MEASUREMENT OF ECONOMIC RETURNS TO RESEARCH AND DEVELOPMENT: THE CASE OF WHEAT RESEARCH IN KENYA

By:

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This Research Paper is my original work and has not been presented for a degree in another University.

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This Research Paper has been submitted for examination with our approval as University Supervisors.

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TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

ABSTRACT

Returns to investments in Research and Development (R & D) need to be evaluated just like any other investments with a view to improving resource allocation and the performance of R & D. This study carried out such an evaluation for R & D in wheat in Kenya from the economic point of view, with the hypothesis that returns have been comparable to or higher than returns to conventional development projects. Various approaches and problems in evaluating R & D were reviewed and, given the data available, the production function approach was adopted for this study using both the log-linear (Cobb-Douglas) and the linear cases. Area planted with wheat (hectares), rainfall (decilitres i.e. mm/100) and real (deflated) research expenditures (K£) were regressed on annual wheat production (tonnes) for the period 1921 to 1982, including lags of up to 15 years for the R & D expenditures. Notably, fertilizers were omitted because of lack of data but the analysis showed that omission of fertilizers as a variable may not be so serious for the case of R & D in wheat in Kenya for two reasons: Fertilizers began to be used only in the later half of the series which the study considered and an examination of the trend of yields per hectare indicated no spectacular change in that period that would be associated with fertilizer use. Further, apart from the residual effect, the analysis showed that whatever fertilizer effect may have been present might also have been caught in the land (area) coefficient which indicated increasing returns to scale. The coefficient estimates for the log-linear function were 1.060 for area, - 0.258 for rainfall, 0.193 for real research expenditures and 0.965 for R^2, with a lag effect of 12 years for the research expenditures. For the linear function, the coefficients were 1.066 for area, - 13154.703 for rainfall, 0.510 for real research expenditures and 0.925 for R^2, with a lag effect of 10 years for the real research expenditures. In both functions, the area and real research expenditures coefficients were strongly significant at the 1 percent level and the rain coefficient was significant in the log-linear case at the 5 percent level. The greater than unity coefficient for land which indicates possibility of increasing returns to scale could be explained by the possibility of greater use of technology by large farmers as they increase their acreages. The negative sign for the rainfall coefficient was explained by damage to wheat and increase of virility of diseases at higher levels of rainfall. Indeed at lower levels of rainfall we would expect a positive and strongly

significant coefficient. The lag effects of 10 and 12 years for the R & D expenditures are in general conformity with the length of the breeding process for a new wheat variety in Kenya. Using the coefficient estimates to calculate the R & D share of the output, the Internal Rates of Return (IRR) were calculated for both cases. The results indicate an IRR of 33% for the log-linear case and 31% for the linear case. These are quite good returns for any investment and are above an ex-ante estimated average of about 20% IRR for some 227 World Bank development projects and compares quite well with other ex-post estimates of returns to R & D for various commodities in various parts of the world. The side effects are also examined qualitatively. They are indicated to be favourable for foreign exchange, impact on the environment, technology transfer and human capital development. They are rather adverse for income distribution, employment and nutrtional impact. Overall, however, the Wheat Research Programme in Kenya is indicated to be a resounding success, having produced 143 disease resistant varieties from 1920 to 1982, and with high IRR of 33% and real marginal returns of £10 to £1 real R & D expenditures in 1982. Additional investments in the programme could, therefore, be profitable and worthwhile. However, at the same time, there will be need to make policy considerations on ways and means of improving the employment and income distribution impacts of the programme.

CHAPTER ONE

INTRODUCTION

1.1 Scope and Purpose of the Paper

It is widely accepted that Research and Development (R&D) and the knowledge so generated is an important means of raising productivity. For any given technique of production or distribution, there are long run limitations on the growth of productivity which are technologically determined. Consequently, there is clear justification for concentrating attention on the flow of new ideas, inventions and innovations.

There are various contributions that R&D can make which are the key to evaluating its benefits. To increase output directly is the most widely recognised contribution. But research has other effects. It may improve the quality of the products, conserve or save production inputs, bring about improvements in the marketing system, reduce the cost of inputs or improve their quality, improve institutions and economic policy so as to facilitate technical change and influence the distribution of income.

To make a proper evaluation of R&D, the goals of the research programme have to be specified. The long term goals of Kenya's agricultural policy is to increase production and employment opportunities in agriculture in order to meet the needs of her rapidly growing population. The short term challenge in agriculture is to cope with an impending shortage of basic foods.[1] Kenya's strategy in agricultural research is geared towards meeting the long term goals. In fact the major part of the country's total R&D is geared towards the agricultural sector and hence to Kenya's long term agricultural policy goals. It is estimated that about 70 per cent of expenditures in R&D in Kenya goes to agriculture.[2]

In turn, the objectives of the Wheat Research Programme are:[3]

a) Development of widely adapted varieties with high resistance to rust, high in yield, and good in baking quality.

b) Development of a package of agronomic practices which promote high yield. These include:

   i) tillage and soil moisture conservation practices to minimise production costs and to conserve stored moisture;

   ii) soil fertility aspects including micro-nutrients and macro-nutrients;

   iii) weed control through efficient cultural practices and herbicides; and,

iv) farm management and record keeping practices.

c) To de-regionalise wheat and move its production to non-traditional wheat areas where it can be grown under small scale level.

d) To develop efficient plant and produce protection techniques against field and storage pests.

The Wheat Research Programme is carried out and coordinated from the National Plant Breeding Station (here in after referred to as the NPBS) at Njoro, Nakuru. A detailed account of the history of wheat research in Kenya has been given by Pinto and Hurd.[4] Wheat was introduced in Kenya in the late nineteenth century and started with the growing of the crop in small missionary farms. Lord Delamare was the first to grow wheat extensively when in 1906 he planted 1,200 acres of wheat which were attacked by stem and stripe rust. This led to the recruitment by Lord Delamare of a plant breeder from Britain to breed wheat varieties with resistance to rust and other suitable characteristics. The Plant breeder was established at Njoro where the plant breeding facilities were run as a private station from 1907 until 1927 when the Government assumed responsibility for the station.

At the same time that Lord Delamare was conducting wheat breeding privately the Government also established a programme of wheat breeding for rust resistance in 1911 in what was then known as Scott Agricultural Laboratories, later re-named National Agricultural Laboratories at the time of Independence.

The wheat breeding undertaken at the Scott Agricultural Laboratories was transferred to Njoro in 1927 so that the work could be carried out at a more suitable site and it was then that the Government assumed responsibility for the station previously established privately by Lord Delamare. Research objectives continued to be centered around breeding for resistance against stem rust, other parameters largely unattended to. For many years wheat varieties were bred which were resistant to rust but poor in yield, quality and adaptability. As a result of this, large quantities of wheat were imported for blending purposes and to meet the deficit. No work was done on agronomy. In 1967 the objectives of the Research Programme were expanded to include agronomy and the wider objectives outlined above. Since the days of Delamare, many plant breeders and other scientists have made important contributions to the Wheat Research Programme in Kenya. Apart from tremendous improvements in wheat quality, their effort has resulted in the release of 143 wheat varieties in Kenya from 1920 to 1982.[5]

In addition to the wheat programme, Njoro had also been the headquarters of maize research with out-stations at Kitale and Katumani until 1964 when maize research headquarters was transferred to Kitale. This means that until 1964 the budget for the NPBS included funds for both wheat and maize research. The station also currently works on other small cereal grains and oil seed crops. Therefore the budget for the NPBS has to be apportioned accordingly to arrive at the true cost of wheat research.

