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THE RETURNS TO INVESTMENT IN AGRICULTURAL RESEARCH IN FINLAND 1950—1984

Selostus: Maataloustutkimuksen tuotto Suomessa 1950—1984

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ACADEMIC DISSERTATION
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AT 12 O'CLOCK NOON.

SUOMEN MAATALOUSTIETEELLINEN SEURA HELSINKI

Preface

The returns to agricultural research have been analysed to a rather limited extent in the Nordic countries. The interest in the research on this subject is, however, increasing. On the initiative of The Scandinavian Association of Agricultural Scientists (NJF) a research symposium was held in the spring 1985 in Sweden where the topic was discussed. The participants from Finland and Sweden decided to start working on this field immediately. Some preliminary results were presented on the XVIII Congress of NJF in the summer 1987. The present study is an outcome of this concrete cooperation between the Nordic countries.

The study was carried out at the Agricultural Economics Research Institute. Without the encouragement, guidance and generous help of Professor Lauri Kettunen, Head of the Marketing Research Department of the Institute, the study would not have reached its present extent. His daily readiness to listen, discuss and suggest methodological solutions to specific problems has been an invaluable help for me.

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Finally, I want to express my thanks to Heidi for her patience during my work.

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The Returns to Investment in Agricultural Research in Finland 1950—1984

Abstract. This study attempts to estimate the value marginal product and the marginal internal rate of return for agricultural research in Finland. Based on production function analysis, different Cobb-Douglas and linear models are specified and estimated. A variable for the research input is measured through the flow of public expenditures for research and university-level education in 1950—1984. In addition, a stock of research capital consisting of funds accumulated since 1920 is constructed and included in the models. The estimates of elasticity with respect to public research are used to compute rates of return. State expenditures for extension agencies are also taken into account on the cost side.

It is concluded that the stock of research capital estimates are more believable than the flow estimates, because of difficulties in identifying an appropriate lag. Based on the stock estimates, the value marginal product for public research during the period studied seems to have been 1.83—1.91. The conclusion implies that additional public investment in agricultural research would have annually returned by 183—191 % over the inflation rate. The marginal internal rate of return for public research is calculated to have been 20—62 % depending on the length of the lag (4—10 years).

Index words: Returns to research, value marginal product, agricultural research

1. Introduction

The most important variable explaining differences from one country to another as to agricultural productivity is the ability to create a technology adapted to the particular country's physical, environmental and cultural endowments. Despite the importance of this ability, however, the processes by which this capacity creates and diffuses technical innovations have received relatively little attention until recently. The role of agricultural research was pointed out explicitly only in the 1950s and 1960s. Since then, considerable effort has focused on measuring the impact of research on growth in productivity (ARNDT and RUTTAN, 1977).

Estimation of the value of research is a difficult task complicated by great uncertainties. In spite of these difficulties the task seems to be important. Many studies carried out in the USA, Canada, Japan, India, Mexico, Australia, and Brazil have found that the returns to investment in agricultural research and extension in many cases have been very high. The estimated annual rate of return in these countries has varied from approximately 20 to 80 %. Both consumers and producers benefit from this social rate of return through lower costs of food and reduced production costs (PINSTRUP-ANDERSEN, 1982).

In the 1950s T.W. SHULTZ (1956, 1958) pointed out how important it would be to calculate the costs and benefits of technical improvements. He contended that technical improvements in agriculture are not manna from heaven, but represent inputs that should be taken into account when explaining an increase in agricultural production or in agricultural productivity. The majority of studies carried out thereafter have had a similar conclusion: society as a whole, both producers and consumers, benefit from agricultural research.

It is not known whether agricultural research has created a positive economic surplus in the Nordic countries, particularly in Finland. The table in Appendix 1, presenting the estimated annual rate of return from 50 different research programmes, shows a high rate of return in other countries. On average, the annual rate of return was somewhat below 50 % and only four programmes showed an annual rate of return below 20 % (PINSTRUP-ANDERSEN, 1982). A similar compilation of data from 32 studies on research profitability, put together by EVENSON et al. (1979) in the magazine Science, illustrates approximately the same rates of return. The agricultural research input in Finland needs to be investigated in order to determine whether the high rates of return are also true for a northern environment.

More specifically, empirical estimations of the economic returns to agricultural research (or of its benefits) can be justified as follows:

1. Research is an economic activity, competing for the scarce resources of society, which creates something of value by producing knowledge that can be further refined into an input in the production process. To be able to allocate funds between research and other activities of society decision-makers need some measure for determining optimal allocation (SCHULTZ 1971). If the future value of research to society could be estimated, the extent of public spending on agricultural research could be determined on the basis of its relative benefits (PINSTRUP-ANDERSEN 1982).

2. Research leads to a more effective use

of resources by providing knowledge to be used instead of more expensive and scarcer resources, e.g. land, water and labour. The constraints on production imposed by the most expensive or least available resource are alleviated through research; the same production volume is achieved with less inputs than previously (HAYAMI and RUTTAN 1971). Quantification of this marginal product of research enables valuation of the gain in efficiency.

3. It is possible to demonstrate that, in the long run increases in productivity are transferred to consumers through lower food prices. Welfare economics also makes it possible to estimate the consumers' surplus and the producers' surplus thereby making it possible to determine which group benefits more. The total economic surplus is principally often sufficient to compensate probable losers, i.e. late adopters of new methods and means of production (HERTFORD and SCHMITZ 1977).

4. According to one assertion, landowners obtain a large part of the utility from increased productivity, the input industry another part. Thus ROSINE and HELMBERGER (1975) claim that land rents dramatically increased in USA in 1948—1972 as a result of improved productivity. Technological change led to a drop in the prices of agricultural products, whereas the prices of inputs rose and labour did not benefit from increases in productivity. An important question thus is whether landowners and the input industry share in the benefits from investment in agricultural research and extension, and how big is their share ? This study makes no attempt to answer this question since circumstances differ in Finland from those in the USA.

5. It is difficult to set an exchange value on real or expected research results, yet it must be possible, as such values are set all the time, in the form of decisions concerning the allocation of resources to research. Current price setting is insufficient because it is based on imperfect information. The authorities granting funds for agricultural research need objective evaluation of research (PAULSEN 1971).

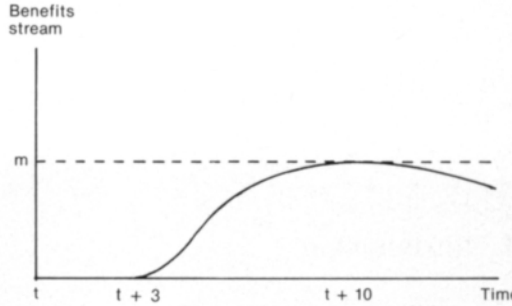

Fig 1. The timing of research benefits (EVENSON 1977).

6. There appears to be a lag between the point in time when research funding takes place and actual results in the form of higher productivity. This lag can be expressed as a function of time, as is illustrated in Figure 1.

Investment in research in the period t starts producing a stream of benefits at $t+3$; this stream increases to m at $t+10$, and thereafter decreases. Attempts have been made to estimate such a lag, with various success. Can a lag be found for aggregate agricultural research in Finland?

Whether or not the growth of knowledge is cumulative, a topic that has been discussed in the philosophy of science, becomes relevant in this connection. Those who, like Karl Popper, are apt to look upon science as a steady process of approaching truth in infinity probably contend that research results have an eternal component of value. From this point of view, research results accumulate rather than replace each other. Those who, like Thomas Kuhn, advocate a view that science should be seen as a sequence of paradigms replacing each other probably consider all knowledge to be perishable even with respect to its practical utilization. Even though Kuhn thought of rather long periods, later philosophers of science e.g. Lakatos have used his concept in the context of shorter intervals. In principle this distinction is important, since the decision whether the benefits of research are cumulative (lasting forever) or concern only a few decades might affect the estimated rate of return. Varying opinions about how the benefits of research should be depreciated are associated with a more general philosophical discussion.

7. In recent years administrators have become engaged in the evaluation of research. The returns of agricultural research can be understod as one of many criteria by which the quality of research is assessed. Research certainly can be justified on grounds other than purely economic ones (environmental, sociopolitical, or quality aspects). This does not, however, decrease the importance of the social rate of return.

These are some resons for evaluating the returns to investment in agricultural research. It is, however, important to keep some central circumstances in mind.

First: The end results are essentially affected by what is included in the research costs, and what is not. According to ZENTNER and PETERSON (1984), this question is difficult to answer. Most studies have included costs for extension too; thus investment in research is also covering the public expenditure for extension. In this study, all funds for university-level agricultural education have also been included. The estimation is thus a calculation of the profitability of research, where the costs of extension and university education are credited on the cost side, a procedure which may overestimate the cost component.

Second: An important part of all research takes place in the private sector. Farmers, however, pay for this research as its costs are included in the prices of agricultural inputs. For this reason it may be unnecessary to include research done in the private sector; inclusion or exclusion of such research depends on the study methods used for a particular investigation.

Third: It should be kept in mind that research spreads across national borders; the benefits of research are not confined to the country of origin. This is often characterized as a "spillover effect". Changing technology is seldom completely specific to the country where the research has been carried out. A central part of research findings is also imported from other countries. It is, however, very difficult to distinguish between the effects of imported research findings and the effects of domestic research on agricultural production. One can only assume that borrowed knowledge plays a greater role in small countries than in large countries. An interesting topic for investigation would be to distinguish imported research from domestic research.

Fourth: How should improved productivity be accounted for when it leads to a national surplus of agricultural products, with little prospects for sales? Is it realistic to assume that all resources find alternative employment at zero cost?

Fifth: SCHULTZ (1956) and PETERSON (1971) point out that research contains a stochastic element and can be compared to drilling oil, when most holes turn out to be dry. Perhaps one out of ten holes strikes oil. The value of this tenth hole, however, makes up for the nine earlier trials that were fruitless.

There is a major gap in knowledge about the yield of Finnish agricultural research in relation to its costs. The purpose of this study is to fill that gap by seeking an answer to the following question:

— What has been the value marginal product (marginal rate of return) as well as the marginal internal rate of return for public expenditure on agricultural research and for total public and private expenditures on agricultural research 1950—1984?

The study concentrates mainly on public research, which includes university education, but also takes into account the private research even though farmers pay for the research done in the private sector.

The empirical study is based on production functions where a specific research variable forms the core of analysis. The estimates of regression coefficients are derived through regression analysis. Two different measures are used to approximate the research input. The first is the conventional measure of research flow, comprising the flow of annual funds to research. The second is a stock measure of the accumulated research capital. The stock of research capital has not been widely used in earlier empirical analyses of returns to agricultural research.

Theoretical discussion of the methods that can be used to estimate economic benefits, earlier studies and the criticism of these are reviewed in chapter 2. Furthermore, productivity can increase because of factors other than research. These issues as well as the specification of a model for estimating the returns to research are presented in chapter 3. The data is explained in chapter 4, and the results of the estimations are reported in chapter 5. In chapter 6 a value marginal product and a marginal internal rate of return for the period studied are calculated, whereas conclusions are summarized in chapter 7.

2. Methods of Estimating the Economic Returns to Research

The methods used for evaluating the returns to research can be divided roughly into two groups. The first approach consists of estimating a production function, in which a variable for research and extension is included. In the next stage the contribution of the research variable to production or to growth in productivity is determined on the basis of the coefficients. Normally the marginal rate of return serves as a measure of profitability. This group of methods is classified here as *production function analysis.* Sometimes these methods are referred to as the regression analysis approach or sources of growth methods.

The second basic approach makes use of either welfare analysis or cost and benefit analysis. An average rate of return is usually calculated and generally refered to as the internal or social rate of return. These methods are said here to use the *welfare economics approach.* Sometimes this group is referred to as an index number or consumers' surplus method. Many scholars in the field have used both approaches. GRILICHES (1958, 1964) is mostly cited for his pioneering cost-benefit work on hybrid maize research, but has also made a profound contribution to the production function analysis. Both major approaches are reviewed in sections 2.3. and 2.4.

Before we proceed to scrutinize these methods, a couple of early attempts belonging to neither major approach will be examined. We shall also define some of the central measures used in these types of studies.

2.1. Early Attempts to Measure the Returns to Research

2.1.1. The Value of Inputs Saved Calculated by Schultz and the Follow-up Study of Peterson

SCHULTZ (1953) uses the value of inputs saved method in the first study to measure quantitatively the returns to investment in agricultural research. Schultz includes all public expenditures for research and extension in his analysis. He examines research at the level of total agricultural production.

Schultz estimates the growth in productivity in American agriculture in the period 1910—1950. Thereafter he proceeds to calculate the value of inputs saved by the increase in productivity. Growth in productivity is attributed to improved production technology and agricultural research. This value is related to total expenditures for research and extension activities.

Schultz makes a rough calculation of the resources needed to produce the agricultural output of 1950 with the technology of 1910. The difference in resource inputs is equal to the value of inputs saved.

An upper and a lower limit for this value is set. The upper limit is established by determining a 14 % growth in resources needed using the prices of 1946—1948 as weights. In 1950 total agricultural production was 75 % higher than in 1910. The output-input ratio had thus grown by 54 %. In other words, 54 % more resources would be needed to produce the output of 1950 with the technology of 1910, this 54 % being worth USD 16.2 billion. Correspondingly, a lower limit is set using the prices of 1910—1914 as weights for the resources needed. With these weights, inputs had grown by 33 % whereas the value of the resources saved to produce the output of 1950 were USD 9.6 billion (the output-input ratio was thus improved by 32 %). This figure, USD 9.6 billion is consequently the lower limit for resources saved during one single year, 1950.

After these calculations Schultz assumes that the expenditures for research and extension per year during 1910—1950 were as great as in 1950, which in fact is a gross overestimation of the actual research costs. Using Shultz's assumption, total expenditures in 1910—1950 would have been USD 7 billion. The total expenditures for a period of 40 years thus were less than the value of inputs saved during one single year, i.e. USD 9.6 billion in 1950. This figure indicates tremendous returns from research.

Schultz however presents a double warning in his argument. First he points out that extension costs may be overestimated since not all of these resources are used to advance agricultural techniques. Second, he points out that the research of the private sector have not been taken into account, and that productivity may rise because of reasons not associated with research (economies of scale, education etc.). On the other hand, the research costs are heavily overestimated and some of the research is necessary to maintain the same level of production as before.

Peterson (1971) used the method of Schultz to follow up the development 1950—1967. The value of inputs saved in 1950 alone, measured in the price level of 1957—1959, was USD 10.11 billion (USD 9.6 billion in the price level of 1950). Using the same price level the value of inputs saved was USD 26 billion in 1967. Even if one assumes that the research expenditures of the private sector are equal those of the public sector, the sum of total research costs for the period 1910—1967 (USD 18.914 billion dollar) is less than the value of inputs saved only in 1967.

The values calculated by Peterson are shown in Table 1. In the table the expenditures of the public sector have been doubled to take into account the expenditures of the private sector. The figure of O/I shows the output-input ratio; the table thus reveals growth of the productivity ratio.

An interesting feature is that the value of inputs saved has risen faster than the expenditures for research and extension. (In 1930, changes in the O/I ratio and the value of inputs saved were negative, and therefore were omitted by Peterson). Peterson also calculated a rate of return for the investments in agricultural research; it is described in section 2.2.

Table 1. Value of inputs employed in agriculture, proportionate change in productivity (O/I) since 1900, values of inputs saved, and expenditure for agricultural research and extension, in millions of 1957—1959 dollars for selected years (Peterson 1971).

Year	Value of Inputs	Proportionate Increase in O/I from 1900	Value of Inputs Saved	Research and Extension
1930	USD 22,380	—[1]	—[1]	USD 193
1940	22,349	0.091	USD 2,034	335
1950	35,103	0.288	10,110	390
1960	34,895	0.591	20,623	727
1967	40,729	0.636	25,904	882

[1] Changes in the O/I ratio and value of inputs saved were negative for 1930 and, thus omitted.

2.1.2. *The Estimate of Tweeten and Hines: Contributions of Agricultural Productivity to National Economic Growth*

In the mid 1960s, TWEETEN and HINES (1965) launched a method for roughly estimating the effects of investment in agricultural research and education. Their method of estimation is based on following reasoning.

The national income in the USA in 1963 was USD 476 billion. Of this 3.7 % originated in the agricultural sector. In 1963, the national income per capita was USD 1,310 in the agricultural sector and USD 2,617 in the rest of the economy. Due to research, extension and vocational training, the need for labour in agricultural production had decreased, and human labour had thus been released from American farms in 1910—1963. This released labour now works in the nonagricultural sector. According to this reasoning the contribution to national income can be calculated on the basis of per capita income differences in the agricultural and the nonagricultural sectors. In 1910 35 % of the American population lived on farms, after which the figure declined. Tweeten and Hines concluded that had the distribution of agricultural people/nonagricultural people of 1910 prevailed in 1963, the national income would have been USD 68 billion, or 14 % lower than the actual national income of USD 476 billion.

The earnings from growth in productivity were USD 1—1.5 billion a year in the beginning of the 1960s. Discounted with a 5 % discount rate, this makes for about USD 20 billion. Public investments in agricultural research, education and vocational training, farm programme expenses and various miscellaneous items accounts for a total expenditure of USD 10 billions. This sum thus includes much more than research expenditures. On the basis of these sums, one can easily see that a benefit/cost quota of 2 is obtained. PETERSON (1971) points out that since costs are estimated only for a current year (1963), it is not possible to compute an internal rate of return. A 10 % external rate of return is obtained with a 5 % discount rate.

PETERSON (1971) also points out a bias in this technique. The estimated contribution to national income depends on the extent of disequilibrium between per capita income in the agricultural and nonagricultural sectors. The larger this difference is, the greater the contribution to national income will be. But through extension the per capita income will increase in the agricultural sector, thereby decreasing the gap in per capita income, making the contribution lower. There is obviously a paradox in the argument. In addition, the increases in productivity of American agriculture during 1910-1930 were not worth mentioning whereas big increases occured in the late 1950s and early 1960s. The method of using per capita income as a determinant, however, gives the same contribution to national income for both periods. The method is evidently incomplete.

The method of Tweeten and Hines has not been applied to a large extent, and is mentioned here as a curiosity.

2.2. External and Internal Rates of Return, Average and Marginal Rates of Return

By comparing the costs of research with the value of inputs saved, like Shultz did, one can form a rough idea of the relation between inputs and returns. More exact measures are needed to create a more detailed picture of the returns from research. Two such general measures are the external and the internal rate of return, commonly refered to as the social rate of return.

The external rate of return according to GRILICHES (1958) is measured as follows: One assumes the development to end at a point in time, cumulating all past expenditures at a reasonable interest, which reflects for instance the opportunity cost in the economy. The cumulated research costs are expressed as a capital sum. The past returns are cumulated to the same point in time, and are also expressed a capital sum. At the same discount rate as earlier used, the rate of return on these cumulated returns is projected into the future. The estimated flows of future returns are added to past returns, to arrive at a perpetual flow of returns. This flow, divided by the cumulated research expenditures gives us the external rate of return.

AKINO and HAYAMI (1975) define the external rate of return by the formula (2.1.)

$$(2.1) \quad r_e = \frac{100\,(iP + F)}{C}$$

r_e = external rate of return
P = the value of past returns
F = the value of future returns
C = research expenditures
i = discount rate

The external rate of return is a subjective measure because it depends on the discount rate chosen. The formula (2.1) can be applied to Petersons figures in Table 1; the result is Table 2. The returns extend from 1937 to perpetuity, the calculating point in time being 1967. All research and extension costs for 1910—1967 are accumulated to 1967.

Table 2. Calculation by PETERSON (1971) of the external rate of return, USD billions.

1. Cumulated past returns	1,238
2. Past returns as an annual flow	124
3. Annual future returns	25
4. Total annual return (2 + 3)	149
5. Cumulated past research expenditures	200
6. External rate of return (100 × 4/5)	75 %

An external rate of return of 75 % is obtained. This should be interpreted to mean that the invested research expenditures have returned to society at an annual rate of 10 % until 1967. From now on, each dollar invested in 1910—1967 will yield 75 % annually by saved inputs (PETERSON 1971).

HAYAMI and RUTTAN (1971, p. 41) present a formula for converting the external rate of return to a benefit/cost ratio.

$$\text{Benefit/cost ratio} = \frac{\text{Annual rate of return}}{\text{100 interest rate}}$$

The external rate of return can thus be interpreted closely to a benefit/cost ratio (GRILICHES 1958). The external rate of return above of 75 % and a discount rate of 10 % equal a benefit/cost ratio of 0.75. Critical questions are whether the value of inputs saved are due only to research, and if they can be thought of as extending to perpetuity?

According to PETERSON (1971), *the internal rate of return* can be defined as the rate of interest that makes the accumulated present value of the flow of costs equal to the discounted present value of the flow of returns, at a given point in time. Another formulation of the internal rate of return is the rate of return for which the B/C ratio = 1. The internal rate of return can be calculated from the formula (AKINO and HAYAMI 1975):

$$(2.2) \quad \sum_{t=0}^{T} \frac{(R_t - C_t)}{(1 + r_i)^t} = 0$$

R_t = the social benefit (return) in year t
C_t = the research cost in year t
T = the year the research ceases to produce returns
r_i = the internal rate of return

If we know R_t and C_t, then we are also able to calculate r_i. For a given interest rate, the discounted flow of returns is equal to the discounted flow of costs. This interest rate r_i is to be interpreted to mean that every unit of investment has, on average, returned by r_i per cent annually above the rate of inflation from the moment the investment was made (ZENTNER and PETERSON 1984).

It is important to note that the internal rate of return is sensitive to the length of the studied period.

Peterson observed that if the figures in Table 1 are applied to the formula of the internal rate of return, the returns were negative for 1910—1937 and positive for 1937—1967. The average internal rate of return for this period was 19 %, clearly less than the 75 % external rate of return. This discrepancy is due to the sensitivity of the rate of return to the length of the period. During 1910—37 costs were also included but no returns were obtained, obviously because of a long lag between investment and visible results in productivity ratios.

EVENSON (1977, p.239, 245) calls it a serious matter that some of the estimates of the returns from research have been derived through the use of systematic econometric formulations. He argues that rates of returns must be seen in a systematic context and that overvalued estimates of the returns have often been reported. He claims it is necessary to supplement the calculations of rates of return with other information. Yet the average rate of return, which preceding formulas (2.1) and (2.2) both measure, is meaningful only in a historical sense. The relevant measure to research policy is, in his opinon, not the average but the more conventional *marginal product* of research. The marginal product tells us the additional productivity or production gain for one more unit invested in agricultural research. The marginal product is easily converted into a marginal rate of return in production function analysis. The partial regression coefficients give us information about the elasticity of research. According to EVENSON (1977), production function analysis should be less subject to error than the welfare economics approach.

In order to assess the returns from research, a lag structure should be involved in the context of a production function analysis. Research does not yield returns immediately but only after a number of years, when the results are applied to the production process. The length of this lag varies, depending on the type of research. The lag structure has been the object of many estimation procedures (cf. EVENSON 1967, and RAVENSCRAFT and SCHERER 1982).

Though it would be interesting to know the average rate of return, Evenson seems to look upon the marginal rate of return as the more appropriate measure for decision-makers. PETERSON and HAYAMI (1977) found in a comparison of studies that the marginal rate of return was higher than the average rate of return. PETERSON (1971) found the marginal returns to be 42 % in the previously mentioned study whereas the internal rate of return was 19 %.

2.3. Production Function Analysis

2.3.1. General Features

One of the major approaches in assessing the profitability of research starts from the estimation of a production function. The estimation may focus upon a special product, a group of products or the whole of agriculture. The production function includes variables for research and/or education. The coefficients of the production function can be estimated by regression analysis, normally with ordinary least squares method (OLS). The coefficients for research can be converted to a marginal product and a marginal rate of return for the research input. A marginal internal rate of return can be derived for the coefficients.

2.3.2. The Aggregated Production Function Study of Griliches

Zwi GRILICHES (1964) was one of the first to include a research variable in the production function. In his estimation of an aggregate Cobb-Douglas function for American agriculture, he used one variable for education per worker and one variable for research and extension. In addition to these variables five "traditional" variables were included. The data consisted of three different cross-sections of data (1949, 1954, 1959) from 39 different states in the USA.

In order to allow for some lags in effects, the research variable was defined as an average of the flow of expenditures in the previous year and the level six years before. Thus the average of 1953 and 1958 was used in the cross-section for 1959.

The estimated research elasticity 0.059 may seem small. Keeping in mind, however, that the expenditures for research and extension for the whole period 1949—54—59 were only

USD 32 per farm and per year (the variable was defined as research expenditure per farm) while gross output per farm and year was USD 7,205, the absolute effect becomes considerable. The estimated marginal product for research and extension is then $0.059 \times 7{,}205/32$ or, approximately USD 13 of output for every additional dollar invested in research and extension (equal to a rate of return of about 1300 % per cent per year).

Even accounting for a large share of research in the private sector and for the fact that the marginal product stated above is an overestimation, the result from Griliches' study indicates a very high return from investment in agricultural research. Griliches himself adjusted the calculations so that both research in the private sector and the support to agriculture were considered. The adjusted marginal product then was found to be USD 3 (a rate of return equal to 300 %).

PETERSON (1971) converted Griliches' marginal product of USD 6.50 (assuming that research in the private sector was roughly equal to that in the public sector) to an internal rate of return of 53 %. This 53 % was based on the assumption that the returns continue to perpetuity. If all benefits are assumed to return once and for all, the internal rate of return becomes 36 %.

GRILICHES (1963 a) also made a study in which he tried to break down the technical change into different sources of growth in productivity during 1940-1960. Education accounts for some of the growth in agricultural productivity. Griliches first computed a statistically significant variable for education, concluding that education affects productivity. However, it was found to be easier to adjust the series for labour by an index of education rather than to include a separate variable for education. Later in the same study he constructed such an index of education per man-year in agriculture. This index was computed by weighting years of school, high school and college completed by the rural population by the average income of all American males in respective schoolyear class. He thereby obtained a rising index, which was multiplied with the labour input series. In this way Griliches was able to reduce the number of variables by one while still taking notice of the effects of education.

2.3.3. The Poultry Study of Peterson

In his attempt to estimate the benefits of poultry research carried on by state agricultural experiment stations, the U.S. Department of Agriculture, and suppliers of poultry inputs, PETERSON (1967) applied both a production function approach and a welfare economics approach ("index number approach"). With a method similar to the one used by Griliches, Peterson calculated the adjusted marginal product of poultry research to be USD 6 which is equivalent to a 33 % internal rate of return if the time lag is ten years. This internal rate of return was actually a marginal return. Calculated with the welfare economics approach, the average internal rate of return was found to be 18 %.

In a later comment PETERSON (1971) states that a ten year lag is probably too long. If a lag of six years is assumed, the marginal internal rate of return is about 50 %, not 33 %.

2.3.4. Production Function Studies of Evenson

EVENSON (1967, 1971, 1977) has carried out a number of studies using the production function approach. An investigation done together with Kislev summarizes several studies (see section 2.3.5.).

EVENSON (1967) estimated the marginal rate of return to aggregate investment in research on the experiment stations and in the United States Department of Agriculture. The analysis applied cross-sectional data on research expenditures for the different states and time-series data for total research. The average lag between research expenditures and effect on production was also estimated.

In the most simple econometric models technological change is treated exogenously as a shift in the production function. Evenson presumes that the contributions of agricultural research cannot be explained by a small number of important research findings. Instead he thinks of the contributions as small changes in the quality of inputs. In the production function

$$(2.3.)\quad Y = f(X_{11}, X_{12}, \ldots X_{1m}, X_{21}, X_{22}, \ldots X_{2m}, \ldots, X_{n1}, X_{n2}, \ldots X_{nm})$$

the subscript n indicates the type of input and the subscripts m denote various qualities. The variables are usually aggregated using relative price weights. The quality differences are not reflected in this typical aggregation. Evenson therefore found that conventional input measures fail to reflect changes in the quality of inputs. Thus it became important to put forward the hypothesis that a specific "research production function" exists in the form:

$$(2.4.)\quad Q = f(Z_{ik}, u)$$

where Z_{ik} denotes the research input in the form of scientific skill, supporting staff, and buildings and supplements, whereas u is an error term. The research input can be measured by public expenditures for research.

The quality improvements in year t are defined as R_t, in the year t—1 as R_{t-1}, etc. If a lag operator is included, the research production function becomes:

$$(2.5.)\quad R_t = W(L)Z_t + C(L)u_t$$

where W(L) indicates a distributed lag function with weights $w_i(w_1Z_1 + w_2Z_{t-1}$, etc.) of research expenditures. $C(L)U_t$ is a distributed lag function of error terms.

With the research production function R_t, a stock of knowledge K is defined. The stock of knowledge is filled in with the help of R_t at the same time as some of the knowledge depreciates (becomes obsolete).

Evenson attempted, in particular to estimate the mean time lag. In doing so he explores both an exponentially declining and a symmetric or inverted V distribution. The length of lag is estimated by ordinary least squares and the alternative with the highest coefficient of determination R^2 is chosen. The data used is from American agriculture. Two different functions are used. The first is an aggregate Cobb- Douglas function including a research variable, and the second is a "residual" function with the ratio of output to input as the dependent variable ($Y/J = AR^d$).

His conclusions are:

1. The highest R^2 is found at six to seven and a half years. The average lag between investment in research and results in production thus seems to be six to seven and a half years. With a 95 % confidence interval, the mean time lag would be three and a half to eleven years.

2. Griliches calculated the marginal product of research and extension to be USD 13 of output produced for each dollar invested in research and extension. Using the same cross- sectional data, Evenson reports to have calculated a similar marginal product of USD 10. Using time-series data, he reports estimates of a marginal product of about USD 40.

3. Cross-sectional data tend to underestimate the research results, as the *"spillover" effect* (cf. chapter 1) between states is not included in the cross-section. The state of research origin cannot capture all the benefits of research, since some of it passes over to other states. The research carried out in one state thus affects the production function of other states.

A study carried out later (Evenson 1971) concerning the organization of agricultural research uses the same theoretical framework. The conclusions of this study support the assumption that economies of scale also applies to research at the experiment stations. It is also commented that a stochastic term could well be included in the research production function R_t.

Evenson (1977) later points out that attempts should be made to distinguish between different types of skills — inventive, technical and engineering, technical-scientific, conceptual-scientific etc. — because their relevance applies to the production function in different ways. Correspondingly an attempt could be made to distinguish between different types of research so that several categories could be utilized.

2.3.5. *The Studies Carried out by Evenson and Kislev*

Evenson and Kislev (1975) summarized their studies on the economics of agricultural research in the book Agricultural Research and Productivity. The perspective is international, and focuses on the diffusion of agricultural innovations to developing countries. Only a few parts of the book will be touched upon here.

A special "knowledge production function" is defined on the basis of scientific publications in agricultural sciences, scientific man-years in agricultural research, expenditures on agricultural research, GNP per capita and the number of newspapers per 10,000 people. Cross-sectional data is used to estimate a Cobb-Douglas knowledge production function. The data is collected from 44 different countries.

Determinants of research investment are estimated in a similar way. The explaining variables used are the value of the product in question out of total output, its share of exports, the proportion of farm labour out of the total labour force, etc.

One chapter deals with research programmes for wheat and maize. The period analyzed is 1948—1968, and the data was collected from 68 different countries. The yields are defined as a function of soil, climate and technology. Technology is determined by the stock of knowledge, which is partly indigenous, partly imported from other countries. Functions for estimating both the regional and the borrowed stocks of knowledge are specified. Figure 2 illustrates the internal relation between the stocks of knowledge.

Two different sets of estimates are calculated, one on the basis of cross-sections and one on the basis of cross-sections and time-series.

The growth of yields in maize and wheat production are expressed as a function of a knowledge function. The knowledge function is expressed through the sum of counts of articles in "Plant Breeding Abstracs" from 1948 to 1968. Regressions were used to calculate the marginal rate of return for one publication. Other explaining factors of the yield increa-

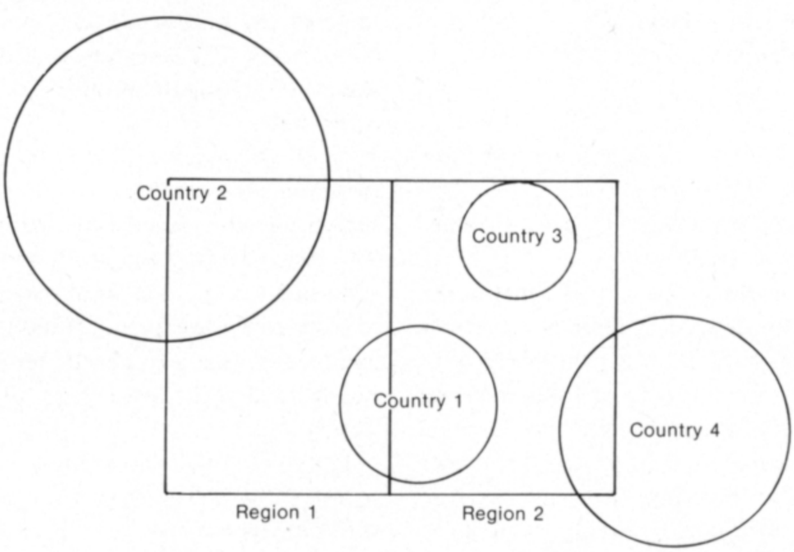

Fig. 2. Stocks of knowledge in regions and countries. Region 2's stock of knowledge is the total stock of country 3 plus parts of the stocks of countries 1 and 4. Country 1's borrowable knowledge is the total knowledge of country 3 and parts of 2 and 4 (Evenson and Kislev 1975).

ses in 1948—1968 are the rate of change of yield in 1920—1939 and a time factor. The marginal rate of return ten years later is USD 30,822 for maize and USD 20,287 for wheat. In the first year the marginal rate of return is USD 2,330 for maize respectively USD 1,581 for wheat.

