Manchester Working Papers in Agricultural Economics

Measuring the Contribution of Publicly Funded Research and Development Expenditure to Increasing UK Oilseed Rape Yields

N.P. Russell and C.G. Thirtle

(WP/88-01)

ARDUUS AD SOLEM

Department of Agricultural Economics

Faculty of Economic and Social Studies
University of Manchester,
Manchester U.K.

Measuring the Contribution of Publicly Funded Research and Development Expenditure to Increasing UK Oilseed Rape Yields

N.P. Russell and C.G. Thirtle

(WP/88-01)

ACKNOWLEDGEMENTS

This study could not have been completed without the help of many people. David Colman (University of Manchester) and Aidan Power (Economics-Resource Use Division, MAFF) helped us set up the study and provided encouragement and support throughout. Dennis Kimber (NIAB) made available the major trial-plot data set and together with Paul Bowerman (ADAS, Cambridge) helped us understand its construction and limitations. Bernard Watts (Economics-Resource Use Division MAFF) helped us assemble the aggregate time-series data and Paul Bottomley (University of Manchester) spent many hours on assembly and computer input of the trial-plot and weather data. To all of you, we extend our thanks.

We also thank Judy Darnton and Jennifer Vaughan who had the difficult task of typing the many drafts of this report.

Last, but not least, we extend our thanks to the Ministry of Agriculture, Fisheries and Food, for funding the research on which this report is based.

CONTENTS

LIST OF TABLES

MEASURING THE CONTRIBUTION OF PUBLICLY FUNDED RESEARCH AND DEVELOPMENT EXPENDITURE TO INCREASING UK OILSEED RAPE YIELDS

INTRODUCTION

This paper reports on a study of publicly funded oilseed rape research in the UK. It measures the rate of return to expenditure for research activities undertaken by the Agricultural Development and Advisory Service of the Ministry of Agriculture, Fisheries and Food on oilseed rape production systems and management practices, and by the Plant Breeding Institute on developing oilseed rape varieties. It also discusses the problems of measuring the contribution of individual components of this research and evaluates the use of regression analysis in this general area.

This study is motivated by the current high level of interest in the evaluation of research and development activities in the UK and elsewhere. It is primarily a response to the need (expressed in Wise 1981, Harvey 1988, Thirtle and Bottomley 1988) for information on returns to R & D to provide base-line estimates for R & D policy discussions and the need for more specific information to support management decision-making for oilseed rape R & D. In the latter case estimates of rates of return provide both an indication of potential losses from budget cuts and a standard against which forecasted returns to specific projects may be judged.

These information requirements are particularly acute in a political environment which uses "value for money" criteria in assessing public expenditure. Such requirements are not eliminated either by criticism of the methodology used to generate this information, (e.g. Wise 1981, 1984, 1986) or by the notion that economic parameters are only a subset of the total information required to support policy and management decisions.

More formally the objectives of the study are,

(a) to establish and quantify the link between UK publicly funded production-related research for oilseed rape and UK oilseed rape yields

(b) to examine approaches to measuring the contribution to changes in oilseed rape yields of individual components of the oilseed rape research programme.

(c) to evaluate the use of regression analysis for identifying and quantifying the contribution to agricultural output of broad-based production-related research programmes.

The remainder of the study considers these objectives in turn. Part I examines the link between the oilseed rape research programme and oilseed rape yields and estimates the return to public expenditure in this area. Part II focuses on the problems associated with extending the methodology to individual components of this programme while Part III provides an evaluation of the regression-based methodology used here as a general evaluation technique for broad-based production related research programmes. Some general conclusions are presented in Part IV.

PART I PUBLICLY FUNDED RESEARCH AND OILSEED RAPE YIELDS

Estimating Returns to R & D

A number of methods for measuring returns to investment have been proposed. These include Net Present Value, Internal Rate of Return and Discounted Benefit-Cost Ratio. The advantages and disadvantages of these measures are well known (see for example Anderson and Settle (1977), Sassone and Schaffer (1981)). The Discounted Benefit-Cost Ratio is used in this study because of its simplicity and ease of interpretation. This measure is easy to compute once the relevant cost and benefit streams have been established.

Three main approaches have been used to measure the benefit streams to agricultural R & D. The change in economic surpluses accruing to producers and consumers is an appropriate measure of benefits when research and development leads to lower consumer prices as well as increased output and farmer incomes. This approach has been implemented by many researchers beginning with Griliches' work on hybrid corn in the 1950's and includes studies by Casimiro Heruzo (1985) and Ulrich, Furtan and Schmitz (1986). It requires data to estimate supply and demand relationships in a market equilibrium framework, and sufficient information to allocate part of the shift in supply to R & D. An alternative approach, which is particularly useful when market flexibility is impaired, is to directly relate changes in productivity to changes in R & D expenditure within a production function framework. This approach requires (data to calculate) an appropriate measure of productivity and sufficient information to determine the change in productivity which is attributable to R & D. This type of study is exemplified by Griliches, (1964); Bredahl and Peterson, (1976); Doyle and Ridout,(1985) and many others. Both these approaches may be applied at aggregate or product level and do not depend on the availability of detailed technical information on specific research projects. Where this information is available and where the research results are embodied in a specific production method or physical equipment the benefits stream may be computed directly (Power and Russell, 1988). This requires estimates of the impact of the new techniques/equipment on output, estimates of adoption by farmers and forecasts of obsolescence as techniques and equipment are replaced by more up-to-date results. However the usefulness of this approach is severely limited by the large amount of information required.