From 1954 onwards considerable investment in new laboratories, extra land and facilities has been made so that the wheat research programme could be greatly expanded. This development has been undertaken with colony and Kenya Government Development Funds, a cess from the Kenya Wheat Board, a Colonial Development and Welfare (C.D. & W.) Scheme and grants from the Rockefeller Foundation, the United Nations Food and Agricultural Organisation (FAO), the Canadian International Development Agency (CIDA) and the International Development Research Centre of Canada (IDRC). However, as we shall see later in Chapter Four, not all these funds can be attributed to the wheat research programme alone.

The Station has 165 hectares of land of which about 130 hectares are used for experiments and rotation and the remainder is taken up by office and laboratory buildings and accommodation quarters.

The Wheat Research Programme will be assessed taking into account the extent to which it has met the objectives stated above. Where there are indicated trade-offs such as the effect of diverting resources to small farmers these will be pointed out and assessed. Knowledge of the trade-offs between these goals and objectives is an important part of assessing the productivity and effectiveness of R&D. This is part of the final set of issues concerning the side effects of technical change. Some of these side effects will be positive and thus contribute to the benefit of the research programme. Others will be of a negative nature, and must either be added to the cost of the research process or subtracted from the benefit side. Among the side effects that need to be considered when increased output is the primary goal are the impact of technical change on the distribution of income, its impact on employment, the consequences to the environment and the possible shift from food to cash crops and vice versa.

The paper is divided into four chapters. In Chapter One, the scope and purpose of the paper is outlined after which there is a discussion on the investments in R&D and the reasons for evaluating R&D. Here the argument is made that R&D competes for resources with other projects and therefore a comperative evaluation on the returns to these resources spent on R&D should be made. Worldwide and Kenya's expenditures on R&D are given in this section. Here agriculture in Kenya emerges as the major user of R&D resources. Finally, in Chapter one, the hypothesis and test criteria of the success or otherwise of the Wheat Research Programme is discussed.

The review of the methods used in evaluating R&D is undertaken in Chapter Two. Then the paper goes on to examine the problems to be tackled in evaluating R&D in Chapter Three. Here we find that in evaluating R&D there are special difficulties which are not encountered in the usual run-of-the mill project appraisal. These difficulties include, among others, the definition of output, negative results, technological decay, R&D inputs and technological transfer considerations, and the problems of disentangling research/diffusion effects. These problems, and others, as well as the special issues of the side effects of technical change are discussed in Chapter Three.

Thus the rationale and analytical framework for the economic evaluation of R&D programmes is developed in Chapters One, Two and Three. This analytical framework is then applied in Chapter Four to the case of wheat research in Kenya and certain conclusions are made.

It should be emphasised that there are many factors which affect the effectiveness of R&D. These factors may be sociological, psychological, organisational/structural, managerial and economic. This study looks mainly at the relationships between indicators of economic resources and the effectiveness of R&D. To the extent that the study does not concern itself with the sociological and psychological factors affecting the effectiveness of R&D, the analysis presented here can therefore be regarded as partial but, nevertheless, an important contribution to the measurement and understanding of R&D productivity.

1.2 Investments in R&D and the Reasons for Evaluating R&D

In Kenya, by 1971, scientific and technological activities were estimated to be involving the nation in an expenditure of £24 million of which approximately £5 million was estimated to be devoted to R&D and £19 million to scientific and technological services (STS). In respect of the R&D expenditures, agricultural sciences accounted for 70%, natural and medical sciences 10% each and industrial sciences 7%.

Some 300 scientists and 8800 technicians and technical supporting personnel were involved.

Table 1.1: Financial and Manpower Resources Allocated to Science and Technology in 1970/71 in Kenya

SCIENCE GROUP	EXPENDITURE		MANPOWER			
	R&D* £ Mill.	STS* £ Mill.	R&D* Sc.*	R&D* Tech.*	STS* Sc.*	STS* Tech.*
Natural	0.53	2.01	68	65	99	316
Agricultural	3.57	10.33	371	525	228	4300
Medical	0.56	6.03	55	382	988	2219
Industrial	0.40	0.92	30	62	1070	1000
Social	0.06	0.42	45	-	22	-
TOTALS	5.14	19.71	569	1034	2407	7835

*R&D - Research and Development
STS - Scientific and technological services
Sc. - Scientists, engineers and techologists
Tech. - Technicians

Source: Republic of Kenya, 1974. Development Plan 1974-78, Part I. Nairobi, Government Printer, p.185.

The Government funded 75% of the R&D and 81% of the scientific and techological services (STS), representing 2.30% and 11.17% of the national budget respectively. The remainder was funded through higher education and the private sector. Basic (fundamental) research represented only 1.7% of the total R&D expenditure.

It is possible that some of the R&D expenditures shown in Table 1.1 was, in fact, not supporting R&D because many R&D departments were, of necessity, involved in the administration of scientific and technological services (STS). However, the figures indicate that the Gross National Expenditure on R&D (GNERD) was about 0.9% of GDP, which was well above the world average though less than that of the major technologically advanced countries (see Table 1.3 below).

The Government expenditures on R&D rose from £3.9 million (75% of £5.14 million in Table 1.1) in 1970/71 to £10.84 million in 1979/80 at current prices (Table 1.2). The agricultural share of expenditures on R&D was maintained at 70%. This reflects the large contribution of agriculture to GDP (about 35%) and the infrastructure that agricultural research has built over the years.

Table 1.2: Government Expenditures on Science and Technology in 1979/80 in Kenya

	R&D*		STS*	
SCIENCE GROUP	£ '000	% of Total	£ '000	% of Total
Agricultural	7611	70.2	41074	43.5
Natural	1240	11.4	4503	4.8
Medical	1234	11.4	22812	24.2
Industrial	557	5.1	18263	19.4
Social	-	-	3312	3.5
Physical	-	-	548	0.6
Other	201	1.9	3870	4.1
TOTAL	10844	100.0	94382	100.0

*R&D - Research and Development
STS - Scientific and Technological Services

Source: Muturi, S.N. 1981, 'The System of Resource Allocation to Agricultural Research in Kenya. Kenya National Council for Science and Technology.

The total Government expenditures on R&D was planned to rise from £10.84 million in 1979/80 to £16 million in 1982/83. Although this is a rise in the R&D expenditures in absolute terms, it represents a decline from 0.53% of the GDP to 0.42% of the GDP respectively.[6] Thus although the stated Government policy is to raise the Gross National Expenditure on R&D (GNERD) to 1% of the GDP,[7] the expenditure by the Government, which is the main financier of R&D in the country, has been declining relative to the GDP. This calls for increased allocation of resources to R&D both by the public and private sectors in order to realise the target of 1% of the GDP on the GNERD.

With regard to global expenditures on R&D, these are shown in Table 1.3 below for the year 1973. The table indicates that large amounts of resources are spent on R&D but their global distribution is highly uneven.