Besides this direct contribution to productivity by indigenous research, the publication has another indirect value. It consists of accelerating effects of the country's own work on knowledge borrowed from abroad. Still another value is the spillover effect, spreading over the borders of the original country of research.

One chapter examines the aggregate production function for 36 different countries. The production function is specified in order to consider the differences in productivity, partly between countries ("level" coefficient) and partly over time (time trend coefficient) as illustrated by Figure 3.

Four different regressions are calculated, one with both level and time trend differences, two with one difference considered each, and one without either difference. In each case the research variable is positive.

On the basis of these estimations a marginal benefit/cost quota of 2 is obtained. This quota, however, does not take into account that the knowledge becomes obsolete. According to this study, the marginal productivity of research would be considerable.

2.3.6. Some Other Production Function Studies

KAHLON et al. (1977) used two different methods in a study of Indian agricultural research. The first method was similar to the one described in section 2.3.1. The second method consisted of estimating the output for two different periods with fixed levels of inputs. The difference in production between these periods was attributed to additional investment in agricultural research.

The returns from research were estimated partly on the state-level, partly on the all-India level. In the analysis the relative share of each factor in the growth of output for the two

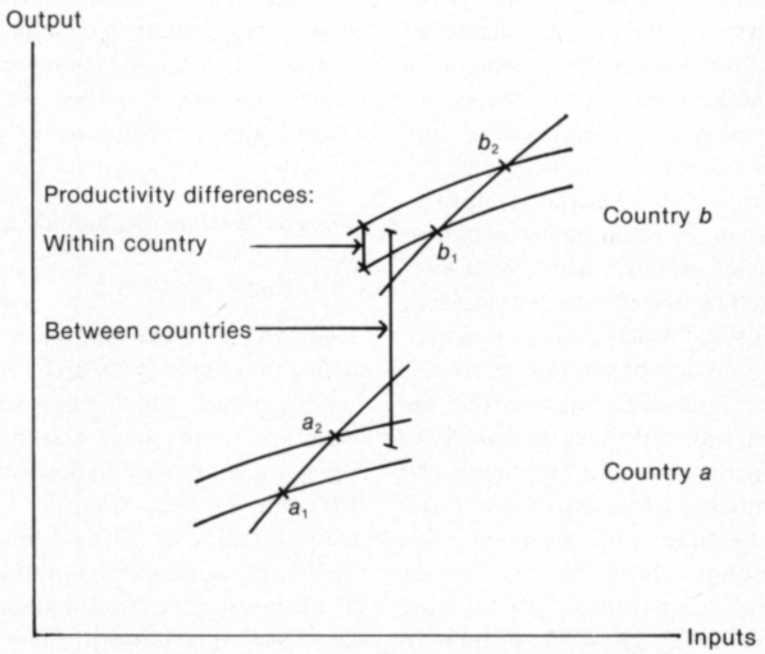

Fig. 3. Country-specific "level" differences and country-specific trend differences (EVENSON and KISLEV 1975).

Table 3. Returns to investment in agricultural research in India.

Output and Investment	First Period (1)	Second Period (2)	Difference (2)—(1)
Estimated output (million rupees)	6,592.00	6,945.00	353.00
Average investment in agricultural research (thousand rupees)	3,372.05	6,412.28	3040.23

$$\text{Return to 1 rupee invested} = \frac{353.00 \text{ million rupees}}{3{,}040.23 \text{ thousand rupees}} = 11.61 \text{ rupees.}$$

periods, 1960/61—1964/65 and 1967/68—1972/73, are calculated. Using dummies, the shares of net sown area, human labour, fertilizers and irrigation in the output growth rate are presented. The production function is of the Cobb-Douglas type.

The returns from research estimated through the different periods are presented in Table 3.

From the table it is possible to see that 1 rupee invested in agricultural research yields 11.61 rupees, with a lag of five years. This is equal to an annual internal rate of return of 63.3 %. This estimate is comparable to the estimated internal rate of return to Indian research of 50 % calculated by Evenson and Jha when the lag was assumed to be eight years.

Bredahl and Peterson (1976) estimated the marginal product and the internal rates of return for the four most important commodity groups in American agriculture. These four groups were cash grains, poultry, dairy, and livestock. The purpose was to determine the internal importance of the marginal return by commodity group. By reallocating research inputs in favour of products with a high marginal rate of return, the efficiency of research could be improved. Production functions were used in the estimation of the rate of return.

The marginal internal rate of return for the USA as a whole varied between 36 and 46 %. The returns fluctuated more at state level. The commodity with the highest payoff to research was generally found to be the commodity with the largest absolute value of output. Thus on state-level the highest returns were in the most important commodity group. The spillover effect between states, however, was not considered. A final comment is made that the figures should not be read literally. They are inteded to complement rather than to serve as a substitute for common sense and good judgement.

The purpose of a study by Knutson and Tweeten (1979) was to determine an optimal rate of future investment in agricultural research. In doing this, marginal rates of return for earlier decades were calculated first. These were then projected from 1976 to 2015 under various scenarios defining the rate of increase in research expenditures, demand for farm output, and inflation. The results showed that the optimal rate of future investment in agricultural research depends on the growth of demand. For instance, slow growth of demand coupled with rapid increases in research could pose economic hardships for farmers. If on the other hand demand grows fast, incremental research outlays are required to keep the rate of return as low as 10 %.

2.4. The Welfare Economics Approach

2.4.1. General Features

The second major approach used in estimating the returns to research is based on welfare economics. The intersections of the demand and supply curve and the shift of the supply curve are used to determine the benefits from research. Changes in prices and quantities serve as the base for estimating a consumers' surplus and a producers' surplus or, taken together, an economic surplus for the whole society. Sometimes separate benefits and costs have been estimated instead of the economic surplus. Normally not the marginal but the average returns to research are estimated. The pioneering study in this field was the study on the returns from hybrid maize research carried out by Zvi Griliches.

2.4.2. The Study on Hybrid Maize by Griliches

GRILICHES (1958) estimates the realized social rate of return of private and public funds invested in hybrid corn research. He calculates the loss in surplus to society that would take place if hybrid corn were to disappear. Griliches computes an external rate of return exceeding 700 %. The internal rate of return, however, was 35—40 %.

Griliches starts from the assumption that the annual gross social returns of research approximately equal the value of an increase in maize production as a result of this research. The additional costs for producing this maize are subtracted from these gross returns, giving an annual flow of net social returns. These are then compared to the costs of research, expressed as a capital sum.

The value of hybrid maize research is illustrated by Figure 4.

In case a) in the figure the supply of maize is assumed to be infinitely elastic, in case b) as completely inelastic. Both cases represent extremes. Griliches now calculates the loss of benefits, had no hybrid maize been developed, i.e. the shift of both curves from S to S′.

In case a) the benefits of research are equal to the value of lower production costs for the production volume Q_2 and the growth of consumers' surplus as a consequence of lower prices. This value is equal to the area of the rectangle $P_1P_2P_2'P_1'$ and the triangle $P_1'P_2'P_1''$. In this case the total loss to society would be equal to the area $P_1P_2P_2'P_1''$. This area can be approximated by the formula:

(2.6) LOSS 1 = kP_1Q_1 (1—1/2 kn)

k = Percentage change in yield
n = Absolute value of the price-elasticity of demand
P_1 = Price
Q_1 = Quantity

In case b) the loss to society consists of the loss of the production ($P_1'P_1''Q_1Q_2$) to the old price P_1 and the additional loss in consumers' surplus ($P_1'P_2'P_1''$) or:

(2.7) LOSS 2 = kP_1Q_1 (1 + 1/2 kn)

On the basis of (2.6) which gives a lower estimate, Griliches calculates the returns to hybrid maize research using the following figures. Yields have increased by 15 %, the price elasticity is 0.5, 90 % of all future maize cropping areas are planted with hybrid seed and the value of the average production volume for 1937—1948 was USD 3 billion (in the prices of 1955). According to (2.7) the loss to society had no hybrid seed research taken place would be:

0.9 × 15/115 × USD 3 billion (1 — 1/2 × 0.9 × 15/115 × 0.5) = USD 341 million.

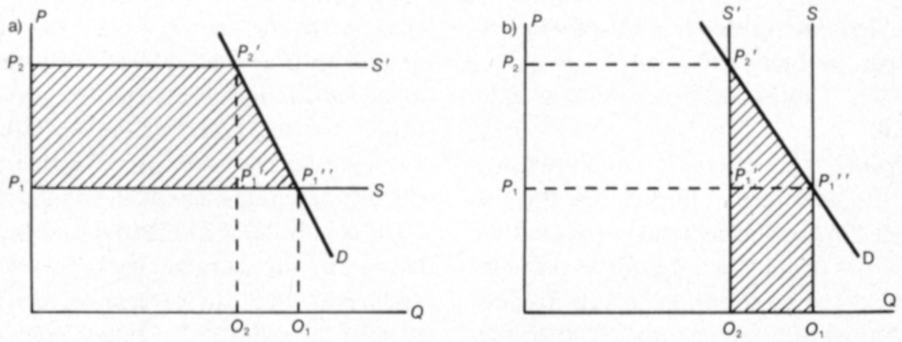

Fig. 4. The effects of a shift in supply caused by increasing productivity (GRILICHES 1958).

Subtracting the annual cost of hybrid seed, production and research, USD 93 million, the net social return becomes USD 248 million.

The study gives an external rate of return of 743 % and an internal rate of return of 35—40 % for hybrid maize research. This is the average (historical) rate of return, not the marginal rate of return.

This study of Griliches has since been criticized on some points. It only takes into account research applying directly to hybrid maize, neglecting all resources devoted to basic research on hybridization. There can be no doubt, however, that genetic research has strongly affected the development of hybrid maize (Peterson and Hayami 1977). As such, research expenditures seem to have been underestimated.

Evenson (1977) critcizes Griliches among others, for having estimated extraordinarily high rates of return on the basis of erroneous econometric formulations. He finds this a serious matter. According to Evenson and Kislev (1975) Griliches is guilty of a systematic mistake in neglecting quality improvements in labour.

2.4.3. The Welfare Economics Approach According to Hertford and Schmitz

Many different variations of the welfare economics approach have been used since the study of Griliches. A general theoretical framework has been outlined by Hertford and Schmitz (1977). The central Marshallian concept of economic surplus is important in this analysis.

The economic surplus consists of consumers' surplus and producers' surplus as earlier pointed out. These concepts are illustrated by Figure 5.

According to Hertford and Schmitz (1977), the consumers' surplus has the following meaning: The demand curve D in the figure shows the maximum price a consumer would be prepared to pay for successive, additional units of a commodity. Thus to buy one more unit, the consumer is only willing

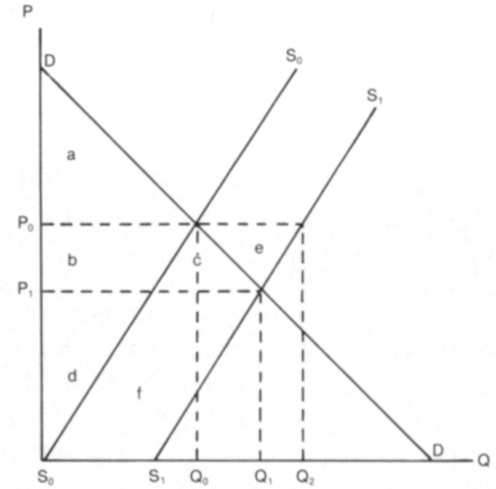

Fig. 5. Combined consumers' and producers' surplus (Hertford and Schmitz 1977).

to pay a lower price. If we assume the falling demand curve to intersect the supply curve at Q_1, the consumer is only ready to pay P_1 per unit purchased. Had he bought the units successively, the total costs would be equal to the area left of the demand curve. When buying all units directly on the market instead, he only has to pay P_1 for each of the units. His savings are thus equal to a + b + c. This area is the consumers' surplus. It can be regarded as a collective surplus for all consumers on the market.

The producers' surplus analogically refers to the difference of what a producer receives for the sale of a good and the smallest price at which he would be prepared to sell the good. In Figure 5 the supply curve S_o reflects the lowest price the producer is willing to sell for, thus being 0 in origo and P_o at market balance. On the market he can sell all units for a higher price than successive sales of additional units would bring in. The producers' surplus for the supply curve S_o is thus the area equal to b + d, i.e. the collective surplus of return resulting from selling on the market.

The supply curve of the industry represents the sum of the marginal costs curves of the producers, while the area under the supply curve of the industry is equal to the variable costs of production. If productivity increases the supply curve shifts from S_0 to S_1, and costs will decrease. If the price stays at the preceeding level P_0, the producer will receive an increase in his surplus equal to e + c + f, the total producers' surplus now being b + d + e + c + f.

When productivity in agriculture increases due to new research results, the supply curve shifts in Figure 5 from the initial position of S_0 to the new position of S_1, and the price falls from P_0 to P_1. The increase in consumers' surplus that results from the price fall is then equal to the area b + c in the figure. The increase in producers' surplus due to the sale of a larger quantity is c + f, and the decrease in producers' surplus due to the price fall is equal to b + c, or the net change in producers' surplus will be c + f − b − c = f − b. When both surpluses are combined the total economic surplus is b + c + f-b = c + f. The latter area can be calculated from the formula (2.8).

$$(2.8) \quad kP_1Q_1\ (1\frac{1/2}{n + e})$$

where
k = percentage increase in production due to research
n = price elasticity of demand
e = price elasticity of supply

The percentage increase k can be calculated by dividing the distance between the supply curves with the value of final production Q_1. In practice the critical determinant of the economic returns from research is the factor k.

Hertford and Schmitz point out that when research leads to the development of new production methods for a certain product, the finding can affect the use of other resources. For instance, producers who lack the possibility to utilize the new production methods may be forced out of business, and other production resources may not find any alternative use. The benefits may be overestimated if this is not taken into account.

An advantage of the welfare economics approach is that it enables classification of who benefits from research, producers or consumers, and how the returns are divided between these groups.

Comments on the welfare economics approach have led to the consideration of more complex issues. Some of these are reviewed in the next section.

2.4.4. Comments on the Welfare Economics Approach

Normally the demand and supply curves are not linear as in Figure 5. A more realistic illustration is shown in Figure 6.

The increase in the combined consumers' and producers' surpluses in the figure above is indicated by the area OBA. This area corresponds to the area c + f in Figure 6.

LINDNER and JARRETT (1978) note the essential difference between the assumption of a parallel, a divergent and a convergent shift in the supply curve. This is shown in Figure 7, where the demand curve is conveniently assumed to be completely inelastic.

According to Lindner and Jarrett, earlier studies did not distinguish between the types of supply shift. Important comments on the shift of the supply curve have also been made by JARRETT and LINDNER (1977), ROSE (1980), WISE and FELL (1980) and LINDNER and JARRETT (1980).

WISE (1981, 1984 a) outlined a welfare economics analysis of the benefits from research which is not based on the consumers' and producers' surplus concepts, but on costs and

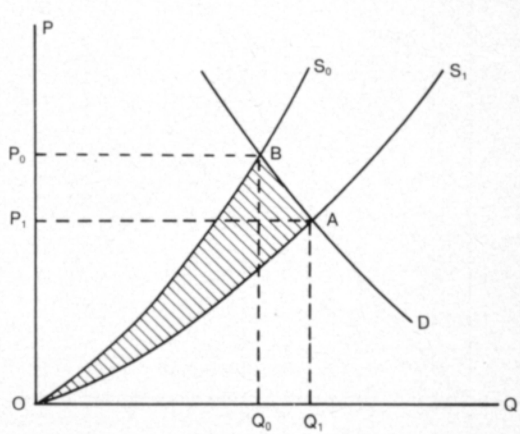

Fig. 6. Effect of a new technology in shifting supply curves (DALRYMPLE 1977).

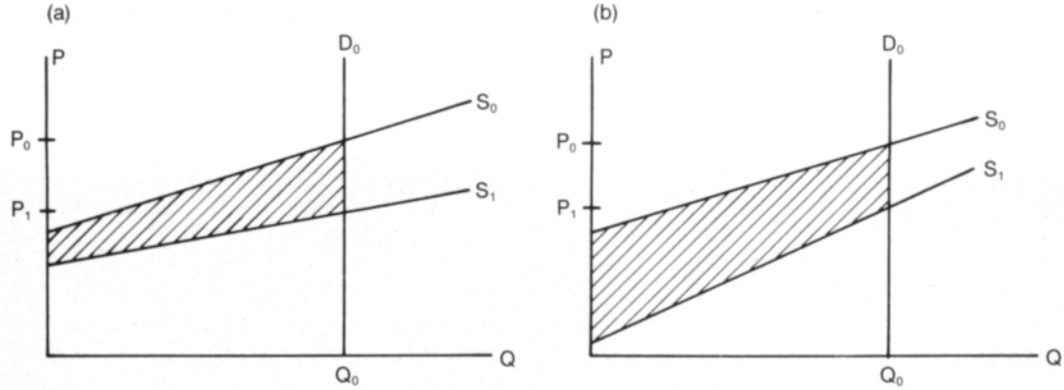

Fig. 7. Divergent (a) and convergent (b) shifts of the supply curves.

benefits. Wise argues that the essential curve to consider in benefit analysis is the cost curve and not the supply curve. In elementary models the two coincide, but Wise draws upon Capstick for many cases when factors other than costs affect the supply. Wises analysis is shown in Figure 8.

Figure 8 a) corresponds to Figure 6, and is based on the assumption of identical cost and supply curves. In Figure b) AM is the original cost curve showing the national output X.

According to Wise, it is not necessary to estimate the new curve resulting from technological change. It is enough to note that the original level of production X changes to a new level X*.

The economic benefits in case b) consist of three components B_1, B_2 and B_3. B_1 is equal to the value of increased production. B_2 corresponds to the value of fewer producers being able to produce the previous output, enabling some of the producers to move into other sectors. Essential for this part of the benefits is that alternative possibilities for employment are found. All costs of creating places for work for displaced people must otherwise be

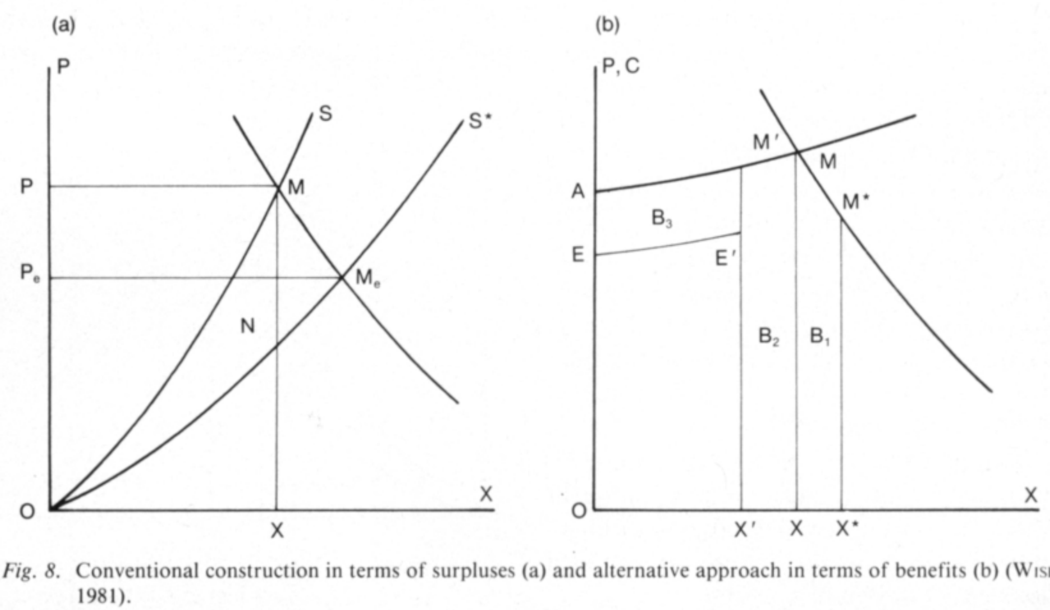

Fig. 8. Conventional construction in terms of surpluses (a) and alternative approach in terms of benefits (b) (WISE 1981).

subtracted from B_2. B_3 is, finally, the value of specific input savings needed to produce X. The input savings are a consequence of better production methods.

FREEBAIRN et al. (1982) analyzed the importance of research at different levels of production; research on nonfarm input, farming and marketing. In a model based on pure competition the benefits of research will, however, be equally divided between the various levels.

Discussion of the welfare economics approach has shown that the conclusions and the size of the rate of return are largely dependent on the assumptions made about the form and shift of the supply curve. Practical application of the welfare economics approach thus must be done with care.

2.4.5. Returns from Rice Breeding in Japan Estimated by Akino and Hayami

With the help of a model of demand and supply curves like the one in Figure 6, AKINO and HAYAMI (1975) estimated an internal rate of return for rice breeding in Japan for two different periods, 1915—1953 and 1932—1961. Two different cases, an autarky case and an open economy case, and two alternative assumptions as to the streams of returns were used. One assumption was that net returns in 1935 and in 1951 would have continued forever, the other assumption was that net returns would become zero after 1953 and after 1961. The difference between the autarky case and the open economy case was minimal. For the first period the internal rate of return was 26—27 % in the autarky case and 25 % in the open economy case. These figures concern both assumptions on the stream of returns. The internal rate of return was 73—75 % for both cases and both asumptions in the second period.

2.4.6. The Study on Returns to Pasture Improvement Research by Duncan

DUNCAN (1972) attempted a) to identify important pasture research findings and b) to estimate the internal rate of return to research

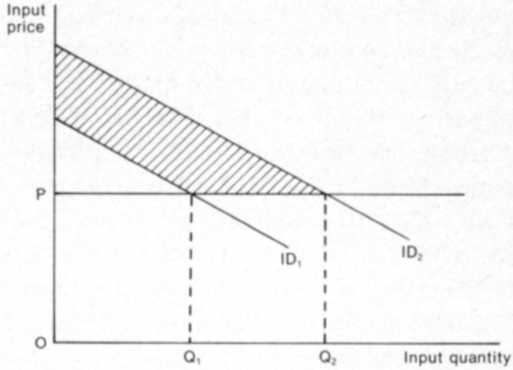

Fig. 9. The gains from an increase in the productivity of an input (DUNCAN 1972).

on pasture improvement. The study focused on an input resource, pasture. What was the effect of this research on demand for pastures? The benefits were assumed to correspond to the area between the new and the old demand curve for pastures above the price. Three different regions were separated in the study.

Figure 9 shows that supply is assumed to be perfectly elastic. A regression model was formulated to estimate the own price elasticity of demand. The demand for pastures was assumed to be a function of the real price and the state of pasture technology. Polynomial distributed lags of degree three and four (Almon lags) were fitted to each of these independent variables.

Briefly, the results were as follows:

1) The most important research contribution has been in the field of plant nutrition
2) The internal rate of return was very high, 20—80 % depending on region and elasticity.
3) Both adoption lags and lags in adjustment of the stock of improved pastures to changes in prices were very short

No firm conclusion could be made concerning the effects of research on the demand for pastures.

2.4.7. Canadian and Spanish Studies of Crop Development Research

NAGY and FURTAN (1978) studied the returns from public and private investment in rapeseed breeding in Canada. Consumers' and producers' surpluses were estimated. A computed internal rate of return of 101 % indicated that the investment level in rapeseed breeding has been too low. Consumers obtained 53 % of the total net benefits, producers 47 %. The method used was similar on the whole, to that of AKINO and HAYAMI (1975) in their study of rice breeding in Japan. The relevant figure is the same as illustrated by Figure 6.

The recent Canadian studies include the one carried out by ZENTNER and PETERSON (1984). The internal rates of return for research on new varieties and for all research dealing with wheat production ranged between 30 and 39 %. Only direct resource expenditures and extension activities were considered as costs.

HERRUZO (1985) has estimated the returns to rice breeding in Spain. Following the work of SCHMITZ and SECKLER (1970), the study assessed two types of social benefits from rice breeding: gross social benefits and net social benefits their difference being wage losses resulting from the adoption of new technology. The internal rate of return as computed from gross social benefits was 18 %. If labour displacement is considered, with 50 % of the displaced population receiving compensation, the value of the internal rate of return drops to 17 %. The study further showed the consumers to be the sole beneficiaries of research, whereas producers suffered losses due to the low price elasticity of demand.

2.4.8. *The Distribution of Economic Benefits from Agricultural Research*

The introduction of new production methods created by research affects the prices of the products. An increase of the supply decreases the price. Conventionally measured, some of the benefits will accrue to consumers and some to producers through the drop in prices. The distribution of these mutual benefits has been explained in Figure 5. Are there any losers in agricultural research?

Producers unable to apply the new methods, whether because of the small size of their firm or for other reasons are the losers. The total social benefits from modern technology have generally been sufficient to compensate the losers, though compensation has not usually been made even in cases were it would have been possible (PINSTRUP-ANDERSEN 1982).

In a well-known, controversial study of the tomato harvester in California, SCHMITZ and SECKLER (1970) concluded that the gross social rate of return from aggregate research and development expenditures on the tomato harvester was nearly 1,000 %. If displaced tomato workers are compensated the net social rate of return ranges —8 to 929 %, depending on the amount of compensation (from 0 to 100 %). If 50 % of the displaced workers do not find alternative working opportunities and receive compensation, the net social return is 460 %, thus still an extremely high rate.

HERTFORD and SCHMITZ (1977) emphasize that aggregative models tend not to consider distributional effects. For a given commodity there are many types of producers: small-scale farmers, large-scale farmers, landowners, sharecroppers, and farmers with unmechanized and mechanized farms. The estimated returns often tend to neglect this subdivision between producers and the respective distribution of benefits.

SCHULTZ (1977) argues that, in the long run, the major share of benefits from research is transferred to consumers. The distribution between various consumer groups can also be different, since the price elasticity of demand may vary between different consumer groups.

On the whole, however, lower food prices tend to decrease income disparities (PINSTRUP-ANDERSEN 1979).

Many studies have focused on the distribution of benefits between producers and consumers. It was pointed out in section 2.4.7. that NAGY and FURTAN (1978) estimated consumers' gains from rapeseed breeding in Canada to be 53 % and producers' gains to be

47 %. AKINO and HAYAMI (1975) examined two cases in their study of the returns from rice breeding in Japan. In the first case made under the autarky assumption all benefits went to consumers, while in the second case, based upon an open economy assumption, both producers and consumers became better off. SCOBIE and POSADA (1978) found that the major share of the benefits of technological change in rice production in Colombia went to consumers, wheras small producers suffered losses. The benefits exceeded total costs in spite of this. HERRUZO (1985) concluded that consumers were the main beneficiaries of rice breeding in Spain while producers, or at least some of them, became worse off because of the low price elasticity of demand.

SCOBIE (1976) argues that analysis of the distribution of the economic surplus should include two additional simple questions: 1) Under what conditions will consumers gain more than producers as a result of technological change?, and 2) Under what conditions will the producers' surplus be positive?

Scobie presents a clear example in order to show the difficulties in calculating how benefits are distributed. A Minister for Allocation of Agricultural Research Funds is confronted with a proposal to grant USD 10 million for research on the "bongoyam". His office informs him that the demand and supply elasticities for bongoyams respectively are —0.7 and 0.4. After receiving this information he poses both the above mentioned questions to his economists. The answers they give him depend on the formula used, and are illustrated in Table 4.

Table 4. Relative magnitudes of consumer and producer benefits for bongoyams (SCOBIE 1976).

Formula used	Will consumers gain more than producers?	Will producers' benefits be positive?
Akino and Hayami	YES	NO
Hertford and Schmitz	YES	YES
Ramalho de Castro and Schuh	NO	YES

The conclusion is that the Minister must be confused by these contradictory answers. This fable also illustrates some of the difficulties connected with the welfare economics approach.

2.5. Criticism of the Examined Studies

2.5.1. General Criticism

The research field of estimating the economic returns to research has been a controversial subject since the first study made by Schultz in 1953. The credibility of estimated returns has been questioned, in particular the reliability of the earlier studies. Both of the reviewed methods for estimating the returns to research have been criticized on many points. The criticism has resulted in more detailed models where a more accurate approximation of research costs and a bigger cautiousness in estimations have been considered. According to RUTTAN (1982), this tendency has led to more recent credible studies which tend rather to underestimate the returns to research. Anyhow it is clear that many of the earlier studies, particularly those with a welfare economics approach, have been subject to methodical errors and insufficient data on research costs. The next sections review these aspects.

ROSENBERG (1982, p. 25, 141—159) maintains that the rate of growth of an industry's output depends on factors of demand at least as much as it does depend on factors of supply. This can even be expressed in another way, i.e. technological change should not be seen as a predetermined exogenous factor automatically evolving according to a given pattern. Rather, it should be regarded as an endogenous force. Economists have tended to be interested more in the consequences of technological change than in the determining factors. Omission of these decisive, exogenous factors and the assumption that technological change develops according to a past pattern mean that science and technology are treated as though independent from economic and social circumstances.

Rosenberg further stresses the importance of inter-industry relationships when considering the contribution of technical progress to productivity growth. The growth of productivity, for instance in American agriculture during the 19th century, was dependent on a stronger regional product specialization. This, in turn, was connected with the development of transport facilities (roads, railways, the steam engine and refrigeration) which made regional specialization possible. Technological improvements in one sector clearly depend on developments in other sectors. This fact has not been considered clearly enough in the early studies of returns to research.

Rosenberg also notes that the estimation of returns to industrial research overlooks the improvement in the quality of final products bought by the consumers, which may prove to be as important as growth in productivity. Agricultural research is easier to evaluate in this respect, since the final products are more homogeneous because the food industry is not included in most of the studies.

In connection with Rosenberg's inter-industry relationships it is worth mentioning the considerable importance of the spillover effect particularly in small countries. A large proportion of the research results are imported from other countries, modified only to a certain degree. It could thus be argued that the wisest thing for small countries to do would be to let bigger nations carry out all research and only to import ready results. There are, however, two functions of a domestic research capacity that cannot be compensated, as pointed out by EDWARDS and FREEBAIRN (1981). One function is to facilitate the utilisation of imported research results, both basic and applied. The other function is to investigate those promising areas and specific problems which are not covered by foreign research. Feeding methods based on silage as the main source of protein is perhaps one such from Finland. Nevertheless the problem of how to measure the spillover contribution from abroad still seems to be an unsolved problem in the field.

VUORI (1984) argues that estimates may be too high if one or more variables indirectly affecting productivity not have been taken into account. One such variable could be the growth of human capital. Usually this factor is attributed to increased education and increased experience through learning by doing. Human behaviour, however, consists of many factors that are difficult to estimate.

PASOUR and JOHNSON (1982) also question whether the calculated rates of return are appropriate measures for comparing agricultural research and other public activities. WISE (1984 b) emphasizes that an economic criterion of welfare is only one of several possible criteria for political decision-making. Thus our values will decide whether or not this economic criterion is a sufficient criterion. A modest analysis of the economic benefits will be better suited to detect not only the many logical pitfalls but also the influence of value assumptions, and it should take care not to extend the economic quantification beyond normative and technical limits.

2.5.2. Criticism of the Production Function Approach

One of the most difficult methodical problems in the production function analysis is the collinearity between the research variable and other variables. According to LUND et al. (1980), this fact in connection with the incapacity to analyze separate production branches has led to the conclusion that the production function approach has only limited applicability.

WISE (1984 b) reports that re-interpretation of several earlier studies reveals the estimated rates of return to have been considerably lower in reality. According to him, both production function analysis and the welfare economics approach have used relatively simple models which are insufficient. They are inadequate in explaining how research affects the system it is part of.

Wise points out that the marginal product was calculated as b Q/R in PETERSON's (1967) production function study of poultry research in the USA. Here b represents the index for the research variable in the production function and R/Q the value of the research input in relation to the output. A ten-year lag was incorporated. According to Wise, the model is faulty. He argues that the marginal product should be calculated as b Q/RN, where N is the number of years over which the original research continues to affect output. If N is infinite, the marginal product approaches zero.