A measure of R & D costs, which includes the cost of personnel, facilities, equipment and materials is also required. This information must be available to researchers and cannot be inferred from other data sets.

Oilseed Rape Production, Research and Development in the UK

Oilseed rape has been grown as a commercial crop in the UK since the introduction of EC subsidies in the early 1970s. Almost all U.K. research and development work on this crop began in the early 1970s. Almost 300 thousand ha. were grown in 1985, producing abut 900 thousand tonnes of seed and accounting for just over 2% of gross agricultural output. The future of the crop is uncertain, however, since support levels may be curtailed in the 1990s for those, currently popular, varieties which do not meet certain quality criteria.

Model, Data and Estimation Procedures

Studies of R & D productivity based on production relationships linking inputs and output date from the 1960s (Griliches, 1964; Peterson, 1967). Since technical change, resulting from R and D expenditures, occurs over time and its effect on output is subject to considerable lags, time series data are required. Since time series data for agricultural inputs are collinear, the number of input groups must be restricted and, even then, if the full production function is fitted, parameter estimates for inputs which account for minor proportions of output may not be robust. This problem has been circumvented in the recent literature by dividing the inputs into two groups, conventional and novel, and disposing of the conventional inputs by incorporating them in a total factor productivity index. Then, changes in the productivity index should be explained by the non-conventional inputs such as R and D expenditures. Using the Cobb-Douglas function for simplicity, if Q is total aggregate output, the X_j's are traditional inputs and the Z_i's are novel inputs and the α_i's and γ_j's are parameters and Π denotes multiplication, then:

$$Q = \prod_{j=1}^{m} X_j^{\gamma_j} \prod_{i=1}^{n} Z_i^{\alpha_i} \tag{1}$$

which gives the total factor productivity index (TFP)

$$TFP = \frac{Q}{\prod_{j=1}^{m} X_j^{\gamma_j}} = \prod_{i=1}^{n} Z_i^{\alpha_i} \tag{2}$$

The X_j's include all conventional inputs such as land, labour, capital, machinery, buildings, chemicals and other miscellaneous inputs. The Z_i's are normally the stock of knowledge, K, (accumulated research capital), extension services (S) and farmer education (E).

Accumulated research capital (K) could be defined very simply as the sum of past R and D expenditures:

$$K_t = \sum_{i=1}^{n} R_{t-i} \tag{3}$$

but, if there is no research, the absence of maintenance expenditures will result in negative growth of K_t. The alternative to including an arbitrary depreciation factor in the calculation of K_t is to include a finite number of lagged R_{t-i}'s as explanatory variables. Initially, the effect of R and D on productivity is small; then the effect rises to a peak, before diminishing to zero as the new technology becomes obsolete. Following this procedure and adding a constant (A) and a stochastic error term gives the 'conventional' model:

$$P_t = A \prod_{i=0}^{n} R_{t-i}^{\alpha_i} S_t^{\beta_1} E_t^{\beta_2} e^{\beta_3 W_t} e^{u_t} \tag{4}$$

where P_t is the productivity index, W_t is a weather index that explains a proportion of the variations in P_t, and U_t is the remaining stochastic error that cannot be accounted for.

Taking logarithms of (4) gives the conveniently linear equation

$$\ln P_t = \ln A + \sum_{i=0}^{n} \alpha_i \ln R_{t-i} + \beta_1 \ln S_t + \beta_2 \ln E_t + \beta_3 W_t + u_t \qquad (5)$$

However, the dozen or so lagged values of R are likely to be highly correlated and to use up too many degrees of freedom, so a distributed lag structure is often assumed. This is normally an inverted V or an Almon polynomial lag, which resembles an inverted U-shape. This type of function has been fitted to data for US agriculture by Evenson (1967), Lu, Cline and Quance (1979), Knutson and Tweeten (1979), Evenson, Waggoner and Ruttan (1979) and others; to Australian and Irish agricultural data, and to UK agriculture by Doyle and Ridout (1985) and Thirtle and Bottomley (1988).

