technological advance, we can make some conclusions about technologically determined returns to scale.

Evaluating the results by region we can see that until 1968 the rate of technological change was faster in southern Finland than the average rate on all research farms. Substitution elasticity grew by 81.4 per cent from 1947/48 to 1968 in southern Finland compared with 50 per cent on all research farms and by 21.7 per cent in the rest of Finland. Since 1968 the growth of substitution elasticity has been very moderate in southern Finland compared with the very rapid growth in central and northern Finland.

Changes in the substitution elasticity imply differences in technological change. In southern Finland rapid technological progress started earlier than in the rest of Finland. In southern Finland the change has advanced further and the change has been stabilized earlier than in the other region. This is partly due to the differences in the line of production between southern and northern Finland.

By line of production it seems that grain farms have adapted to new technology faster than other farms. Since 1968 the parameters have grown very little on the grain farms compared with the rapid growth on farms specialized in cattle husbandry or on the farms engaged in mixed production. Technological progress seems to have speeded up since 1968, on cattle husbandry farms.

Although the results by different farm size classes are very limited, it can be seen that large farms of over 50 ha have adapted to new technology earlier or more quickly than small farms. On large farms technological progress has been stabilized but on smaller farms the rate of technological change is still increasing.

In the future technological change will be a very important source of productivity growth. By adapting to new technology small farms in Finland, can develop very quickly in terms of structure and productivity. This is especially true on cattle husbandry farms and in central and northern Finland. According to line of production, grain farms have adapted to new technology so fast that in the future their productivity will grow more slowly than that of animal husbandry. This will be a very important factor in agricultural policy in the near future. In assuring the farming population a fair improvement in income and a fair distribution of income within the agricultural sector, technological change and its effect on productivity growth must be taken into special consideration.

It would seem that technological development will also proceed along the lines described in this study in the near future. Technological change can be expected to require capital and save labour. It will also have a very strong influence on increasing output especially in cattle husbandry. If the policy makers want to make some changes as to the development of agricultural production or production structure, they will have to use measures which can alter technological development and the fundamental characteristics of production technology.

7. Summary

The purpose of this study was to analyse and measure the technological change that has occurred in agriculture. The study presented in the foregoing is above all methodological with interest in developing a method for measuring technological change and in testing this method.

The study was divided into a theoretical and an empirical part. Besides the concepts connected with a technological change and its characteristics, the most common methods for measuring technological change were examined in the theoretical part of the study. The empirical part dealt with testing the applicability of the measuring method based on the CES function for estimating the parameters of technological change in agriculture.

The parameter estimates calculated comply to a great extent with what was anticipated. The measuring method for the components of technological change based on the CES function was found very suitable for estimating the elasticity of substitution and the degree of returns to scale. The income share parameter can also be solved simply by using this method. Measurement of the efficiency of a technology with a method based on the CES function must, however, be carried out with caution, for the efficiency parameter is very sensitive to changes in the data used. When calculating the efficiency parameter, the data used must be divided into narrow, strictly limited classes before the results are unambiguous. Besides the efficiency parameter, the estimates calculated for the other characteristics of technological change are more reliable the more homogeneous the farm group concerned. When farm group is very limited and homogeneous, production technique, labour force and real capital are uniform. In this case the parameter estimates calculated for technological change are also unambiguous.

Although the parameter estimates calculated are formally unambiguous, their calculation poses certain difficult problems. As in many other studies the greatest problem in this study was also the difficulty concerning the statistical material and its processing.

As the property values of the bookkeeping farms were defined according to their taxation values since the reform of agricultural taxation in 1968, the bookkeeping results since 1968 cannot be directly compared with those of the previous years. Before the reform of taxation estimating the value of property was in principle based on current values. However, following the normal bookkeeping procedure, the value of single capital groups did not change except through depreciation unless purchases or sales were made. Because of the inflation that has prevailed in Finland during the post-war years, the undervaluation of capital stock has tended to increase through time. This is especially true in the case of long-term capital investments. To eliminate the influence of inflation the bookkeeping values of capital items were increased in 1947, 1951 and 1968 to correspond to current market values. In the intervening years undervaluation has increased. This makes it complicated to utilize the data in question here. In this study the main problem concerned comparison of the results for 1979 with those of the previous years studied. Although the data for the final research year were corrected in order to make the property values and capital cost correspond to the current values as accurately as possible, comparability of the results with regard to the other years studied remained to some extent indeterminate.