Should Wise's criticism be justifiable at this point, the estimated value of the marginal product is highly overestimated. But it seems hard to understand the criticism, since b represents the elasticity of production in the Cobb-Douglas function. According to the definition of elasticity, it shows the percentage change in production when research input is changed by 1 %. It is difficult to understand why this change should be divided by the number of years the research affects output.

PETERSON (1985) calls attention to the conventional inputs in the production function. If they have not been corrected for a change in quality, the research variable will pick up these quality improvements. As the quality of fertilizer, buildings and other external inputs has risen faster than their prices, these changes will influence output. If the research variable only measures public research, the effects of private research will be included incorrectly . These changes in the quality of inputs are hard to measure if only the publicly funded research is taken into account. This argument is a call to pay explicit attention, in one way or another, to private research in the models.

On the other hand, expenditures for private research are included in the prices of products. Farmers thus actually pay for private research. Thus the problem of taking private research expenditures into account is not self-evident if a variable for external inputs is included in the production function. Depending on which view is accepted, private research is either included or omitted.

VUORI (1984) calls attention to the treatment and content of the research variable which, she thinks, considerably influences estimated returns. It is especially difficult to value how the effects of research are distributed among individual years. In her own study on the rates of return from industrial research in Finland and Sweden in 1964—1980 Vuori used geometrically distributed lags and an Almon lag of second degree. Still one more difficulty, Vuori states, is the aggregation of research expenditures. Different types of research have different lengths of lags; in other words the time lags are assymetric. The difficulties in estimating the profitability of industrial research are further aggravated by the disparity between different industries, a cicumstance which does not concern agricultural research to the same degree.

2.5.3. Criticism of the Welfare Economics Approach

PINSTRUP-ANDERSEN (1979) states that a considerable portion of the studies on how the returns from research have been distributed between consumers and producers are based on incomplete analysis. Various supply curves of production costs should be considered in order to observe the division of producers' surplus between separate groups of farmers. However, he contends that distributional issues are more easily dealt with through political measures than through research. There is a significant difference between an open and a closed economy. In countries where technological change has contributed to production growth but where export possibilities are limited because of unprofitable price relations, the situation is near that of a closed economy.

WISE (1981, 1984 a, 1984 b) has stated that methods based on consumers' and producers' surpluses have been too simple. He considers the internal rate of return to be an inappropriate measure for the economic utility of research. It is a suitable indicator of profitability only when the returns can be reinvested, while its analogous use in the context of a national economy has not a comparable content. PASOUR and JOHNSON (1982) and later, PETERSON (1985) have also suggested that a "social internal rate of return" not is comparable to the internal rates of return in the private sector.

WISE (1984 b) further points out that the treatment of costs of implementing new innovations has been ambiguous in the earlier studies. Implementation costs can be treated as negative benefits and subtracted from the sum of benefits whereafter the difference becomes a benefit/cost quota. But implementation costs can also be treated directly as costs. The alternative chosen will considerably influence the result, as can be seen from the expressions $B/(P+Q)$ and $(B-P)/Q$. In the former case the implementation costs represent pure costs, whereas they represent negative benefits in the latter. As Wise puts it:

"No great mathematical skill is required to see that the negative benefit approach can lead to very high benefit-cost ratios if, say, P is large but Q is small and P is treated as a negative benefit" (WISE 1984 b).

In GRILICHES' (1958) hybrid maize study and in PETERSON's (1967) poultry study, implementation costs were treated as negative benefits; this may have lead to overestimated rates of return.

WISE (1981, 1984 a) has presented his alternative to the economic surplus method on the basis of cost and benefit analysis (see section 2.4.4.). He still stresses that the magnitude of error probably has not been great in the earlier formulation. Wise establishes four criteria that should be met in order to calculate reliable estimates of the benefits:

(i) The appropriate market mechanism must be identified.
(ii) The original cost curve must be adequately defined.
(iii) The technical parameters relating to willingness to adopt new technology, to the implementation costs of so doing and to the yield increases obtained must be satisfactorily established; any variations among producers in these respects must also be duly incorporated in the calculations.
(iv) There must be no covert, and possibly unjustifiable, assumptions such as that displaced resources, at zero cost, immediately find equivalent employment elsewhere in the economy, that demand curves adequately evaluate agricultural surpluses, or that there is a large pool of efficient producers waiting on the sidelines, etc. (WISE 1984 a).

WISE (1984 b) further questions whether the studies carried out have considered possible defects or adverse effects appropriately. Mechanical use of formulas without criticism can lead to distorted views of the long-term benefits of research. Thus he calls attention to the fact that the internal rate of return in the welfare economics approach avoids the problem of dealing with certain drawbacks. If, for instace, some built-in defect in the hybrid maize in the study of GRILICHES (1958) had led to all maize production being wiped out forever after 1955, the internal rate of return would have sunk only from 35 % to 34 %.

HELANDER (1985) states that the fundamental goals of society for agricultural policy should be the starting point for evaluating the relevance of research. If the economic benefits represent one aspect of this overall relevance to society, the social benefits of research represent the other aspect. This study makes no attempt to evaluate social benefits. Certain examples of what such social benefits could consist of need to be mentioned, however. Improved working and social conditions for the agricultural population, a decreased use of energy, environmental aspects and new complementary sources of livelihood for the rural population could represent social benefits which should be evaluated on basis other than the strict econometric analysis used in this study.

3. The Returns to Investment in Agricultural Research — An Aggregated Production Function Study 1950—1984

3.1. Productivity Increase, Technological Change and Economies of Scale — the Connections

3.1.1. The Concept of Productivity

In two previous chapters we reviewed the reasons for estimating the returns to agricultural research as well as methods that have been applied to do so. Research raises the quality of inputs in such a way that it is possible to produce a greater output with a given quantity of resources. This is analogous to growth in productivity. Because other factors can influence increases in productivity as well, a distinction between these sources needs to be made.

The internal relations between technological change, productivity and economies of size are illustrated by UHLIN (1985) in Figure 10:

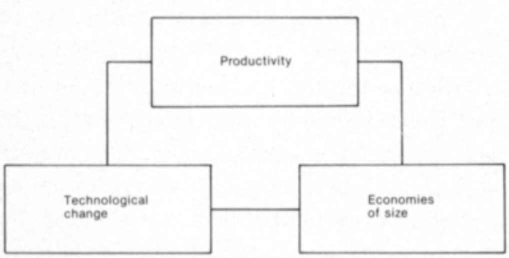

Fig. 10. The connections between sources of growth in productivity.

Productivity is defined as the empirical relation between production and unit of input:

$$P = \frac{Q}{A}$$

P = productivity
Q = production
A = input

Growth in productivity implies that less resources are used for the production of one unit of a good, alternatively a higher production for a given quantity of resources. Growth in productivity accounts for that portion of a production increase that cannot be explained by an increase in the amounts of inputs.

Economies of scale is defined by PETERSON and HAYAMI (1977) as a more efficient organization of traditional inputs stemming from an increase in the size of the firm. Technological change refers to an increase in productivity stemming from new inputs or quality improvements of traditional inputs.

Economies of scale refers to the effect of increased output on average costs when all inputs are increased in the same proportions. The similar concept economies of size, however, refers to the effect of an increased output on average cost when inputs are increased not in proportional but in least cost combinations (DOLL and ORAZEM 1978).

Difficulties in distinguishing between the concepts arise from the fact that technological innovations are often developed with certain requirements for the minimal size of the firm. By definition technological change is conceptually different from scale economies.

3.1.2. Technological Change

Adaption of a technology not previously used in the production process implies technological change. There are numerous definitions of technological or technical change. According to HAYAMI and RUTTAN (1971), it is the substitution of cheaper and more abundant factors of production for more expensive and scarcer ones at a certain volume of production. The constraints on production caused by inelastic supplies of resources can be released through technological change. The quality of inputs will be improved or totally new inputs will be developed. The quality improvements of inputs, both physical and labour, are due to research, education and learning by experience.

Pinstrup-Andersen (1982) refers to the technological state of any given production process as the composition and combination of inputs and technologies that exist at a given time. Thus, technological change describes a movement from one technological state to another. According to Vuori (1984), although difficulties are encountered in the estimation of technological change, it is usually measured with growth in productivity.

In the context of production function analysis, technological change manifests itself in several ways. We examine the Cobb-Douglas function

$$(3.1) \quad Q_t = aK_t^{\alpha} L_t^{\beta}$$

where Q_t represents production, K capital, L labour, a is a constant and α and β corresponding elasticities of production. According to Heertje (1977, p. 126, 147), technological change can be mirrored, *firstly,* as an increase in coefficient a, which means that the maximum of Q is higher though the combination of production factors remains the same. At the same time, it can be viewed as a shift in the production function. In the case of a microeconomic production function, technological change, *secondly,* can alter the elasticity of scale (α + β), but a difficulty here is that such alteration can also be caused by growth of the firm. *Thirdly,* technological change can alter the elasticity of production so that growth in either α or β occurs separately, resulting in more capital-intensive or labour-intensive production methods.

Heertje (1977) reviews two forms of technological change: the case when technological change is embodied in capital goods used by the firm and the case of disembodied technological change not related to capital goods. The division is made in order to create an operationally suitable distinction between quality improvements in capital goods and other quality improvements (cf. also Hemilä 1982).

The embodied form of technological change implies that the farm is supplied with innovations in the form of capital assets and equipment of a certain vintage (machines, buildings, seed etc.). One central force behind this type of technological change is agricultural research, which increases productivity in many ways. It lowers production costs, increases production, improves the quality of the product, creates totally new products or lessens the vulnerability to uncontrolled factors.

The disembodied form of technological change is not dependent on capital. It consists mainly of factors that increase farmers professional skills, e.g. education and learning by doing. Increased opportunities for education raise the farmer's own productivity and increase the marginal product for a given volume of inputs. Better education also increases the ability to acquire information, to interpret statements about costs and prices, and the adaption of new production methods.

There are, however, also a number of factors affecting changes in productivity which are more difficult to grasp. According to Rosenberg (1982), the role of inter-industry relations, improved roadnetworks and transport facilities are important in considering the contribution of technical progress to growth in productivity. Changing patterns in values and attitudes probably have a substantial influence in the very long run. They may be of crucial importance when technical change is viewed with a historical perspective. The importance of knowledge borrowed from abroad has also been discussed rather little. All these factors are examples of disembodied technological change.

It is important to distinguish between the two types when attempts are made to quantify the technological change. Heertje (1977, p. 174—178) shows that the production function can be expressed in the following way. When technological change is embodied in capital goods produced in the year v (vintage) production in the year t will depend on the state of technology in the year v. The production function becomes:

$$(3.2.)\quad Q(v,t) = A(v)F(K(v,t), L(v,t))$$

If technical change is not embodied in capital goods the level of production (as far as technological change is concerned) depends only on the general trend factor in period t:

$$(3.3.)\quad Q(v,t) = A(t)F(K(v,t), L(v,t))$$

In the former case one should construct a model which shows that the productivity of capital goods depends on the year v in which they were made. With a Cobb-Douglas function, the technological change embodied in capital goods can be expressed as:

$$(3.4.)\quad Q(v,t) = Be^{\tau v} L(v,t)^{\alpha} K(v,t)^{1-\alpha}$$

where $e^{\tau v}$ is the embodied technological change. The disembodied technological change is easy to introduce through the trend factor $e^{\tau v + rt}$ where r is a measure of the rate of disembodied technological change.

Another important divider between different forms of technological change is that between exogenous and endogenous technologi cal change. When technological change is treated as an externally predetermined factor without explaining the sources behind it, it is exogenous. Technological change is then attributed the passing of time. The previous expressions (3.2), (3.3) and (3.4) can all be considered exogenous treatments. Technological change embodied in capital goods is always exogenous, while the increase in the productivity of capital goods is attributed time (the vintage) (HEERTJE 1977).

According to SATO (1981) endogenous technical progress is regarded as the result of the rational behaviour of human beings. Models that treat technological change endogenously can explain it with one or more factors, e.g. (HEERTJE 1977):

a) changes in the long run in price relations between factors of production,
b) a process of learning by experience,
c) an investment in education and research.

Technological change is not then treated as a predetermined quantitative factor in the production function, but as a result of how scarce resources with alternative use are allocated.

Technological change has an endogenous character. HEERTJE (1977) therefore advocates an endogenous treatment when using production function analysis. It is, however, important at the same time to observe that an exogenous treatment does not necessarily imply that technological change is independent of economic factors, such as education, extension and research.

This study attempts to explain technological change endogenously. The endogenous explaining factors consist of investment in agricultural research and extension.

3.1.3. Economies of Scale and Changes in the Prices of Production Factors

In the context of a production function, technological change can be seen as a shift in the function, whereas economies of scale can be thought of as moving along the function in the direction of increased production. Naturally, it is possible that the firm is situated on a point below the production function, being efficient neither technically nor in the sense of scale (UHLIN 1985). In a Cobb-Douglas function economies or disceconomies of scale are reflected in the sum of elasticities (the sum $\alpha + \beta$ in (3.1)) (HEMILÄ 1982).

Price reductions shift the supply curve to the right. They are connected with technological change and research, but can also stem from reductions of monopoly power or easing of import restrictions. An important example of price reductions at a given quality of input is the reduction in the real price of fertilizer (PETERSON & HAYAMI 1977).

Agricultural research can result in new knowledge and new materials. These may be used directly for technology, or can serve as new inputs in the research process. Research which serves only as a base for further research is sometimes called basic research, whereas research with a direct application is called applied research. Yet this division is largely arbitrary and sometimes misleading. Through improving technical efficiency and lowering production risks, agricultural research exerts an influence on farm and consumer real income, on exchange earnings and on human nutrition. These effects have consequences for the three major goals of society, shown in Figure 11: growth, equity and security against crises (PINSTRUP-ANDERSEN 1982).

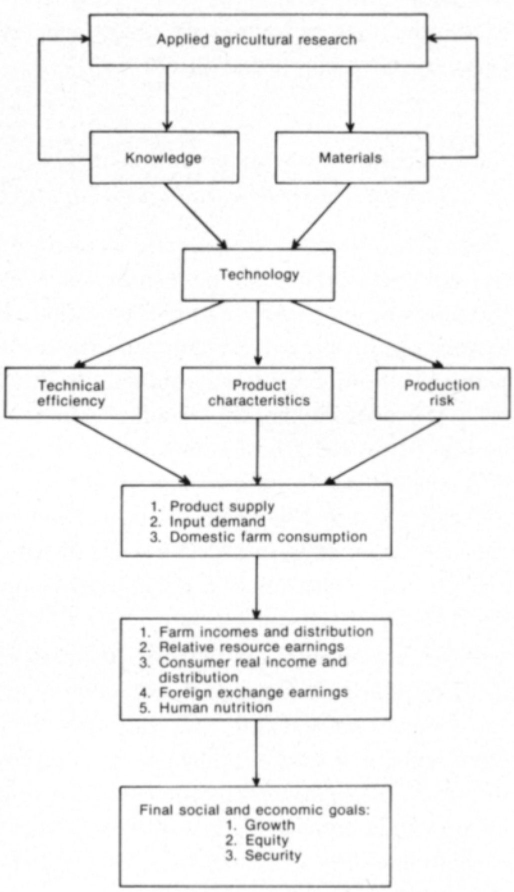

Fig. 11. Illustration of the potential outcome and implications of agricultural research (PINSTRUP-ANDERSEN 1982).

3.2. Starting Point for the Specification

Let us repeat that the purpose of this study is to estimate the value marginal product of agricultural research in Finland. The second chapter reviewed studies carried out in the field, and issues related to technological change were accounted for in section 3.1.

In the study an aggregated production function for agriculture is estimated. A separate research variable is included in the production function. On the basis of the regression coefficient with respect to research a value marginal product, i.e. a marginal rate of return and a marginal internal rate of return for investment in agricultural research and university education will be calculated. The method used is therefore reminiscent of the studies presented under the heading "2.3. Production Function Analysis".

The study focuses on the whole agricultural sector and the aggregated research input. The welfare economics approach would offer another method for estimating the rate of return. This method has been criticized on the basis of the arguments reviewed in section 2.5. The main reasons for not using this approach in the current study are, however, twofold.

Firstly, the supply curve in a heavily regulated market like the Finnish one is affected by a multitude of market interventions. Since the economic surplus is calculated as the area between the old and the new supply curve, the supply management linked with several measures dictated by agricultural policy make it even more difficult to decide upon the nature of the supply shift depending on research.

In addition, the assumption of an open or a closed economy is crucial.

Secondly, the object of study is aggregate agricultural research. Application of the welfare economics approach requires an estimation of the real supply and demand curve. Since elasticities are estimated by product and aggregated supply and demand curves seem impossible to estimate, supply curves for the different products need to be estimated. The question of how to split up the research input for different products then arises; how should, for instance, research on agricultural machines be divided among plant, dairy, and meat production? This argument is the major reason for abandoning the welfare economics approach. In addition, the elasticities of the various products change over time, a fact further complicating the estimation.

The method chosen is the production function approach. Technological change is treated as an investment in research, extension and university education. This method makes it possible to attribute relative shares of the various independent variables in production growth. Unfortunately it is not possible to calculate the distribution of the returns between consumers and producers with this method. At the same time, the returns to agricultural research are seen from the viewpoint of the whole national economy.

The inclusion of university education as well as agricultural research needs to be explained. In data collection, it was impossible to separate university education from university research. In fact, it seemed like such a division would have been rather arbitrary. If there was no university education, there would probably be a drastic decrease in the number of agricultural researchers. Thus the university education was included in the research costs. University research and education during 1950—1984 has been 24—52 % of total research input. Most persons educated at the university have, however, not been working with research after graduating. The research costs would thus be overvalued for that component of education which actually does not belong to the research input.

In the study the imported research results, based on studies originally carried out in other countries, were not taken into account. The spillover effect, in other words, is assumed to be zero, i.e. the benefits exported from indigeneous research are assumed to be as great as the imported benefits. This assumption is not correct, since the major share of agricultural machines and plant protectants are imported, while exports are small. The spillover effect is clearly a problematic issue, and needs to be treated more exhaustively than has been possible within this study. The same simplifying assumption of no spillover effects from abroad, however, has been made e.g. in the work by Wyatt (1983) on the rates of return from industrial research in Finland and Sweden in 1960 to 1980.

The possibility to include the effects of education in the form of a variable measured with a knowledge and skill index, as in the study by Ihamuotila (1972), was considered. In that study the knowledge and skill index was constructed on the basis of the number of farmers with professional training as listed in the agricultural censuses of 1950, 1959 and 1969. The proportion of farmers with professional training was further adjusted by the farmer's share of total labour input.

Because of high intercorrelation problems with the explanatory variables, which make the tests on individual regressors weak, education was not included in the specification. The possibilities to adjust labour for quality improvements according to the number of years in vocational schools were also investigated. The data on school years proved to be quite rough, thus being dubious; in addition, the effects of adjusting the labour series would not have been great. The idea of adjusting the labour series for training was therefore dropped.

The relationship specified between the inputs in the Cobb-Douglas function is complementary. According to the Wicksell-Johnson theorem the sum of the two elasticities α and β in the Cobb-Douglas function is equal to the elasticity of scale (Heertje 1977). This is true if one is prepared to assume no relevant factors have been excluded. Increasing, constant or decreasing returns to scale prevail depending on whether a small proportional increase in all inputs leads to a more than proportionate, proportionate or less than proportionate increase in output (Heady and Dillon 1961) (cf. also Hemilä 1982). The enlargement of average farm size and exploited economies of scale are therefore reflected by a change in the elasticity of scale ($\alpha + \beta$) in expression (3.1). The sum of these elasticities should be about 1.0 or slightly more since economies of scale have not been exploited to a very big extent in Finland. Substitution of capital for labour is reflected in the changes in both α and β (cf. also GRILICHES 1963 a).

Changes in the relative prices due to research are reflected in the research variable. The development of productivity during the 1960s and 1970s was most likely affected by production and import restrictions on farm products and production inputs. The effects of these measures were contradictory at least to certain degree; On the one hand, the whole production capacity has not been in use, a situation which has resulted in a smaller output than the potential; on the other hand, the protection of agriculture from imports has guaranteed a higher price for outputs. Here the assumption is made that the combined effect of these interventions on the market equals zero.

Owing to the relatively homogeneous conditions in Finnish agriculture, a time series study appears to be the most natural. The study should not be seen as a prognosis of research contribution in the future, but as a historical study of past returns to agricultural research. In other words, the study is of the ex post and not of the ex ante type.

3.3. Specification of the Model

3.3.1. The Form of the Production Function and the Variables

The basic model in the study is an aggregated production function that explains the gross production of agriculture.

A production function can be expressed as:

(3.5) $Y = f(X_1, X_2, \ldots, X_n)$

where Y denotes gross production and X_i the different inputs and the form of the function. The simplest form of the production function is the linear function:

(3.6) $Y = b_1X_1 + b_1X_2 + \ldots + b_nX_n + \varepsilon$

The linear production function expresses a constant marginal ratio between output and the various inputs. The random disturbance term ε is an expression for the unsystematic component of the variation which cannot be explained by the systematic component $X_1 + X_2 + \ldots + X_n$ (HEADY and DILLON 1961).

At declining marginal products the Cobb-Douglas function

(3.7) $Y = aX_1^{b_1} \times X_2^{b_2} \times \ldots \times X_n^{b_n}$

has been used frequently because of its statistical simplicity and convenience. In expression (3.7), a is a constant and b_i are exponents equal to the elasticity of the various inputs i.e.

$$E = \frac{dy}{y} : \frac{dx}{x} = \frac{x}{y} \times \frac{dy}{dx} = \frac{x}{y} \times b_i$$

When $b_i < 1$, the marginal products will decline as X increases because $X^b < X$. Graphically illustrated the curve of the production function flattens out.

The Cobb-Douglas function is easily changed into logarithmic form:

(3.8) $\text{Log}(Y) = \text{Log}(a) + b_1\text{Log}(X_1) + b_2\text{Log}(X_2) + \ldots\ldots + b_n\text{Log}(X_n) + \varepsilon$

In Finnish studies of aggregate agriculture or aggregate crop and livestock production functions the Cobb-Douglas function has been used by ROUHIAINEN (1972), KETTUNEN and ROUHIAINEN (1972) and IHAMUOTILA (1972). Ihamuotila also used linear production functions.

The Cobb-Douglas function has been commonly used to estimate the returns from agricultural research. Two pioneering examples are the studies by GRILICHES (1964) and EVENSON (1967) (see sections 2.3.2. and 2.3.4).

Other possible forms of the production function could be offered by the transcendental function, the quadratic function, the Spillman function (cf. HEADY and DILLON 1961) and the CES function (cf. HEMILÄ 1982). This study is, however, based on the conventional Cobb-Douglas function. A linear production function is also estimated, though mainly in order to compare results with the Cobb-Douglas form.

In the formulation of the production function the specifications of GRILICHES (1964), EVENSON (1967) and NORTON and DAVIS (1981) have been followed. The choice of variables has, to a large extent, been done analogically with the production function study of IHAMUOTILA (1972).

The agricultural gross production is produced by labour, external purchased inputs and by capital (including cultivated area, soil and water constructions, machinery, buildings and animals). The vocational skills acquired through education, experience and extension also influence the production results.

The dependent and independent variables can be seen from the model formulated below:

(3.9) $Q = A L^{b_l} K^{b_k} I^{b_i} R^{\alpha} N^{\sigma}$

Q = the volume of production
A = a constant
L = labour input
K = capital input
I = external purchased inputs
R = research input
N = extension factor
b_j = elasticities of the different inputs
α = elasticity of research
σ = elasticity of extension

This production function differs from the one formulated by Ihamuotila in including a research variable and an extension variable. Ihamuotila, on the other hand, included a special variable for human knowledge and skill, measured by an index of farmers' share of total labour input adjusted in proportion to an index of trained farmers. Furthermore, Ihamuotila also had a certain technological factor constructed on the basis of an index where the real capital stock was divided by the corresponding labour input (assuming that technological change is reflected by the amount of human labour saved). In this respect, the present study differs by measuring technological change as a result of investment in research. Labour input is not quality adjusted (for discussion, see section 4.4.). No weather variable is included.

In comparison with the model by TERLECKYJ (1980), there are two additional variables in this specification: purchased inputs and extension.

The effect of an increase in average farm size and its contribution to growth in productivity is reflected by the change in relation between the elasticities of different inputs b_i. Increasing returns to scale are indicated by growth in the sum of elasticities, which becomes larger than 1 (HEADY and DILLON 1961, p. 589).

The variables of capital, labour and external inputs in (3.9) may be specified on two different levels, the aggregate level and the farm level. Farm level variables can be derived by dividing the aggregate variables by the number of farms. Research and extension are measured only at aggregate level. This is due to the way research affects agriculture. On a single farm, it is difficult to single out a special research input in the way it is possible to point at purchased inputs, fields, machines or labour.

In most studies the expenditures for research and extension have been added up and expressed as one single variable. The reason for this is that research results spread to farmers primarily through information activities. According to earlier studies this is, strictly taken, the correct procedure. The practice has probably been used, since in many cases the data for research and extension are not separated but presented together. There are, however, two immediate reasons why this course of action not has been applied here. Firstly, the data available for extension activities is based on State support for extension which actually was bigger than research expenditures in the first half of the 1950s. Since the purpose of this study is to estimate the returns primarily to research, not extension, the use of a single variable cannot be considered appropriate here. Secondly, the data on extension is deficient, since linear extrapolation was used to derive the figures between 1951—55, 1955—60, 1960—1965 and 1965—1970. The figures on research expenditures, however, can be characterized as fairly reliable.

Since State support for extension will be taken into account as costs in the final calculation of the value marginal product (section 6.4.), the returns will not be biased in a positive direction. In fact, one could argue that the omission of extension expenditures when calculating the elasticity of research probably leads to a more realistic elasticity. Extension merely represents a complementary input for spreading research results, not a measure of research input. It should certainly be credited on the cost side in the final calculation. But the effect of extension on increasing the stock of knowledge or improving the quality of inputs is minor. One can ask whether studies not distinguishing between research and extension in elasticity calculation really are as valid as if a distinction had been made? A separate parameter for extension to use for sensitivity analysis is still incorporated in the models.

After consideration, a trend factor was not included in the model. The trend is assumed to pick up some of the potentially omitted variables. The trend could be assumed to include a number of factors rather difficult to measure. These could comprise changes in the pattern of values and attitudes which, in the long run, may considerably affect agriculture; the effects of agricultural policy; development in other sectors; infrastructural improvements; and other factors with effects on a higher hierarchical level. The problem is that it uncertain what a trend factor (a linearly growing series) actually measures. Preliminary results showed that a trend component did not improve the model in any way. There is good reason to believe that the trend factor does not add any significant explanatory power to the model. In the alternative formulation in section 3.3.3. a factor representing the disembodied technological change, i.e. a trend, is incorporated.

The form of the theoretically somewhat illogical linear production function is

(3.10.) $Q = A + b_lL + b_kK + b_iI + b_rR + b_nN$

where
bj = the marginal product of the input

In the estimation of the Cobb-Douglas function, the ordinary least squares criterion is used. In addition, ridge regressions and autoregressive models are applied. The estimates of the different parameters are derived from index series of the different variables.

When we take the logarithms of (3.9), we obtain:

(3.11) $\ln(Q) = \ln(A) + b_l\ln(L) + b_k\ln(K) + b_i\ln(I) + b_r\ln(R) + b_n\ln(N)$

Here the elasticities b_r and b_n indicate the share of growth in production due to research and extension respectively.

3.3.2. *Research Stock*

There are two different possibilities for measuring the research input; as either a flow or a stock. The flow concept has been used in the absolute majority of studies on the economic returns to research. A different possibility is, however, offered by formulating a stock of research capital.

In the following, a research capital R_k is formulated, on the basis of a specification of Peterson (1985) for three different cases:

a) The research capital is assumed to be equal to the sum of of all previous funds for agricultural research since 1920, i.e. is accumulating to 100 % ($d_t = 0$). Funds allocated to research before 1920 are assumed not to have had any effect on production.

(3.12) $R_K = \Sigma(K_t - d_tK_t)$, where $d_t = 0$

R_k = research capital
K_t = accumulated funds
d_t = rate of depreciation

b) Half of the research capital is assumed to become obsolescent 20 years after the funding took place, and is thus depreciated by 50 %. The other half is added to the research stock. Research carried out before 1920 does not have any effect.

(3.13) $R_K = \Sigma(K_t - d_tK_{t-20})$,
where
$d_t = 0.5$

c) As in b), except that all of the research capital is assumed to become obsolescent 20 years after funding, and is depreciated by 100 %.

(3.14) $R_K = \Sigma (K_t - d_t K_{t-20})$,

where

$d_t = 1.0$

The initial figure for the research capital is derived by simple trend analysis back to 1920, omitting the years 1940—1944, since normal research activities were seriously disturbed during the war years. In (3.12)–(3.14) K = 54.3 + 16.6 t for public research, 23.0 + 22.5 t for total research. Accumulating the flows up to 1950 gives an initial stock. On the basis of the index series of real flows of funds for research, this initial value is further accumulated up to 1984. A series of accumulating research capital is thereby obtained.

The research capital has the convenient advantage of not demanding any lag operator. In this respect the research stock measure seems rasier to handle than the research flow measure. In the estimations both the flow and the stock concept of the research input will be used to estimate (3.9).

3.3.3. A Productivity Index Specification

The research stock will also be needed in the specification of an alternative model. In the empirical part of the study, the internal collinearity of the variables was found to be a serious problem. One purpose of this alternative specification is, therefore, to reduce the number of independent variables and thus to reduce the multicollinearity.

The following presentation of an alternative model is largely based upon the works of TERLECKYJ (1980), GRILICHES (1980) and VUORI (1984). The difference in relation to the presentation in section 3.3.1. lies mainly in the use of a productivity index instead of gross production as the dependent variable. NORTON and DAVIS (1981) state that an alternative specification similar to (3.15) has been popular because of intercorrelation problems with time series in models like (3.9). The advantage with this specification is that the traditional variables can be omitted, and thus the problem of internal collinearity disappears, or at least becomes smaller.

A general lack of data for conventional variables has also contributed to the use of this model. The purpose of specifying a productivity index model is to obtain another estimate of the returns to research in order to see whether the estimates lie in the same range.

The productivity at a point in time t can on the basis of (3.9) be explained as the relation between gross production Q and the "conventional" inputs labour, capital and external inputs, i.e. L, K and I:

(3.15.) $$P_t = \frac{Q_t}{L_t^{b_l} K_t^{b_k} I_t^{b_i}} = eA^{\tau t} R^{\alpha} N^{\sigma}$$

t = time factor

τ = coefficient of time factor

This relation consists of three parts: one component representing the cumulative effects of autonomous technological change (e raised to the power of τt), i.e. a trend factor (this autonomous technological change factor has been added to (3.9)); one component representing the stock of research capital R raised to the power of an exponent representing the elasticity of research with respect to this research capital; and one extension component. In order to simplify the presentation the extension component N_t raised to the power of σ is omitted. Thus we obtain

(3.16.) $P_t = Ae^{\tau t} R^{\alpha}$

The function can then be written as

(3.17) $\ln P_t = \ln (Ae^{\tau t} R^{\alpha})$

By estimating a research capital R as specified in section 3.3.2., it is possible to avoid a long and difficult deduction such as those in the specifications of GRILICHES (1980), TERLECKYJ (1980) and VUORI (1984). τ denotes the autonomous technological change (trend). The dependent variable is thus an production/input index.

3.3.4 Distributed lags

The contribution of research to growth in productivity is not immediately observable in the same year that research was funded. There is one lag in the "availability" of technology, i.e. between research funding and ready production inputs, and another lag in the "acceptance" of technology. The incorporation of lags is thus an important and critical issue in estimating the returns to research (see, for instance, PASOUR and JOHNSON 1982). Nevertheless, satisfactory treatments of the lag structure are rare in the field.

The formulation of a lag function seems to be a difficult part of evaluating the returns to research. VUORI (1984) points at the difficulties in specifying a general lag for aggregated research. The length of the lag may vary for different categories of research, and the problem consequently consists of finding an average lag.

GRILICHES (1964) basic way of treating the lags was to define research costs as the average of the research costs of the previous year and six years prior to the observed output year. This arbitrary treatment cannot be considered sufficient. Since simple lags do not provide a satisfactory explanation; a specific lag function needs to be specified.

One possibility is to estimate different lags directly by applying the ordinary least squares criterion. According to PINDYCK and RUBINFELD (1981) this leads to problems through losses of degrees of freedom and because of the heavy multicollinearity resulting from the large number of variables. Moreover, the picture of the form of the lag may remain unclear.

RAVENSCRAFT and SCHERER (1982) note that it takes three years, on average, to complete industrial research and development projects. They also state that in measuring the returns from research and development, the time-lag factor in most econometric studies has been assumed to have a constant rate of decline, because of the convenience of the Koyck transformation. They argue that, for instance a bell-shaped curve describing the lag structure may be more correct. Such a curve could be provided by Almon lags. Preliminary experiments with Almon lags, however, uncovered serious drawbacks, according to them. Whether this is the case for agricultural research is not known.