The analysis of oilseed rape research and development follows the same approach but allows a simpler specification. Since this research is assumed to affect yields rather than labour productivity, we can write:

$$Q = C \prod_{i=0}^{n} R_{t-i}^{\alpha_i} \; F^{\alpha} A^{1-\alpha} e^{\gamma w_t} e^{u_t} \qquad (6)$$

where C is a constant, F is the fertilizer and chemical inputs, and A is land. Assuming constant returns to scale and taking logarithms, equation (6) can be rewritten as,

$$\ln Q - \ln A = \ln C + \sum_{i=0}^{n} \alpha_i \ln R_{t-i} + \alpha(\ln F - \ln A) + \gamma w_t + u_t \qquad (7)$$

Thus, changes in yields are explained by lagged R & D expenditure, fertilizer application rates, and an index of the weather (i.e. education and extension are ommitted).

One of the principal results of previous studies is that the lag between R & D expenditure and its effects may be quite substantial. Thus any attempt to evaluate and quantify these effects must be based on a series of observations extending over a large number of years. Since U.K. oilseed rape production and research began in the 1970s the methodology of previous studies cannot be applied directly in this study because the data required does not extend over a sufficiently long time period.

This problem is overcome by viewing the research expenditure-yield linkage as comprising two components; a research expenditure - trial yields component and a trial yields-farm yields component. In this scheme trial yields are viewed as an "intermediary" between research activities and farm yields in that they are expected to be based on more up-to-date research findings than those being implemented at farm level. The lag between research expenditure and trial yields is therefore expected to be short enough to be identifiable within the time frame of available data. The lag between trial yields and farm yields is also expected to be identifiable since this represents the remaining portion of the overall lag.

Within this framework the relationship between trial plot yields and R & D expenditure may be expressed as follows

(a) $$YP_{kt} = C_p \prod_{i=0}^{N} R_{t-i}^{\alpha_i} F_{kt}^{f} e^{wW_{kt} + \sum_j D_{jt}} U_k V_{kt}$$

where YP_{kt} is yield on plot k in year t

C_p is a constant term

R_{t-i} is lagged R & D expenditure (i=0 to N)

F_{kt} is fertilizer application rate

W_{kt} is weather,

D_{jt} are dummy variables to account for other time varying influences

α_i, f and w are elasticities while U_k and V_{kt} are components of the error term. Our interest here is focused on the α_i parameters since these provide estimates of the percentage change in current yields attributable to a one per cent change in R & D expenditures in previous years. Since we assume a stable relationship between R & D expenditures and yields these parameters may also be interpreted as the pecentage change in trial plot yields in future years of a one per cent change in current R & D expenditure. The marginal impact of one unit change in R & D expenditure for a given year (say 1985) may be derived as follows;

(b) $$\beta_i = \alpha_i \frac{YP_{85}}{R_{85}}$$

where β_i is the marginal impact of one (index) unit change in R & D expenditure on future trial plot yields (i=0...N) and YP_{85}, R_{85} are average trial plot yield and R & D index value for 1985.

The second component of the lagged relationship may be expressed as follows:

(c) $$YF_t = C_f \sum_{j=0}^{M} y_j \, YP._{t-j} + C_1 \, AI_t + Z_t$$

where YF_t is average farm yield,

C_f is a constant term

AI_t is aggregate average input use in year t

$YP._{t-j}$ is average plot yield in year t-j

Z_t is the error term

The relationship between changes in farm yields and changes in R & D expenditure may then be expressed as follows:

$$\Delta YF_t = \sum_{j=0}^{M} y_j \left[\sum_{k=0}^{N} \beta_k \Delta R_{t-j-k} \right]$$

which simplifies, by expanding and collecting terms, to:

(d) $$\Delta YF_t = \sum_{i=0}^{L} y_i \beta_{L-i} \Delta R_{t-i} = \sum_{i=0}^{L} \delta_i \Delta R_{t-i}$$

where Δ = change in...

$L = M + N$

$y_i = 0$ for $i > M$,

$\beta_{L-i} = 0$ for $(L-i) > N$,

and $\delta_i = y_i \beta_{L-i}$

The δ_i coefficients are equivalent to measures of the marginal impact of a one (index) unit change in R & D expenditure on farm-level oilseed rape yields i years in the future.

The discounted Benefit/Cost ratio for an increase in R & D expenditure in any given year (say 1985) may then be computed as follows:

(e) $$B/C = \sum_{j=0}^{L} \left[\frac{\delta_j \tilde{P}\tilde{H}}{(1+I)^j} \right] / Co$$

where B/C is the discounted Benefit/Cost ratio,

$\tilde{P}$ is the assumed oilseed price per tonne over L years

$\tilde{H}$ is the assumed hectares planted each year,

and Co is the cost of one (index) unit of R & D

The following data series were needed to estimate the parameters in these relationships.