The other problem concerning the data was the relatively small number of farms studied. Because the study covered only the farms which have participated in the bookkeeping survey throughout the research period, there were only 78 farms in this study. Such a small number prevented a very thorough examination of the farms according to their size and line of production.

The method for measuring the components of technological change used in this study proved quite satisfactory in measuring the technological change that has taken place in agriculture. The parameter estimates calculated, as such, give a quite reliable picture of the development of technology. The information concerning the measuring method obtained from the empirical experimentation may also be of use in any further research aimed at estimating the parameters of technological change.

REFERENCES

ABRAMOVITZ, M. 1956. Resource and Output Trends in The U.S. since 1870. Amer. Econ. Rev. 46: 5–23.

ANON. 1966. Encyclopedia of science and technology. Part 13/SPIR-TOU. McGraw-Hill. New York.

— 1974. Uusi sivistyssanakirja. Editor Annukka Aikio. Kustannusosakeyhtiö Otava. Fourth edition. 653 p. Keuruu.

— 1975. Maatalouden hintaindeksit. Research Reports of the Agricultural Economics Research Institute (AERI) 29: 1–39.

ARCHIBALD, C. G. 1964. Investment and Technical Change in Greek Manufacturing. p. 40–58. Athens.

ARROW, K. J. 1962. The Economic Implications of Learning by Doing. Rev. Econ. Studies 29: 155–173.

— , SCHENERY, H. B., MINHAS, B. S. & SOLOW, R. M. 1961. Capital–Labor Substitution and Economic Efficiency. Rev. Econ. Statist. 43: 225–250.

BISHOP, C. E. & TOUISSAINT, W. D. 1958. Introduction to Agricultural Economic Analysis. XIV + 258 p. New York and London.

BROWN, M. 1968. On the Theory and Measurement of Technological Change. XII + 214 p. Cambridge.

— & de CANI, J. S. 1963. Technological Change and the Distribution of Income. Intern. Econ. Rev. 4: 289–309.

— & POPKIN, J. 1962. A Measure of Technological Change and Returns to Scale. Rev. Econ. Statist. 44: 402–411.

CHEN, E. K. Y. 1976. The Empirical Relevance of the Endogenous Technical Progress Function. p. 256–271. Kyklos.

DAVID, P. A. & van de KLUNDERT, T. 1965. Biased Efficiency Growth and Capital-Labor Substitution in the U. S., 1899–1960. Amer. Econ. Rev. 55: 357–395.

DENISON, E. F. 1962. United States Economic Growth. J. Business 35: 109–121.

— 1964. The Unimportance of the Embodied Question. Amer. Econ. Rev. 54: 90–94.

DOMAR, E. 1961. On the Measurement of Technological Change. Econ. J. 71: 709–729.

FLECK, F. H. 1973. Die ökonomische Theorie des technischen Fortschritts und seine Identifikation. XII + 253 p. Meisenheim am Glan.

GRILICHES, Z. 1963. The Sources of Measured Productivity Growth: United States Agriculture 1940–1960. J. Polit. Econ. 71: 331–346.

GULBRANDSEN, O. & LINDBECK, A. 1969. Jordbruksnäringens ekonomi. 280 p. Stockholm.

HAYAMI, Y. & RUTTAN, V. W. 1971. Agricultural Development. An International Perspective. XIV + 367 p. Baltimore and London.

HEADY, E. O. 1949. Basic Economic and Welfare Aspects of Farm Technological Advance. J. Farm Econ. 31: 296–297.

— & DILLON, J. L. 1961. Agricultural Production Functions. VIII + 667 p. Ames.

HEERTJE, A. 1977. Economics & Technical Change. VII + 334 p. London.