In many nations, especially the more developed ones (MDCs), there has been a belief in the intrinsic ability of R&D to assure developmental or political supremacy in terms of commerce, defence, self-sufficiency

Table 1.3: World R&D and Related Economic Indicators in 1973

	Developing Countries	Developed Countries	World Total
Population (mill.)	2679	1176	3855
GNP (bill. US $)	792	4102	4894
Total R&D Expenditure (mill. US $)	2876	97300	100176
R&D Expenditure as % of World Total	2.9	97.1	100
R&D Expenditure as % of GNP	0.36	2.37	2.05
R&D Expenditure per capita (US $)	1.1	82.7	26.0
R&D Expenditure per EAP* (US $)	3.0	189.2	67.5
Total No. of Researchers ('000)	304	2410	2714
No. of Researchers as % of World Total	11.2	88.8	100
No. of Researchers per mill. Population	113	2049	704
No. of Researchers per mill. EAP*	313	4687	1828

*EAP — Economically Active Population
Source: Extracted from Appendix 1.1

in food, etc. In the less developed countries (LDCs) there is an increasing emphasis on R&D more than ever before along the same lines as the MDCs. For example, R&D expenditure in LDCs grew nearly 600% from 1951 to 1974.[8] However, despite that growth, the expenditure is still low relative to that in MDCs as is evident in Table 1.3, and there is a continuing dependency on the results of R&D work conducted in MDCs. For example, it has been estimated that in 1965 89% of all spending on agricultural research occurred in the developed countries.[9] Such dependency is particularly undesirable for agriculture because most research has related to the crops and conditions of temperate climates and has thus not been relevant to the needs of most developing countries. Quite apart from climatic considerations, much Western research has been adapted to the fact of declining agricultural labour forces and hence has tended to be labour-saving and capital-intensive. This too reduces its relevance to conditions in the LDCs, with their unemployment and growing rural populations. It appears that multinational corporations (MNCs) have re-inforced this state of affairs in that they carry out most of their R&D in their home countries and have been generally averse to contributing to the local R&D in LDCs. And even if MNCs carry out R&D in LDCs, international conventions and law on intellectual property and patents may not allow the LDCs to use the results without excessively high costs. Some organisations also buy the rights to patents so as to pre-empt competition and early relative obsolescence of their plants and products by preventing the free flow of inventions and innovations into the market.

The need for increased resources expenditure on R&D in LDCs are further indicated by the low productivities compared to MDCs shown in Table 1.4. And even in the MDCs, Fishel points to a growing concern in the rate of increase of agricultural production such as in the USA where it has declined from 24% during the 1950s to 11% in the 1960s and has continued to decline in the 1970s.[10] He notes that one of the reasons given for this decline is the stabilised level of research and extension that in real terms has not increased since the mid-sixties, the research that is done being more costly and the problems being investigated being increasingly more complex. He notes that there is now real and documented concern that agricultural production in this particular situation (of the MDCs) is reaching the biological limits of existing knowledge in several areas and this calls for an even more committed emphasis on R&D.

This limit may not have been reached in the case of the LDCs as there is considerable scope for the transfer of technology from MDCs to LDCs. However, as noted above, apart from developing new and indigenous techologies, there is need to adapt transferred technologies to the environmental and resource endowment situations of the LDCs. This calls for considerable investments in R&D.

In the case of Kenya, a recent report notes that capital formation in agriculture (which provides the bulk of the employment, 80% of foreign exchange and over one third of GDP) declined by 40% from 1977 to 1978.[11] Further, it is estimated that with the present rate of population increase, the amount of good land per capita may fall from 0.88 hectare in

1970 to 0.36 hectare by the year 2000.[12] These indicators pose a challenge to increased productivity in agriculture and consequently increased expenditures in R&D, among other factors that need to be taken into account.

Table 1.4: Estimated Land and Labour Productivity (in tons) and Their Growth Rates

	MDCs	LDCs
Output per hectare (1960)	2.41	0.94
Output per male worker (1960)	40.9	8.1
Growth rate of output per hectare (1955-65)	2.1	2.1
Growth rate of output per worker (1955-65)	4.7	1.4

Source: Hayami, Y. and V.W. Ruttan, 1971. Agricultural Development: An International Perspective. Baltimore, Johns Hopkins Press. Tables 4.1, 4.3, pp. 70, 74.

Another problem particularly associated with agricultural research is that a good many of the benefits of successful research are external to those who undertake it and this reduces the incentive of farmers to undertake research. Considered commercially, it is also a high risk activity and farmers are already burdened with enough risks. What is implied by this is the view that, left to itself, the market mechanism will neglect socially desirable agricultural research.

It should, therefore, be a task of the state to remedy this neglect.

In conclusion, we note that there has been high and rising investments in R&D. In the support for R&D important questions of resource allocation arise since these resources have competing uses. The question arises, for example, whether the wheel should be re-invented or whether it is better to import food or break the technological barriers to growing it locally; or in general, depend on imported technology or develop local R&D capability or stay without the technology for ever. One has to make a choice between these alternatives or a mixture of them.

In view of these questions concerning resource allocation and in view of the large and rising investments in R&D, it has become, in more recent times, a legitimate concern to conduct studies to show the speed and success of R&D responses to various socio-economic challenges, and the rate of practical application of the results. It has therefore become increasingly imperative that returns on investments on R&D be measured and compared with returns from other investments.

1.3 Hypothesis of the Study

The long term nature of R&D projects, the unpredictable nature of their outcome and the sometimes "invisible" nature of their product puts R&D in a disadvantaged position against other projects of more immediate consumption or "visible" benefit. And indeed studies have shown that R&D is characterised by long gestation periods, high investment rates, high risk and an unusually high rate of failure.[13] This means that a disproportionately large share of R&D is undertaken only by large firms or by the government which can underwrite the high risk/high investments involved.

However, on the other hand, a wide range of studies have demonstrated that in both MDCs and LDCs returns to R&D are frequently in excess of 50% and rarely fall below 20%, so that where organisations venture into R&D the high risks and large investments undertaken are usually compensated well in excess of returns to normal or conventional development projects.[14] In agriculture, these studies have shown the internal rate of return (IRR) to range from 21% to over 93% for several countries and a number of different agricultural commodities.[15] A summary of studies of agricultural research productivity is given in Appendix 1.2 where the productivity measurements indicate highly favourable returns.

With regard to the rate of return on conventional development projects, a frequency analysis of the economic returns to 227 projects of the World Bank and the International Development Association in developing countries was undertaken to find out the most prevalent range of economic returns and therefore a reasonable cut-off rate of return for our case study on wheat. The results are shown in Table 1.5.

68% of the projects were found to fall in the range of 11 to 25% economic rates of return. This range, as is clear from the distribution, should be the relevant range to consider. The mid-point of this range is 18%. We round this to 20% as the cut-off economic rate of return for development projects in developing countries. (The mean for 211 of the Projects is 23, but calculation using the frequency distribution is preferred to avoid undue weight from unusual projects).

Table 1.5 Frequency Distribution of Economic Rates of Return for Development Projects in Developing Countries.

CLASS (economic rates of return)	FREQUENCY (number of projects)
0 - 5	2
6 - 10	14
11 - 15	44
16 - 20	68
21 - 25	43
26 - 30	12
31 - 35	9
36 - 40	2
41 - 45	6
46 - 50	9
50+	18
TOTAL	227

Source: Computed from Appendix 1.3

However, the following observations need to be kept in mind with regard to the use of 20% as the cut-off rate of return:

a) The figure of 20% is obtained from ex-ante analysis of the World Bank projects. The actual performance of these projects is probably lower on the average.

b) There is an increasing consensus of opinion that the discount rate to use for public projects should generally be risk-free, that is, low.[16]

c) The Kenya Government has on the average been using a low discount rate of 10% for public projects.

Taking the above considerations into account, we come to the conclusion that a cut-off social discount rate of 10% should be used for national comparisons. However, due to the paucity of data on social prices as discussed later in Chapter Four, it will only be possible to compute an economic rate of return on R&D in this study rather than a true social rate of return. We therefore take the economic rate of return of 20% as our cut-off rate of return and use the social discount rate of 10% as our lower limit below which the project would be rejected. For economic rates of return between 10% and 20%, the project would be regarded as marginal. We therefore proceed to state our hypothesis as follows:

Returns to wheat R&D in Kenya have been high and comparable to or higher than returns to conventional development projects: If the estimated economic rate of return for R&D in wheat in Kenya is equal to or higher than 20%, then our hypothesis will have been vindicated. Or conversely, if the Net Present Value, using a 20% economic discount rate, is positive, then our hypothesis is true. The project would be marginal if the Internal Rate of Return (IRR) falls between 10 and 20%. The hypothesis is rejected at IRR below 10%.