1) Trial Plot Yields (YP_{kt}, $YP_{.t-j}$), Fertilizer Application Rate (F_{kt}) and Control Varieties

Data on experimental variety trials conducted jointly by ADAS and NIAB provided information on crop yield by variety in a number of locations from 1976/77 to 1984/85. Information on fertilizer use, chemical use, cultivation practices and soil type is also available. The complete oilseed rape variety trials data set covers nine years and 13 aggregate sites[1] giving a total of 117 potential observations. However 8 trials were abandoned over this period and most locations were not involved in trials in some years. Few sites had a complete time series of observations, and at some sites too few observations were available to warrant their inclusion. A final set of 93 observations was used. A list of the sites involved is at Annex A.

The yield from the control plot in each trial is used as the dependent variable in (a) and the average control yield over all plots in each year (Table 1) is used as the main explanatory variable in (c). Data for Nitrogen, Phosphorous and Potassium fertilizer use is available but these data series are highly colinear. In the absence of a suitable set of aggregation weights, Nitrogen is used as a proxy for total fertilizer use. In addition information is available on the varieties used in each control plot. The impact of varietal change on yield is an important component of total yield change. This component represents a major part of the impact of non-UK research on oilseed rape yields and is accounted for here using dummy variables.

2) R & D Expenditures (RD_{t-i})

Data on resource use in production related oilseed rape research, based on previous work by one of the authors is available by kind permission of

---

[1]. Aggregate "sites" are developed by treating adjacent sites in the original data set as a group. Details of the groupings used are in Table A2 of Annex A.

M.A.F.F. This provides an index of research effort in this area which is extended, to reflect earlier research efforts.

3) Weather (W_{kt})

Monthly weather observations for sites close to (and often coincident with) trial sites were obtained from the Meteorological Office, Monthly Weather Report. These allowed estimates of a number of weather indices (Stallings, 1960; Oury, 1965) as well as the construction of specific impact variables based on agronomic information; the use of average precipitation at establishment (September, October), minimum February-March temperature and average precipitation in May, June-July, was justified on this basis. The relationship between trial sites and weather stations is detailed at Annex A.

4) Average Farm Yields (YF_t) and Average Variable Input Use

Data on average annual oilseed rape yields was obtained from M.A.F.F. (Table 1), while data on average variable input use is derived from the results of oilseed rape Enterprise Cost Studies.

Relationship (a) is estimated from pooled time series and cross-section data where each cross-section has varying numbers of observations over time. Estimation and inference are based on the "error-components" model. The estimation procedure used, outlined in Judge et.al. (1982), involves a simple mean-differencing procedure. This provides unbiased but inefficient parameter estimates.[2] A more complex scheme, using weighted mean differences to improve efficiency, is given in Baltagi (1985). However a suitable set of weights could not be generated for the model used in this study.

---

2 Parameter estimates are inefficient when it is known that the variance of these estimates could be reduced using other more complex estimation procedures. These procedures are not always a practical alternative to the simpler "inefficient" procedures.

Relationship (c) is estimated from time series data using explicit lags. Efficiency of estimation is improved by using autoregressive procedures. relationships (b), (d) and (e) are identities.

Table 1 : Index of Oilseed Rape Research and Development Expenditures, Average Annual Trial Plot Yields and Average Annual Farm Yields

Year	R & D Index (1980=100)	Average Trial Plot Yields (tonnes/ha)	Average Farm Yields (tonnes/ha)
1985	446	3.24	3.06
1984	483	3.75	3.43
1983	367	2.36	2.53
1982	341	3.57	3.33
1981	223	2.69	2.57
1980	100	3.33	3.27
1979	326	2.83	2.64
1978	147	2.13	2.40
1977	122	2.75	2.56
1976	127	-	2.32
1975	108	-	1.72
1974	91	-	-
1973	28	-	-

Results - Response of Yields to R & D Expenditure

The parameters of relationship (a) were estimated, in double log form, using a number of alternative specifications. These included explicit lag structures and 2nd degree and 3rd degree polynomial lags (Almon, 1965) for lag lengths of 2 to 9 periods. Constraints were imposed on initial and final lag coefficient values and a number of specifications of the weather variable were tested.

Choice between alternative specifications was based on both statistical criteria, including goodness-of-fit measures, and on a priori criteria focusing on the signs and relative magnitude of the coefficients. Econometric and other results for some of these models are in Annex B.

The model which performed "best" under these criteria involved a 4-period, 3rd degree polynomial lag, constrained to zero in the initial period, included a weather specification based on agronomic information, and used dummy variables to control for the impact on yield of varietal improvement. The estimated parameter and lag coefficient values for this relationship are shown in Table 2. All coefficients and parameters are positive, as expected,

Table 2 : The Relationship between Plot Yields and R & D Expenditures[1]

Explanatory Variable	Coefficient Value	t-Statistics	
R & D Expenditure			
R_t	0		
R_{t-1}	0.289		
R_{t-2}	0.817	4.40	
R_{t-3}	0.944		
R_{t-4}	0.030		
Fertilizer	0.045	0.56	
Weather			
Establishment	0.0024	6.00	
Winter Damage	0.0010	0.70	
Growing Season	0.0019	0.83	
Varietal dummies	1.5818	5.74	$\bar{R}^2 = 0.62$

Note: 1. Based on Estimate 1(a) in Annex B.

though the elasticity of fertilizer use and two of the weather variables are not significantly different from zero. The adjusted coefficient of determination ($\bar{R}^2$) is not unduly low given the nature of the data and the model. In addition the lag coefficients are associated with a relatively high t-value and show an asymmetric U-shaped response of yield to R & D expenditure.