PINDYCK and RUBINFELD (1981) present the general form for a distributed lag model as:

$$(3.18)\quad Y_t = \alpha + \beta_0 X_t + \beta_1 x_{t-1} + \beta_2 X_{t-2} + \ldots\ldots = \alpha + \sum_{t=0}^{\infty} \beta_z X_{t-z} + e_t$$

VUORI (1984) used a geometric (Koyck) time lag and an Almon lag. DUNCAN (1972) also used Almon lags of degrees three and four in estimating the returns from Australian pasture research (see section 2.4.6.). The geometric lag depends on only two parameters. The parameters β are assumed to decrease exponentially with time (WONNACOTT and WONNACOTT 1970). If the general form of the model is:

$$(3.19)\quad Y_t = \beta_0 X_t + \beta_1 X_{t-1} + \beta_2 X_{t-2} + \ldots + \beta_n X_{t-n} + e_t$$

the geometric lag will be expressed by:

$$(3.20)\quad \beta_j = \beta_0 \tau^j \quad \text{where } 0 < \tau < 1$$

Since the weights of the lagged explanatory variables decline with time, the geometric lag cannot be considered the best possible. Instead a polynomially distributed lag, or Almon lag, theoretically could fit the research variable.

The Almon lag is based on the assumption that the lag structure is a polynomial of some degree n, with n + 1 parameters. The original lag specification with S number of lags is:

$$(3.21)\quad Y_t = \beta_1 + \beta_2 X_t + \beta_3 X_{t-1} + \ldots + \beta_{s+2} X_{t-s} + e_t$$

Instead of estimating the coefficients β_i directly (as could be done in the geometric lag), we think of the lag as a polynomial. The polynomial of degree three is:

$$(3.22)\quad \beta_j = Y_o + Y_{1j} + Y_{2j}^{2} + Y_{3j}^{3}$$

In a more general formulation β_j is a function f(j). The polynomial (3.22) can be approximated by more simple functions. Through the Almon procedure these simpler

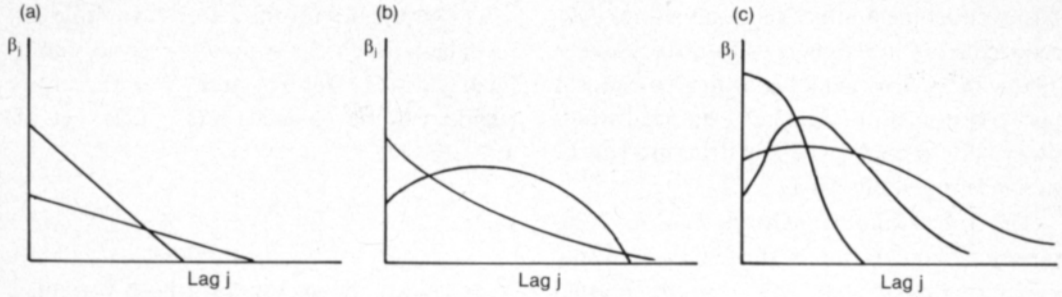

Fig. 12. Some polynomials of various degrees: (a) Degree 1, (b) Degree 2, and (c) Degree 3 (Wonnacott and Wonnacott 1970).

transformations are estimated in order to receive estimates $\hat{\beta}_j$. The procedure reduces the number of parameters to be estimated, and probably also problems with losses of degrees of freedom and multicollinearity.

Figure 12 shows possible shapes of the Almon lag for polynomials of various degrees.

The Almon lags of degrees higher than one seem to provide a suitable possibility to take the adjustment process into account. The main effect of the explanatory variables can be assumed to lie many periods of time in the past. In order to estimate the transformed variables, certain assumptions on the distribution and length of the lag structure need to be made. The polynomial of degrees two and three seem to be logical in estimating the lags for research.

The Almon procedure was used by Nevala (1976) in a model estimating the lagged responses of firms to changes in the variations in prices of fertilizer. The model below is, to a great extent, based on the formulation of Nevala. The dependent variable here is, however, gross production, and the explanatory variable is the lagged research input. A basic model including distributed lags, where the effects of research are distributed over m number of years, can be presented as:

$$(3.23) \quad Y_t = \sum_{j=0}^{m} \beta_j X_{t-j}$$

Y_t = gross output in year t
X_{t-j} = research input in year $t-j$

If the coefficients of regression β_j $(j=2,\ldots m-2)$ can be assumed to be on the numerator of a polynomial of degree three, which is equal to zero when $i=m$ the vector β_j can be compensated by

$$(3.24) \quad \beta_j = \sum_{f=0}^{3} b_f \frac{(m-j)^f}{Sf}$$

$$(3.25) \quad \text{where } S_f = \sum_{j=0}^{m} (m-j)^f, \quad (f = 0, 1, 2, 3)$$

When this transformation is substituted for b_j in (3.23) we have:

$$(3.26) \quad Y_t = b_o \sum_{j=0}^{m} \frac{(m-j)^0}{S_o} X_{t-j} + b_1 \sum_{j=0}^{m} \frac{(m-j)^1}{S_1} X_{t-j} + b_2 \sum_{j=0}^{m} \frac{(m-j)^2}{S_2} X_{t-j} + b_3 \sum_{j=0}^{m} \frac{(m-j)^3}{S_3} X_{t-j}$$

$$(3.27) \quad \text{where } S_1 = \sum_{j=0}^{m} (m-j)^1$$

$$(3.28) \quad S_2 = \sum_{j=0}^{m} (m-j)^2$$

$$(3.29) \quad S_3 = \sum_{j=0}^{m} (m-j)^3$$

(j = the first year of influence, m = the last year of influence)

This model will be used to estimate the parameters b_o, b_1, b_2 and b_3. In relation to the basic model the number of variables has been reduced from m numbers to four (cf. NEVALA 1976). In a polynomial lag of degree two, the last component b_3 in (3.26) naturally falls away. For the rest, the lag structure can be derived in a similar way.

The four Almon transformations in (3.26) presume that a notion of the length of the lag is acquired in advance. EVENSON (1967) found the length of the lag to be three and a half to eleven year, with a confidence of 95 %. He estimated the average lag to be six to seven and a half year. When the transformations

$$(3.30) \quad Z_{0t} = \sum_{j=0}^{m} \frac{(m-j)^0}{S_0} X_{t-j}$$

$$(3.31) \quad Z_{1t} = \sum_{j=0}^{m} \frac{(m-j)^1}{S_1} X_{t-j}$$

$$(3.32) \quad Z_{2t} = \sum_{j=0}^{m} \frac{(m-j)^2}{S_2} X_{t-j}$$

$$(3.33) \quad Z_{3t} = \sum_{j=0}^{m} \frac{(m-j)^3}{S_3} X_{t-j}$$

have been calculated, the coefficients b_0, b_1, b_2, and b_3 can, in turn, be calculated for different lengths of adjustment with ordinary least squares. With these coefficients the model for the lagged research input can be presented as:

$$(3.34) \quad \hat{\beta} = \hat{b}_0 \frac{(m-j)^0}{S_0} + \hat{b}_1 \frac{(m-j)^1}{S_1} + \hat{b}_2 \frac{(m-j)^2}{S_2} + \hat{b}_3 \frac{(m-j)^3}{S_3}$$

$$(j = 0, \ldots m)$$

With the help of these coefficients the model can be expressed in the basic form (3.23)

$$(3.35) \quad Y_t = \sum_{j=0}^{m} \hat{\beta} X_{t-1}$$

The coefficients estimated for different lengths of the lag are thus dependent on the lagged research variables b_0, b_1, b_2 and b_3. The form of the β-vector can be presented graphically.

The elasticities for the research variable can be calculated in the ordinary way. A cumulated elasticity for research over the entire period can be calculated (see CHEN et al. 1972, p. 81).

$$(3.36) \quad e = \sum_{j=0}^{m} \hat{\beta}_l \frac{\overline{X}}{\overline{Y}}$$

$\overline{X}$ and $\overline{Y}$ are the averages for both variables. When the Almon lag is put into the Cobb-Douglas function (3.9) in section 3.3.1. the function becomes:

$$(3.37) \quad Q = A\, L^{b_l} K^{b_k} I^{b_i} R^{\sum_{j=0}^{m} (\hat{\beta}_{t-j})} N^{\sigma}$$

where $\hat{\beta}_{t-j}$ denotes a certain research elasticity for each lagged year $t-j$. The cumulative research elasticity for all years was expressed by (3.36).

3.4. How the Model Works

Two production functions have been specified parallelly: one Cobb-Douglas function (3.9) and one linear production function (3.10). An alternative specification (3.17) based on a productivity index instead of gross production have also been formulated. In addition, polynomial lags of degrees two and three have been specified for the Cobb-Douglas function. All models are based on the following assumptions:

i. There are no linear relations between the explanatory variables L, K, I, R and N (does not apply to the productivity index model (3.17)).
ii. The expected value for the residual $\varepsilon = 0$ and the variance σ^2 is constant.
iii. The residuals ε_j for the different observations do not correlate.
iv. The residuals are normally distributed.

The first condition i. can be controlled by studying the intercorrelation between the explanatory variables. The second condition ii. concerning the expected value and variance of ε can be examined by investigating the distribution of residuals. An uneven distribution of the residuals, the so-called heteroscedasticity, is thus incosistent with hypothesis ii. of this model.

The third condition iii., that of the residuals not being autocorrelated, can be verified by the Durbin-Watson test. The fourth and last condition iv., which can also be seen from the distribution of residuals, is needed to enable testing the significance of the coefficients. When the residuals are normally distributed they can be studied by the t-test.

The partial coefficients of regression for the explanatory variables explain the increase in the dependent variable when the variable in question is changed by one unit, on the condition that the other explanatory variables stay constant. The assumption of the other variables remaining unchanged is of crucial importance. Thus the coefficient of research input explains the increase in gross production (or the production/input relation in the productivity index model) that follows from a one unit change in research input, provided that capital and labour and external inputs remain unchanged. In the linear models the coefficients explain this increase as a *marginal product*. Because the coefficients are derived from index series, the absolute level of the marginal product cannot be seen directly, but first need to be transformed into an elasticity. In the Cobb-Douglas model (3.9) the coefficients represent the *elasticity* directly.

When the Almon lag is applied to the research variable, different research elasticities are obtained for each lagged year $t-i$. The influence of the research input has a maximum value between the first year $t-i$ and the last year t, and it declines in both directions according to Figure 12. On the basis of (3.36), the elasticity for the whole period is calculated. The Cobb-Douglas function is the logic form of the production function when measuring the gross production on farm level at a certain point in time. A linear production function is hardly justifiable in this case because the marginal product is constant. The law of diminishing returns is valid also on the aggregate level in case we use cross-section data. But in time series studies the situation is somehow different, since the production function shifts upwards each year. Thus we have a series of shifting production functions. The Cobb- Douglas function is, however, less controversial and should thus be regarded as the major model. The linear model should be seen as an additional source of information, one which complements the Cobb-Douglas function.

The model measures research input as a flow of funds for agricultural research as well as a stock of research capital. The flow measure implies that if no funds are available for one year, the model values the effects of research on gross production as zero for this year. A stock of the research capital has, however, been formulated in section 3.3.2. Interpretation of this research capital is different. The quantity of this research capital K, which exists at any point in time, is equal to the sum of all previous funds of research subtracted by the proportion that has depreciated over time according to formulas (3.12)—(3.14). The elasticity of this research capital, therefore, is different from the elasticity of the research flow. The lag structure need not be incorporated with the research stock.

4. Data

4.1. Time Series

The sum of the squares of errors will be minimized in order to estimate the Cobb-Douglas production function. As the absolute level of time series need not be known in this procedure, the estimates can be derived from index series. Since the conventional variables in the study have been chosen on the basis of the production function study for 1950—1969 by Ihamuotila (1972), the same series are followed up until 1984.

The capital variable is defined here as the gross capital stock, whereas Ihamuotila rather used a net capital stock (see section 4.3.).

The data for research and extension have been collected separately. Since agricultural research is the focus of this study, a detailed description of the contents of the research variable will be given in this chapter. The time series are presented in Appendix 2.

4.2. Gross Production in Agriculture

The source used for measuring agricultural gross production was the "total accounts of agriculture" calculated at the Agricultural Economics Research Institute (AERI). Another possibility would have been to employ the national income account drawn up by the Central Statistical Office. The two series differ, since the total accounts of agriculture calculated by AERI include only basic agriculture (crop production, animal husbandry and outdoor garden production), whereas in addition to basic agriculture, the national income account also includes reindeer, bee and fur animal husbandry and incomes from services, including the hiring of machines. Outdoor garden production was not included in the total accounts before 1975. The total accounts series was chosen because the study primarily concerns basic agriculture.

The data from the total accounts of AERI have been converted to the price level of 1970. The sources of total accounts are the following: Ihamuotila (1972) for 1950—1960; Siltanen (1977) for 1961—1975; and the corresponding figures released by AERI for 1976—1984. The figures for 1950—1969 have been adjusted to correspond to calendar years, not crop years. State support (subsidies and compensations) as well as changes in the value of animal stock have not been included in the time series. The subperiods have simply been linked at 1961, 1964 and 1975.

4.3. Capital Stock

According to Vihavainen et al. (1980), the capacity of production of the capital stock is best approximated by the gross capital stock. This concept does not allow machines or buildings to depreciate before being taken out of production once and for all. The gross capital stock thus expresses the value of the real capital stock. In the net capital stock, on the contrary, the annual depreciations are subtracted from the capital stock.

In this study the gross capital stock has been used to measure the productive capacity of the capital stock. The main portion of the capital stock has been taken from the national income account at the price level of 1980. It includes agricultural buildings, soil and water constructions and machines, inventories and means of transport. The capital stock as defined in the national income accounts is presented in Appendix 5.

The capital stock measured by the preceding items has been corrected by adding cultivated land and livestock. Stores, any other land improvements, capital invested in growing crops and receivables, however, have not been included even though both IHAMUOTILA and STANTON (1970) and IHAMUOTILA (1983) took them into account. Moreover, their share in the whole capital stock is minor.

The information on cultivated area is based on the Monthly Review of Agricultural Statistics (Board of Agriculture) 1955—1984 and on the Official Statistics of Finland (OSF III, Agriculture 1950—1954). The value of land has been calculated according to the same principles used by IHAMUOTILA (1983) but at the price level of 1980. According to that study, this value was FIM 9,163 per hectare of field in production, whereas uncultivated field was valued at one-third less (FIM 6,109 per hectare).

The values for field mentioned above may seem low and certain reservations should be made, as the figures express averages for the whole country. There are large regional discrepancies in the value of land. Table 5 shows the total area and its value in the price level of 1980.

Table 5. The area and value of land 1950—1984 at the price level of 1980.

	Area (1,000 hectares)		Value of field FIM mill.
	in production	not in production	
1950	2,430.9		22,274
1951	2,458.2		22,524
1952	2,499.4		22,902
1953	2,516.4		23,058
1954	2,540.2		23,276
1955	2,565.7		23,510
1956	2,579.9		23,640
1957	2,596.1		23,788
1958	2,611.1		23,926
1959	2,633.3		24,129
1960	2,670.7		24,472
1961	2,670.7		24,472
1962	2,686.6		24,617
1963	2,703.2		24,769
1964	2,716.7		24,893
1965	2,731.2		25,026
1966	2,741.2		25,118
1967	2,743.6	2.8	25,157
1968	2,746.1	4.3	25,189
1969	2,666.3	86.5	24,960
1970	2,577.2	92.9	24,182
1971	2,554.8	113.0	24,100
1972	2,463.7	201.3	23,805
1973	2,435.5	223.8	23,684
1974	2,446.8	206.8	23,684
1975	2,453.8	187.5	23,630
1976	2,463.9	149.0	23,487
1977	2,452.2	191.0	23,636
1978	2,412.3	190.6	23,268
1979	2,401.5	187.5	23,150
1980	2,372.0	190.7	22,900
1981	2,355.7	184.2	22,711
1982	2,327.7	188.9	22,483
1983	2,314.4	152.2	22,137
1984	2,292.7	146.1	21,901

In order to include the value of livestock, information on the stock of animals for 1950—1980 has been taken from the studies mentioned earlier, i.e. IHAMUOTILA and STANTON (1970) and IHAMUOTILA (1983). The index series in the former has been linked to the latter in 1961. The series obtained in this way has been multiplied by the value of livestock in 1980. The result is an estimation of the value of livestock for the period 1950—1980.

On the basis of the latter study, the development of livestock in 1981—1984 has been followed up using the same principles. The value of cattle has, accordingly, been calculated as follows.

The value of one dairy cow at constant prices cannot be measured by multiplying the unit price in 1980 by the number of cows, since milk yield per cow has improved continuously and slaughter weight has varied. The current value is first calculated as in the study of IHAMUOTILA (1983) with slaughter weight as the starting point. This minimum value for a dairy cow has been positively adjusted by 35 % per year, a value considered to represent the difference between slaughter weight and the value of production in 1961 (IHAMUOTILA and STANTON 1970). This value has been raised by half of the index series showing the average milk yield per cow. The obtained value has been further adjusted by the price ratio of milk to meat, the result being the current value of one cow.

In 1980 the value of one cow was FIM 4,918 according to this calculation procedure. Rearing cattle has been valued at 60 %, and a calf at 25 % of the value of a dairy cow. This constant price for a young animal has been calculated on the basis of the price development of beef in the same manner as IHAMUOTILA (1983). Thus the price development is adjusted further by the price ratio of milk to beef. This figure, called the price component, is multiplied by the values current in 1981—1984, as mentioned earlier.

The value of pigs has been calculated simply on the basis of the volume of pork, using three different weight groups: 140 kg (over 6 months old), 72 kg (2—6 months old) and 15 kg (less than 2 months old). The volume of pork obtained in this way is multiplied by the price of pork in 1980 (FIM 10.09 per kg). In the same way sheep have been divided into two groups: ewes (over 1 year old, 20 kg) and lambs (under 1 year, 10 kg). The volume of mutton has been multiplied by the unit price in 1980 (FIM 18.53 per kg). The value of wool has not been considered. The value of one hen in 1980 was rated at 19 FIM per kg, that of one broiler FIM 8.40 per kg. The value of horses is simply based on the slaughter weight in 1980, which was FIM 3,870.

Table 6. The total gross capital stock in 1950-1984 in the prices of 1980 (FIM. million).

1950	56,448	1968	80,948
1951	58,012	1969	82,234
1952	60,097	1970	81,701
1953	61,307	1971	82,749
1954	62,861	1972	83,026
1955	64,303	1973	83,763
1956	65,401	1974	84,408
1957	66,614	1975	85,071
1958	67,845	1976	86,134
1959	69,169	1977	86,876
1960	70,868	1978	87,354
1961	72,480	1979	88,278
1962	74,124	1980	89,428
1963	75,734	1981	90,524
1964	77,075	1982	91,293
1965	78,197	1983	92,276
1966	79,626	1984	92,777
1967	80,528		

All figures on the size of livestock in 1950—1980 have been taken from the previously mentioned studies (IHAMUOTILA and STANTON 1970), (IHAMUOTILA 1983). The period 1950—1960 has been linked to the period 1961—1980. The whole period 1950—1980 has been multiplied by the constant values of livestock in 1980.

The total gross capital stock (Table 6) is the sum total of the value of land, livestock and the gross capital stock figures obtained from the national income account (agricultural buildings, soil and water constructions, machines, inventories and means of transport).

4.4. Labour and Education

The labour input is measured in working days done by family members and hired labour. The data for the period 1950—1960 are based on the index series of IHAMUOTILA (1972), which has been linked to the series of the Board of Agriculture for total labour input in agriculture 1961—1984 (Official Statistics of Finland III—Annual Statistics of Agriculture, and Monthly Review of Agricultural Statistics 8, 1985). In 1971—1972 a new basis of calculation was introduced in these series. For this reason the former and the latter series have been linked at 1972 in order to observe the difference of level (+29 % in the latter). The time series so obtained shows the amount of working days put into production (see Figure 13 and Appendix 2).

The quality of labour has improved in the period 1950—1984 through increased education and through learning by doing, as was pointed out by GRILICHES (1963 a). His method for adjusting labour input for these quality changes has been explained in section 2.3.2. A similar approach in this study proved to be difficult because of inadequate information on the number of years of schooling completed by the agricultural population.

The agricultural censuses of 1950, 1959 and 1969 (Official Statistics of Finland III) enquired into farmers' vocational and institute (first and second level) training as well as university education. From 1969 onwards this enquiry became part of the population censuses carried out every five years. The information from the censuses are not directly comparable. The census of 1950 shows that training had been received for farmer or the farmer's spouse only on 6.4 % of the 234,432 farms which responded. In the census of 1959 only 5.7 % of all 541,203 persons living on farms for which results were received had had training. In 1969 still only 7.5 % of farmers or farmers' spouses (454,228 people) had received an examination certificate, whether agricultural or non-agricultural. In 1980 17.6 % of farmers (203,201) had first, second or third level education of any sort, whereas the corresponding figure for the whole farm family (422,873 people) was 24.1 %. A very crude estimate would therefore be that the educational level of farmers has risen from 5 % to 20 % of farmers. Since adjustment of the labour input contains the subjective element of how to weigh an index series for the educational level, and since the effect of this adjustment would probably lead only to minor changes in the labour input index, the idea was totally abandoned.

Table 7. Examination certificates granted at agricultural schools in 1950—1984.

Year	National Board of Vocational Education	Central Statistical Office
1950	2,063	
1951	2,185	
1952	2,230	
1953	1,962	
1954	2,029	
1955	2,560	
1956	2,248	
1957	2,504	
1958	2,369	
1959	2,400	
1960	2,287	
1961	2,047	
1962	2,032	
1963	2,183	
1964	2,675	
1965	2,392	
1966	2,324	
1967	2,329	
1968	3,120[1]	
1969	3,040	
1970	2,800	
1971	2,310	2,388
1972	2,268	2,354
1973	2,302	2,377
1974		2,248
1975		2,020
1976		2,077
1977		2,221
1978		2,535
1979		2,913
1980		3,179
1981		3,518
1982		3,711
1983		3,774
1984		3,994

[1] Gardening, fur, fishery, dairy produce and other schools, not belonging to the sector of basic agriculture were not included before 1968.

Time series on the number of examination certificates granted at agricultural schools and institutes since 1971 are, however, collected by the Central Statistical Office. In addition, relatively rough figures on examination certificates prior to 1971 were obtained from the National Board of Vocational Education. These time series are shown in Table 7. A large proportion of the people obtaining a certificate go to sectors other than agriculture.

4.5. External Inputs Used in Production

Goods purchased by agriculture from other sectors of the economy comprise basic prerequisites e.g. fertilizer, concentrates, animal expenses including depreciation, obsolescence, and the maintenance of capital goods such as machinery and buildings. The time series on external inputs are based on the total accounts of agriculture by AERI, the sources being: Ihamuotila (1972) for 1950—1960; Siltanen (1977) for 1961—1975; Laurila (1981) for 1976—1980, and the corresponding figures of the Institute for 1981—1984. The series for the subperiods have been adjusted to make them correspond with each other. Thus animal expenses have been summed up with the series of Ihamuotila, while wage costs, social costs and rents have been subtracted from the series of Siltanen and Laurila. The period 1950—1969 has again been adjusted to correspond to calendar years. After this the subseries have been linked as gross production, again at the same points in time. The absolute values of the series on external inputs in constant prices are presented in Appendix 3.

4.6. Extension

Farmers receive information about research results through extension services. The role of extension is thus to speed up the application of results from research. In the model extension has been observed explicitly through the inclusion of a separate extension variable.

The extension variable is estimated on the basis of total State expenditure to public extension agencies, including the following: the Association of Agricultural Centres; the agricultural centres; the Association for Agricultural Societies of Swedish Speaking Farmers; the agricultural societies and the small farmer organizations (Pienviljelijäin keskusliitto, Pienviljelijäin liitto and Suomen pienviljelijäin liitto). Public expenditures for the specialized extension agencies, i.e. organizations giving extension services on a particular production line, e.g. bee, fur or lamb husbandry, have not been included. Strictly speaking, their inclusion would have been preferable since their share has been rising during the latter part of the period 1950—1984. The lack of available data on State support for these agencies limits the possibilities of including them in the total State expenditure for extension. The share of extension services paid by farmers themselves has not been included, the obvious reason being that farmers pay for these services themselves, and should thus not be accounted for. The extension activities of the private sector have been omitted for the same reason.

A complete time series for the period 1970—1984 was used in the study. The period 1951—1970, however, rests on data with five

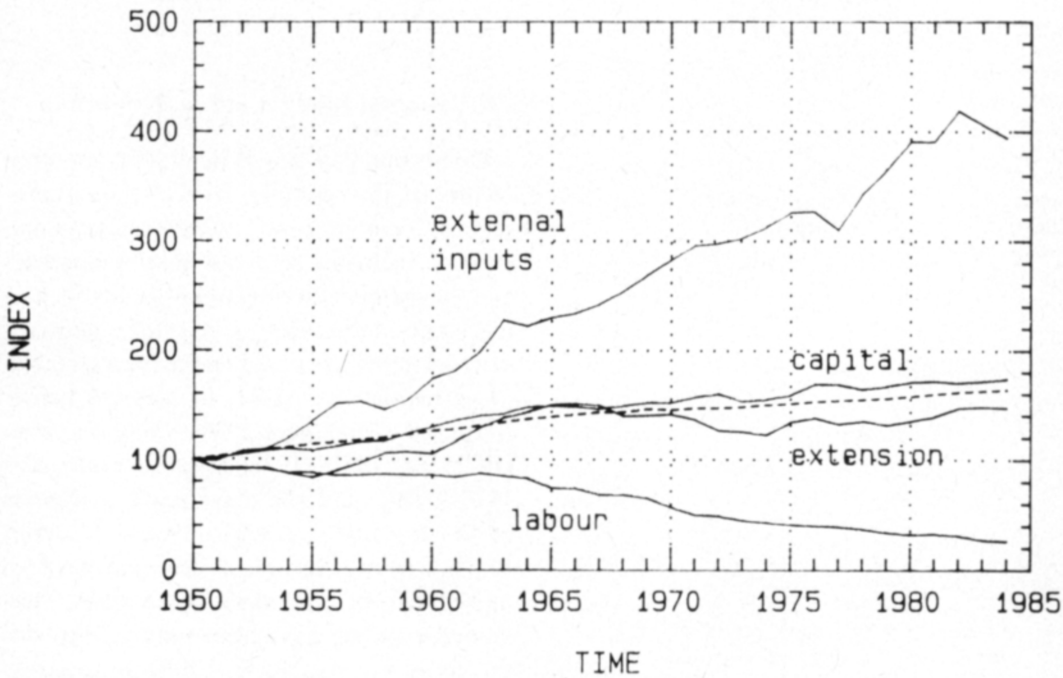

Fig. 13. Capital, labour, external inputs, extension and agricultural production (dotted line) in 1950—1984.

year intervals. The missing values have been estimated by linear interpolation. Extension expenditures in 1950 were assumed to be equal to those of 1951.

The total expenditures (including services paid by farmers) and State expenditures are presented in Appendices 3 and 4. The share of State expenditure out of total expenditures was the greatest in 1970 (66.6 % of expenditures) and has declined to 45.4 % in 1984.

The development of the capital stock, labour, external inputs, extension and gross output are presented in Figure 13.

4.7. The Research Input in the Public Sector in 1950—1984

Public research is defined here as research financed by public funds and carried out mainly at public research institutes and universities. Agricultural research, in turn, is understood to be research connected with basic agriculture and focusing on crop production, animal husbandry, agricultural economics, policy and technology. Research on garden production, indigenous energy sources (peat, straw, willow etc.), forestry and subjects which in the broad sense could be considered agricultural are not included in the research input in this study.

A particularly difficult question is which items of public expenditures allocated to agricultural research should be included in the research input of the public sector. How should capital costs, for instance, be treated? In a way, they do not affect research results in the short term, yet buildings, for example, are necessary in order to carry out research. To be certain not to underestimate the funds allocated to research, capital costs have been included in the data to the extent information about these costs have been reported. This may give rise to discussion, since the estimated returns, obviously, will be lower than if capital costs were not included. As was mentioned earlier, a major criticism of the early studies in this field was that too little of the costs of research were taken into account.

Another issue difficult to handle is the role of universities and how to distinguish education from research. Most students completing an university degree do not go into research but move into other occupations, often outside agriculture. Inclusion of the expenses of university education in research expenses will cause negative bias in the returns. One could, of course, also argue that without university education there would be no researchers. Because of the difficulties in distinguishing research from education, all university expenditures for both agricultural research and education are included in the variable, which may, of course, give rise to criticism. As was pointed out earlier, university research and education represent 24—52 % of total research input during the period studied.

No basic research (biological, chemical or mathematical) is included in the research variable. One can naturally uphold their appreciable value to applied research. The critical question is however: Through what channels does basic research affect applied research? The answer obviously, is through university education. The effects of basic research spread, through graduate education and research training, to applied agricultural research.

4.7.1. Research at Institutions under the Ministry of Agriculture and Forestry

The major share of public agricultural research carried out in Finland is done at institutions under the Ministry of Agriculture and Forestry. Only two of these institutions are research institutes in the real sense (the Agricultural Research Centre and the Agricultural Economics Research Institute), while the others are institutions mainly carrying out inspections. The Agricultural Research Centre is definitely the most important research institution. According to the estimate in this study, the Agricultural Research Center has represented three-fourths of the total research input carried out at institutions under the Ministry of Agriculture and Forestry during the 1970s.

Table 8. Agricultural research percentage; share of all subsidies to the institutions.

Institution	Percentage share representing research
Agricultural Research Centre	100 %
Agricultural Economics Research Institute	100 %
State Institute for Dairy Research	70 %
State Research Institute of Engineering in Agriculture and Forestry	30 %
State Horse Breeding Institute	25 %
National Veterinary Institute	20 %
State Control Office for Dairy Products	10 %
State Institute of Agricultural Chemistry	10 %
State Seed Testing Station	10 %
Seed Investigation Institute[1]	100 %

[1] This figure is not based on the report of Lemola et al.

The values reported by LEMOLA et al. (1975) have been used to assess how much of the activities at each institution is devoted to research purposes. They found the percentage of research of all activities in 1970—1975 to be that shown in Table 8. For the sake of simplification, the same percentage rates are assumed to have been relevant also in the 1950s.

This is obviously not the case since the research activities vary from one period to another. Because the Agricultural Research Centre is the institute accounting for the absolute major share of the expenditures and because 100 % of its funds are included, the risk of error should be only moderate.

So-called jointresearch projects carried out by other institutions, private or public, have been financed by the Ministry since 1975. The expenditures for these projects have been collected separately and added to the research input. All grants awarded to the Agricultural Development Fund, which has existed at the Board of Agriculture since 1975, have also been gathered and added to the sum. Moreover, some smaller issues, e.g. support for private laboratories, export control of agricultural produce, support for plant breeding and special grants, have been added to the final sum. Some minor issues may not be regarded as research in the strict sense, which may cause doubt. These issues are slight, however, and are included in order not to leave room for the accusation of having undervalued the allocations for agricultural research.

4.7.2. The University of Helsinki and the College of Veterinary Medicine

A considerable part of agricultural research and education is carried on at the Faculty of Agriculture and Forestry of the University of Helsinki. About an equal amount of money is granted to the College of Veterinary Medicine. According to the estimate in this study, the part of agriculture of the total funds for the University were about FIM 1 million in 1960 and about FIM 20 million in 1984. These figures include no other scientific discipline at the Faculty (forestry, food, environmental sciences etc.). The total funds for the College of Veterinary Medicine were FIM 1.3 million and FIM 24 million in the same years.

Collecting information about the funds spent on agricultural sciences in relation to the whole budget of the Faculty of Agriculture and Forestry proved to be very difficult. The largest share of the expenditures are, however, wages and salaries. The following simplification was made to calculate the share of the agricultural sciences. It was assumed that the number of agricultural professors and assistants in relation to the total number of professors and assistants in the University rather satisfactorily indicates the extent of resources spent on agriculture out of all grants to the University of Helsinki. This assumption includes the share of administration expenses in the agricultural sciences as well. Alternatively, the number of teachers could have been included. However, since the number of visiting lecturers was very high in the early 1950s, it would have led to an incorrect assessment of the development of funds for agricultural research and education.

On the whole, the size of the margin of

error involved in this method for valuing university expenditures for agriculture is not known. It is noteworthy that the figure obtained for 1984 (FIM 20 million) for agricultural research and education is the same as the figure reported by the Central Statistical Office of Finland for all research activity in the whole faculty, i.e. including forestry, food and environmental sciences, without education and administration.

According to the above calculation method for university expenses, the College of Veterinary Medicine and the Faculty of Agriculture and Forestry represent the largest share of research input after the Agricultural Research Centre. These three institutions taken together stand for the absolute major share of research input in agriculture.