Having established the rates of return to be used as indicators of performance of the project under study, it should be reiterated that these economic rates of return as calculated reflect economic efficiency only and this rate has to be qualified with assessments of the project externalities. For example, Kenya's research in agriculture has been criticised for failing to pay adequate attention to small scale farming and laying more emphasis on cash crops at the expense of food crops and therefore failing to exploit any potential that R&D may have in bringing about a better distribution of incomes in Kenya.[17] Where there are externalities, these will be assessed on how far they adversely or positively affect the major impact of the Wheat Research Programme. This often takes the form of a qualitative analysis in many project evaluations but, where possible, an attempt will be made to internalise the externalities in the calculations.

Footnotes to Chapter One.

1. Kenya, 1980. Sessional Paper No. 4, Nairobi, Government Printer. pp. 24-5.

2. See Tables 1.1 and 1.2.

3. Kenya. National Plant Breeding Station, Njoro. (NPBS). 1980. General Information, NPBS, Njoro.

4. Pinto and Hurd, 1970. p.1.

5. The names of the wheat varieties are listed in Appendix 4.3.

6. Kenya, 1979. Development Plan 1979-83, Part I. Nairobi, Government Printer. Table 3.2 and pp. 57, 84.

7. ibid. p.57.

8. Scobie, 1979. p. (i).

9. Evenson and Kislev, 1975. Table 2.1, p. 17.

10. Fishel, 1980. pp. 10-11.

11. International Service for National Agricultural Research (ISNAR), 1981. p.9.

12. The World Bank, 1975. p. 454.

13. Mansfield, 1971. p.57.

14. Scobie, 1979. p.(i).

15. Evenson and Kislev , 1975. pp. 11-13. Also see Appendix 1.2

16. See pages 150 to 152 for a discussion on the discount rate to be used for public projects.

17. Heyer and Waweru, 1976. pp. 202-205.

APPENDIX 1.1

WORLD R&D AND RELATED ECONOMIC INDICATORS IN 1973.

	Population	GNP (bn US$)	Total** R&D Expend. (mn)	R&D** Expend. as % of World Total	R&D** Expend. as % of GNP	R&D** Expend. per EAP*	R&D** Expend. per capita	Total No. of Researchers (000')	No. of Researchers as % of World Total	No. of Researchers per mn EAP*	No. of Researchers per mn Popul.
A. World Total	3855	4894	100176	100	2.05	67.5	26.0	2714	100	1828	704
B. LDCs	2679	792	2876	2.9	0.36	3.0	1.1	304	11.2	313	113
i) Africa	341	87	276	0.28	0.32	2.6	0.8	23	0.8	218	67
ii) Latin America	295	242	773	0.77	0.32	7.7	2.6	46	1.7	461	156
iii) Asia	2043	454	1827	1.82	0.39	2.4	0.9	235	8.7	307	115
C. MDCs	1176	4102	97300	97.1	2.37	189.2	82.7	2410	88.8	4687	2049
i) East Europe (incl. USSR)	378	773	33018	33.0	4.27	179.0	87.4	1142	42.1	6191	3021
ii) West Europe (incl. Israel & Turkey)		1384	21585	21.5	1.56	136.2		395	14.5	2489	
iii) N.America	798	1435	33716	33.7	2.35	331.1	80.6	548	20.2	5386	1589
iv) Other (incl. Japan/Australia		510	8981	9.0	1.76	129.5		325	12.0	4687	

*EAP - Economically Active Population. **Expenditures are in US $.

Source:-Annerstedt, J. 1979. A Survey of World Research and Development Efforts. Paris, OECD Development Centre. Tables 2, 3; pp. 12, 17.

-UNCTAD. 1980. Co-ordinated Technological Research and Development in Deve[illegible] Countries: Regional Cooperation to Strengthen Indigenous Capaciti[illegible] TD/B c.b/63. Geneva, UNCTAD. Table 2, p.10.

APPENDIX 1.2

SUMMARY STUDIES OF AGRICULTURAL RESEARCH PRODUCTIVITY

STUDY	COUNTRY	COMMODITY	TIME PERIOD	ANNUAL INTERNAL RATE OF RETURN (Percentage)
INDEX NUMBER				
Griliches, 1958	USA	Hybrid corn	1940-55	35-40
Griliches, 1958	USA	Hybrid sorghum	1940-57	20
Peterson, 1967	USA	Poultry	1915-60	21-25
Evenson, 1969	South Africa	Sugarcane	1945-62	40
Ardito Barletta, 1970	Mexico	Wheat	1943-63	90
Ardito Barletta, 1970	Mexico	Maize	1943-63	35
Ayer, 1970	Brazil	Cotton	1924-67	77*
Schmitz & Seckler, 1970	USA	Tomato harvester	1958-69	
		With no compensation to displaced workers		37-46
		Assuming compensation of displaced workers for 50 percent of earnings loss		16-28
Ayer & Schuh, 1972	Brazil	Cotton	1924-67	77-110
Hines, 1972	Peru	Maize	1954-67	35-40*
Hayami & Akino, 1977	Japan	Rice	1915-50	50-55+ 25-27

S T U D Y	COUNTRY
Hayami & Akino, 1977	Japan
Hertford, Ardila, Rocha & Trujillo, 1977	Colombia
	Colombia
	Colombia
	Colombia
Pee, 1977	Malaysia
Peterson & Firtzharris, 1977	USA
Wennergren & Whitaker, 1977	Bolivia
Pray, 1978	Punjab (British India)
	Punjab (Pakistan)
Scobie & Posada, 1978	Bolivia
PRODUCTION FUNCTION	
Tang, 1963	Japan
Griliches, 1964	USA

COMMODITY	TIME PERIOD	ANNUAL INTERNAL RATE OF RETURN (Percentage)
Rice	1930-61	73-75
Rice	1957-72	60-82
Soybeans	1960-71	79-96
Wheat	1953-73	11-12
Cotton	1953-72	None
Rubber	1932-73	24
Aggregate	1937-42	50
	1947-52	51
	1957-62	49
	1957-72	34
Sheep	1966-75	44.1
Wheat	1966-75	-47.5
Agricultural research and extension	1906-56	34-44
Agricultural research and extension	1948-63	23-37
Rice	1957-64	79-96
Aggregate	1880-1938	35
Aggregate	1949-59	35-40

STUDY	COUNTRY	COMMODITY	TIME PERIOD	ANNUAL INTERNAL RATE OF RETURN (Percentage)
Latimer, 1964	USA	Aggregate	1949-59	Not significant
Peterson, 1967	USA	Poultry	1915-60	21
Evenson, 1968	USA	Aggregate	1949-59	47
Evenson, 1969	South Africa	Sugarcane	1945-58	40
Ardito Barletta, 1970	Mexico	Crops	1943-63	45-93
Duncan, 1972	Australia	Pasture improvement	1948-69	58-68
Evenson & Jha, 1973	India	Aggregate	1953-71	40
Kahlon, Bal, Saxena & Jha, 1977	India	Aggregate	1960-61	63
Lu & Cline, 1977	USA	Aggregate	1938-48	30.5
			1949-59	27.5
			1959-69	25.5
			1969-72	23.5
Bredahl & Peterson, 1976	USA	Cash grains	1969	36++
		Poultry	1969	37++
		Dairy	1969	43++
		Livestock	1969	47++
Evenson & Flores, 1978	Asia-national	Rice	1950-65	32-39
			1966-75	73-78
	Asia-international	Rice	1966-75	74-102

STUDY	COUNTRY	COMMODITY	TIME PERIOD	ANNUAL INTERNAL RATE OF RETURN (Percentage)
Flores, Evenson &	Tropics	Rice	1966-75	46-71
Hayami, 1978	Philippines	Rice	1966-75	75
Nagy & Furtan, 1978	Canada	Rapeseed	1960-75	95-110
Davis, 1979	USA	Aggregate	1949-59	66-100
			1964-74	37
Evenson, 1979	USA	Aggregate	1868-1926	65
	USA	Technology oriented	1927-50	95
	USA — South	Tech. oriented	1948-71	93
	USA — North	Tech. oriented	1948-71	95
	USA — West	Tech. oriented	1948-71	45
	USA	Science oriented	1927-50	110
			1948-71	45
	USA	Farm management research & agricultural extension	1948-71	110

* Returns to maize research only

\+ Returns to maize research plus cultivation package

++ Lagged marginal product of 1969 research on output discounted for an estimated mean lag of 5 years for cash grains, 6 years for poultry and dairy and 7 years for livestock.