The parameters of relationship (c) were estimated using both explicit and polynomial lag structures. Results for some of these specifications are equations (2a) and (2b) in Annex B. The "best" model in this case involved a 3-period lag with response in 4th and subsequent periods constrained to zero. The estimated lag coefficients and test statistics are in Table 3. The main response in the current period indicates a rapid transfer of research results

Table 3 : The Relationship between Farm Yields and Plot Yields, and Between Farm Yields and R & D Expenditure

Farm Yield v. Plot Yields[1]			Farm Yields v. R & D Expenditures[2]	
Plot Yield	Lag Coefficient	Test Statistics	R & D Expenditure	Farm Yield Response Coefficients
YP.t	0.586	7.27	R_t	
YP.t-1	0.008	1.14	R_{t-1}	1.16E-3[3]
YP.t-2	0.001	1.03	R_{t-2}	3.30E-3
YP.t-3	0.0	0.52	R_{t-3}	3.84E-3
		R^2 = 0.99	R_{t-4}	1.77E-4
		= -0.79	R_{t-5}	8.66E-6
		d.w.= 1.75	R_{t-6}	8.51E-7
			R_{t-7}	2.03E-8

Notes: 1. Based on Estimate 2(a) in Annex B.
2. Obtained by combining estimate 1(a) and 2(a) in Annex B.
3. 1.16E-3 = 1.16×10^{-3}

consistent with a largely commercial farming industry. Response decreases rapidly becoming insignificant after period 3. These results when combined (in relationship (d)) with those for relationships (a) and (b) show the response of farm yields to R & D expenditure (Table 3).

Results - Returns to R & D Expenditure

The returns to expenditure on oilseed rape research and development are obtained by translating the coefficients in the last column of Table 3 into a stream of benefits at national level which may then be compared to R & D costs. Estimates of hectares of oilseed rape grown and appropriate oilseed rape price estimates are required here. To support policy decisionmaking these estimates should reflect likely future developments in the oilseed rape enterprise. In the absence of detailed forecasts this study uses a range of estimates which are expected to encompass most foreseeable changes, as well as differences of opinion about appropriate values to use.

The range of values used and the corresponding benefit/cost ratios computed according to relationship (e) are shown in Table 4. These results indicate that in the worst case oilseed rape research should provide discounted benefits of 22 times the required expenditure. If current conditions are projected forward (approximately 300,000 hectares and £250 per tonne) then this research provides discounted benefits of 327 times the required expenditure.

Table 4 : Discounted Benefit/Cost Ratios for Oilseed Rape Research Using Alternative Crop Values and Hectares Grown

Crop Value £/tonne	250	200	150	100	50
Hectares Grown ('000)					
400	436	348	261	174	87
300	327	261	196	131	65
200	218	174	131	87	44
100	109	87	65	44	22

These extremely high rates of return are consistent with many previous estimates of returns to agricultural research at disaggregated levels (see for example Power and Russell). These results exaggerate the true returns to the extent that they do not account for the impact on costs and benefits of related advisory services and the general impact of more basic research in agricultural, biological and physical sciences. The impact of non-UK research may also be important, although its principal impact on UK oilseed rape yield, through the development of new varieties, is explicitly accounted for here. Finally the impact of private research may be important especially in the development of fertilizers, pesticides, fungicides and herbicides. However it is unlikely that the combined impact of these factors would seriously affect the high returns measured in this study.

PART II MEASURING THE IMPACT OF THE COMPONENTS OF THE OILSEED RAPE RESEARCH PROGRAMME

The research being evaluated in this study is that undertaken since the early 1970's by ADAS and the Plant Breeding Institute. A summary of the main components of this research is in Table 5.

Table 5 : Components of the Oilseed Rape Research Programme

ADAS	PBI
Experimental Husbandry Farms	Development
Agronomy	Propogation
Soil Science	Testing
Plant Pathology	
Wildlife	
Entomology	

The model used in Part I of this study may in principle be extended to evaluate the contribution of these individual components when separate expenditure indices are available for each. An example of the type of model which might be developed is as follows

$$(8) \qquad Y_t = A \prod_{i=1}^{K} \left[\prod_{i=1}^{N} R_{tk-j}^{\alpha_i} \right] F_t^{\beta} e^{wW_t + \Sigma D_{lt}} V_t$$

where Y_t is oilseed rape yield in year t

R_{tk-j} is lagged R & D expenditure for component k of the research programme.