HOGAN, W. P. 1958. Technical Progress and the Production Functions. Rev. Econ. Statist. 40: 407–411.
IHAMUOTILA, R. 1971. Productivity and Aggregate Production Functions in the Finnish Agricultural Sector 1950–1969. AERI Publ. 25: 1–104.
INTRILLIGATOR, M. D. 1965. Embodied Technical Change and Productivity in the United States 1929–1958. Rev. Econ. Statist. 47: 65–70.
JANTSCH, E. 1967. Technological forecasting in perspective. OECD. 401 p. Paris.
JORGENSON, D. W. 1966. The Embodiment Hypothesis. J. Polit. Econ. 74: 1–17.
— & GRILICHES, Z. 1967. The Explanation of Productivity Change. Rev. Econ. Studies 34: 249–283.
KEHRBERG, E. & REISCH, E. 1969. Wirtschaftslehre der landwirtschaftlichen Production. 263 p. München.
KENDRICK, J. 1961. Productivity Trends in the United States. LII + 630 p. Princeton.
— & SATO, R. 1963. Factor Prices, Productivity and Economic Growth. Amer. Econ. Rev. 53: 974–1003.
LAVE, L. B. 1966. Technological Change: Its Conception and Measurement. XX + 228 p. Englewood Cliffs. New Jersey.
MASSELL, B. F. 1960. Capital Formation and Technological Change in United States Manufacturing. Rev. Econ. Statist. 42: 182–188.
McKINNON, R. J. 1962. Wages, Capital Costs and Employment in Manufacturing: A Model Applied to 1947–58 U. S. Data. Econometrica 30: 501–521.
McLEAN, J. W. 1973. Growth and Technological Change in Agriculture: Victoria 1870–1910. Econ. Rec. 49: 560–574.
NELSON, R. R. 1964. Aggregate Production Functions and Medium Range Growth Projection. Amer. Econ. Rev. 54: 575–606.
NIITAMO, O. 1958. Tuottavuuden kehitys Suomen teollisuudessa vuosina 1925–1952. Kansantaloudellisia tutkimuksia XX. 192 p. Helsinki.
— 1969. Tuotantofunktio, sen jäännöstermi ja teknillinen kehitys. Til. päätoim. monist. tutk. 9: 1–49.
OTT, A. E. 1959. Technischer Fortschritt. Handwörterbuch der Sozialwissenschaften. p. 302–316. Stuttgart.
PERNU, A. 1957. Tilasto- ja arviolukuja Suomen maataloudesta. Pellervon Kalenteri. p. 130–149.
PHELPS, E. S. & PHELPS, C. 1966. Factor-Price Frontier Estimation of a "Vintage" Production Model of the Postwar United States Non-farm Business Sector. Rev. Econ. Statist. 48: 251–265.
RESEK, R. W. 1963. Neutrality of Technical Progress. Rev. Econ. Statist. 45: 55–63.
REVANKAR, N. S. 1971. Capital-Labor Substitution, Technological Change and Economic Growth: The U.S. Experience 1929–1953. Metroeconomica. p. 154–176.
ROUHIAINEN, J. 1972. Aggregate Crop Production Functions in Finnish Agriculture in 1956/57–1968/69. AERI Publ. 28: 1–71.
RUTTAN, V. W. 1954. Technological Progress in the Meatpacking Industry. USDA Marketing Research Report 59: 1–38. Washington, D.C.
— , BINSWANGER, H. P., HAYAMI, Y., WADE, W. & WEBER, A. 1978. "Factor productivity and Growth: A Historical Interpretation" in Hans P. Binswanger and Vernon W. Ruttan, Induced Innovation: Technology, Institutions and Development. Baltimore.
SALONEN, I. 1981. Teknisen kehityksen mittaamisesta tuotantofunktion avulla ja sovellutus Suomen kansantalouteen. Suomen Pankin julk. D: 51: 1–93.
SALTERS, W. E. G. 1960. Productivity and Technical Change. Cambridge.
SCHAEFER-KEHNERT, W. 1961. Wandlungen in der Agrarstruktur unter dem Einfluss der Technik. Berichte über Landwirtschaft 39; 2: 217–229.
SCHERTZ, L. P. 1968. The Role of Farm Mechanization in Developing Countries. Foreign Agriculture 6: 1–8.
SHESHINSKI, E. 1967. Test of the "Learning by Doing" Hypothesis. Rev. Econ. Statist. 49: 568–578.
SIMULA, M. 1979. Tuottavuus Suomen metsäteollisuudessa. Kansantaloudellisen metsäekonomian lisensiaattityö. Helsingin yliopiston maa- ja metsätaloustieteellisen tiedekunnan kirjasto. 193 p.
SOLOW, R. M. 1957. Technical Change and the Aggregate Production Functions. Rev. Econ. Statist. 39: 312–320.
— 1960. Investment and Technical Progress. Mathematical Methods in the Social Sciences. p. 89–104. Stanford.