4.7.3. The Academy of Finland

The Academy of Finland consists of seven research councils including the Research Council for Agriculture and Forestry. Furthermore, there is one central committee for the research councils and an administration office. Before 1961 there were only two research councils: one for natural sciences and one for the humanities. The distribution of resources between different research councils at the Academy, including the agricultural and forestry sciences, are available for 1975—1984 and for 1964—1969. The figures for the period 1970—1974 have been valued on the basis of the information available on all resources granted for research and researcher training purposes and the percentage distribution of research grants (see the annual reports of the research councils in Valtion tieteelliset toimikunnat 1961—1969, Tieteen keskustoimikunta ja Tieteelliset toimikunnat 1970—1974, Kertomus Suomen Akatemian toiminnasta 1975—1983). The expenditures for the central committee for the research councils and administration have not been included because of the lack of more detailed information over time and the small share of total expenses (about 10 % or less).

The share of the agricultural sciences out of all expenditures granted by the Research Council for Agriculture and Forestry is not given in the annual reports before 1977. During 1977—1984 the share of agricultural sciences of these resources rose from 29.9 % to 44.8 %; see Table 9:

Table 9. The share of agricultural sciences of all funds granted by the Research Council for Agriculture and Forestry in 1977—1984.

Year	Percentage
1977	29.9
1978	29.6
1979	33.1
1980	38.8
1981	30.2
1982	34.5
1983	36.7
1984	44.8

The arithmetic average during these years was 34.7 %, or roughly one-third. The simple assumption that the agricultural sciences have received one-third of all funds for the agricultural and forestry sciences also during the period of 1961—1976 is therefore made. In current value, the funds amounted to FIM 3.5 million in 1983 and FIM 5.4 million in 1984.

The figures for the period 1950—1961 are based on the minutes of the Research Council for Natural Sciences. The information gathered on this period is very unreliable, and is partly mere guesswork. However, it probably reflects the order of the size of funds for agricultural sciences granted by the Academy to research, researcher training and scientific societies.

4.7.4. Finnish National Fund for Research and Development and Public Foundations

The funds granted by the Finnish National Fund for Research and Development (SITRA) as well as the Finnish Cultural Foundation (Suomen Kulttuurirahasto) and the Maj and Tor Nessling Foundation have been included in the the research input. SITRA has granted resources since 1968, and the funds reached their peak in 1981, when FIM 4.7 million were granted for agricultural research. In some years agricultural sciences received no funds at all from SITRA.

Because it proved to be very difficult to separate the agricultural and forestry sciences, all funds for these sciences granted by the Maj and Tor Nessling Foundation and the Finnish Cultural Foundation were included. The funds granted by the Finnish Cultural Foundation have only been around FIM 0.5 million (1983—1984) or less to all agricultural and forestry sciences, the grants of the Maj and Tor Nessling Foundation even smaller.

4.7.5. Work Efficiency Association

The Work Efficiency Association was founded in spring 1924. Alreday from the start the Association has received a certain amount of government support, but the major share of its activities has been financed by the Association's own means. The research activities have traditionally been divided into three areas: forestry, home economics, agricultural and construction research. A certain amount of extension is practised as well. The primary goal is to investigate rationalization methods in these areas.

The construction and agricultural research represents the type of research that is the focus of this study. In 1983 the expenses of the Association's agricultural and construction department were about FIM 2.8 million.

The research expenditures of the Work Efficiency Association have been based on the following assessments. The expenditures of the agricultural and construction department are reported in the annual reports for 1974—1984. This part of all research efforts is not separately reported for earlier years. The department's share of total expenditures in 1974—1983 equalled 10.0—16.5 %. The department seem to have received about the same share of resources also in earlier years. Based on the assumption that 14 % of the Associations' expenditures have been devoted to construction and agricultural research, a time series was constructed for 1950—1973. Minor cost items (rent, depreciation, the interest rate) and expenditures for the vocational centre have been subtracted from total expenditures. The total time series for 1950—1984 is added to the previous research input.

4.7.6. Agricultural Research Outside the Research Definition

The *Technical Research Centre of Finland* carries out a small amount of research in the primary sector. Lemola et al. (1975) stated that 1.1 % of research expenditures in the operational plan 1976—1980 was devoted to agriculture and forestry, hunting and fishing. A large part of this share was research connected with forestry. At the Domestic Fuel Laboratory the major part of research work is connected with peat production, which very broadly could be regarded as agricultural research. The Biotechnical Laboratory and the Food Research Laboratory carry out some research relatively close to agriculture; for instance, malt barley has been bred in order better to suit the needs of malt houses. Research connected with gene technology will increase in the future, but so far the magnitude of this research has been very small. If agricultural research were defined very broadly, at the most FIM 1 million of the current research expenditures could be regarded as connected with agriculture. The research carried out at the Technical Research Centre, however, does not agree with the definition of agricultural research applied in this study.

The Ministry of Trade and Industry grants funds for research on domestic fuel resources. As mentioned above, this can hardly be considered agricultural research.

The expenditures of the *Pellervo Economic Research Institute* have not been included in the research input. Strictly speaking, these funds should have been included. The research institute has, however, existed only since 1979, and the volume of the research input has been small. Though the omission is probably not justifiable, it hardly affects the estimation.

4.7.7. The Development of the Public Research Input in 1950—1984

In order to obtain the aggregate research input, all the expenditures mentioned in the previous subsections of 4.7. have been summed up. The sum has been deflated by the GDP market index and is expressed in the pricelevel of 1980. The aggregate volume of public research is presented in Table 10 and Figure 14.

Table 10. Expenditures for public agricultural research in 1950—1984, deflated to the level of 1980 (FIM 1,000).

Year	Research expenditures	Year	Research expenditures
1950	17,610	1968	70,080
1951	24,180	1969	65,653
1952	22,437	1970	60,882
1953	20,936	1971	60,798
1954	20,727	1972	69,325
1955	24,934	1973	70,312
1956	28,442	1974	65,222
1957	27,151	1975	80,503
1958	40,513	1976	84,423
1959	39,713	1977	109,600
1960	37,507	1978	92,712
1961	39,130	1979	109,753
1962	51,995	1980	111,538
1963	53,319	1981	114,319
1964	52,039	1982	107,503
1965	62,740	1983	108,186
1966	64,508	1984	109,123
1967	64,221		

The research input has risen faster than other inputs since 1950. Therefore it seems natural that the effects of research have also grown more rapidly. Variations in the outlays for certain years can be noted. Funds for the University of Helsinki and the Agricultural Research Centre increased rapidly at the end of the 1970s, which can be seen from the time series. Since the peak in 1981, the funds have remained on the same level as at the end of the 1970s.

4.8. The Research Input in the Private Sector in 1950—1984.

The private sector carries out a considerable amount of research. The issue whether or not research carried out in the private sector should be included in research input is intricate. The arguments for taking the private research into account shall be discussed first.

Given the fact that means of production improve because of the research done in the private sector, it seems only natural to include private research. Because information about the volume of this research has been difficult to acquire, simple assumptions have often been made. To give an example, Peterson (1971) assumes that private research was equal to public research in the follow-up study of Schultz' (1953) pioneering calculation.

Peterson (1985) maintains that the value of the marginal product of newer inputs is higher than their prices, and that the impact of private research is thus higher than prices reflect. In other words, one kilogram of fertilizer in 1980 has a bigger effect on production than one kilogram of fertilizer in 1950. Public research may catch some of the quality improvements carried out in the private sector in case private research is not considered.

On the other hand, one could argue that the private sector transfers expenditures for research on the input prices (i.e. the external inputs), and that farmers in this way actually pay for the research carried out by private firms. One part of the prices of purchased inputs can be called a ''research cost''. To include the private research would be to count the same cost twice as a separate variable for external inputs has been included in the model. Most studies seem to neglect this important issue, since some studies account for private research while others do not.

In this study a middle road was chosen. Two different research variables are used parallelly in the estimation procedures. One measures only the public research input, whereas the other measures the total private *and* public research input. The data for the public sector has already been reported earlier in this chapter (4.7.).

The information about the research expenditures of the private sector is deficient, and the estimates of the elasticity with respect to total research must therefore be seen with caution. First of all, it has to be noted that expenditures only cover part of the aggregate expenditures invested in research by Finnish firms.

The following procedure was used to construct a variable for total agricultural research in 1950—1984 that would include both the private and the public sectors. To start with, eight of the most important companies dealing with agricultural research were contacted. Statements on research expenditures for improving inputs used in agricultural production were received. However, only a few firms gave information that covered the whole period. The data was therefore reliable for all the companies only for the 1980s. In addition, some of the companies could give exact information only about operating expenditures, not on capital outlays. The companies that were willing to give statements on their capital outlays differed clearly as to the relation of operating costs to capital outlays.

A simplifying assumption is therefore necessary. It is assumed that capital costs equal half of the operating expenses. This assumption enables an estimation of all expenditures for the private sector. A time series of total private expenditures in 1950—1984 can be constructed for the private sector, based on the assumption that the expenditures have grown at the same rate as for the few companies that provided information about their expenses for the whole period 1950—1984. The time series calculated by such assumptions was then deflated by the GDP market price index. The index series obtained is presented in Appendix 2. In Figure 14 a graphic illustration of the index series is given.

A clear warning must be given that the data is unsatisfactory and that the calculated value marginal products for the total public and

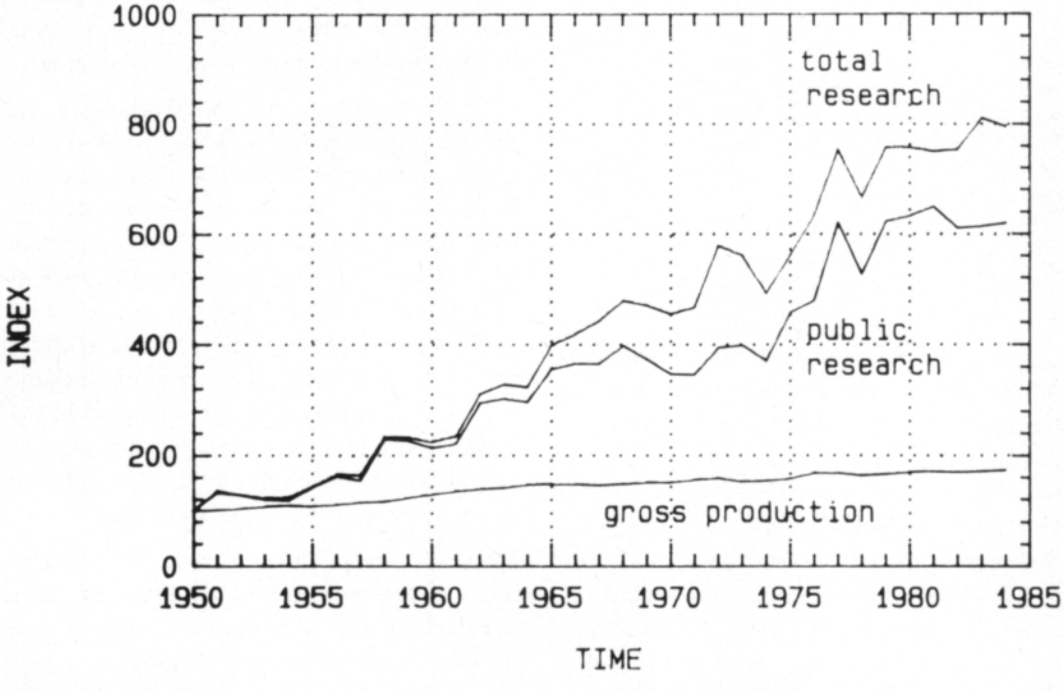

Fig. 14. The development of the public and the total research input and of agricultural production in 1950—1984.

private research should not be taken literally. Too little of the expenditures on research by the private sector have been included. The best way to interpret the estimates is therefore to see them in relation to the coefficients estimated only on the basis of the public research input. Seen in this way, the total research input provides some complementary facts to the results based solely on the public research expenditures.

5. Presentation of the Results

5.1. The Research Input Measured as a Flow

Various specifications of the production function have been formulated in chapter 3. The most important distinctions are those between

1. Specification of the research variable as a flow of annual funds or as a stock of research capital;
2. A linear or a Cobb-Douglas form of the production function;
3. An unlagged or a lagged research variable;
4. A public research variable or a total research variable;
5. Traditional input variables capital, labour, external inputs (and production) specified at aggregate or at per farm level.

The following Figure 15 illustrates the various alternatives for specification used in this study:

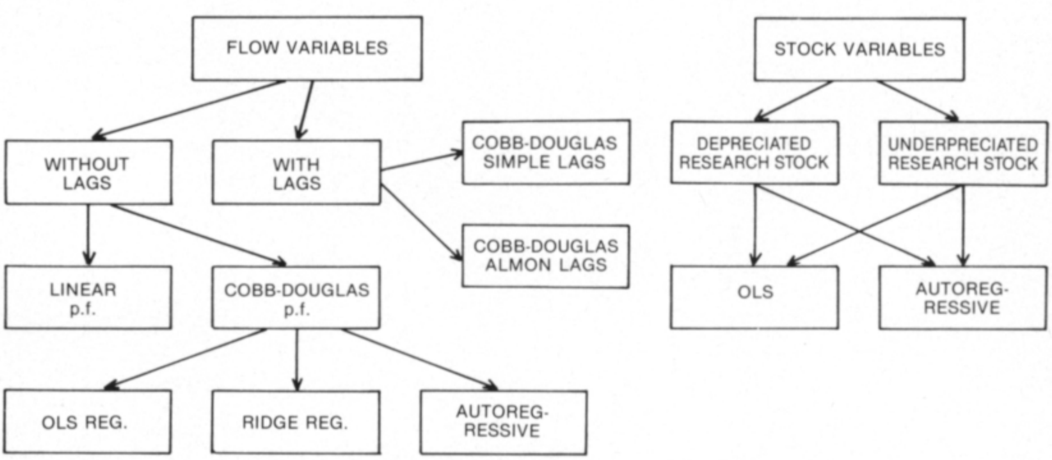

Fig. 15. Various alternatives of model specification and methods of regression.

The results of the regressions, including a specification of the research variable as a flow of annual public or total funds, are reported in sections 5.1. and 5.2. The regressions that include a stock of research capital are presented in section 5.3.

Section 5.1. analyses the results of specifications with no lags included for the research variable specified as a flow. For each unlagged research variable the traditional inputs have been specified in two ways, on aggregate and on farm level. Sensitivity analysis is applied so that in the regressions, the extension factor is added later. The internal correlation between explaining variables is examined, and the results of ridge regressions are reported. The regression results from autoregressive models of the first and second order (without any lag) are reported, and Cobb-Douglas regressions for the shorter periods 1950—1969 and 1965—1984 are finally summarized.

Section 5.2. reports the results of the models including simple lags and polynomial lags for the public research variable.

The results of the regression specifications including the research variable as an undepreciated or depreciated stock are discussed in section 5.3. In subsection 5.3.3., the results of regressions which include a total productivity index as the dependent variable are presented.

Finally, in chapter 6, a value marginal product and a marginal internal rate of return are computed.

5.1.1. Linear Flow Models without Lags

The results of the linear functions specified as (3.10) are presented in Tables 11 and 12 (public research) and in Appendices 6 and 7 (total research). The parameter estimates of the inputs should be interpreted as marginal physical products.

The linear models specifying the three traditional variables at aggregate level (Table 11) have fairly high coefficients of determination, exceeding 0.98. Analysis of variance for the full regression shows a high F-ratio, with a level of significance less than 0.001 %. The Durbin-Watson test value of 0.96—1.02 indicates a heavy autocorrelation between the residuals. The standard error of the estimate is approximately 3.3 in both regressions.

An examination of the correlation matrix (Tables 15) shows that the independent variables are highly correlated. Except for the extension, all the simple correlation coefficients are over 0.90, a fact which seriously limits the reliability of the coefficients. The parameter estimate of capital could be accepted on a level of significance less than 0.001 (i.e. a confidence level of over 99.9 %). The external parameter estimates of inputs and labour prove to be problematic. The labour coefficients are insignificant with high standard errors, while the parameter estimate of external inputs is negative. One reason could be the collinearity between variables, as it is difficult to sort out the influence of one regressor, e.g. external inputs from another. Thus the parameter estimate of capital seems

Table 11. Linear production functions with public research. All variables measured at aggregate level. Regression coefficients and their standard errors in parenthesis below the coefficients, significance levels, coefficient of determination, F-ratio and Durbin-Watson test values.[1]

Regression	(1)	s.l.[2]	(2)	s.l.
Constant	—43.460 (15.464)	0.009	—20.674 (23.351)	0.383
Capital	1.277 (0.149)	0.000	1.081 (0.211)	0.000
Labour	0.116 (0.098)	0.250	0.006 (0.129)	0.963
External inputs	—0.010 (0.043)	0.820	—0.014 (0.043)	0.750
Public aggregate research	0.018 (0.012)	0.154	0.016 (0.012)	0.200
Extension			0.094 (0.073)	0.207
R^2	0.982		0.983	
Stand.error of estimate	3.354		3.317	
F-ratio[3]	420.86***		344.52***	
D-W test value	0.960		1.023	

[1] These coeffients, the F-ratio and D-W test-value will be presented in all the regression tables.
[2] Significance levels with t-test. The abbreviation applies to all regression tables.
[3] *** = Significance level for F-ratio ≤ 0.001 %. The abbreviation applies to all regression tables.

Table 12. Linear production functions with public aggregate research. Output, capital, labour, external inputs measured at farm level, research and extension at aggregate level.

Regression	(3)	s.l.	(4)	s.l.
Constant	—19.053 (10.904)	0.091	—18.553 (10.836)	0.098
Capital	1.091 (0.117)	0.000	1.061 (0.119)	0.000
Labour	0.031 (0.093)	0.738	—0.024 (0.104)	0.818
External inputs	—0.023 (0.036)	0.531	—0.019 (0.036)	0.601
Public aggregate research	0.046 (0.023)	0.053	0.040 (0.024)	0.101
Extension			0.090 (0.075)	0.243
R^2	0.997		0.997	
Stand.error of estimate	5.303		5.267	
F-ratio	2344.6***		1902.1***	
D-W test value	1.133		1.164	

to be rather high, the values varying between 1.08 and 1.28. The inclusion of a trend factor in the regressions did not improve the coefficient of determination.

Figure 16 shows how the regression line of regression (2) fits the observations. From the Figure it is evident that autocorrelation occurs. In Figure 17 the distribution of residuals for regression (2) is presented.

The parameter estimate of the research variable is of particular interest in this study. The size of the estimate is approximately the same in the aggregate regressions, 0.016—0.018. The level of significance for this estimate varies from 0.154 to 0.200 thus not being significant.

Table 12 shows that when models with the traditional variables specified at farm level were estimated, the coefficient of determination rose to 0.997, while the standard errors of the estimates rose to approximately 5.3. The residuals are autocorrelated to a slightly lesser degree than in Table 11. The parameter estimates of the research variable gain confidence, being modestly significant and clearly higher, ranging from 0.040 to 0.046. The parameter esimate of external inputs is still negative, and after the inclusion of the extension factor the sign for the parameter estimate of labour also becomes negative. The interpretation of the parameter estimates of traditional variables must be treated differently when defined at farm level. The parameter estimate of research has the same interpretation, since it is defined at aggregate level in both cases. The observed values and the corresponding values estimated by regression (4) are illustrated in Figure 18.

The results of the regressions including a total research variable differ somewhat from the previous results (see Appendices 6 and 7). The parameter estimates of labour are higher than in Tables 11 and 12, with a better significance. When traditional inputs are specified at aggregate level, the parameter estimate of total research varies from 0.022 to 0.025, with a clearly higher significance (0.057 and 0.102) than in regressions (1) and (2). When traditional variables are specified at farm level, the parameter estimate of research rises to 0.054 and respectively, 0.047 and the parameter significance increases to 0.020,

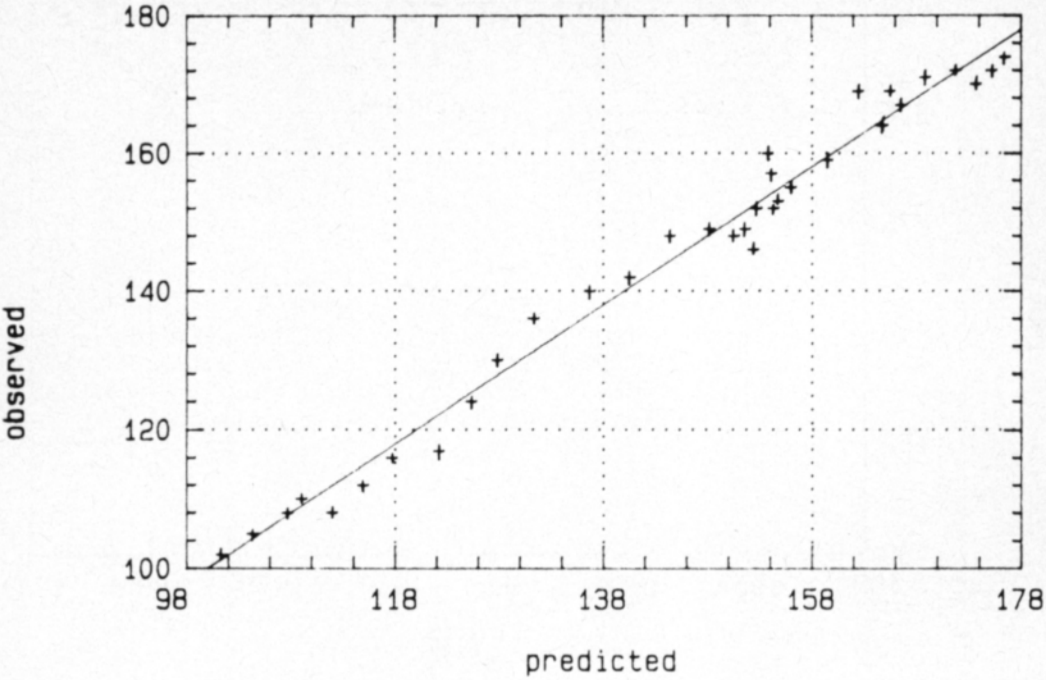

Fig. 16. Regressions for the linear model (2).

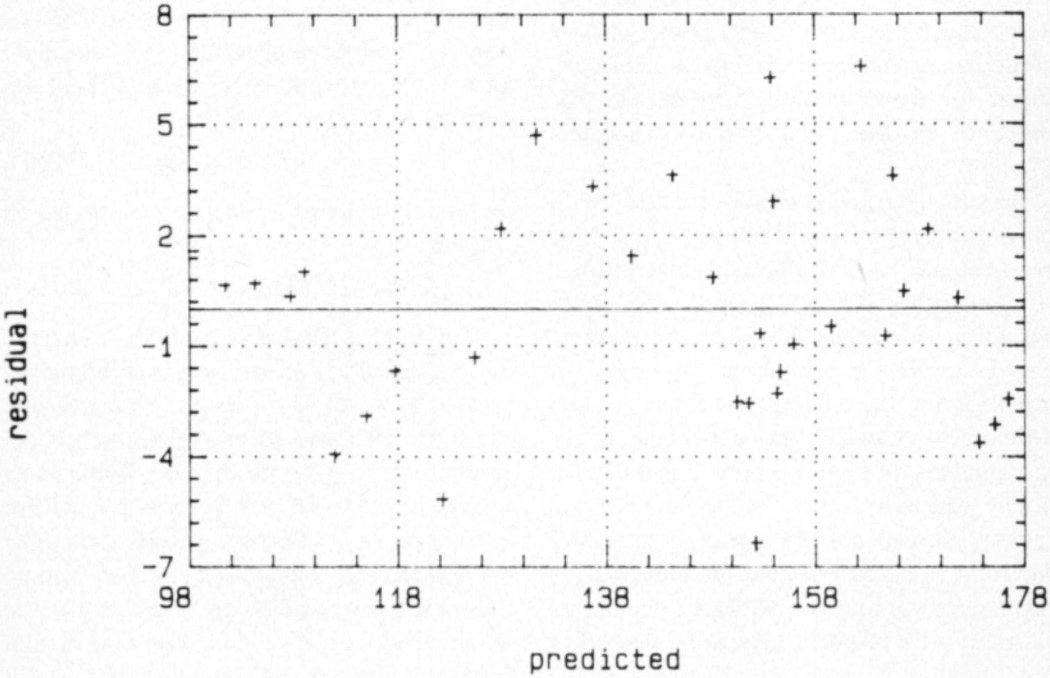

Fig. 17. Residuals for the linear model (2).

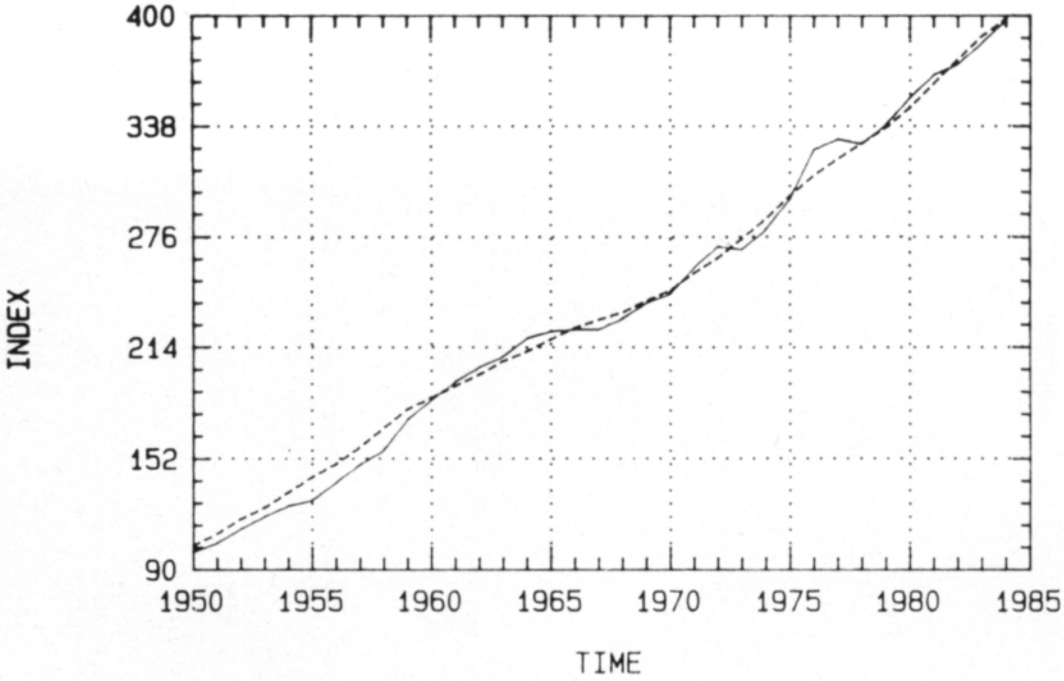

Fig. 18. Observed values of production and corresponding values estimated by regression (4) (dotted line).

and respectively, 0.067. The coefficient of determination rises to 0.997, compared with 0.983—0.984 when the traditional variables were specified at aggregate level, and the autocorrelation slightly decreases. The inclusion of a trend factor did not raise the coefficient of determination, whereas the significance of the other variables becomes lower.

Because the regressions are estimated on the basis of index series, it is not possible to read the absolute level of the marginal product straight from the parameter estimates of the variables; rather they have to be changed into elasticities. If for a moment we forget the doubts about the reliability of the parameter estimate of research, which is equal to the marginal product, and assume it is 0.016 for public research, which is the smallest parameter estimate of public research, and 0.022 for total research estimate, as indicated by regressions (2) and (6), we can calculate an elasticity with respect to research input. For the function $y = f(x)$, the elasticity of the change in y to changes in x is given by:

$$(5.1) \quad E = \frac{dy}{y} : \frac{dx}{x} = \frac{x}{y} \times \frac{dy}{dx} = \frac{x}{y} \times b$$

The average for gross production in the index series is 143.03, for public research 354.00 and for total research 428.00. The elasticity with respect to public research is then, according to (5.1):

$$E_p = 354/143.03 \times 0.016 = 0.040$$

and the elasticity with respect to total research similarly:

$$E_t = 428/143.03 \times 0.022 = 0.066$$

This implies that during 1950—1984 the agricultural gross production would have increased by 0.040 % for every 1 % increase in the funds allocated to public research. Correspondingly, gross production would have increased with 0.066 % for every 1 % increase in total public and private spending on agricultural research. To make it easier we assume these elasticities, which are averages for the whole period, to be valid in 1984. Subtracting the State subsidies and compensations as well as outdoor production from the gross production in agriculture in 1984, one obtains FIM 19,403.9 million as the value of gross production. Since the public funds for research were FIM 157.0 million and total public and private research spending was FIM 230.1 million a preliminary value marginal product can be computed according to expression (6.2).

Public research: VMP =

$$\frac{0.040 \% \times \text{FIM } 19{,}403.9 \text{ million}}{1 \% \times \text{FIM } 157.0 \text{ million}} = 4.94$$

Total research: VMP =

$$\frac{0.066 \% \times \text{FIM } 19{,}403.9 \text{ million}}{1 \% \times \text{FIM } 230.1 \text{ million}} = 5.57$$

In case the reservations made concerning the linear production function are accepted and the elasticities with respect to public and total research are valid, a value marginal product of 4.94 for public research and 5.57 for total research is obtained. This means that every additional FIM allocated to public research would return as an annual value of FIM 4.94. Similarly total private and public research would yield a return of FIM 5.57 for an additional increase of FIM 1 in research spending. This is clearly not the true value marginal product, since the costs of extension not have been included, no lags are accounted for, and research expenditures are undervalued on the part of total research. Despite these deficiencies, the very high value marginal products still gives some preliminary information about the returns from research.

5.1.2. Cobb-Douglas Models without Lags

The Cobb-Douglas function is the most common form of the production function used in estimating the returns to research. The estimates of the parameters in (3.9) are presented in Tables 13 and 14. According to a well-known theorem in price theory, the exponent in the Cobb-Douglas function is equal to the production elasticity of that input. The parameter estimates of the variables should therefore be interpreted as elasticities.

The coefficient of determination is 0.984 in regression (9) and increases to 0.986 when extension is added. The total variation explained is thus slightly higher than in the linear regression. The inclusion of a trend factor did not improve the coefficient of determination. The standard errors of estimates lie in the

Table 13. Cobb-Douglas production functions with public research. All variables measured at aggregate level.

Regression	(9)	s.l.	(10)	s.l.
Constant	—0.343 (0.926)	0.714	0.026 (0.906)	0.977
Capital	0.902 (0.305)	0.007	0.765 (0.303)	0.017
Labour	0.043 (0.024)	0.085	0.008 (0.030)	0.800
External inputs	0.064 (0.094)	0.503	0.064 (0.090)	0.483
Public aggregate research	0.059 (0.037)	0.120	0.034 (0.037)	0.374
Extension			0.121 (0.062)	0.061
R^2	0.984		0.986	
Stand.error of estimate	0.024		0.023	
F-ratio	452.16***		396.29***	
D-W test value	1.039		1.106	

Table 14. Cobb-Douglas production functions with public research. Output, capital, labour, external inputs measured at farm level, research and extension at aggregate level.

Regression	(11)	s.l.	(12)	s.l.	(13)	s.l.
Constant	—0.418 (0.336)	0.223	—0.225 (0.350)	0.526	—0.560 (0.381)	0.152
Capital	0.933 (0.142)	0.000	0.853 (0.147)	0.000	0.947 (0.150)	0.000
Labour	0.057 (0.027)	0.042	0.044 (0.027)	0.118	0.010 (0.031)	0.762
External inputs	0.095 (0.079)	0.241	0.088 (0.094)	0.266	0.035 (0.079)	0.663
Public research			0.059 (0.037)	0.121	0.018 (0.041)	0.661
Extension					0.107 (0.057)	0.070
R^2	0.997		0.997		0.997	
Stand.error of estimate	0.025		0.024		0.023	
F-ratio	3026.5		2383.7***		2068.8***	
D-W test value	0.833		1.011		0.990	

range of 0.024. The level of significance for the F-value is less than 0.001 %, indicating a strong linear-logarithmic relation between the whole group of explanatory variables and the independent variable. The Durbin-Watson test value shows a heavy autocorrelation also for the Cobb-Douglas function.

The parameter estimate of capital is significant and seems to be high, 0.77—0.90. The parameter estimate of labour is relatively significant in regression (9) but becomes insignificant when the extension factor is added. The parameter estimate of external inputs has the same value in both regressions, 0.064, but is clearly insignificant. The parameter estimate of the research variable is almost significant at the 10 % level in (9), but confidence decreases when the significant variable extension is added. The total sum of parameter estimates for the explaining variables is 1.068, and respectively 0.992, which does not indicate economies of scale. This could be expected, since farm size has increased during the period studied only to a relatively small degree.

Although the sum of the parameter estimates appears acceptable, one could question the size of the parameter estimate for capital. Because of the multicollinearity, the capital estimate could erroneously be attributed to some influence originating from one of the other factors. Some experiments with ridge regressions (see section 5.1.4.) suggest this to be the case.