The parameters A, α_i, β, w and D_{it} might be estimated using a modified version of the two step procedure used above. However, in moving to a lower level of the disaggregation, the problems associated with this specification and estimation procedure are magnified.

Problems of specification become more pressing because of major differences in the success of individual components and because of interaction between them. For example, research efforts on developing oilseed rape varieties at the PBI have not been directly successful since no useful variety has emerged from this research. In fact all successful oilseed rape varieties used by UK farmers have been developed by research establishments in Europe, particularly those in France, W. Germany and Denmark. This creates the so-called "dry-hole" problem associated with any exploratory/discovery endeavour. This problem arises in the current situation out of the dual role of PBI expenditures. In the first place, they represent part of the R & D expenditure index for which no corresponding benefits exist, i.e. they are no more than statistical noise which may impede efforts to estimate the parameters in equation (8). This problem cannot be ignored at this level of disaggregation (as it usually is at higher aggregation levels) since PBI expenditures represents at least one identifiable component, among the k components in equation (8). In the second place these expenditures are recognizable costs of the research programme in toto and must be taken into account when rates of return are computed.

The problems associated with interaction between research programme components may also be illustrated using PBI expenditures as an example. In the case of this research, the absence of direct benefits does not preclude the possibility that indirect benefits may arise, since varietal research is an integral part of a production-related research programme. Similar indirect benefits, arising from interaction between scientists working in varying disciplines, may arise for other components of the programme, irrespective of their individual success or failure. These interactions require explicit consideration in specifying the model when the impact individual components of the research programme is being assessed. There are obvious difficulties in achieving this specification.

There are also difficulties in estimating the model specified in (8) and these difficulties are compounded with the specification problems discussed above. The principal problem, one of data sufficiency, arises from the expanding number of explanatory variables required. In this study the available data set could not provide sufficiently robust estimates for the expanded specifications tested. For this reason no results are reported here. However these problems present an interesting area for future enquiry.

PART III AN ASSESSMENT OF THE METHODOLOGY USED

The production function approach to research evaluation has been used by a large number of authors to measure returns to R & D both at aggregate sector level and for individual research programmes (see Part I). The major difficulties with this approach are discussed in detail in Bottomley and Thirtle (1987). These include the usual statistical problems associated with choice of model specification and reliability of results, problems associated with measurement of R & D expenditures and productivity changes; and more general specification problems associated with our limited understanding of the R & D process. Bottomley and Thirtle conclude that

> "At high levels of aggregation, there is little feel for the data. We cannot identify individual important innovations and track their effects. The system is ill-defined so that we can do little except fish with a very blunt hook and rely on dubious statistical tests. The results at the aggregate level probably can't be significantly improved without much more and better data. A better understanding of the underlying processes would also help, but that is a tall order at this level of aggregation.
>
> At low levels of aggregation, for example at the level of the individual project, externalities abound, and no matter how good the results, the author will be suspected of selectivity, since for every success there are n failures. In this instance, Morton's fork can be avoided, by selecting an intermediate level of aggregation."

Part I of this study is focused on the intermediate level of aggregation and so avoids a number of these problems. In particular by focusing on yield changes we avoid many of the problems associated with measuring aggregate productivity. In addition the R & D expenditure series used may be more reliable than those available for the total agricultural research system. Many of the statistical problems are also avoided by using pooled time-series/cross-section data and an Almon specification for the lag relationship. However these statistical gains are partly offset by the short time-span covered by the data (see Part I).

However the fundamental specification problems remain. These take a dual form. Firstly the traditional model avoids measuring "research output" by treating R & D expenditures as auxiliary inputs to the agricultural production process. As a result we cannot separate productivity gains in the research process from those generated by R & D in the agricultural production process. Where the R & D process is becoming more efficient (due to basic research and educational effects) the estimated returns to applied R & D will be biased upwards. Secondly the model used in this study does not take account of other influences on the productivity of the agricultural production process such as general education and the efforts of the agricultural advisory service. This too will lead to upward bias in estimated returns.

Nevertheless the methodology is not without its merits. In particular it provides an objective approach to the assessment of R & D programmes where detailed evaluation of individual project results is not feasible. Though the results using the standard model are biased, the direction of bias is known and can be taken into account by decisionmakers. In addition this approach is potentially useful in assessing the returns to components of a research programme, even if this potential could not be fully realised in the present study.

PART IV SUMMARY AND CONCLUSIONS

This project uses a production function approach to estimate the rate of return to publicly-funded oilseed rape research in the U.K. The standard economic and statistical models, adapted to the needs of the problem and the data, provide estimates of discounted benefits from this research which vary between 436 and 22 times the expenditure needed to produce these benefits, depending on assumed production levels and prices in the future. If current price and production levels persist, discounted benefits of more than 300 times expenditure are estimated.