Source: Evenson, R.E. 1971. 'Benefits and obstacles to Appropriate Agricultural Technology'. Centre Paper No. 313. Economic Growth Centre, Yale University. Table 3, p.64.

APPENDIX 1.3

RATES OF RETURN ON PROJECTS SPONSORED BY THE WORLD BANK (WB) AND ITS AFFILIATE THE INTERNATIONAL DEVELOPMENT ASSOCIATION (IDA).

WB News Release No.	Project Title	Country	Duration of Project (Years)	Project Cost ($mill)	Economic Rate of return (%)
80/54	El Cajon Power	Honduras	6	582.7	13-5
80/55	Petroleum Production Rehabilitation	Peru	2	50.7	+100
80/67	Eleventh Highway	Yugoslavia	2	785.2	24
80/69	Third Urban Development	Philippines	4	120	26
80/70	Power Distribution	Brazil	4	314	12
80/70	Water Supply & Sewerage	Brazil	2	439	7
80/71	Fifth Telecommunications	Colombia	4	110	16-8
80/73	North-East Savannah Rural Development	Ivory Coast	6	21.1	
	- Irrigation				11
	- Rice Project				22
80/74	Second Education	Botswana	5	14.6	-
80/76	Third Highway	Morocco	4	199	50
80/78	Agricultural Development	Uruguay	5	111	26
80/79	Water Supply	Chile	5	119.64	12-4
80/80	2nd Agricultural Credit	Honduras	4	38.5	55
80/82	NUCLEUS Estate and Smallholders IV	Indonesia	6	64.5	19

WB News Release No.	Project Title
80/83	Fourth Highway
80/84	2nd HEVECAM Rubber
80/85	Seventh Railway
80/86	Second Textile
80/87	Oyo-North Agricultural
80/89	National Agricultural Research
80/90	Fourth Highway
80/93	Third Railway
80/94	Karakaya Hydropower
80/95	Fifth Highway
80/97	Summerbank Cotton Textile Rationalization
80/98	Loukkos Rural Development
80/99	Pulp and Paper
80/100	3rd Minas Gerais Water Supply and Sewerage
80/102	Mae Moh Lignite (Mining)
80/103	Forestry Establishment, Marketing and Extension
80/104	Ekiti-Akoko Agricultural Development

Country	Duration of Project (Years)	Project Cost ($mill)	Economic Rate of Return (%)
Senegal	4	59.5	30
Cameroon	5	95	15
R. of Korea	3	604.27	22
Egypt	4	104.3	22
Nigeria	5	69.4	20
Indonesia	9	101.5	n.a.
Tunisia	4	92.1	80
Zambia	4	184.3	19
Turkey	7	1160.4	15
Costa Rica	5	43.3	+50
Turkey	3	150.5	24
Morocco	6	67.6	15
Egypt	3	71.5	20 & 32
Brazil	4	446	8
Thailand	3	130.3	14
Portugal	5	170	19
Nigeria	5	80.5	20

WB News Release No.	Project Title
80/83	Fourth Highway
80/84	2nd HEVECAM Rubber
80/85	Seventh Railway
80/86	Second Textile
80/87	Oyo-North Agricultural
80/89	National Agricultural Research
80/90	Fourth Highway
80/93	Third Railway
80/94	Karakaya Hydropower
80/95	Fifth Highway
80/97	Summerbank Cotton Textile Rationalization
80/98	Loukkos Rural Development
80/99	Pulp and Paper
80/100	3rd Minas Gerais Water Supply and Sewerage
80/102	Mae Moh Lignite (Mining)
80/103	Forestry Establishment, Marketing and Extension
80/104	Ekiti-Akoko Agricultural Development

Country	Duration of Project (Years)	Project Cost ($mill)	Economic Rate of Return(%)
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Morocco	6	67.6	15
Egypt	3	71.5	20 & 32
Brazil	4	446	8
Thailand	3	130.3	14
Portugal	5	170	19
Nigeria	5	80.5	20

WB News Release No.	Project Title
80/105	Third Ports Construction
80/83	Third Highway
80/108	Fisheries Development
80/112	5th Livestock Development
80/113	Provincial Water Supply
80/114	2nd Natural Gas Pipeline
80/117	Northeast Basic Education
80/119	3rd Population Planning
80/120	2nd Accelerated Rural Electrification
80/121	Ninth Power Development
80/122	Power Transmission and Distribution
80/123	Mechanical Industries
80/124	Orchards Development
80/125	Minas Gerais 2nd Rural Development
80/126	Colon Urban Development
80/130	Sixth Highway
	- Feeder Roads
	- Maintenance

Country	Duration of Project (Years)	Project Cost ($mill)	Economic Rate of Return(%)
Philippines	5	165	30
Papua New Guinea	3	42.4	18
Kenya	6	13.3	16
Turkey	7	125	70
Thailand	5	59.3	8
Tunisia	3	88	50
Brazil	5	91.4	n.a.
Indonesia	4	72.6	n.a.
Thailand	5	270	15
Indonesia	5	700.8	12
Cyprus	3	39.6	13
Portugal	2	89	20
Romania	7	323.9	27
Brazil	5	184.6	16
Panama	3	133.3	21
Ecuador	4	104	
			46
			+50

WB Release No.	Project Title
80/131	Sixth Highway
80/132	First Telecommunications
80/133	Third Agricultural Credit
80/134	Third Power Hydro & Thermal Power Development
80/135	Farakka Thermal Power
81/1	Inland Waterways and Coastal Ports
81/2	Watershed Management and Erosion Control
81/3	Seventh Agricultural Credit
81/4	Fourth Highway
81/8	ELETROSUL 2nd Power Transmission
81/9	1st Power Transmission and Distribution
81/10	Kandi Watershed & Area Development
81/17	Vocational Training and Technical Education
81/20	Ocoroni Irrigation
81/22	2nd Medium Size Cities Water Supply & Sewerage
81/23	Highway Sector

Country	Duration of Project (Years)	Project Cost ($mill)	Economic Rate of Return(%)
Nigeria	4	178	30
Oman	4	97.22	18
Tunisia	3	60.8	18 - 92
Egypt	6	677.8	10
India	6	499.4	13
Thailand	2-3	80.4	20
Philippines	6	75	18
Mexico	3	1179	n.a.
Algeria	5	206.3	90
Brazil	5	265.31	10
Ivory Coast	5	46.5	16
India	5	60.8	16
Argentina	4	149.5	n.a.
Mexico	5	54.6	15
Mexico	4	318	13
Ivory Coast	3	166	12.6-19

WB News Release No.	Project Title
81/25	Bangkok & Sattahip Ports
81/27	Cyclone Reconstruction
81/28	National Agricultural Research
81/31	Ceara 2nd Rural Development
81/33	Urban Rehabilitation & Development
81/34	Highway Reconstruction
81/37	Fourth Railway Improvement
81/42	San Jose Water Supply
81/43	Fourth Power: Hydro & Thermal
81/43	Irrigation (BBSP)
81/43	Livestock IV (Cattle) Improvement
81/44	Electric Power System Coordination
81/45	Power (Diesel, Lines & Sub-stations)
81/48	2nd Urban Development
81/49	Rainfed Agricultural Development
81/55	Playas Hydro Scheme
81/59	Rompin-Endau Area Development (La[illegible] Reclamation & Dam Building)
81/60	Swamp Reclamation