The coefficient of determination rises to 0.997 when specifying the traditional variables on farm level in the Cobb-Douglas model (the same happened in the linear model). The most notable difference is that the regression coefficient for research falls from 0.059 in (12) to 0.018 when extension is added (in 13). There is not a big difference in most other measures. Remarkable, however, is that the coefficient of determination is 0.997 even before the research coefficient is added. This shows that the research coefficient does not improve the explanatory power of the model when the traditional inputs are defined on farm level.

Regressions (14) and (15), which include a variable for total public and private research with the traditional variables specified at aggregate level, are presented in Appendix 8. The regression coefficients do not differ much from the regressions measuring only public research. The parameter estimate of total research is, as could be expected, somewhat greater and slightly more significant than the coefficient for only public research. It is 0.078 (s.l. 0.079), respectively 0.050 (s.l. 0.261), depending on whether or not the extension factor is included.

Regressions (16) and (17) measuring the traditional production factors on farm level are presented in Appendix 9. Compared to the regressions measuring research with the public funds, differences can be noted in the size of the coefficients for external inputs and for research. The regression coefficient for total research is 0.061 (s.l. 0.089) respectively 0.021 (0.602).

The following summary of the size and significance levels of the research variable can be made: The public research elasticity for the linear production function is 0.040—0.044 when transformed from the marginal product in regressions (1) and (2). When the traditional variables are measured at farm level in regression (3) and (4), the estimate of elasticity with respect to public research becomes 0.099—0.114. Both the latter research elasticity estimates in the linear production function are accepted at a confidence level of at least 90 %. In the Cobb-Douglas function the elasticity with respect to research in (9) and (10) varies between 0.034 and 0.059, and in (12) and (13) between 0.018 and 0.059. The marginal product of 0.016 was transformed according to (5.1) to an elasticity of 0.040. This was used as a crude estimate to compute a value marginal product of 494 % for public research. The estimate cannot, however, be taken seriously because of lack of reliability owing to autocorrelation problems, intercorrelation between explanatory variables and positive bias because of the omission of all lags.

In the linear production functions the coefficient of total research can be transformed into an elasticity of 0.066—0.075 when traditional inputs are measured in aggregate, and an elasticity of 0.14—0.16 when traditional inputs are measured at farm level. The inclusion of a significant extension factor decreases the elasticity to a certain degree. The higher the elasticity is, the better the significance level appears to be (for an estimate of the elasticity with respect to total research, 0.16, the corresponding confidence is almost 98 %). Cobb-Douglas functions give the corresponding elasticities of 0.050—0.078 (traditional variables specified at aggregate level) and 0.021—0.061 (at farm level). The estimates of elasticity with respect to total research seem to be higher than the estimates of elasticity with respect to public research, but this is perfectly logical since total research also include private research in addition to the public funds. The same serious limtations mentioned in connection with the public research estimates concern the reliability of these nonlagged total research coefficients.

5.1.3. Multicollinearity and Ridge Analysis

One of the most common difficulties occurring in time series analysis is intercorrelation between the explaining variables. This study was no exception. When the internal correlation between the regressors was examined, a strong multicollinearity could be observed for both the linear variables and their logarithmic transformations. The correlation matrix for the variables is illustrated in Table 15.

All of the explaining variables except extension show a high linear relationship. Capital, labour, external inputs and public research correlate by more than 0.90. Public research correlates 0.77—0.96 with the other regressors (and, naturally, the total public and private research do so as well). The correlation between the dependent variable and the explaining variables on the contrary, forms the basis of the whole regression analysis. The internal correlation between the regressors, however, probably leads to unstable coefficients, which implies that the real values may be substantially different.

To examine further the internal correlation between the logarithmic transformations of the variables their correlation matrix are shown in the next Table 16.

Table 15. Correlation matrix for the variables.

Variable	Dependent variable Y	Regressors X				
		Capital	Labour	External inputs	Public research	Extension
Output	1.000					
Capital	0.990	1.000				
Labour	—0.909	—0.929	1.000			
External inputs	0.963	0.977	—0.967	1.000		
Public research	0.944	0.948	—0.935	0.962	1.000	
Extension	0.877	0.862	—0.659	0.785	0.775	1.000

Table 16. Correlation matrix for the logarithms of the variables

Variable	Dependent variable Y	Regressors X				
		Capital	Labour	External inputs	Public research	Extension
Output	1.000					
Capital	0.990	1.000				
Labour	—0.848	—0.873	1.000			
External inputs	0.982	0.993	—0.899	1.000		
Public research	0.976	0.979	—0.872	0.972	1.000	
Extension	0.903	0.882	—0.622	0.854	0.878	1.000

No major difference can be noticed between the ordinary expressions of the variables and their logarithmic tranformations. The reason why extension is less correlated with the other variables is probably because it has been derived by interpolation with five-year intervals for the period 1950—1970.

The strong correlation between the regressors introduce some heavy doubts about the reliability of the estimated parameters. The estimates may have the wrong sign, or may be of completely wrong size. Methods to investigate multicollinearity have been developed, however. One such method is ridge analysis. An overview of ridge analys is given in Draper and Smith (1981), while a shorter summary is found in Fomby et al. (1984). The original presentation was made by Hoerl and Kennard in 1970.

The ridge procedure is intended for situations where the correlation between regressors causes the X′X matrix to be close to singular, thereby giving rise to unstable parameters which are unreasonably high or have the wrong sign. By introducing a slight bias the parameters may, in case of correlated independent variables, be closer to the true parameters than the unbiased ordinary least squares (OLS) estimates. The ridge parameter θ (theta) is allowed to control the bias.

The normal equations in the OLS procedure are given by

$$(5.2) \quad X'X\,\beta = X'y$$

and

$$(5.3) \quad b = (X'X)^{-1}\,X'y$$

In the ridge procedure the ridge parameter $\theta \geq 0$ is introduced as follows

$$(5.4) \quad b(\theta) = (X'X + \theta I)^{-1}\,X'y$$

In applications the interesting numbers of θ are usually found in the range of 0.1, though values up to 1.0 are used. When $\theta = 0$ the resulting ridge estimator is the same as the OLS estimator. For different values of θ we can plot different values of the estimates, i.e. we can plot a ridge trace to enable a direct comparision to be made between the relative effect of the various coefficients. As θ is increased the estimates become smaller in absolute value, tending to zero in infinity. At a certain value of θ the system will stabilize and have the general characteristics of an orthogonal system. Cofficients with incorrect signs will change to become correct (DRAPER and SMITH 1981).

According to Draper and Smith, blind use of ridge regression can be dangerous and misleading. They suggest two cases for which it is absolutely correct to use ridge regressions in spite of the subjective element involved (the choice of θ). The first is when prior knowledge (or belief) exist that smaller values of the estimates are more likely than larger ones. If a small value is used for θ it means that we believe the OLS is not producing unreasonably big values. The second case we need not deal with here. We note two dangers involved in ridge regressions:

1. Are we really sure about the prior knowledge of too high coefficients?
2. The nonsignificant estimated regression coefficients change to a greater extent than the significant estimated coefficients.

On the basis of the OLS estimates presented in subsections 5.1.1 and 5.1.2., prior questions on the size of the capital estimate could have been raised. In the linear production function, the estimate of capital (the marginal product) was slightly above or below 1.00. In the Cobb-Douglas functions the estimate (the elasticity) was approximately 0.7—0.9. This is rather much, as the sum of elasticities not should exceed 1.00 in the case of constant returns to scale over time. The external inputs had a negative sign in many cases. This prior knowledge makes it reasonable to believe that the capital coefficient is likely to be too high.

The aim of our use of the ridge regressions is still a different. We can hypothetisize that the estimated research elasticities are too high as a consequence of the intercorrelation between explaining variables. If this is the case their value should drop in ridge regressions. Our actual purpose in doing this is, however, the opposite. If the values of the research coefficients do not fall, it means that the estimates of research *are not overvalued because of multicollinearity*. If this holds true, we do not speculate whether the estimates are too low, but simply accept the estimates as not being overestimated. This means that ridge regressions are not used in order to produce new biased estimates but are used to investigate in which direction the serial correlation affects the elasticity of research.

In order to avoid the second danger outlined above, parameters which are insignificant to a large degree should not be tested. The significance determined by the t-test is a partial guide as to which of the regressions should be analysed. In the OLS regressions chosen for investigation by ridge regressions, the significance of the research coefficient (public or total) was according to Table 17:

Table 17. Research coefficient and significance level for different regressions.

Regression	Traditional variables	Research coefficient	Significance
(1) linear	aggregate	0.018	0.154
(4) linear	per farm	0.040	0.101
(5) linear	aggregate	0.025	0.057
(9) Cobb-Douglas	aggregate	0.059	0.120
(10) Cobb-Douglas	aggregate	0.034	0.374
(12) Cobb-Douglas	per farm	0.059	0.121
(14) Cobb-Douglas	aggregate	0.078	0.079

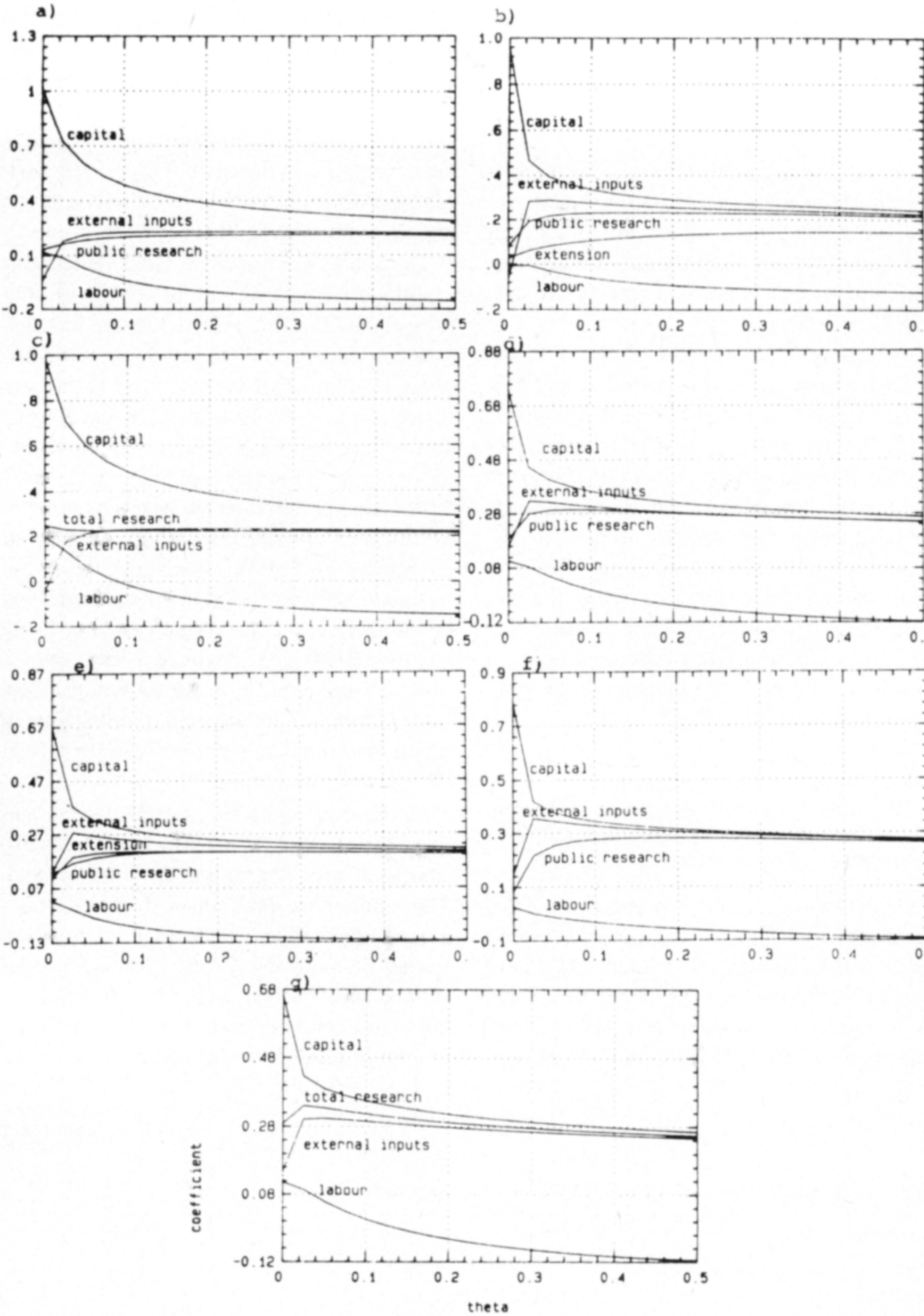

Fig. 19. Ridge traces. Horizontal axis value for ridge parameter theta, vertical axis corresponding values for the coefficients. The ridge regressions correspond to the following OLS regressions: a) = (1), b) = (4), c) = (5), d) = (9), e) = (10), f) = (12), g) = (14).

Table 18. The research coefficient by OLS and by ridge regressions.[1]

	Regression						
	(1)	(4)	(5)	(9)	(10)	(12)	(14)
OLS	0.018	0.040	0.025	0.059	0.034	0.059	0.078
Ridge parameter							
$\theta = 0.000$	0.132	0.080	0.249	0.189	0.108	0.082	0.289
$\theta = 0.025$	0.164	0.192	0.229	0.280	0.178	0.217	0.341
$\theta = 0.050$	0.185	0.217	0.226	0.293	0.191	0.253	0.333
$\theta = 0.100$	0.204	0.230	0.225	0.294	0.199	0.277	0.317

[1] "Statgraphics", the data program used here, standardizes and centers all variables at the same time so that the resulting estimates differ from the OLS for $\theta = 0$ (the values for $\theta = 0$ should be equal to the OLS). This will not affect its use here, since only the development of θ is relevant, not the absolute values of θ.

Next these seven different ridge traces for the unlagged production functions earlier estimated are examined. It should be noted that the elasticities are not directly comparable, since the interpretation differ for the various regressions.

5.1.4. *Ridge Traces*

The seven regressions chosen for ridge analysis are presented in Figure 19. As θ increases, the effects of multicollinearity decreases at the same time as the bias of the estimates increases. The estimates decrease, tending to zero in infinity. For values on $\theta \leq 0.05$ the coefficients change rapidly, stabilizing at $\theta = 0.05$ or slightly less. After this the increased effects of the bias can be seen in sinking curves. Obviously the critical values for θ should lay between 0 and 0.05. As was mentioned earlier, values of $\theta \geq 1.00$ are seldom used because of the stronger bias.

A general feature of all the figures is the fall in the regression coefficients of capital and labour. The prior belief that the capital coefficient is too big is supported by the ridge traces. It is difficult to understand that the coefficient of labour in some regressions becomes negative for $\theta \geq 0.05$ or even less. Obviously, values of $\theta \geq 0.05$ should be considered critically and with caution. The external inputs seem to increase and turn from negative (in some of the OLS regressions) to positive.

The estimate of the research parameter does not change much. In all regressions except (5) (where it stays almost constant) it increases slightly. Taking into account the purpose of the ridge analysis stated in the preceding section, it is now possible to draw a conclusion: rather small values for the ridge parameter θ show that the internal correlation between explanatory variables does not lead to overestimated coefficients of the research parameter.

Table 18 gives the ridge estimates a numerical description.

The trend in the development of the research coefficient is that it grows as the bias increases. The coefficient starts to decrease when the bias becomes sufficiently large.

The use of ridge analysis may be subject to criticism. Taking into account what has been stated above, it is put to careful use here; it is not, e.g. used to produce separate elasticities. Still we cannot be completely sure whether or not the multicollinearity is a problem. But at least the incidence given by ridge analysis shows that the multicollinearity need not be problematic.

5.1.5. *Autocorrelated Errors and Autoregressive Models*

The models (3.9) and (3.10) are based on the assumptions stated in section 3.4. One of these assumptions was that errors were not serially correlated. In case such autocorrelation occurs, the coefficient may be overestimated or underestimated. The results of the estimation show that this basic assumption was erroneous. A misspecification of the model results in autocorrelation, which may depend on the omission of variables or an incorrect form of the production function. Because of the wrong specification, some of the information appears as serial correlation in the errors. The Durbin-Watson test value in the flow models with no lags varied from 0.96 to 1.16, thus showing substantial autocorrelation.

The autocorrelation is further examined through the use of autoregressive models. In these models the correlation in the errors is used to explain the variation in the dependent variable.

If the basic form of the Cobb-Douglas function is

$$(5.5) \quad Q = A\, L^{b_l} K^{b_k} I^{b_i} R^{\alpha} N^{\sigma} + \varepsilon_t$$

where the number of observations is t, the simplest assumption on the form of correlation between errors is

$$(5.6) \quad \varepsilon_t = \theta\varepsilon_{t-1} + v_t \qquad \theta \leq \theta \leq 1$$

where v_t is normally distributed $N(0,\sigma^2)$ and not dependent on other errors. In this autoregressive model of first order, the residuals ε_t in the period t are explained only with the use of the residuals in the preceding period t—1 (times θ) and a and a random variable v_t. Instead of using only a single residual, ε_t can be explained by a larger number of residuals located further back in time:

$$(5.7) \quad \varepsilon_t = \theta_1\, \varepsilon_{t-1} + \theta_2\, \varepsilon_{t-2} + \dots + \theta_t\, \varepsilon_{t-p} + v_t$$

A model like (5.7) is called an autoregressive model of order p. In order to determine whether the influence on the serial correlation of the residuals decreases, autoregressive Cobb-Douglas models of first and second order were applied.

Table 19 shows results for the first order and Table 20 those for the second order models for public research. The autocorrelation diminishes considerably compared to the normal OLS regressions (9) and (10). In the first order models the Durbin-Watson test value increases to approximately 1.75. In the

Table 19. First order autoregressive Cobb-Douglas production functions with public research. All variables measured at aggregate level.

Regression	(18)	s.l.	(19)	s.l.
Constant	—2.037 (1.151)	0.087	—1.550 (1.295)	0.241
Capital	1.398 (0.330)	0.000	1.246 (0.384)	0.003
Labour	0.044 (0.034)	0.207	0.026 (0.041)	0.535
External inputs	—0.025 (0.090)	0.779	—0.014 (0.091)	0.877
Public aggregate research	0.013 (0.032)	0.694	0.010 (0.033)	0.771
Extension			0.060 (0.081)	0.464
θ_1	0.519 (0.147)	0.001	0.500 (0.149)	0.002
R^2	0.986		0.988	
Stand.error of estimate	0.020		0.020	
F-ratio	573.12***		451.22***	
D-W test value	1.749		1.762	

Table 20. Second order autoregressive Cobb-Douglas production functions with public research. All variables measured at aggregate level.[1]

Regression	(20)	s.l.	(21)	s.l.
Constant	—0.875 (0.913)		—0.640 (0.896)	
Capital	1.088 (0.291)	<0.001	0.990 (0.291)	<0.002
Labour	0.033 (0.030)	n.s.	0.011 (0.033)	n.s.
External inputs	0.047 (0.088)	n.s.	0.030 (0.089)	n.s.
Public aggregate research	0.016 (0.031)	n.s.	0.014 (0.031)	n.s.
Extension			0.092 (0.061)	n.s.
θ_1	0.685 (0.161)	<0.001	0.599 (0.163)	<0.001
θ_2	—0.288 (0.161)	<0.100	—0.257 (0.163)	n.s.
R^2	0.989		0.989	
Stand.error of estimate	0.019		0.020	
D-W test value	1.915		1.980	

[1] n.s. = not significant. s.l. > 0.01

autoregressions of second order it ranges from 1.91 to 1.98, thereby indicating that practically all of the serial correlation is explained.

From the tables it is evident that the estimate of elasticity with respect to research decreases to 0.011—0.013 in the first order models and to 0.014—0.016 in the second order models. The significance also decreases. This should be compared with regressions (9) and (10), where the estimate was 0.034—0.059. The coefficient of determination slightly increases. The regression coefficients of the residuals are big, about 0.05—0.07 and significant, thus explaining a large part of the variations. It is evident, therefore that the explaining power of the error term is considerable, indicating a certain degree of misspecification in the basic model (3.9). It is still possible that some of the information in the errors is connected with the research coefficient. On the whole, the second order autoregressive models seem to have a better explanatory power, though none of the research coefficients in either model is significant.

In addition to the elasticity estimate with respect to research, the elasticity estimate with respect to extension decreases. The sign of external inputs shifts to negative in the first order models, which is hardly understandable, but changes to positive again in the second order models. The effects of intercorrelated variables should be the same as explained earlier.

Using autoregressive models on the research measure, total funds give much the same results as for public research (Appendices 10 and 11). The elasticity estimates with respect to total research decrease to 0.022—0.025 in the autoregressions of first order and to 0.028—0.031 in the autoregressions of second order, again with insignificant values. The influence of autocorrelation decreases in the first order autoregressions and virtually disappears in those of second order. Correspondingly, the coefficients of the residuals θ_1 and θ_2 are big, especially for the first one. The coefficient of determination reaches a level of 0.990 in (25). The inclusion of extension in the regressions changes the coefficients of neither public nor total research more than slightly.

To summarize the section, it is concluded that the elasticity estimate with respect to research decreases in the autoregressive models. The OLS estimates may therefore be overvalued because of serial correlation in the errors. In the autoregressive models the regression coefficients of research are between one-half and one-fourth of the values in the OLS regressions. But because of the high regression coefficients of the residuals, which may include some information connected with the research variable, the estimates in this section are not necessarily more correct. The estimates in the autoregressive models are not necessarily closer to the real parameter values, but give an explanation where the influnce of serial correlation is not allowed to exert influence on the coefficients of the other parameters. What we have gained in this section is a picture of the possible effects of the autocorrelation.

5.1.6. Cobb-Douglas Regressions for Shorter Periods

In the preceding section unlagged elasticities with respect to research were estimated for the period 1950—1984. During the same period the funds for agricultural research have grown manifold. From this point of view the following question arise: How have the elasticity and value marginal product developed over time? Have the returns increased or decreased since the 1950s? Has the elasticity changed or has it stayed on the same level as previously even though more resources were allocated to research?

Cobb-Douglas functions were estimated for shorter periods of 20 years, i.e. 1950—1969 and 1965—1984. The estimates of the elasticity with respect to public research in Table 21 correspond to the regressions (9) and (10) in Table 13. The estimates of the elasticity with respect to total research in Appendix 12 correspond, in turn to regressions (14) and (15) in Appendix 8.

Table 21. Cobb-Douglas production functions with public research for shorter periods. All variables measured at aggregate level.

Regression	(26) 1950—69	s.l.	(27)	s.l.	(28) 1965—84	s.l.	(29)	s.l.
Constant	—2.497 (1.697)	0.162	—2.721 (1.230)	0.044	4.311 (2.559)	0.113 (3.035)	4.351	0.174
Capital	1.231 (0.450)	0.015	1.216 (0.325)	0.002	0.089 (0.555)	0.874	0.079 (0.699)	0.912
Labour	0.242 (0.103)	0.034	0.194 (0.076)	0.023	—0.087 (0.070)	0.229	—0.088 (0.084)	0.309
External inputs	0.029 (0.131)	0.828	0.004 (0.095)	0.965	0.015 (0.120)	0.905	0.016 (0.129)	0.906
Public research	0.034 (0.052)	0.523	—0.059 (0.045)	0.215	0.092 (0.043)	0.050	0.092 (0.045)	0.059
Extension			0.235 (0.061)	0.002			0.003 (0.096)	0.979
R^2	0.977		0.989		0.920		0.920	
Stand.error of estimate	0.025		0.018		0.019		0.020	
F-ratio	160.65***		248.28***		43.22***		32.27***	
D-W test value	0.905		1.425		1.708		1.711	

It is interesting to note that the estimate of the elasticity with respect to research seems to have increased in the period studied. The estimate for the earlier period of 1950—1969 is insignificant and even becomes negative when extension is added. This negative sign is illogical and must be attributed to the inclusion of the extension variable. The estimate for the period 1965—1984 is significant, with a confidence of approximately 95 %. The latter period has a low coefficient of determination (0.92) and the error terms are not very serially correlated, as is the case for the whole period. The F-value for the whole model has dropped in the latter period, but is still significant at a level of 0.001 %.

We can compare the elasticities for the period 1965—1984, 0.092 with the ones for the whole period 1950—1984, which were 0.059 and respectively 0.034 in Table 13. Taking into account the sixfold rise in research input, it should not be surprising to find that the elasticity has increased over time. The low t-values of regressions (26) and (27), however, limit our conclusions, so that it is not possible to compute a reliable value marginal product for the period 1950—1969.

Contrary to the research coefficient, the table shows significant parameter estimates for capital, labour and extension in the period 1950—1969 and insignificant estimates for the period 1965—1984. The sign of labour becomes negative for the latter period. If any conclusion could be drawn on the basis of Table 28, it is that research has taken over part of the importance as a production factor earlier possessed by capital and labour.

Interpretation of the total research regressions (see Appendix 12) are much similar to Table 21. Many of the coefficients are again insignificant, and some of them have illogical signs. The elasticity estimate with respect to total research seems to increase, as did the public research estimate. A negative sign appears again in the earlier period. The elasticities with respect to capital and labour once more seem to decrease, as does extension. It is difficult to say anything about the external inputs estimate. The same explanation is likely for the regressions including a total research variable; part of the role earlier played by traditional production factors has been taken over by research. Since the total research input has increased eightfold this has not necessarily led to a higher value marginal product, however.

5.2. Cobb-Douglas Flow Models with Lags

There will be a lag between the point in time when money is being funded for research purposes and the final effects in the form of higher production per input unit (or less inputs per produced unit). The previous estimations are based on the obviously unrealistic implicit assumption of research funds immediately affecting production results. One step forward towards a closer resemblance to the real world, therefore, is to take a lag into account in the model. The lag structure of agricultural research seems to be a problematic issue in studies of returns from research and thus far most production function studies make assumptions concerning the length and form of a distributed lag function. Naturally this does not apply to the welfare economics approach.

Estimations which include lags are examined in this sections. Simple lags were used to start with, after which Almon lags of degree two and three according to (3.37) were included in the model.

5.2.1 Regressions with Simple Lags

The simple lags estimated are based on the lag operator $x_{t-i} = \beta^k x_t$. The research input is thus allowed to affect the gross production only a certain number of years after the funds have been allocated. The effects of research thus take place at once instead of being distributed over a period of years, as in the case of a distributed lag. The estimated lags are allowed to vary between two and 15 years.

The results of the estimations are not very encouraging. When simple lags of less than ten years were included in the previous regressions (1)—(17), almost all of them showed the same tendency. The coefficient of determination falls, the drop being greater the longer the lag is. The research coefficient decreases in the beginning and partly becomes negative when lags of four to eight years are added and so does the significance, which makes it hard to believe the coefficients. For lags less than ten years the same autocorrelation problem as earlier appears. The highest coefficient of determination (0.991—0.997), the best significance and the least serially correlated errors are achieved in regressions where the traditional variables are defined on farm level.

Estimations using lags of 12—13 years are somewhat more encouraging, since they are both positive and significant. The serial correlation of errors is also less here (Durbin-Watson test value = 1.45—1.75 for the regressions in next table). Closer inspection of Figure 17, however, shows this should not be surprising, as the autocorrelated errors seem to appear mostly in the early part of the time series. Lags of ten years or more only make it possible to estimate the period of 1960—1984, which automatically eliminates the problematic period of serially correlated errors. It can therefore be doubted whether the longer simple lags of 12—13 years are any better. In order to illustrate the simple lags, the estimates for public research for two different sets of regressions are presented in Table 22. When no lags are included the regressions are similar to regressions (9) and (12) in Tables 13 and 14.

From the table it is clear that only estimates which include lags of 13 years are both positive and significant. These elasticity estimates were also higher than the estimates in regressions (9) and (12). It was, however, already pointed out that there is reason to believe this is because of the problems inherent in the time series. In addition, the above table does not show the negative parameter estimates of the other elasticities, which appeared regularly in the regressions (the intercorrelation problem is the same as earlier).

Table 22. The coefficient of research for different values on the simple lags. The table corresponds to (9) and (12).

Length of the lag, in years	Coefficient of research			
	(9)	s.l.	(12)	s.l.
2	0.016	0.694	0.035	0.296
3	0.013	0.741	0.028	0.401
4	—0.041	0.318	0.002	0.941
5	—0.088	0.027	—0.034	0.312
6	—0.046	0.194	—0.014	0.629
7	—0.048	0.163	—0.009	0.763
8	—0.021	0.555	0.016	0.629
9	0.000	0.991	0.014	0.630
10	0.013	0.663	0.008	0.762
11	0.003	0.931	0.010	0.752
12	0.033	0.359	0.046	0.194
13	0.092	0.005	0.089	0.006
14	0.089	0.019	0.084	0.033
15	—0.021	0.642	—0.038	0.432

A conlusion of the simple lag regressions is that the lag structure should be subject to more advanced methods of analysis. In spite of the problems encountered, some estimations including Almon lags are presented in the next section.

5.2.2. Regressions with Almon Lags

The a priori assumption of a polynomially distributed (Almon) lag revealed significant drawbacks. Not only were the estimates of elasticity with respect to research including a polynomial lag mostly insignificant; they were also negative, indicating a negative coefficient for research, which is most improbable. In addition, the size of the estimated coefficients varied to a large degree. This may be caused by intercorrelation between the various research variables in the lag structure, but it is more likely that the Almon lags do not fit the data and thus cannot give any sensible results. The polynomial lag behaved similarly when applied to a linear function. The coefficient of determination was clearly lower than for the unlagged functions except when traditional variables were measured at farm level where this difference not was as noticeable. The results for Almon lags of degree two and three for three different lengths of the lag are illustrated in Appendix 13.

A cumulated elasticity can be summed up on the basis of (3.36). The sum of estimated lag coefficients according to this are as follows (see Table 23):

Table 23. Sum of Almon lag coefficients. a = aggregated conventional variables, p = conventional variables per farm.

Regression	Length of lag	Degree	Sum of coefficients
(34)	3	2 a	0.047
(35)	3	2 p	0.044
(36)	3	3 a	0.046
(37)	3	3 p	0.042
(38)	7	2 a	—0.266
(39)	7	2 p	—0.047
(40)	7	3 a	—0.266
(41)	7	3 p	—0.049
(42)	13	2 a	—0.041
(43)	13	2 p	—0.064
(44)	13	3 a	0.019
(45)	13	3 p	—0.026

From Table 23 it is evident that the negative sum of estimated lag coefficients is very illogical. In addition, the positive estimates are often found in the beginning or at the end of each lag, thus indicating an upside down bell-shaped structure (a positive parable) of the lag. The choice of estimated polynomial sum of elasticities cannot be made upon any rational criteria. Thus the Almon lag does not provide any help in estimating a research elasticity.

Why doesn't the Almon lag fit the data? Why are estimates of the elasticity with respect to research for the simple lags negative? The reason may be the aggregated data, which do not consider that different types of research have different lengths of the lag. Research on machine technology may have a more immediate effect on production than, for instance, crop breeding, which depends on the vegetation period. Since the aggregated data include research institutions which have been founded during the period 1950—1984, the proportions of different types of research have changed, and the average aggregate lag has probably changed accordingly. One way of dealing with this problem could have been to split up the data into different branches, each of which would be estimated separately for different lengths of the lags.

A more plausible hypothesis is, however, connected with the distinction between research stocks and research flows. By far the most common way of measuring the research input in production function analysis has been in the form of an annual flow of research funds (Peterson 1985). It is obvious that the research input for one year does not represent the total stock of research capital accumulated over the years. If the relevant measure is the research stock and not the annual research flow, an initial basis value should be found for 1950. This initial value should grow with the annual research funds and depreciate according to the formulas (3.12)—(3.14) presented in section 3.3.2. Conceptually, computation of the research stock is similar to the calculation of a stock of tractors. An annual flow of tractors bought does not measure the same thing as the total stock of tractors. Because the earlier tractors are omitted, the production effects measured neglect the effects of all previously purchased tractors. The annual flows of tractors fluctuate considerably more than the total stock of tractors. As a consequence, the fluctuations of the research flow vary more than the fluctuations of the research stock.

The research stock is a kind of proxy for all the physical, scientific, and intellectual resources that exist at a point in time. If one thinks of the research stock concept in this sense, it will possess a computational advantage, since lags seem not to be needed. The gathered effect of an accumulated stock is immediate. It is more troublesome to decide on the right rate of depreciation. On the one hand, there is a view that all research accumulates and contributes to an ever-growing stock of knowledge (which according to Popper approaches truth in infinity). Accordingly, research would have a value that does not depreciate at all. On the other hand, there is the view that research results replace each other totally, either through obsolescence or as a result of changes in the environment. A third view, somewhere between these two standpoints, states that some research results lose their relevance while other provide useful knowledge for later scientists to build upon. The three different standpoints can be thought of as a 0 %, a 50 % and a 100 % depreciation 20 years after funding, as formulated in (3.12)—(3.14). All three cases are examined next.