Because of modelling and data problems no explicit analysis was carried out to allocate these benefits to specific components of this programme.

Many of the well known problems associated with this approach are avoided in this study by careful choice of the economic and statistical models and by used pooled rather than time series data in estimating the parameters. However the fundamental specification problems which remain mean that estimated returns are biased upwards. Nevertheless this is an objective approach to measuring returns to R & D which provides information useful to policy decisionmakers.

References

Almon, S. (1985) "The Distributed Lag Between Capital Appropriations and Expenditure". Econometrica, 178-96.

Anderson, L.G. and R.F. Settle (1977) Benefit-Cost Analysis: A Practical Guide, Lexington, Ma.

Baltagi, B.H. (1985) "Pooling Cross-sections with Unequal Time-Series Lengths". Economic Letters, 18, 133-36.

Bottomley, P. and C. Thirtle (1987). The Rate of Return to Public Sector R & D: A Critical Assessment. Manchester University, Agricultural Economics Department, Working Paper, WP 87/01.

Bredahl, M. and W. Peterson (1976). "The Productivity and Allocation of Research: U.S. Agricultural Experiment Stations", American Journal of Agricultural Economics, Vol.58, pp.684-92.

Casimiro Herruzo, A. (1985), Returns to Agricultural Research: The Case of Rice Breeding in Spain, European Review of Agricultural Economics, Vol.12, pp.265-282.

Doyle, C.J. and Ridout, M.S. (1985). The Impact of Scientific Research on UK Agricultural Productivity, Research Policy, Vol.14, pp.109-116.

Evenson, R.E. (1967). The contribution of agricultural research to production, Journal of Farm Economics, Vol.49(5), pp.1415-25.

Evenson, R.E., Waggoner, P.E. and Ruttan, V.W., (1979). "Economic Benefits from Research: An Example from Agriculture". Science, Vol.205, pp.1101-1107.

Harvey D.R. (1988) "Research Priorities in Agriculture" Journal of Agricultural Economics, Vol.39, No.1, January, pp.81-97.

Judge, G.G., R.C. Hill, W. Griffiths, H. Lutkepohl and T.C. Lee (1982). Introduction to the Theory and Practice of Econometrics, Wiley.

Knutson, M. and L. Tweeten (1979). "Toward an Optimal Rate of Growth in Agricultural Production Research and Extension". American Journal of Agricultural Economics, Vol.61, pp.70-76.

Lu, Y., Cline, P. and Quance, L. (1979). Prospects for Productivity Growth in U.S. Agriculture, Agriculture Economic Report, No.435, ESCS, USDA, Washington D.C.

Meteorological Office, Monthly Weather Report.

Ministry of Agriculture, Fisheries and Food. Annual Review of Agriculture, HMSO, Published monthly.

Oury, B. (1965). "Allowing for Weather in Crop Production Modelling", J.Farm Econ. 47, 271-83.

Peterson, W.L. (1967). Returns to Poultry Research in the US, Journal of Farm Economics, Vol.49(3), pp.656-99.

Power, A.P. and N.P. Russell (1988) Economic Evaluation of Scientify Research: A Case Study - Poultyr Layer Feeding Systes. GES Working Paper 101, April Ministry of Agriculture, Fisheries and Food.

Sassone, G. and L.M. Schaffer (1981) Principles and Practice of Cost-Benefit Analysis.

Stallings, J.L. (1960). Weather Indices, Journal of Farm Economics, Vol.42, pp.180-186.

Thirtle, C. (1986). The Production Function Approach to the Relationship between Productivity Growth and R & D. Working Paper No. 86/05, Department of Agricultural Economics, University of Manchester.

Thirtle, C.G. and P.A. Bottomley (1988), "Is Publicly Funded Agricultural Research Excessive" Journal of Agricultural Economics, Vol.39, No.1, January, pp.99-111.

Ulrich, A., Furtan, H. and Schmitz, A. (1986), Public and Private Returns from Joint Venture Research: an Example from Agriculture. Quarterly Journal of Economics, pp.103-129.

Wise, W.S. (1981). The Theory of Agricultural Research Benefits. Journal of Agricultural Economics, Vol.32, No.2, May, pp.147-57.

Wise, W.S. (1984). The Shift of Cost Curves and Agricultural Research Benefits. Journal of Agricultural Economics, Vol.35, January, pp.21-30.

Wise, W.S. (1986). The Calculation of Rates of Return on Agricultural Research from Production Functions. Journal of Agricultural Economics, Vol.37, No.2, May, pp.151-161.