Country	Duration of Project (Years)	Project Cost ($mill)	Economic Rate of Return(%)
Thailand	4	109.2	21
Fiji	4	31	15
Thailand	8	91.5	n.a.
Brazil	4	163.19	19
Mauritius	3	24.5	17
Chile	3	91.7	41
Mexico	3	1527	22
Costa Rica	2	55.3	12-4
Romania	3	3011.5	10-7
Romania	4	375.3	22
Romania	4	412.2	22
Brazil	4	140.3	13
Barbados	4	121.7	13-5
Morocco	5	81.1	18
Mexico	4	797	21
Colombia	5	346.4	15-5
nd			
Malaysia	6	141	17
Indonesia	5	44.6	13

WB News Release No.	Project Title
81/67	3rd Urban Transport
81/68	Rural Roads
81/69	2nd Fruit and Vegetable Development
81/72	Multi-State Water Supply and Sewerage
81/73	Caracal-Titu Irrigation
81/74	4th Urban Services Development
81/78	Kosovo Railway
81/80	Livestock Development
81/81	National Urban Land Development and Housing
81/82	Bauchi State Agricultural Development (extension, inputs, roads, water)
81/83	Managua Water Supply
81/85	Fertilizer Plant Rehabilitation
81/86	4th Power (transmission and distribution)
81/88	Fruit/Vegetable Development and Export
81/89	Alcohol & Biomas Energy Development -Sugar cane -Cassava

Country	Duration of Project (Years)	Project Cost ($mill)	Economic Rate of Return (%)
Brazil	3	257	+50
Colombia	3	63	11
Turkey	5	107	25
Brazil	3	589	10
Romania	5	379.3	20
Indonesia	6	86.1	18
Yugoslavia	3	67.5	22
Paraguay	4	60	32
Korea	4	240	16-5
Nigeria	5	350.6	18
Nicaragua	4	5.06	n.a.
Turkey	5	236.6	43
Jordan	3	81.12	21
Cyprus	5	32.9	21
Brazil	4	5115	17-21 10-16

WB News Release No.	Project Title	Country	Duration of Project (Years)	Project Cost ($mill)	Economic Rate of Return (%)
81/90	2nd Urban & Regional Development (housing & infrastructure)	Mexico	6	468	14
81/91	Puerto IIa-Chone Rural Development (extension, credit, tenure, roads, water, health & schools)	Ecuador	7	57.1	18
81/94	Kosovo Agricultural Development	Yugoslavia	5	270	25
81/97	1st Irrigation Rehabilitation	Colombia	7	86.3	+50
81/98	Northeast Rural Development I	Tunisia	15	61.5	16
81/99	State Industrial Enterprise (Machinery for sugar and steel and copper works)	Turkey	5	299.7	31
81/100	Village Electrification	Colombia	4	68.7	13
81/101	Power Subsector (Hydro)	Thailand	5	781.7	12
81/102	Eastern Province Agricultural Development	Zambia	6	28.1	
	- Crop production				17
	- Tsetse Control				16
	- Input stores				15
	- Overall				12
81/103	Iron & Steel Co. Rehabilitation	Egypt	4	105.6	42
81/104	3rd Power (transmission & distribution)	Tunisia	5	89.6	11-6
81/106	Health & Population	Tunisia	5	41	n.a.
81/108	Nucleus Estate & Smallholders Development (food crops)	Indonesia	6	322	16

WB News Release No.	Project Title	Country	Duration of Project (Years)	Project Cost ($mill)	Economic Rate of Return(%)
81/109	Guavio Hydro Power	Colombia	6	1303	15
81/110	Third Power (Hydro)	Swaziland	3	59.2	12
81/113	Textile Rehabilitation	Tunisia	2	32.9	30
81/116	Piaui Rural Development	Brazil	5	84.4	20
82/2	Telecommunications	Uruguay	4	204.8	30
82/3	Land Transportation (roads & rail)	Romania	5	767.1	20
82/4	Provincial Roads	Thailand	4	69.7	20
82/5	Anambra Water Supply and Sanitation	Nigeria	5	120.6	9
82/7	Macedonia Agricultural Development	Yugoslavia	5	232.2	17
82/9	3rd Telecommunications	Egypt	4	141.3	21
82/13	Madhya Pradesh Major Irrigation	India	5	439.2	21
82/13	Tamil Nadu Newsprint (pulp and paper mill)	India	4	237.5	19.4
IDA News					
80/25	Small Rural Operations	Senegal	4	14.1	14
80/27	Water and Sanitation	Madagascar	5	33.7	7-4 (water only)
80/30	Low lift Pumps	Bangladesh	4	48	+100
80/31	2nd Chittagong Water Supply	Bangladesh	4	39.7	9
80/32	Smallholder Rubber Development	Indonesia	4	70.5	14
80/33	Fifteenth Irrigation	Indonesia	4	71.7	17
80/34	National Agricultural Extension II	Indonesia	5	81.9	n.a.

WB News Release No.	Project Title	Country	Duration of Project (Years)	Project Cost ($mill)	Economic Rate of Return(%)
80/36	Forestry Development	Upper Volta	5	17.5	28
80/37	Third Highway	Pakistan	3	93.2	50
80/40	Uttar Pradesh Tubewells	India	2	36	36
80/42	3rd Power (hydro units)	Sudan	5	290	16
80/43	Expansion of Pyrethrum Production	Tanzania	5	12.7	17
80/44	2nd Maharashtra Irrigation	India	5	451	16
80/46	Gujarat Community Forestry	India	6	76	17
80/48	Road Transport	Sri Lanka	3	86.4	20
80/50	Community Forestry & Training	Nepal	6	24.8	16
80/51	Volta Agricultural Development	Ghana	5	48.7	16
80/52	2nd Livestock Development	Cameroon	5	36	16
80/54	4th Tihama Development (irrigation)	Yemen	4	20.8	17
80/56	2nd Gujarat Irrigation	India	6	360	17
80/56	Cashewnut Production	India	4	45.7	25
80/57	Niena Dionkele Rice Production	Upper Volta	5	7.2	9
80/59	Wood Energy Project (incorporating smallholder woodlots)	Malawi	5	16.3	14
80/62	Grain Storage & Milling	Tanzania	6	58.4	38
80/64	Smallholder Rubber Rehabilitation	Sri Lanka	6	28	23
80/88	2nd Urban Transport (P. Aleg)	Brazil	4	312.8	24

IDA News Release No.	Project Title	Country	Duration of Project (Years)	Project Cost ($mill)	Economic Rate of Return (%)
80/70	Telecommunications	Sri Lanka	4	36.3	33
80/71	3rd Agricultural Rehabilitation and Development	Lao	5	18.8	32
80/72	New Halfa Irrigation Rehabilitation	Sudan	6	105	75
80/74	Fertilizer Industry Rehabilitation	Bangladesh	3	46.6	62
80/76	Fisheries Development	Yemen	5	30.3	22
80/77	2nd Maradi Rural Development	Niger	5	47.5	28
80/78	2nd Singrauli Thermal Power	India	7	914.3	13
80/79	Kerala Agricultural Extension	India	6	15.3	50
80/82	3rd Highway (emergency maintenance)	Ghana	2	38.6	+100
80/86	Calcutta Urban Transport	India	3	121.71	23
80/87	Karnataka Sericulture (agric)	India	3	95.1	22
80/88	Coconut Rehabilitation and Rodent Control	Comoros	6	5.7	13-9
80/90	Smallholder Tea Consolidation	Tanzania	6	20	21
80/91	Greater Aden Water Supply	Yemen	4	39.2	11
80/92	Integrated Forestry and Livestock Development	Rwanda	6	23.6	14
80/93	Smallholder Maize Production/ Marketing	Zaire	7	38.5	45
80/89	Urban Development	Lesotho	5	7.066	22