— 1962. Substitution and Fixed Proportions in the Theory of Capital. Rev. Econ. Studies 30: 201–226.

SUOMELA, S. 1958. Tuottavuuden kehityksestä Suomen maataloudessa. Summary: Development of Productivity in Finnish Agriculture. AERI Publ. 1: 1–128.

SZAKOLCZAI, G. & STAHL, J. 1969. Increasing or Decreasing Returns to Scale in the Constant Elasticity of Substitution Production Functions. Rev. Econ. Statist. 51: 84–90.

TINBERGEN, J. 1942. Zur Theorie der langfristigen Wirtschaftsentwicklung. Weltwirtschaftliches Archiv. 55: 511–549.

TINTNER, G. 1944. Econometrica. 370 p. New York.

TORVELA, M. 1966. Tuotantopanosten käytöstä ja käytön edullisuudesta Etelä-Suomen kirjanpitoviljelmillä. AERI Publ. 8: 1–141.

— 1971. Eri tuotantosuuntaa harjoittavien kirjanpitoviljelmien taloudesta vuonna 1968. AERI Res. Rep. 14: 1–85.

— & MÄKI, S. 1974. Perheviljelmän koko rationaalisessa maataloustuotannossa. Summary: The size of holding that farm family can operate using different types of technology. AERI Publ. 30: 1–79.

UPTON, M. 1976. Agricultural production ecomomics and resource-use. 357 p. Oxford University Press.

UZAWA, H. 1962. Production Functions with Constant Elasticities of Substitution. Rev. Econ. Studies 29: 291–299.

VASAMA, P. & VARTIA, Y. 1972. Johdatus tilastotieteeseen osa II. 384 p. Helsinki.

WEBER, A. 1973. Arbeit – und Bodensparende Technologien. Agrarwirtschaft 2: 57–68.

WEINBERG, A. M. 1978. The Age of Substitutability. Paper presented at the Conference on Economic and Demographic Issues for the 1980s. International Union of Population. Aug. 28 – Sept. 1. Helsinki.

WEINSCHENK, G. & MEINHOLD, K. 1969. Landwirtschaft im nächsten Jahrzehnt. Vorschläge zur künftigen Agrarpolitik in des Bundesrepublik Deutschland. 208 p. Stuttgart.

WESTERMARCK, N. C. 1973. Lectures for Program on Technology and Social Change in Foreign Cultures. Engineering Research Institute, Iowa State University, Ames, Iowa.

WILLER, H. 1967. Technischer Fortschritt und Landwirtschaft. 218 p. Hamburg und Berlin.

YAMADA, S. & RUTTAN, V. W. 1975. International Comparisons of Productivity in Agriculture. Paper presented at The National Bureau of Economic Research Conference on Productivity Measurement. November 13 and 14. Williamsburg, Virginia.

YOU, Y. K. 1976. Embodied and Disembodied Technical Progress in the United States, 1929–1968. Rev. Econ. Statist. 58: 123–127.

YUDELMAN, M., BUTLER, G. & BANERJI, R. 1971. Technological Change in Agriculture and Employment in Developing Countries. Development Centre of OECD. Employment Series 4. 204 p. Paris.