ANNEX A TRIAL PLOT DATA AND WEATHER DATA AVAILABLE

Table A1 : AVAILABILITY OF PLOT DATA

Plot No.	Trial Site Location	Years for which Data is Available 77	78	79	80	81	82	83	84	85	86	87
2	Cockle Park O.C.							x	x	x		
	Cleveland						x	x	x	x		
31	Northumberland/ Newcastle	x			x							
41	North					x						
42	Northumberland		x		x							
3	York											
4	Humberside (North)							x		x		
19	Humberside	x		x	x	x						
33	Yorkshire		x									
36	Headley Hall O.C.			x	x	x	x		x	x		
	High Mowth											
5	Nottingham			x	x	x	x			x		
44	Shardlow:Nottingham	x										
9	Lincoln											
22	Lincolnshire			x	x	x	x	x				
43	Shardlow: Lincoln	x										
21	Northampton		x	x		x		x	x			
7	Bedford									x		
26	Boxworth: Cambridge	x	x		x	x	x					
35	Cambridge OC: Caxton			x	x		x		x	x		
39	Cambridge OC: Landbeach				x							
40	Cambridge OC: Ickleton		x									
46	Bridgets OC:Michledever									x		
47	Sparsholt OC: Bridgets	x	x	x	x	x	x					
12	Bridgets							x		x		
30	Sparsholt.Sutton Scotney	x	x	x	x	x			x			
37	Morley O.C.	x		x	x	x	x	x	x	x		
38	Rosemaund	x	x	x	x		x	x	x	x		
45	Sutton Bonington	x	x	x	x	x	x	x	x	x		
34	Cambridge OC Bedford	x	x	x	x	x	x		x	x		

Table A2 : WEATHER STATIONS, TRIAL SITES AND AGGREGATE "SITES" USED IN THE ANALYSIS

Weather Station	Original Trial Sites No.	Description	Aggregate "Sites" used in Analysis No.
Cockle Park	2	Cockle Park O.C.	1
	31	Northumberland/ Newcastle	1
	41	North	1
	42	Northumberland	1
Hull	3	York	
	4	Humberside (North)	2
	19	Humberside	2
	33	Yorkshire	2
High Mowthorpe	36	Headley Hall O.C. HM	3
Sutton Bonington	5	Nottingham	4
	44	Shardlow: Nottingham	4
	45	Sutton Bonington	13
Lincoln	22	Lincolnshire	5
	43	Shardlow: Lincoln	5
Raunds	21	Northampton	6
Boxworth	7	Bedford	7
	26	Boxworth	7
	35	Cambridge: Caxton	8
	39	Cambridge: Landbeach	8
Cambridge NIAB	40	Cambridge: Ickleton	8
Sparsholt	46	Bridgets: Micheldever	9
	47	Sparsholt: Bridgets	9
	12	Bridgets	10
	30	Sparsholt:Sutton Scotney	10
Morley	37	Morley O.C.	11
Preston Wynne	38	Rosemaund	12

ANNEX B SOME ECONOMETRIC RESULTS

Estimate	Explanatory Variables	Coefficient[1] Estimates	t Values	R^2	Dependent Variable
1(a)	Almon variables			0.62	Plot Yield
	Z41	-0.0446	0.29		
	Z42	0.4402	5.56		
	Z43	-0.1068	7.35		
	Fertilizer	0.0445	0.56		
	Weather Variables	0.0018	2.51		
	Varietal Dummies	1.5818	5.74		
1(b)	Almon Variables			0.38	Plot Yield
	Z41	0.2328	1.21		
	Z42	-0.0575	1.11		
	Fertilizer	-0.1014	1.02		
	Weather Variables	0.0010	1.02		
	Varietal Dummies	0.4304	1.67		
1(c)	Almon Variables			0.50	Plot Yield
	Z51	-0.5094	3.14		
	Z52	0.1990	2.18		
	Z53	-0.0175	1.33		
	Fertilizer	-0.1522	1.67		
	Weather Variables	0.0016	2.04		
	Varietal Dummies	-0.6052	1.98		
1(d)	Almon Variables			0.59	Plot Yield
	Z61	-0.1458	3.75		
	Z62	0.0306	4.14		
	Fertilizer	-0.1103	1.36		
	Weather Variables	0.0008	1.14		
	Varietal Dummies	-0.1094	1.25		
2(a)	Variable Inputs	0.0797	3.26	0.99	Farm Yield
	Plot Yields (t)	0.5862	7.27		
	(t-1)	0.0078	1.14	(dw=1.75)	
	(t-2)	0.0012	1.03		
	(t-3)	0.0001	0.52		

2(b)	Variable Inputs	0.0622	1.85	0.99
	Plot Yield (t)	0.6694	6.93	
	(t-1)	0.0092	0.09	(dw=3.31)

Notes: 1. Average coefficient values and t-values are given for weather variables and varietal dummies

2. The Almon variables are constructed as polynomials of R & D expenditure using the formula

$$Z_{ld} = \sum_{i=0}^{l} (R_{t-i})(i^d) \quad \text{where } l = \text{length of lag}$$

and d is the degree of polynomial considered. The coefficients of Z_{ld} are used to estimate the lag coefficients.