IDA News Release No.	Project Title
80/94	Dosso Agricultural Development
80/95	2nd Water Supply and Sewerage
80/96	Mangrove Afforestation
80/103	Rajasthan Water & Sewerage
80/104	6th Power (transmission & distribution)
80/106	Urban Development
80/112	Mahakali Irrigation I
81/2	Telecommunications
81/3	Telecommunications
81/4	3rd Water & Sewerage
81/7	Grain Storage
81/11	Livestock Development
81/13	Gorgol Irrigation
81/16	2nd South. Uplands Rural Development
81/21	2nd Rural Development
81/23	Mahanadi Barrages (irrigation and drainage)
81/25	2nd Madras Urban Development
81/26	New Land Development
81/31	2nd Agricultural Minimum Package

Country	Duration of Project (Years)	Project Cost ($mill)	Economic Rate of Return (%)
Niger	5	39.2	25
Sri Lanka	5	94	4-6
Bangladesh	6	17.2	18
India	5	164	6
Sri Lanka	4	63.3	12
Burundi	5	16.7	19
Nepal	5	19.5	14
Rwanda	5	17.5	18
Burundi	5	9.1	20
Nepal	6	33.3	3
Nepal	3	8.04	18
Guinea	6	21	25
Mauritania	6	93.2	7-4
Yemen	5	81.6	23
Sri Lanka	6	50.01	17
India	7	110.3	21
India	5	87.9	22
Egypt	6	193	10-8
Ethiopia	2	77.2	20

IDA News Release No.	Project Title
81/32	Kwilu-Ngongo Sugar Production
81/33	2nd Feeder Roads
81/34	Bakhrabad Gas Development
81/35	Grain Storage
81/37	Eastern Integrated Agricultural Development
81/39	Fertilizer Transport
81/40	2nd Bougouriba Agricultural Development
81/42	4th Highway
81/43	Agricultural Extension & Research
81/44	Hill Food Production
81/45	Regional Electrification
81/46	Forestry Development
81/47	Road Maintenance
81/55	8th Telecommunications
81/57	Wood Industries (sawmills)
81/59	Karnataka Tank Irrigation
81/61	Blue Nile Pump Rehabilitation
81/61	White Nile Pump Rehabilitation
81/63	Port Development

Country	Duration of Project (Years)	Project Cost ($mill)	Economic Rate of Return (%)
Zaire	5	80.4	17-5
Benin	3	8.7	20
Bangladesh	4	164	+55
Burma	3	39.1	29
Sierra Leone	6	25	34
Bangladesh	4	40.8	33
Upper Volta	5	17.5	23
Malawi	4	39.2	18
Nepal	5	20.85	50
Nepal	6	9.7	58
Yemen	3	21.5	16
Senegal	4	17.1	12-8
Mali	2	43.3	50
India	4	1619.4	17
Burma	4	63.8	25
India	5	77.4	20
Sudan	6	67.3	32
Sudan	6	54.7	57
Haiti	3	23.7	24

IDA News Release No.	Project Title
81/67	Hazira Fertilizer Complex
81/68	Lake Kivu Coffee Improvement and Foodcrop
81/70	Borgou Rural Development
81/72	North. Integrated Agricultural Development II
81/74	3rd Highway
81/77	Maharashtra Agricultural Extension I
81/78	Maharashtra Agricultural Extension II
81/78	Tamil Nadu Agricultural Extension
81/79	Hand Tubewells
81/85	3rd Highway
81/85	Wadi Beihan Agricultural Development
81/86	2nd Cooperative Development Corporation
81/97	Grain Storage
81/98	Agricultural Research
81/99	Al Mukalla Water Supply Rehabilitation
81/100	Village Irrigation Rehabilitation

Country	Duration of Project (Years)	Project Cost ($mill)	Economic Rate of Return(%)
India	5	1276.9	17
Rwanda	5	16.6	22
Benin	5	41	21
Sierra Leone	6	27.7	21
Burundi	4	35	19
India	5	38.2	50
India	6	60	50
India	6	45.6	50
Bangladesh	4	30.1	44
Yemen	3	42.8	16
Yemen	5	18.1	24
India	5	267	23
Pakistan	4	68	28
Pakistan	5	36.75	n.a.
Yemen	3	4.4	10
Sri Lanka	5	43.6	20

IDA News Release No.	Project Title	Country	Duration of Project (Years)	Project Cost ($mill)	Economic Rate of Return (%)
81/101	2nd Mangoro Forestry Development	Madagascar	3	30.2	12
81/103	On-Farm Management	Pakistan	4	111.6	+50
81/104	4th Highway	Upper Volta	4	73	60
81/105	Kirimiro Rural Development	Burundi	5	21.4	18
81/106	Mahaweli Ganga Development III (irrigation & drainage)	Sri Lanka	6	201.8	18
81/110	Railway Rehabilitation	Ghana	4	64	32
82/1	2nd Korba Thermal Power	India	7	1387	15
82/2	Telecommunications	Tanzania	4	47	24
82/3	2nd Drainage & Flood Control	Bangladesh	5	41.4	23
82/14	Kanpur Urban Development	India	4	51.7	21

Source: Various World Bank and International Development Association News Releases.

CHAPTER TWO

REVIEW OF METHODS OF EVALUATING RESEARCH AND DEVELOPMENT (R&D)

2.1 Introduction

This Chapter contains a review of the various methods and procedures that have been used to evaluate the effectiveness of research programmes, with particular reference to agricultural research projects. The material is organised under two main headings: ex-post evaluations and ex-ante evaluations.

Schuh and Tollini note that most of the analyses of agricultural R&D have been on an ex-post basis.[1] The ex-ante analyses have been mostly applied in industrial R&D projects. The ex-post evaluations serve to determine how efficient particular research programmes or institutions have been. This approach has therefore been used in agricultural R&D evaluation to assess the role of agricultural R&D in economic development and to determine whether these investments have been viable. Ex-ante evaluations are useful in determining the resources to be allocated to R&D to attain a certain objective.

Thus, whether to use ex-post or ex-ante evaluations will depend on the objectives of the evaluation. There are different schools of thought aligned with the two different approaches. However, both approaches are useful and required: one can provide an understanding of the research and technology processes and consolidate the knowledge and gains achieved, while the other provides forward looking estimates under highly subjective judgements, which can gain from ex-post insights. Thus Fishel notes that as statistical estimation is improved, so will resource allocation and policy making information be improved by the hybridization of ex-post and ex-ante analysis methodologies.[2]

2.2 Ex-post Evaluations:

2.2.1 Inputs Saved Approach

In this method resource savings are estimated by determining how many resources would have been used to produce the output of a base period using the techniques of production of an earlier period. A comparison of this with the resources actually used provides an estimate of the resources saved.

In turn the value of the resources saved constitutes the benefits from the research. These benefits are then compared with the research expenditures to compute the returns on R&D.

The approach can be used for small or large research programmes. It was first used by Schultz on the United States agriculture as a whole.[3] He had however, to deal with the problem of index numbers which arose from relative factor price changes over time as he was using resource savings data on an extended period of time. To deal with the problem he computed upper and lower limits for the resources saved by, in one case, using price weights from the early part of the period and in another case price weights from the end of the period.

Schuh and Tollini also note that since aggregate data are not likely to be available for resource savings in sufficient details for this approach, it would be necessary to make estimates either from experimental data or surveys of farms.[4] When combined with data on the extent of use of the innovation, an estimation of the total resources saved could be made.

This approach is more useful for evaluating innovations that are more directly resource-saving than output-increasing. An example would be the development of a crop variety which is resistant to certain pests and that would therefore reduce or eliminate the need to spray against the pests.