Teknologisen muutoksen mittaaminen maataloudessa CES-tuotantofunktioon perustuva sovellutus

Kalevi Hemilä

Maa- ja metsätalousministeriö

Tämän tutkimuksen tarkoituksena on maataloustuotannossa tapahtuneen teknologisen muutoksen analysointi ja mittaaminen. Tutkimus jakautuu teoreettiseen ja empiiriseen osaan. Teknologiseen muutokseen liittyvien käsitteiden ja teknologisen muutoksen ominaisuuksien ohella tutkimuksen teoreettisessa osassa tarkastellaan yleisimpiä teknologisen muutoksen mittausmenetelmiä. Empiirisessä osassa testataan tilakohtaisten kirjanpitotulosten avulla CES-tuotantofunktioon perustuvan mittaamismenetelmän soveltuvuutta maataloudessa tapahtuneen teknologisen muutoksen parametrien estimoimiseen.

Tässä tutkimuksessa käytettävä menetelmä perustuu poikkileikkausaineistoihin. Tutkimuskaudelta, vuosilta 1947–1979, valitaan tarkastelun kohteeksi neljä tutkimusvuotta, vuodet 1947/48, 1956/57, 1968 ja 1979, joilta koottuihin aineistoihin CES-funktio sovitetaan. Tällöin poikkileikkausaineistosta estimoidut parametrit osoittavat teknologian tilan ko. tutkimusvuonna. Teknologista muutosta voidaan mitata ja kuvata vertaamalla eri vuosilta saatuja parametriestimaatteja toisiinsa.

Lasketut teknologisen muutoksen neljää perusominaisuutta kuvaavat parametriestimaatit ovat suurelta osin odotusten mukaisia ja ne antavat sellaisenaan hyvän kuvan tuotantoteknologian kehityksestä. Käytetty CES-funktioon perustuva teknologisen muutoksen ominaisuuksien mittausmenetelmä osoittautui sopivan varsin hyvin substituutiojouston ja tuottojen asteen estimoimiseen. Myös tulonjakoparametri voidaan ratkaista yksinkertaisesti tätä menetelmää käyttäen. Teknologian tehokkuuden mittaamiseen CES-funktioon perustuvalla mittausmenetelmällä on kuitenkin suhtauduttava suurella varauksella, sillä tehokkuusparametri on hyvin herkkä käytettävän aineiston muutoksille. Tehokkuusparametriä laskettaessa on käytettävä aineisto ryhmiteltävä hyvin tarkasti rajattuihin ja kapea-alaisiin luokkiin ennen kuin tulokset ovat yksiselitteisiä. Tehokkuusparametrin ohella myös muille teknologisen muutoksen ominaisuuksille saadut estimaatit ovat sitä luotettavampia ja parempia mitä homogeenisemmasta tilaryhmästä on kyse.

Tulosten mukaan teknologinen muutos on nopeuttanut työn korvautumista pääomalla. Samalla teknologinen muutos on lisännyt kokonaistuotosta ja tuottavuutta.

Etelä-Suomessa ja suurilla tiloilla teknologiset muutokset on otettu nopeammin käyttöön ja kehitys on myös tasaantunut aikaisemmin kuin muualla maassa ja pienillä tiloilla. Viljantuotantoon erikoistuneilla tiloilla teknologinen kehitys on jo tasaantunut kun sen sijaan varsinkin nautakarjatiloilla nopea teknologinen kehitys näyttää edelleen jatkuvan.

Lähitulevaisuudessa teknologinen muutos tulee edelleen olemaan hyvin tärkeä maatalouden tuottavuutta kohottava tekijä. Pienet maatilamme muuttuvat hyvin nopeasti niin tuotantorakenteeltaan kuin tuottavuudeltaankin, kun ne ottavat käyttöön uutta teknologiaa. Näin tulee käymään varsinkin Keski- ja Pohjois-Suomen nautakarjatiloilla. Viljatilat ovat omaksuneet uuden teknologian niin nopeasti, että viljatilojen tuottavuuden kasvu on tulevaisuudessa hitaampaa kuin kotieläintiloilla. Kun maatalouspolitiikan tavoitteena on lähivuosina turvata viljelijäväestölle oikeudenmukainen tulotaso, on teknologinen kehitys ja sen vaikutus tuottavuuden kasvuun otettava erityisesti huomioon.