5.3. The Research Input Measured as a Stock

The estimations of elasticities with respect to research analyzed up to this point have been based on the research flow concept. This section presents estimations specifying the research input as a research capital. The Cobb-Douglas function (3.9) serves as the basic model of regression. Contrary to the research flow models, no lag structure seems to be needed with a research stock. This is because of the different nature of the research capital. A stock which mainly includes investments in research made several years earlier does not seem to need an additional lag.

The initial figure for the research capital was derived by simple trend analysis from 1950—1984 back to 1920. The period 1940—1944 was, however, excluded because of the Second World War, when normal research activities were seriously disrupted. This initial figure is used to formulate a research capital for the three different rates of research depreciation formulated in expressions (3.12), (3.13) and (3.14) in section 3.3.2.

The research carried out is accumulated on the basis of three different assumptions:

a) no depreciation
b) a 50 % depreciation 20 years after the research funding and finally
c) a 100 % depreciation (total obsolescence) 20 years after funding.

At first a research capital is constructed only for public research, whereafter a total research capital is derived. The derivation and the index series obtained by this procedure are found in Appendices 14 and 15.

5.3.1. Undepreciated Research Stock.

When the public research stock is $R_k = \Sigma (R_t - d_t R_t)$ and $d_t = 0$, the estimations of the Cobb-Douglas model (3.9) will be according to Table 24. All the variables are measured at aggregate level. The table should be compared with Table 13, since all variables except the research input are estimated with the same series. The results from the regressions specifying research as an undepreciated research stock for total research are presented in Appendix 16.

Compared to the estimations with research measured as a flow, the coefficient of determination is slightly higher and, respectively, the standard error of total estimation slightly lower. The F-ratio is high, and the model is again acepted at a level of significance of less than 0.001 %. The autocorrelation decreases as the Durbin-Watson test value shows (it rises from 0.96—1.02 to 1.09—1.11), but is still high. The estimate of the research capital parameter seems to fit the model slightly better than does the research flow estimate.

Inspection of the elasticity estimates with respect to the different variables immediately draws attention to the considerably lower estimates for capital, which, however, has also lost confidence. The significance of the elasticity with respect to labour is modest, while the external inputs estimate is clearly insignificant and in the former regression has a negative sign. Inclusion of an extension variable does not affect the model very much.

The elasticity estimate with respect to the research capital changes in an interesting way. First of all, compared to the flow elasticities the estimate increases to 0.338 in regression (46) and 0.247 in regression (47). This is natural, since the estimate represents an elasticity relating a percentage change in production to a percentage change in the research input.

Table 24. Cobb-Douglas production functions with public research measured as an undepreciated stock.

Regression	(46)	s.l.	(47)	s.l.
Constant	1.326 (1.219)	0.286	1.224 (1.193)	0.313
Capital	0.171 (0.462)	0.714	0.242 (0.454)	0.598
Labour	0.207 (0.071)	0.007	0.135 (0.834)	0.117
External inputs	—0.005 (0.090)	0.953	0.015 (0.089)	0.868
Research stock	0.338 (0.133)	0.016	0.247 (0.142)	0.093
Extension			0.096 (0.062)	0.131
R^2	0.985		0.987	
Stand.error of estimate	0.023		0.022	
F-ratio	507.71***		425.876***	
D-W test value	1.094		1.115	

Since a percentage change in the whole research capital is considerably higher than a percentage change in the annual funds, the elasticity is naturally higher. The second interesting feature is the rise in the confidence of the research coefficient. In regression (9) the significance was 0.120, and in (46) it is 0.016. The significance in (10), was, analogously, about 0.374, and in (47) it is 0.093. Obviously, the elasticity estimate with respect to the undepreciated research capital seems to be more reliable than the research flow estimate as the significance is higher.

The results from the total research stock in Appendix 16 mainly show the same results as for the public research. The most obvious feature is the slightly smaller estimate of elasticity with respect to the total research stock than the elasticity estimate of the public research stock. The difference is, however, not large.

5.3.2. Depreciated Research Stock

In the following the estimations including a depreciated research stock are reported. Research results were assumed to become obsolescent or superfluous because of changes in the environment 20 years after research grants were made. The two alternative assumptions of depreciation for $R_k = \Sigma (R_t - d_t R_{t-20})$ were $d_t = 0.5$ and $d_t = 1.0$, i.e. a 50 % and a 100 % rate of depreciation. The results when the research stock includes only public research are presented in Tables 25 and 26.

Only minor changes take place in the parameter estimates. The coefficient of determination, the F-ratio and the Durbin-Watson test value in Table 24 are slightly better than in Table 25. The significance of capital in Table 25 is, however, better and no negative signs for external inputs appeared. The elasticity of the research capital in Table 25 is almost the same in size, or 0.212—0.297, and the confidence is a little lower. The differences are so small, however, that it is difficult to judge which table gives more reliable results.

Table 26 shows that a total depreciation of the research capital does not improve the regressions. The same tendencies continue as when research capital was depreciated by 50 %. The estimate of the research coefficient decreases to 0.174-0.252, the former value

Table 25. Cobb-Douglas production functions with public research measured as a stock with 50 % depreciation after 20 years.

Regression	(50)	s.l.	(51)	s.l.
Constant	0.757	0.482	0.774	0.463
	(1.063)		(1.040)	
Capital	0.349	0.402	0.387	0.344
	(0.411)		(0.403)	
Labour	0.185	0.007	0.116	0.144
	(0.064)		(0.077)	
External inputs	0.002	0.979	0.021	0.813
	(0.090)		(0.089)	
Research stock	0.297	0.018	0.212	0.113
	(0.119)		(0.129)	
Extension			0.096	0.137
			(0.063)	
R^2	0.985		0.986	
Stand.error of estimate	0.023		0.022	
F-ratio	503.63***		421.38***	
D-W test value	1.082		1.105	

Table 26. Cobb-Douglas production functions with public research measured as a stock with 100 % depreciation after 20 years.

Regression	(52)	s.l.	(53)	s.l.
Constant	0.215	0.820	0.368	0.692
	(0.936)		(0.020)	
Capital	0.535	0.151	0.530	0.146
	(0.363)		(0.355)	
Labour	0.158	0.009	0.093	0.186
	(0.057)		(0.069)	
External inputs	0.006	0.951	0.025	0.785
	(0.091)		(0.090)	
Research stock	0.252	0.023	0.174	0.142
	(0.106)		(0.115)	
Extension			0.098	0.133
			(0.063)	
R^2	0.985		0.986	
Stand.error of estimate	0.023		0.022	
F-ratio	496.44***		416.05***	
D-W test value	1.045		1.084	

being insignificant, however. The capital coefficient continues to increase.

The depreciated research stock for the total research capital at both depreciation rates is presented in Appendices 17 and 18. The estimate of elasticity with respect to the total research stock for some reason seems to be slightly smaller than the elasticity estimate with respect to the public research stock.

In order to investigate the autocorrelation for the three different cases of research capital, autoregressive models of first order were also investigated. The autoregressions corresponded to the regressions (46)—(57) reported above. Autocorrelation declined substantially in these regressions. This could be noticed from the Durbin-Watson test value which showed values of 1.68—1.71. The research coefficient in these autoregressive estimations varied from 0.10 to 0.15 for public research and from 0.08 to 0.12 for the total research. In the autoregressions the estimate of the elasticity with respect to the research stock was clearly insignificant, and the regression coefficient of the residual was high (approximately 0.50) and significant. The autocorrelation procedure has been explained in section 5.1.5.

As a summary of the estimates of elasticity with respect to the research capital, it is now possible to state that resasonably reliable elasticity estimates of the research capital seem to be found in the range of 0.15—0.30 depending on depreciation rate. The autocorrelation, however, is still a problem since the model assumes that the residuals are not correlated. The total research coefficient is slightly lower than the public research coefficient despite good t-value for both, a result which is hard to explain. Autocorrelation disappears in the autoregressive models, and the elasticity falls to 0.10—0.15 for public research and to 0.08—0.12 for total research, but is insignificant.

5.3.3. *Productivity Index Model*

In order to avoid the problem caused by multicollinearity an alternative model using a productivity index as dependent variable was specified in subsection 3.3.3. Through the specification of (3.17), the number of regressors was reduced to two variables, the research capital and a time factor. The dependent variable was a production/input index which included labour, capital costs (4 % of the stock of gross capital) and external inputs in the inputs. The results for this regression are presented in Table 27.

Table 27. Cobb-Douglas functions with productivity index as dependent variable. Research stock undepreciated.

Regression	(58)	s.l
Constant	3.036 (0.563)	0.000
Public research stock	0.346 (0.122)	0.008
Time factor	—0.002 (0.008)	0.787
R^2	0.973	
Stand.error of estimate	0.036	
F-ratio	575.18***	
D-W test value	0.807	

The estimate of elasticity with respect to public research shows a good significance at a level of 0.008 (i.e., a confidence level over 99 %). The time factor is insignificant and has an illogical sign. The coefficient of determination is slightly lower than in the regressions with gross production as dependent variable. The autocorrelation is, however, substantial. The elasticity estimate with respect to research should be interpreted in a different way from previous estimates. The simplest way is to say that for a 1 % increase in research funds, the relation of production to input rises by 0.346 %.

6. The Returns to Agricultural Research and University Education

6.1. The Selection of an Elasticity

The primary question to be answered was stated in the introduction as:

— What has been the value marginal product (marginal rate of return) and the marginal internal rate of return for public expenditure in agricultural research and for total public and private expenditures on agricultural research in 1950—1984?

To be able to draw a conclusion, a set of parameter estimates with respect to public and to total research was estimated in the previous chapter, and is used to calculate the value marginal product, which is easily changed to a marginal rate of return. Various options for the estimations were presented in Figure 15. It was possible to use either a flow elasticity or a stock elasticity. For the research flow it is possible to distinguish between an unlagged elasticity and an elasticity that includes a lag. For research stock it is possible to use either an undepreciated or a depreciated parameter estimate. Which estimate, then, should be used?

6.2. Research Flow Elasticities

On the basis of the coefficients of the linear production function, an unlagged marginal product for public research of 0.016 was estimated which, however, was insignificant. This parameter estimate of the marginal product is equal to an elasticity 0.04 with respect to public research. When the capital, labour and purchased input variables were specified on farm level, marginal products of 0.046 and 0.040 were estimated (the latter when the extension variable was added). Both these unlagged marginal products could be accepted by the t-test at reasonable significance levels. Converting them into elasticities (according to expression 5.1) gives elasticities of 0.099 and 0.114 with respect to public research.

The Cobb-Douglas function elasticities with respect to public research were 0.034 and 0.059 in the regressions where capital, labour and external inputs variables were specified on the aggregate level. If these conventional variables were specified on farm level, the parameter estimate of the elasticity with respect to research was 0.059 without the extension factor and 0.018 if extension was added. It is noteworthy that the lower elasticities, 0.018 (conventional variables on the farm level) and 0.034 (conventional variables on the aggregate level), which appear when extension is added have very low t-values and therefore are not reliable.

Multicollinearity between the explaining variables was strong. Ridge regressions, however, showed that the internal correlation did not lead to overestimated research coefficients.

The problem with all the unlagged parameter estimates of elasticities was heavy autocorrelation. In the autoregressive models of first degree, the autocorrelation declined and practically disappeared when models of degree two were used to explain the output. The parameter estimates of elasticities with respect to public research in these unlagged models were 0.010—0.016. The regression coefficients of the lagged residuals were high, however, and their content is unclear. In addition, the elasticity estimates with respect to research were clearly insignificant.

The parameter estimates of the unlagged elasticities with respect to public research thus vary between 0.010 and 0.114. Taking the possibility of errors into account, an estimate of elasticity of 0.040, previously used in section 5.1.1. may be too high. A modest approximation of the unlagged elasticity estimate may therefore lie in the range of 0.015—0.025. This approximation, however, suffers from lack of reliability because of the omission of a lag.

The estimation of total research parameters by linear functions with conventional variables specified at the aggregate level gave an estimate of the marginal product of 0.022—0.025, which was converted to an elasticity of 0.066—0.075. When traditional variables are specified at the farm level, the research marginal product estimate varies from 0.047 to 0.054 and the estimate of elasticity is consequently higher (0.141—0.162). The significance was good. The Cobb-Douglas functions produced estimates of elasticities with respect to total research of 0.050—0.078 when the conventional variables were specified on the aggregate level, and of 0.021—0.061 on the farm level. Both the higher parameter estimates of 0.078 and 0.061 were accepted by the t-test at a 10 % confidence level. In the autoregressive models, autocorrelation declined and insignificant estimates of elasticity with respect to total research of 0.022—0.031 were obtained. The estimate of the unlagged elasticity of total research thus ranges from 0.021 to 0.162. Taking into account the deficient data an approximation of 0.030 for the estimate of the unlagged elasticity for total research seems appropriate.

The estimation of elasticities with respect to public research including simple lags (Table 22) proved to be troublesome as many negative signs appeared, and they were also statistically insignificant in most cases. The only estimates of elasticities which could be accepted by the t-test were an estimate for a simple five-year lag with a negative sign (—0.088) and four rather high estimates of elasticities (0.084—0.092) for lags of 13 to 14 years.

The results for estimations including Almon lags of degrees two and three were discouraging. The total inconsistency of signs for different lengths of the lag proved to be no better than for the simple lags. As to the estimates of lagged elasticities with respect to the research flow, no acceptable estimate could thus be found. Thus the estimations carried out in this respect have clearly failed.

6.3. Research Capital Elasticities

On the basis of three different assumptions of depreciation of the stock of research capital (0 %, 50 % and 100 % depreciated 20 years after research grants were made), elasticities with respect to a research capital of 0.252—0.338 were estimated at a significance of 0.016—0.023. The inclusion of an extension variable in the regression decreased this estimate of elasticity to 0.174—0.247 and decreased the significance to 0.093—0.142. Autocorrelation problems appeared in all cases.

In the autoregressive models of first order, research elasticities of 0.10—0.15 were estimated and autocorrelation decreased substantially. These estimates suffered from being clearly insignificant. Taking these facts into consideration, approximation of the estimate of elasticity with respect to an undepreciated research capital at a value of 0.20 seems acceptable. In case a depreciation rate of 50 % and 100 % after 20 years is practised, the estimate of elasticity should be in the range of 0.17 and, respectively, 0.15.

The estimates of elasticities with respect to total research stock were smaller than with respect to public research, a result which is hard to explain since the flow estimates indicated the opposite. The coefficients varied from 0.219—0.278, with a significance of 0.017—0.022. When extension was added the estimates declined to 0.169—0.222, with a significance of 0.052—0.074. The autoregressive models of first order gave insignificant estimates (0.08 and 0.12) of the elasticities with respect to total research stock.

The estimate of the elasticity of an undepreciated total research capital could, on this basis be approximated to 0.15, or slightly lower than public research. Depending on the rate of depreciation, the elasticity estimate is approximated by 0.12—0.13. The reason for the lower value of total research probably depends on deficiencies in data, and a clear warning concerning this point is in order.

6.4. Value Marginal Product

On the basis of the elasticities discussed in the previous sections of this chapter, it is now possible to calculate a value marginal product VMP (a marginal rate of return) for agricultural research. This is done by relating the increase in output to the costs of the marginal increase in research costs. As agricultural and veterinary university-level education has been included in research costs, the calculated value marginal product concerns both research and university education. Extension activities carried out to speed up the adaption of innovations by farmers also need to be considered in some way. To do so, the public expenditures for extension services are included in the costs.

The formula for calculation of the marginal product is, according to Davis (1981):

$$(6.1) \quad MP = d\,\frac{Q}{R}$$

where
MP = marginal product of research
Q = gross production
R = research expenditures
d = elasticity of research

If research has been measured as a flow, research expenditures are the average annual expenditures. Research capital must be regarded as research expenditures when a stock elasticity is used.

If the original production level is Q_1 the value marginal product is the MP priced by product price P_1:

$$(6.2) \quad VMP = d\,\frac{Q_1P_1}{R}$$

When extension costs are added the value marginal product is:

$$(6.3) \quad VMP = d\,\frac{Q_1P_1}{R + N}$$

Davis (1981) points out two assumptions underlying the VMP calculations (6.1), (6.2) and (6.3).

The first is that the level of use of all other inputs remains the same. This assumption can, on the one hand, be questioned, since it implies that technological change is neutral (neither capital nor labour intensive) to a change in research intensity. It means that the marginal products of the other inputs do not change as a consequence of research activities. But in reality new research results affect the volume of capital, labour and external inputs. On the other hand, as we are only dealing with a marginal increase in the research input, this assumption may be acceptable.

This assumption of fixed input levels also implies a divergent shift in the supply curve, caused by research. If the supply curve in reality shifts in a parallell direction, the VMP may be underestimated by up to half.

The second implicit assumption is that the product price is not affected by the change in output and that demand is perfectly elastic. In reality demand is unlikely to be perfectly elastic and so the VMP overestimates the benefits. The overestimation caused by this latter assumption is, according to Davis, relatively small in comparison to the first possibility of underestimation.

The volume of gross production for the period 1950—1984 is derived by the same index series as were used to measure independent variables in the regressions. The volume of this production was reported by Kettunen (1985) to have been FIM 21,022.3 million in 1984. Because State subsidies, State compensations and outdoor garden production are included in this figure, they are subtracted. The gross production figure derived is then FIM 19,403.9 million at the domestic price level of 1984.

Public expenditures for research and university education in 1984 were FIM 157.028 million, the value of total research FIM 230.132 million. Public expenditures for extension were FIM 60.557 million. Use of the explaining index series for research and extension gives the cumulated total value of these inputs in 1950—1984 at the price level of 1984. This results in following figures (see Table 28):

Table 28. Cumulated and average volume in 1950—1984 of gross production, research flow and State expenditures for extension, (FIM million).

	Cum.vol.	Average
1. Volume of gross production in 1950—1984	558,252	15,950
2. Public research flow in 1950—1984	3,138	89.7
3. Total research flow in 1950—1984	4,336	123.9
4. State expenditures for extension in 1950—1984	1,791	51.2

If the unlagged estimate of elasticity with respect to the public research flow, approximated at 0.020, is used, the VMP according to (6.3) will be

$$VMP_p = \frac{0.020\ \% \times \text{FIM } 15{,}950 \text{ million}}{1\ \% \times \text{FIM } (89.7 + 51.2) \text{ million}} = 2.26$$

The value marginal product of 2.26 would imply that every additional Finnish mark invested in agricultural research and university education would have returned by 2.26 mark annually since that moment. This value marginal product is equal to a marginal rate of return of 226 %, which seems to be exceedingly high. Since no lag was applied this is obviously an overvalued estimate.

Applying the same formula to the total research flow with an unlagged elasticity of 0.030 gives

$$VMP_t = \frac{0.030\ \% \times \text{FIM } 15{,}950 \text{ million}}{1\ \% \times \text{FIM } (123.9 + 51.2) \text{ million}} = 2.73$$

The value marginal product of total public and private research thus seems somewhat higher than for only public research.

So far, the research flow concept has been considered. If the focus is changed to the research capital, do these high estimates gain validity from the estimations of the stock of research capital?

In order to calculate the rate of return to research capital, we need to sum up the research capital existing each year in 1950—1984. The accumulated sums as well as the figures for the derivation of research capital are found in Appendices 14 and 15. Table 29 presents the summed up research capitals and averages for different assumptions of the depreciation:

Table 29. The sum and average of accumulated research capitals 1950—84 mill. FIM.

Rate of depreciation after 20 years	Public		Total	
	Sum	Average	Sum	Average
0 %	56,685	1,619.6	70,272	2,007.8
50 %	50,122	1,432.1	63,284	1,808.1
100 %	43,559	1,244.5	56,295	1,608.4

The sum of accumulated undepreciated research capitals during the whole period 1950—1984 was FIM 56,685 million (public) and, respectively, FIM 70,272 million (total). On average the undepreciated public research capital was FIM 1,619.6 million, the undepreciated total research capital FIM 2,007.8 million. The value of the undepreciated research capital only in 1984 was estimated to FIM 3,480.0 million (public) and, respectively, FIM 4,688.3 million (total).

The estimates of elasticities with respect to the undepreciated public research capital and the undepreciated total research capital were approximated at 0.2 and 0.15. If these approximations are used in formula (6.3), the following value marginal products are obtained:

Research stock depreciation rate = 0 %

$$VMP_p = \frac{0.2\ \% \times \text{FIM } 15{,}950 \text{ million}}{1\ \% \times \text{FIM } (1{,}619.6 + 51.2) \text{ million}} = 1.91$$

$$VMP_t = \frac{0.15\ \% \times \text{FIM } 15{,}950 \text{ million}}{1\ \% \times \text{FIM } (2{,}007.8 + 51.2) \text{ million}} = 1.16$$

In the case of a 50 % and a 100 % depreciated research capital, the estimates of elasticities with respect to the public research were approximated at 0.17 and, respectively 0.15. The elasticity estimates with respect to the total research capital for both depreciation rates are 0.13 and 0.12. Since the estimations carried out would not give reason to more than minor change in these coefficients, there is reason to say the elasticities chosen well represent the depreciated research capital. The value marginal product then becomes:

Research stock depreciation rate = 50 %

$$VMP_p = \frac{0.17\ \% \times \text{FIM } 15{,}950 \text{ million}}{1\ \% \times \text{FIM } (1{,}432.1 + 51.2) \text{ million}} = 1.83$$

$$VMP_t = \frac{0.13\ \% \times \text{FIM } 15{,}950 \text{ million}}{1\ \% \times \text{FIM } (1{,}808.1 + 51.2) \text{ million}} = 1.12$$

Research stock depreciation rate = 100 %

$$VMP_p = \frac{0.15\ \% \times \text{FIM } 15{,}950 \text{ million}}{1\ \% \times \text{FIM } (1{,}244.5 + 51.2) \text{ million}} = 1.85$$

$$VMP_t = \frac{0.12\ \% \times \text{FIM } 15{,}950 \text{ million}}{1\ \% \times \text{FIM } (1{,}608.4 + 51.2) \text{ million}} = 1.15$$

The VMP for public research thus varies between 1.83 and 1.91 for public research depending on the assumed depreciaton rate. Correspondingly, the VMP for total research varies between 1.12 and 1.16. In fact, the undepreciated and depreciated research stocks give almost identical value marginal products. This is an interesting feature. The value marginal product of the public research stock is 80 % of the research flow VMP. The value marginal product for the total research capital is only about 40 % of the flow VMP. Since the research stock conceptually does not need any lag, the estimates in this respect are more reliable than the flow estimates. The research stock estimates are also more reliable with respect to significance and autocorrelation.

The critical issue is: Are we sure the stock of research capital needs no lag? Further assessment of the returns to research estimated on the basis of a research capital would seem interesting.

There is one more way to determine a marginal rate of return. Through the production/input elasticity with respect to public research, 0.346 as reported in subsection 5.3.3., it is possible to calculate the value of the improved production/input ratio. This ratio would have risen with 0.346 % for an additional 1 % of research capital. In other words, with the same set of inputs production would have risen with 0.346 % for a 1 % increase in research capital. The production/input index was measured in the prices of 1970; the average annual production in 1950—1984 was FIM 3,503.3 million in this price level, with an average annual undepreciated research capital of FIM 381.5 million in the prices of 1970 (FIM 1,619.6 million in the prices of 1980, deflated by the market price index), and extension, respectively, FIM 12.1 million. The value marginal product becomes:

$$\frac{0.346\ \% \times \text{FIM } 3{,}503.3 \text{ million}}{1\ \% \times \text{FIM } (381.5 + 12.1) \text{ million}} = 3.08$$

In other words, if the whole stock of research capital had increased by FIM 1, then FIM 3.08 more of production would have been gained. The difference from the former VMPs is partly caused by the fact that relatively minor differences in the elasticities are reflected as large differences in VMPs. It is also necessary to take into account that the errors were heavily autocorrelated in the regression, which casts some doubt on the reliability of the elasticity estimate.

6.5. Marginal Internal Rate of Return

The internal rate of return (IRR) is a method of investment analysis which explicitly considers the time value of money. The method is best understood with the net present value (NPV) method as a starting point. With the NPV method the cash flows of an investment project are discounted at a minimum acceptable compound annual rate. If the present value of net cash returns exceeds the initial investment outlays, i.e the net present value is greater or equal to zero the investment is accepted. The IRR method in turn, computes the discount rate for which the net present value equals zero. The discount rate is thus the maximum interest rate a project can pay out and still cover total outlays (LEE et al., 1980).

According to (2.2) the IRR was formulated as

$$\sum_{t=0}^{T} \frac{(R_t - C_t)}{(1 + r_i)^t} = 0$$

R_t = the social benefit (return) in year t
C_t = the research cost in year t
T = the year the research ceases to produce returns
r_i = the internal rate of return

Besides the value marginal product this measure is the most widely used rate of return for the returns to agricultural research. In general an average IRR is computed, but PETERSON (1967, 1971) and RUSSELL (1987) have computed a marginal internal rate of return (MIRR). For shorter periods, the MIRR is very sensitive to the length of the period discounted (i.e. the value of T). If T grows, however, the MIRR stabilizes around a certain value.

MIRRs for the estimates, with respect to the unlagged research flow elasticities of 0.02 (public research) and 0.03 (for total research), are computed according to (2.2). A lag is incorporated afterwards, assuming that the unlagged elasticity affects production alternatively, four, six or ten years later. In other words, a four-year lag assumes that the research input in 1950—1980 has affected production in 1954—1984. Extension is thought to have an immediate effect, i.e. the costs are credited for the same year as the production increase. The returns are assumed to stop at 1984.

The results of the MIRR calculation on the various assumptions of the lag are presented in Table 30.

Table 30. The marginal internal rate of return (MIRR), %.

Assumed length of lag	Public research	Total research
4 years	62.2	76.8
6 years	37.7	46.0
10 years	20.9	25.9

The MIRR for public research according to this would be in the range of 20—62 % (above inflation) for various assumptions of the length of the lag. The corresponding MIRR for total research is approximately 25—76 %. It is noteworthy that this is a marginal figure, not an average. If the assumption that benefits stop at 1984 is eased, the change in MIRR is minor (less than 1 %). The MIRR for total research may be overestimated because too few costs have been included. On the other hand, extension expenditures are included for both public and total MIRR, which substantially decreases the estimates. This MIRR falls in the same range as the average IRRs (cf. Appendix 1) computed in other studies. The difference from the VMP and corresponding marginal rates of return (226 % for public research and 273 % for total research) seems to depend on the fact that the flow measure took no account of lags and the estimates were biased upwards. The VMP and the corresponding marginal rates of return estimated by research capital, 183—191 % for public research and 112—116 % for total research, rest on the assumption of a research stock which can be estimated. The different rates of return give different expressions of the same phenomenon.

7. Summary and Conclusions

This study undertook to estimate the returns to investment in agricultural research in Finland in 1950—1984. The primary reason motivating this investigation is the fact that public research funds are limited. A measure for assessing the allocation of resources to research could be created, in part based on these study results, if the monetary value of agricultural research could be estimated. A second reason is the current interest of administrators in research evaluation.

More specifically the purpose of the study was to estimate the following two measures of returns to agricultural research:

1. The value marginal product (VMP, a marginal rate of return)
2. The marginal internal rate of return (MIRR).

These rates of return were estimated for two different definitions of resource expenditures:

a) Public expenditures on agricultural research and university education and
b) Total public and private expenditures on agricultural research and university education.

Two major approaches — production function analysis and welfare economics — have been used in most studies estimating the returns to investment in agricultural research. These approaches and studies, carried out in North America, Asia and Australia, were reviewed in chapter 2.

In the production function analysis, a separate variable for research is included in the production function. A value marginal product can be computed on the basis of the estimate of elasticity with respect to research.

The welfare economics approach is based on the changes in consumers' and producers' surpluses. Welfare economics makes it possible to determine an average rate of return and the distribution of benefits from research between producers and consumers.

This study used the production function approach. Two models, a linear and a Cobb-Douglas model, were specified. Gross production was the dependent variable, and the explanatory variables were capital, labour, purchased inputs, extension and research. Capital included buildings, machinery, water constructions, land and livestock. The research input was measured in two alternative ways: firstly, as a flow of annual funds granted for research and university education; secondly, as a stock of research capital, which consisted of funds accumulated since 1920 with three different assumed rates of depreciation. Almon lags of second and third degree were specified for the former way of measuring the research input. Finally, a third model with a productivity index as the dependent variable was specified.

The time series data for public research expenditures included the agricultural research institutes and other institutions under the Ministry of Agriculture and Forestry, the Faculty of Agriculture and Forestry of the University of Helsinki for the part of agriculture, the College of Veterinary Medicine, the Academy of Finland, the Finnish National Fund for Research and Development (SITRA), public foundations, the Work Efficiency Association and joint research projects financed by the Ministry. In the final calculation of the VMP and the MIRR, public expenditures for extension agencies were accounted on the cost side.

Because of deficiencies in the data on the research input of the private sector, the total public and private research VMPs and MIRRs should be interpreted with care. The expenditures accounted for on the side of the private sector did not cover the total expenditures. This biased the estimate positively.

The results of the estimations are presented in chapter 5. Models measuring the research input as a flow of expenditures were analysed first, whereafter the models measuring research input as a stock of accumulated expenditures were examined. Finally, four different return measures were calculated. The results were as follows:

The results for estimations with the research input specified as a flow including no lags were discussed first. A preliminary VMP was derived on the basis of the linear models, though because lags were omitted it was an overestimation. The results for the linear and the Cobb-Douglas models were somewhat ambiguous. Multicollinearity between explanatory variables as well as serial correlation in the residuals posed problems. The multicollinearity was investigated by ridge regressions, which strongly indicated that the internal correlation between explanatory variables does not lead to overestimated estimates of the research elasticity. The autocorrelated errors were analysed by autoregressive models of first and second order. In the autoregressive models of the first order, the autocorrelation decreased considerably, and it virtually disappeared in the second order models. The estimate of elasticity with respect to research also decreased considerably, and the regression coefficients for the error terms increased.

The results for models including either simple lags or Almon lags were somewhat paradoxical: Negative signs appeared for the estimate of elasticity with respect to research. The estimate was also insignificant. The biggest problem encountered in the study, therefore, was the failure to determine a satisfactory lag structure.

The study proceeded to report results for Cobb-Douglas models measuring the research input as a stock of research capital based on a 0 %, a 50 % and a 100 % depreciation of the research capital 20 years after grants were made. Reliable elasticity estimates of the research capital were located in the range of 0.15—0.30, depending on the depreciation rate. The estimates of total research elasticity were somewhat lower. The research capital concept was thought to have an advantage, since it needs no lags.

The estimates of returns presented in this study were based on the assumption that no research results were imported, which biased the returns positively. The total university education and the public expenditures for extension, however, constituted a substantial share of the cost side, which may have underestimated the rate of return. At the risk of oversimplifying the entire interpretation, the following conclusions on the returns to research, discussed at length in chapter 6, can be made:

1. Estimations using the flow measure of research input give a VMP for public research of 2.26 and of 2.73 for total public and private research. The marginal rates of return according to these estimates have been 226 % for public research and 273 % for total research (both over the inflation rate) from the moment the investment was made. The lack of any lag, however, biases the estimate positively, making additional measures necessary.

2. The estimates of elasticity with respect to a research capital give a VMP of 1.83—1.91 for public research and a VMP of 1.12—1.16 for total research. These figures are interpreted as follows: Every additional public investment in agricultural research in 1950—1984 would have returned by 183 % to 191 % annually over the inflation rate from the moment the investment was made. An additional investment in the total public and private research input would correspondingly have returned by 112 % to 116 % annually. These research capital estimates are likely to be closer to the real VMPs than the flow estimates, since the lack of a lag should not be problematic conceptually.

3. A model using a production/input index as the dependent variable, and in which the

number of explaining variables are reduced to only two (a research capital and a time factor) gives a marginal rate of return of 308 %. The errors, however, were heavily autocorrelated in this model.

4. A fourth measure of returns is the marginal internal rate of return (MIRR). This method is used to calculate the discount rate for which the net present value equals zero. On the basis of the research flow elasticity estimates, MIRRs are calculated, with lags of alternatively 4, 6 and 10 years included in these computations. MIRRs of 62.2 %, 37.7 % and 20.9 % for public research are obtained for the respective lags. The corresponding MIRRs for total public and private research are 76.8 %, 46.0 % and 25.9 %.

When funding agencies decide upon the allocation of support for research, mere rates of return are useful but, however, insufficient. They are intended to supplement other value judgements. In a situation of growing national food surpluses, special attention should be paid to alternative ways of making production effective. This implies that greater consideration should be given in the future to input-saving techniques, environmental and ecological concerns, agricultural produce for non-agricultural purposes, and new sources of livelihood for the rural population.

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Appendix 1. Estimated rates of return from investment in agricultural research. (Pinstrup-Andersen 1982).

Commodity	Country	Period	Annual rate of return (%)	Source
Aggregate	India	1953—71	40	Evenson and Jha (1973)
Aggregate	India	—	63	Kahlon et al. (1977)
Aggregate	Japan	1880—1938	35	Tang (1953)
Aggregate	USA	1949—59	35—40	Griliches (1964)
Aggregate	USA	1949—59	47	Evenson (1969)
Aggregate	USA	1937—42	50	Peterson and Fitzharris (1977)
Aggregate	USA	1947—52	51	Peterson and Fitzharris (1977)
Aggregate	USA	1957—62	49	Peterson and Fitzharris (1977)
Aggregate	USA	1967—72	34	Peterson and Fitzharris (1977)
Aggregate	USA	1938—48	30	Lu, Cline and Quance (1979)
Aggregate	USA	1949—59	28	Lu, Cline and Quance (1979)
Aggregate	USA	1959—69	26	Lu, Cline and Quance (1979)
Aggregate	USA	1969—72	24	Lu, Cline and Quance (1979)
Hybrid maize	USA	1940—55	35—40	Griliches (1958)
Maize	Chile	1940—77	32—34	Yrarrazaval, Navarrete and Valdivia (1979)
Maize	Peru	1954—67	35—40	Hines, (1972)
Maize and sorghum	Mexico	1943—64	26—59	Ardito-Barletta (1970)
Hybrid sorghum	USA	1940—57	20	Griliches (1958)
Wheat	Mexico	1943—64	69—104	Ardito-Barletta (1970)
Wheat	Colombia	1953—73	11—12	Hertford et al. (1977)
Wheat	Bolivia	1966—75	—48	Wennergren and Whitaker (1977)
Wheat	Chile	1949—77		Yrarrazaval, Navarrete and Valdivia (1979)
Rice	Colombia	1957—72	60—82	Hertford et al. (1977)
Rice	Colombia	1957—74	94	Scobie and Posada (1978)
Rice	Japan	1915—50	25—27	Akino and Hayami (1975)
Rice	Japan	1930—61	73—75	Akino and Hayami (1975)
Rice	Asia	1950—65	32—39	Evenson and Flores (1978)
Rice	Asia	1966—75	73—78	Evenson and Flores (1978)
Rice	Tropics	1966—75	46—71	Flores-Moya et al. (1978)
Rice	Philippines	1966—75	27	Flores-Moya et al. (1978)
Cash grains	USA	1969	36	Bredahl and Peterson (1976)
Soybeans	Colombia	1960—71	79—96	Hertford et al. (1977)
Potatoes	Mexico	1943—64	69	Ardito-Barletta (1970)
Sugar cane	South Africa	1945—62	40	Evenson (1969)
Sugar cane	Australia	1945—58	50	Evenson (1969)
Sugar cane	India	1945—58	60	Evenson (1969)
Cocoa	Brazil	1923—74	16	Monteiro (1975)
Cocoa	Brazil	1958—74	60	Monteiro (1975)
Cotton	Brazil	1924—67	77 +	Ayer (1970)
Cotton	Colombia	1953—72	Negative	Hertford et al. (1977)
Rubber	Malaysia	1932—73	25	Pee (1977)
Rapeseed	Canada	1964—75	95—105	Nagy and Furtan (1978)
Pastures	Australia	1948—69	65—80	Duncan (1972)
Poultry	USA	1915—60	21—25	Peterson (1967)
Poultry	USA	1969	37	Bredahl and Peterson (1976)
Sheep	Bolivia	1966—75	44	Wennergren and Whitaker (1977)
Dairy	India	1963—75	29	Kumar, Maji and Patel (1977)
Dairy	USA	1969	43	Bredahl and Peterson (1976)
Livestock	USA	1969	47	Bredahl and Peterson (1976)
Tomato harvest	USA	1958—69	37—46	Schmitz and Seckler (1970)

Appendix 2. Index series used in the regressions.

Year	Agricultural gross production	Deflated public research input and univ. education	Deflated total research input and univ. education	Deflated extension[1]	Capital	Labour	External inputs
1950	100	100	100	100	100	100	100
1951	102	137	133	100	103	92	99
1952	105	127	128	99	106	93	108
1953	108	119	123	102	109	91	109
1954	110	118	125	95	111	88	120
1955	108	142	145	91	114	88	135
1956	112	162	167	99	116	85	151
1957	116	154	164	107	118	86	153
1958	117	230	235	116	120	87	145
1959	124	226	233	117	123	86	155
1960	130	213	225	114	126	86	174
1961	136	222	236	128	128	84	182
1962	140	295	311	141	131	88	199
1963	142	303	329	151	134	85	228
1964	148	296	323	157	137	83	222
1965	149	356	399	164	139	74	230
1966	148	366	419	166	141	74	234
1967	146	365	443	163	143	68	242
1968	149	398	479	152	143	68	254
1969	152	373	470	153	146	65	269
1970	152	346	454	155	145	57[2]	283
1971	157	345	467	149	147	50	296
1972	160	394	579	138	147	49	298
1973	153	399	561	136	148	45	303
1974	155	370	491	134	150	43	313
1975	159	457	562	147	151	41	326
1976	169	479	634	150	153	40	327
1977	169	622	754	145	154	39	310
1978	164	526	665	148	155	37	343
1979	167	623	758	143	156	34	365
1980	171	633	758	148	158	32	391
1981	172	650	750	152	160	33	391
1982	170	610	754	160	162	31	419
1983	172	614	811	161	163	27	406
1984	174	620	795	161	164	26	394

[1] Before 1970 interpolated with five years intervals. The value 1950 assumed to be equal to 1951.
[2] The labour input of 1970 calculated as an average of 1969 and 1971.

Appendix 3. The absolute figures for the index series.

Year	Nominal public research input and university education (FIM 1000)	GDP price index to market price	Deflated public research input and university education in prices of 1980 (FIM 1000)	Nominal interpol. public extension support (FIM 1000)	Deflated interpol. public extension support in prices of 1980 (FIM 1000)	External inputs in prices of 1970 (FIM 1000)	Gross capital stock in prices of 1980 (FIM million)	Number of farms[1]
1950	2,087	11.85	17,610	3,396	28,658.2	650,465	56,448	465,655
1951	3,133	12.96	24,180	3,396	26,203.7	643,413	58,012	450,723*
1952	3,008	13.40	22,437	3,484	26,000.0	700,746	60,097	435,790*
1953	2,810	13.42	20,936	3,572	26,617.0	710,871	61,307	420,858*
1954	3,034	14.64	20,727	3,660	25,000.0	778,143	62,861	405,925*
1955	3,925	15.74	24,934	3,749	23,818.3	876,732	64,303	390,993*
1956	4,566	16.05	28,442	4,150	25,856.7	984,696	65,401	376,060*
1957	4,425	16.30	27,151	4,551	27,920.2	995,795	66,615	361,128*
1958	6,597	16.28	40,513	4,953	30,423.8	941,957	67,845	346,195*
1959	6,936	17.47	39,713	5,354	30,646.8	1,007,398	69,169	331,263
1960	7,201	19.20	37,507	5,756	29,979.2	1,133,112	70,868	327,826*
1961	7,904	20.20	39,130	6,749	33,410.9	1,184,491	72,480	324,462*
1962	10,919	21.00	51,995	7,743	36,871.4	1,294,008	74,124	321,061*
1963	11,784	22.10	53,319	8,736	39,529.4	1,482,652	75,734	317,661*
1964	12,333	23.70	52,039	9,730	41,054.9	1,442,212	77,075	314,260*
1965	15,622	24.90	62,740	10,723	43,064.3	1,494,078	78,197	310,859*
1966	16,837	26.10	64,508	11,324	43,387.0	1,520,249	79,626	307,459*
1967	17,982	28.00	64,221	11,925	42,589.3	1,575,007	80,528	304,058*
1968	22,005	31.40	70,080	12,527	39,894.9	1,653,091	80,948	300,658*
1969	21,469	32.70	65,653	13,128	40,146.8	1,746,600	82,234	297,257
1970	20,639	33.90	60,882	13,729	40,498.5	1,840,000	81,701	289,640*
1971	22,191	36.50	60,798	14,205	38,917.8	1,927,600	82,749	282,023*
1972	27,453	39.60	69,325	14,332	36,191.9	1,937,900	83,026	274,406
1973	31,711	45.10	70,312	16,132	35,769.4	1,972,900	83,763	265,938
1974	36,068	55.30	65,222	19,376	35,038.0	2,036,100	84,408	258,200
1975	50,959	63.30	80,503	24,304	38,394.9	2,121,839	85,071	248,736
1976	60,194	71.30	84,423	28,110	39,425.0	2,129,517	86,134	242,682
1977	86,145	78.60	109,600	29,824	37,944.0	2,019,477	86,876	237,679
1978	78,435	84.60	92,712	32,731	38,689.1	2,229,699	87,354	232,820
1979	100,534	91.60	109,753	34,432	37,589.5	2,375,850	88,278	229,349
1980	111,538	100.00	111,539	38,775	38,775.0	2,546,052	89,428	224,721
1981	127,430	111.40	114,390	44,328	39,791.7	2,541,191	90,525	218,904
1982	130,617	121.50	107,503	51,079	42,040.3	2,726,488	91,293	212,630
1983	142,914	132.10	108,186	55,849	42,277,8	2,642,618	92,276	208,229
1984	157,028	143.90	109,123	60,556	42,082.0	2,562,952	92,777	203,933

[1] * = interpolated

Appendix 4. Total expenditures and State support for the agricultural extension agencies (Association of Agricultural Centres, the Agricultural Centres, Association for Agricultural Societies of Swedish Speaking Farmers, the Agricultural Societies and the small farmer organizations) (FIM 1000).

Year	Total expenditures	Total State support	State support in % of total expenditures
1950			
1951	6,581	3,396	51.61
1955	8,249	3,748	45.44
1960	11,281	5,756	51.03
1965	19,143	10,723	56.01
1970	20,613	13,729	66.60
1971	22,229	14,205	63,90
1972	23,563	14,332	60.82
1973	28,421	16,132	56.76
1974	32,292	19,376	60.00
1975	41,762	24,304	58.20
1976	53,563	28,110	52.48
1977	54,940	29,824	54.28
1978	64,380	32,730	50.84
1979	72,671	34,432	47.38
1980	81,668	38,775	47.47
1981	95,489	44,328	46.42
1982	107,333	51,079	47.60
1983	120,374	55,849	46.40
1984	133,013	60,557	45.40

Appendix 5. Gross capital stock in basic agriculture according to the national accounts in prices of 1980 (FIM million).

1950	28,381.2	1968	49,899.6
1951	29,625.0	1969	50,931.7
1952	31,232.4	1970	51,719.2
1953	32,492.3	1971	52,608.2
1954	33,708.5	1972	53,240.7
1955	34,975.7	1973	54,038.8
1956	36,066.1	1974	54,683.3
1957	37,087.3	1975	55,582.1
1958	38,098.9	1976	56,485.6
1959	39,279.2	1977	57,138.4
1960	40,551.9	1978	57,803.5
1961	41,967.7	1979	58,724.7
1962	43,223.8	1980	60,004.5
1963	44,621.6	1981	60,958.0
1964	45,778.8	1982	62,237.4
1965	47,009.2	1983	63,359.2
1966	48,346.4	1984	64,100.3
1967	49,269.7		

Appendix 6. Linear production functions with total research. All variables measured at aggregate level. Regression coefficients and their standard errors in parenthesis below coefficients, significance levels, coefficient of determination, F-ratio and Durbin-Watson test values.[1]

Regression	(5)	s.l.[2]	(6)	s.l.
Constant	—46.232 (14.949)	0.004	—27.315 (23.312)	0.251
Capital	1.227 (0.150)	0.000	1.074 (0.208)	0.000
Labour	0.195 (0.107)	0.070	0.095 (0.143)	0.511
External inputs	—0.010 (0.041)	0.809	—0.012 (0.041)	0.767
Total public & private research	0.025 (0.013)	0.057	0.022 (0.013)	0.102
Extension			0.077 (0.073)	0.300
R^2	0.983		0.984	
Stand.error of estimate	3.263		3.257	
F-ratio[3]	444.85***		357.47***	
D-W test value	0.963		0.990	

[1] These coeffients, the F-ratio and D-W test-value will be presented in all the regression tables.
[2] Significance levels with t-test. The abbreviation applies to all regression tables.
[3] *** = Significance level for F-ratio ≤ 0.001 %. The abbreviation applies to all regression tables.

Appendix 7. Linear production functions with total research. Output, capital, labour, external inputs measured at farm level, research and extension at aggregate level.

Regression	(7)	s.l.	(8)	s.l.
Constant	—20.175 (10.303)	0.059	—20.087 (10.401)	0.063
Capital	0.982 (0.134)	0.000	0.983 (0.136)	0.000
Labour	0.130 (0.098)	0.197	0.084 (0.121)	0.493
External inputs	0.0001 (0.037)	0.997	—0.0007 (0.037)	0.985
Total research	0.054 (0.022)	0.020	0.047 (0.025)	0.067
Extension			0.053 (0.080)	0.512
R^2	0.997		0.997	
Stand.error of estimate	5.158		5.201	
F-ratio	2479.2***		1946.48***	
D-W test value	1.132		1.121	

Appendix 8. Cobb-Douglas production functions with total research. All variables measured at aggregate level.

Regression	(14)	s.l.	(15)	s.l.
Constant	0.009 (1.000)	0.993	0.283 (0.969)	0.773
Capital	0.808 (0.324)	0.019	0.696 (0.317)	0.036
Labour	0.048 (0.024)	0.060	0.012 (0.030)	0.685
External inputs	0.058 (0.093)	0.534	0.062 (0.089)	0.494
Total public & private research	0.078 (0.043)	0.079	0.050 (0.044)	0.261
Extension			0.116 (0.061)	0.067
R^2	0.984		0.986	
Stand.error of estimate	0.024		0.023	
F-ratio	462.60***		403.05***	
D-W test value	1.048		1.115	

Appendix 9. Cobb-Douglas production functions with total research. Output, capital, labour, external inputs measured at farm level, research and extension at aggregate level.

Regression	(16)	s.l.	(17)	s.l.
Constant	—0.307 (0.332)	0.362	—0.574 (0.355)	0.116
Capital	0.898 (0.138)	0.000	0.958 (0.138)	0.000
Labour	0.048 (0.026)	0.078	0.012 (0.033)	0.707
External inputs	0.053 (0.080)	0.510	0.025 (0.079)	0.755
Total research	0.061 (0.035)	0.089	0.021 (0.041)	0.602
Extension			0.103 (0.059)	0.089
R^2	0.997		0.997	
Stand.error of estimate	0.024		0.023	
F-ratio	2423.0***		2074.5***	
D-W test value	0.966		0.976	

Appendix 10. First order autoregressive Cobb-Douglas production functions with total research. All variables measured at aggregate level.

Regression	(22)	s.l.	(23)	s.l.
Constant	—1.798 (1.199)	0.144	—1.338 (1.335)	0.325
Capital	1.329 (0.343)	0.001	1.184 (0.394)	0.006
Labour	0.046 (0.034)	0.184	0.029 (0.041)	0.489
External inputs	—0.022 (0.088)	0.806	—0.011 (0.091)	0.905
Total aggregate research	0.025 (0.036)	0.497	0.022 (0.037)	0.561
Extension			0.057 (0.080)	0.481
θ_1	0.516 (0.147)	0.001	0.495 (0.149)	0.002
R^2	0.986		0.988	
Stand.error of estimate	0.020		0.020	
F-ratio	579.29***		455.38***	
D-W test value	1.741		1.755	

Appendix 11. Second order autoregressive Cobb-Douglas production functions with total research. All variables measured at aggregate level.[1]

Regression	(24)	s.l.	(25)	s.l.
Constant	—0.632 (0.945)	n.s.	—0.429 (0.932)	n.s.
Capital	1.017 (0.296)	<0.002	0.930 (0.297)	<0.005
Labour	0.037 (0.030)	n.s.	0.014 (0.033)	n.s.
External inputs	0.047 (0.086)	n.s.	0.031 (0.087)	n.s.
Total aggregate research	0.031 (0.035)	n.s.	0.028 (0.036)	n.s.
Extension			0.088 (0.061)	n.s.
θ_1	0.679 (0.162)	<0.001	0.600 (0.163)	<0.001
θ_2	—0.287 (0.162)	<0.100	—0.259 (0.163)	n.s.
R^2	0.989		0.990	
Stand.error of estimate	0.020		0.019	
D-W test value	1.931		1.989	

[1] n.s. = not significant. s.l. > 0.01

Appendix 12. Cobb-Douglas production functions with total research for shorter periods. All variables measured at aggregate level.

Regression	(30) 1950—69	s.l.	(31)	s.l.	(32) 1965—84	s.l.	(33)	s.l.
Constant	—2.383 (1.626)	0.164	—2.600 (1.198)	0.048	3.162 (2.268)	0.184	4.361 (2.823)	0.145
Capital	1.168 (0.445)	0.019	1.217 (0.327)	0.002	0.219 (0.495)	0.664	—0.120 (0.683)	0.863
Labour	0.266 (0.104)	0.022	0.159 (0.082)	0.071	—0.035 (0.070)	0.627	—0.061 (0.080)	0.453
External inputs	0.026 (0.129)	0.842	—0.010 (0.095)	0.913	0.012 (0.116)	0.920	0.042 (0.125)	0.741
Total research	0.052 (0.056b)	0.368	—0.066 (0.052)	0.225	0.138 (0.057)	0.028	0.150 (0.060)	0.025
Extension			0.243 (0.066)	0.002			0.070 (0.095)	0.475
R^2	0.978		0.989		0.925		0.928	
Stand.error of estimate	0.025		0.018		0.018		0.019	
F-ratio	165.26***		247.07***		46.46***		36.13***	
D-W test value	1.052		1.373		1.617		1.784	

Appendix 13. Coefficients of regression for different Almon lags with different lengths of lag and different degrees of the polynomial. a = aggregateted conventional variables p = per farm conventional variables

Reg. No.	Length of lag	Degree	X_t	X_{t-1}	X_{t-2}	X_{t-3}	X_{t-4}	X_{t-5}	X_{t-6}	X_{t-7}	X_{t-8}	X_{t-9}	X_{t-10}	X_{t-11}	X_{t-12}	X_{t-13}
(34)	3	2 a	0.024	0.004	0.002	0.017										
			(0.041)	(0.029)	(0.029)	(0.039)										
(35)	3	2 p	—0.003	0.011	0.018	0.018										
			(0.047)	(0.028)	(0.025)	(0.036)										
(36)	3	3 a	0.030	—0.009	0.013	0.012										
			(0.045)	(0.049)	(0.046)	(0.043)										
(37)	3	3 p	0.001	0.001	0.026	0.014										
			(0.051)	(0.049)	(0.043)	(0.040)										
(38)	7	2 a	—0.024	—0.026	—0.028	—0.030	—0.034	—0.037	—0.041	—0.046						
			(0.035)	(0.021)	(0.018)	(0.019)	(0.018)	(0.016)	(0.016)	(0.029)						
(39)	7	2 p	—0.010	—0.009	—0.007	—0.006	—0.005	—0.004	—0.003	—0.003						
			(0.036)	(0.019)	(0.014)	(0.016)	(0.017)	(0.013)	(0.013)	(0.026)						
(40)	7	3 a	0.001	—0.039	—0.048	—0.039	—0.025	—0.017	—0.028	—0.071						
			(0.045)	(0.026)	(0.029)	(0.021)	(0.021)	(0.028)	(0.022)	(0.040)						
(41)	7	3 p	—0.003	—0.012	—0.012	—0.008	—0.003	—0.001	0.000	—0.010						
			(0.051)	(0.023)	(0.027)	(0.020)	(0.020)	(0.028)	(0.020)	(0.040)						
(42)	13	2 a	0.010	0.001	—0.006	—0.012	—0.016	—0.018	—0.018	—0.017	—0.013	—0.008	—0.001	0.008	0.018	0.031
			(0.029)	(0.025)	(0.021)	(0.018)	(0.016)	(0.014)	(0.013)	(0.011)	(0.009)	(0.008)	(0.007)	(0.008)	(0.010)	(0.014)
(43)	13	2 p	0.003	—0.004	—0.010	—0.015	—0.018	—0.019	—0.018	—0.016	—0.013	—0.008	—0.001	0.008	0.018	0.029
			(0.022)	(0.016)	(0.012)	(0.009)	(0.008)	(0.009)	(0.009)	(0.009)	(0.009)	(0.008)	(0.007)	(0.008)	(0.010)	(0.014)
(44)	13	3 a	—0.027	—0.004	0.007	0.010	0.006	—0.002	—0.011	—0.019	—0.024	—0.024	—0.015	0.004	0.036	0.082
			(0.036)	(0.024)	(0.022)	(0.022)	(0.020)	(0.017)	(0.013)	(0.011)	(0.011)	(0.012)	(0.011)	(0.008)	(0.015)	(0.035)
(45)	13	3 p	—0.047	—0.017	—0.000	0.006	0.005	—0.001	—0.010	—0.019	—0.024	—0.024	—0.015	0.004	0.037	0.087
			(0.034)	(0.016)	(0.012)	(0.014)	(0.014)	(0.012)	(0.010)	(0.009)	(0.010)	(0.012)	(0.010)	(0.007)	(0.014)	(0.034)

Appendix 14. Derivation of the public research capital in prices of 1984.

	Grants 1950—84	Derived grants 1920—50	Undepreciated research capital		Depreciated research capital			
					dep.rate = 50 %		dep.rate = 100 %	
			FIM 1000	Index	FIM 1000	Index	FIM 1000	Index
1920		2,930	2,930					
1921		3,826	6,757					
1922		4,722	11,479					
1923		5,618	17,097					
1924		6,514	23,611					
1925		7,410	31,021					
1926		8,306	39,326					
1927		9,201	48,528					
1928		10,097	58,625					
1929		10,993	69,618					
1930		11,889	81,507					
1931		12,785	94,292					
1932		13,681	107,973					
1933		14,577	122,550					
1934		15,473	138,022					
1935		16,368	154,391					
1936		17,264	171,655					
1937		18,160	189,815					
1938		19,056	208,871					
1939		19,952	228,823					
1945		20,848	249,670		248,205		246,740	
1946		21,744	271,414		268,036		264,657	
1947		22,639	294,053		288,314		282,574	
1948		23,535	317,589		309,040		300,492	
1949		24,431	342,020		330,214		318,409	
1950	25,327	25,327	367,347	100	351,836	100	336,326	100
1951	34,698		402,045	109	382,382	109	362,719	108
1952	32,165		434,210	118	409,946	117	385,682	115
1953	30,139		464,349	126	435,036	124	405,724	121
1954	29,886		494,235	135	459,426	131	424,617	126
1955	35,964		530,199	144	489,445	139	448,691	133
1956	41,030		571,229	156	524,083	149	476,937	142
1957	39,004		610,233	166	556,246	158	502,260	149
1958	58,252		668,485	182	607,210	173	545,935	162
1959	57,239		725,724	198	656,713	187	587,702	175
1960	53,947		779,671	212	702,475	200	625,280	186
1961	56,226		835,897	228	750,069	213	664,242	197
1962	74,715		910,612	248	815,704	232	720,797	214
1963	76,741		987,353	269	882,917	251	778,482	231
1964	74,968		1,062,321	289	947,909	269	833,498	248
1965	90,164		1,152,485	314	1,027,650	292	902,814	268
1966	92,697		1,245,182	339	1,109,475	315	973,768	290
1967	92,444		1,337,626	364	1,190,599	338	1,043,572	310
1968	100,801		1,438,427	392	1,279,632	364	1,120,838	333
1969	94,470		1,532,897	417	1,361,887	387	1,190,877	354
1970	87,632		1,620,529	441	1,436,855	408	1,253,182	373
1971	87,378		1,707,907	465	1,506,884	428	1,305,862	388
1972	99,789		1,807,696	492	1,590,591	452	1,373,486	408
1973	101,055		1,908,751	520	1,676,576	477	1,444,402	429
1974	93,710		2,002,461	545	1,755,343	499	1,508,226	448
1975	115,745		2,118,206	577	1,853,106	527	1,588,007	472
1976	121,317		2,239,523	610	1,953,908	555	1,668,294	496
1977	157,535		2,397,058	653	2,091,941	595	1,786,825	531
1978	133,220		2,530,278	689	2,196,035	624	1,861,793	554
1979	157,787		2,688,065	732	2,325,203	661	1,962,341	583
1980	160,321		2,848,386	775	2,458,550	699	2,068,715	615
1981	164,626		3,013,012	820	2,595,063	738	2,177,115	647
1982	154,495		3,167,507	862	2,712,201	771	2,256,895	671
1983	155,508		3,323,015	905	2,829,338	804	2,335,662	694
1984	157,028		3,480,043	947	2,948,882	838	2,417,722	719
SUM 1920—84			56,684,590		50,121,819		43,559,049	
SUM 1950—84			53,402,955		46,871,121		40,339,287	

Appendix 15. Derivation of the total research capital in prices of 1984.

	Grants 1950—84	Derived grants 1920—50	Undepreciated research capital		Depreciated research capital			
					dep.rate = 50 %		dep.rate = 100 %	
			FIM 1000	Index	FIM 1000	Index	FIM 1000	Index
1920		1,097	1,097					
1921		2,168	3,265					
1922		3,240	6,505					
1923		4,311	10,816					
1924		5,382	16,197					
1925		6,453	22,650					
1926		7,524	30,174					
1927		8,595	38,770					
1928		9,666	48,436					
1929		10,738	59,174					
1930		11,809	70,982					
1931		12,880	83,862					
1932		13,951	97,813					
1933		15,022	112,835					
1934		16,093	128,928					
1935		17,164	146,093					
1936		18,236	164,328					
1937		19,307	183,635					
1938		20,378	204,013					
1939		21,449	225,462					
1945		22,520	247,982		247,434		246,885	
1946		23,591	271,573		269,941		268,308	
1947		25,734	297,307		294,054		290,802	
1948		26,805	324,112		318,704		313,296	
1949		27,876	351,987		343,889		335,790	
1950	28,947	28,947	380,934	100	369,609	100	358,284	100
1951	38,500		419,434	110	404,347	109	389,260	109
1952	37,053		456,487	120	437,103	118	417,718	117
1953	35,605		492,092	129	467,874	127	443,656	124
1954	36,184		528,276	139	498,690	135	469,103	131
1955	41,974		570,250	150	534,759	145	499,268	139
1956	48,342		618,592	162	576,661	156	534,730	149
1957	47,474		666,066	175	617,160	167	568,253	159
1958	68,026		734,092	193	677,675	183	621,257	173
1959	67,447		801,539	210	737,075	199	672,611	188
1960	65,132		866,671	228	793,625	215	720,579	201
1961	68,316		934,987	245	852,823	231	770,659	215
1962	90,026		1,025,013	269	933,196	252	841,378	235
1963	95,237		1,120,250	294	1,018,244	275	916,238	256
1964	93,500		1,213,750	319	1,101,019	298	988,289	276
1965	115,500		1,329,250	349	1,205,259	326	1,081,268	302
1966	121,290		1,450,540	381	1,314,754	356	1,178,967	329
1967	128,237		1,578,777	414	1,430,124	387	1,281,471	358
1968	138,658		1,717,435	451	1,555,380	421	1,393,324	389
1969	136,053		1,853,488	487	1,677,495	454	1,501,501	419
1970	131,421		1,984,909	521	1,794,442	485	1,603,975	448
1971	135,184		2,120,093	557	1,910,376	517	1,700,659	475
1972	167,606		2,287,699	601	2,059,456	557	1,831,212	511
1973	162,395		2,450,094	643	2,204,048	596	1,958,002	546
1974	142,132		2,592,226	680	2,328,088	630	2,063,950	576
1975	162,685		2,754,911	723	2,469,786	668	2,184,661	610
1976	183,527		2,938,438	771	2,629,142	711	2,319,846	647
1977	218,264		3,156,702	829	2,823,669	764	2,490,636	695
1978	192,500		3,349,202	879	2,982,156	807	2,615,110	730
1979	219,421		3,568,623	937	3,167,854	857	2,767,084	772
1980	219,421		3,788,044	994	3,354,709	908	2,921,373	815
1981	217,106		4,005,150	1051	3,537,657	957	3,070,163	857
1982	218,264		4,223,414	1109	3,710,908	1004	3,198,401	893
1983	234,764		4,458,178	1170	3,898,053	1055	3,337,928	932
1984	230,132		4,688,310	1231	4,081,435	1104	3,474,560	970
SUM 1920—84			70,271,929		63,283,710		56,295,492	
SUM 1950—84			67,123,932		60,154,653		53,185,374	

Appendix 16. Cobb-Douglas production functions with total research measured as an undepreciated stock.

Regression	(48)	s.l.	(49)	s.l.
Constant	1.023 (1.136)	0.375	1.237 (1.095)	0.268
Capital	0.299 (0.424)	0.486	0.247 (0.408)	0.550
Labour	0.207 (0.072)	0.007	0.143 (0.077)	0.072
External inputs	—0.008 (0.091)	0.930	0.010 (0.087)	0.052
Research stock	0.278 (0.110)	0.017	0.222 (0.110)	0.052
Extension			0.109 (0.057)	0.066
R^2	0.985		0.987	
Stand.error of estimate	0.023		0.022	
F-ratio	505.25***		440.57***	
D-W test value	1.095		1.164	

Appendix 17. Cobb-Douglas production functions with total research measured as a stock with 50 % depreciation after 20 years.

Regression	(54)	s.l.	(55)	s.l.
Constant	0.586 (1.021)	0.570	0.868 (0.991)	0.388
Capital	0.433 (0.387)	0.273	0.362 (0.374)	0.341
Labour	0.191 (0.067)	0.008	0.129 (0.072)	0.085
External inputs	—0.005 (0.091)	0.958	0.013 (0.088)	0.879
Research stock	0.252 (0.102)	0.020	0.199 (0.102)	0.061
Extension			0.109 (0.058)	0.069
R^2	0.985		0.987	
Stand.error of estimate	0.023		0.022	
F-ratio	501.59***		436.47***	
D-W test value	1.066		1.141	

Appendix 18. Cobb-Douglas production functions with total research measured as a stock with 100 % depreciation after 20 years.

Regression	(56)	s.l.	(57)	s.l.
Constant	0.119 (0.908)	0.896	0.474 (0.894)	0.600
Capital	0.585 (0.347)	0.102	0.493 (0.337)	0.154
Labour	0.170 (0.060)	0.009	0.110 (0.066)	0.108
External inputs	—0.001 (0.091)	0.990	0.017 (0.088)	0.848
Research stock	0.219 (0.091)	0.022	0.169 (0.091)	0.074
Extension			0.108 (0.058)	0.073
R^2	0.985		0.987	
Stand.error of estimate	0.023		0.022	
F-ratio	497.80***		431.49***	
D-W test value	1.037		1.117	

SELOSTUS

Maataloustutkimuksen tuotto Suomessa 1950—1984

John Sumelius

Maatalouden taloudellinen tutkimuslaitos

Tämän tutkimuksen tarkoituksena on estimoida yhteiskunnan tuotto maataloustutkimuksesta vuosina 1950—1984. Arvioimalla maataloustutkimuksen yhteiskuntataloudellista korkoa voidaan luoda eräs mittapuu tutkimusvarojen allokoinnille. Tarkemmin määriteltynä estimoidaan maataloustutkimuksen rajakorko sekä sisäinen rajakorko ajanjaksolle 1950—1984. Maataloustutkimuksen tuottoa arvioitaessa on käytetty pääasiassa kahta päämenetelmää: tuotantofunktioanalyysia ja hyvinvointiteoriaa. Menetelmien pääperiaatteet sekä aikaisemmat tutkimukset on selostettu toisessa luvussa. Tuotantofunktioanalyysiin perustuen tässä tutkimuksessa spesifioidaan Cobb-Douglas ja lineaarisia malleja, joihin sisällytetään tutkimusmuuttuja kolmen perinteisen ja yhden neuvontamuuttujan lisäksi. Tutkimusmuuttuja on määritelty kahdella eri tavalla; toisaalta julkisten tutkimus- ja korkeakoulumäärärahojen rahavirran perusteella, toisaalta karttuvan tutkimuspääoman perusteella. Tutkimuspanos on samoin määritelty toisaalta pelkän julkisen tutkimuspanoksen ja korkeakouluopetuksen perusteella, toisaalta julkisen ja yksityisen sektorin tutkimuspanoksen perusteella. Tutkimusjoustoestimaattien avulla lasketaan rajakorko. Valtiontuki neuvontajärjestöille huomioidaan lopullisessa laskelmassa.

Tutkimuspääomaestimaatteihin nojautuen julkisen maataloustutkimuksen rajakoroksi on saatu 183—191 %. Tämä on tulkittava niin, että maataloustutkimuksen yhden markan lisäys kyseessä olevina vuosina olisi palautunut lähes kaksinkertaisena vuotuisena reaalikorkona tuottajille ja kuluttajille. Tutkimusmäärärahojen rahavirran perusteella estimoitu sisäinen rajakorko on ollut 20—62 % riippuen viiveen pituudesta (4—10 vuotta).