2.2.2 Consumer and Producer Surplus Approach

In this method the evaluation of agricultural research is measured by the benefits and losses to consumers and producers caused by technical change. These benefits and losses are called consumers and producers surpluses.

The basic analytical framework is illustrated in figure 2.1. A shift in the supply curve from S to S' is shown, with the shift assumed to be attributed to improved technology. The shift in the supply curve produces a change in the consumers surplus by the area P_o A B P_1, which is equal to the area AEB plus the area P_o A E P_1. This is a benefit to the consumers which arises because the consumers are able to acquire more of the product at a lower price. The shift in the supply curve will also produce a change in producers surplus by the area BEO minus the area P_o A E P_1. The total change in economic surplus is producers plus consumers surplus which is given by the area AOB.

In this analysis the empirical data required is knowledge on the amount of shift of the supply curve caused by the technical change and knowledge of the supply and demand parameters for the product under consideration. For a full cost - benefit analysis, information on the costs of the research programme required to induce the shift in the supply curve is required.

For the cost-benefit analysis, the costs (research expenditures), the benefits (economic surpluses), and the net flow of benefits are constructed on a yearly basis. The net cash flow is then discounted to a Net Present Value (NPV) using an appropriate discount rate.

The NPV is given by

$$B_o - C_o + \frac{B_1 - C_1}{(1 + r)^1} + \frac{B_2 - C_2}{(1 + 2)^2} + \ldots \frac{B_n - C_n}{(1 + r)^n}$$

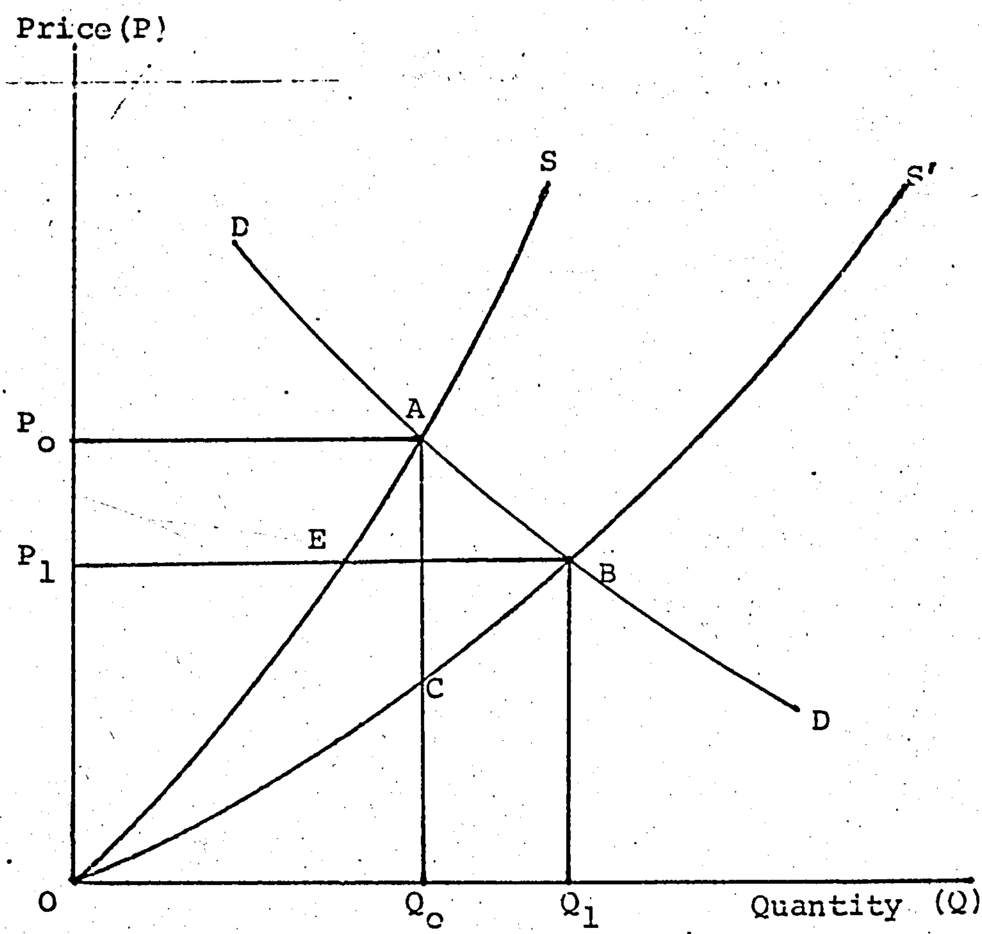
where B = Benefits measured in shadow prices

C = Costs measured in shadow prices

r = Shadow discount rate

n = number of years of the project.

<u>Figure 2.1</u>: Basic Model for the Analysis of Consumer and Producer Surplus.



The cost-benefit ratio is calculated directly as the total net benefits over total costs all discounted to the same base year using the chosen discount rate.

Alternatively, an internal rate of return (IRR) is calculated. This is the rate of return which will equate the flow of costs to the flow of benefits over time. It is also defined as that discount rate which reduces the NPV to Zero, and can be obtained by iteration and interpolation.

The cost-benefit ratio measures of project returns have some limitations which should be borne in mind:

(i) The IRR has a short coming which sometimes renders it meaningless; When a project is characterised by high costs in future years, so that benefits turn negative for some years there may be two or more discount rates which cause NPV to be Zero. When this occurs there is no way we can tell which is the correct IRR. In this case the cost-benefit ratio or the Net Present Value (NPV) is used.

(ii) The IRR tends to underestimate returns to large capital cost projects and long gestation projects.

(iii) The IRR inflates the returns to short life projects.

(iv) The results are very sensitive to the prices and discount rates used.

The evaluation of agricultural research by the consumer and producer surplus approach has been extensively reviewed by Schuh and Tollini[5] and by Norton and Davis.[6] The following discussion heavily draws on the review by these authors.

We start the discussion on the consumers and producers surplus approach by reviewing the pioneering work of Griliches whose repeated quotation by research evaluators is probably a testimony to the care with which the Griliches' evaluation was undertaken although it has been criticised by later workers.[7] Griliches calculated the loss in net social surplus that would occur if hybrid maize were to disappear. His analysis assumed that the adoption of hybrid corn shifted the supply curve downward and to the right (from S to S′ in figure 2.2 & 2.3). He estimated returns for the two extreme cases of perfectly elastic (figure 2.2) and perfectly inelastic (figure 2.3) supplies and assumed demand elasticity of minus 1. He calculated that these extreme assumptions on the supply elasticities would result in a difference of 7% only.

In figure 2.2, the increase in consumer surplus is

$$E + F = K P_1Q_1 \ (1-\tfrac{1}{2} Kn)$$

where $K = \frac{\Delta P}{P_1}$

n = demand elasticity

In figure 2.3, the increase in consumer surplus is A + B, the change in producer surplus is C - A, and the net change in economic surplus is:

$$A + B + C - A = K P_1Q_1 \ (1 + \tfrac{1}{2}\frac{K}{n})$$

where $K = \frac{\Delta Q}{Q_1}$

n = absolute value of demand elasticity.

Griliches' approach had the advantage of simplicity as he did not have to calculate either demand or supply elasticities.

Peterson, in his work on poultry, generalised Griliches' formula for estimating changes in net social surplus.[8] He calculated the case where supply is neither perfectly elastic nor perfectly inelastic and did not require a demand elasticity of minus 1 as in the case of Griliches (figure 2.4).

In figure 2.4, Peterson's gain in net economic surplus is given by:

A + B + C + E + G + (- A - B + H + I + J) = C + E + G + H + I + J. Peterson reasoned that the area C + E + G + H

Figure 2.2: Measures of Consumer Surplus Under Assumption of Perfectly Elastic Supply.

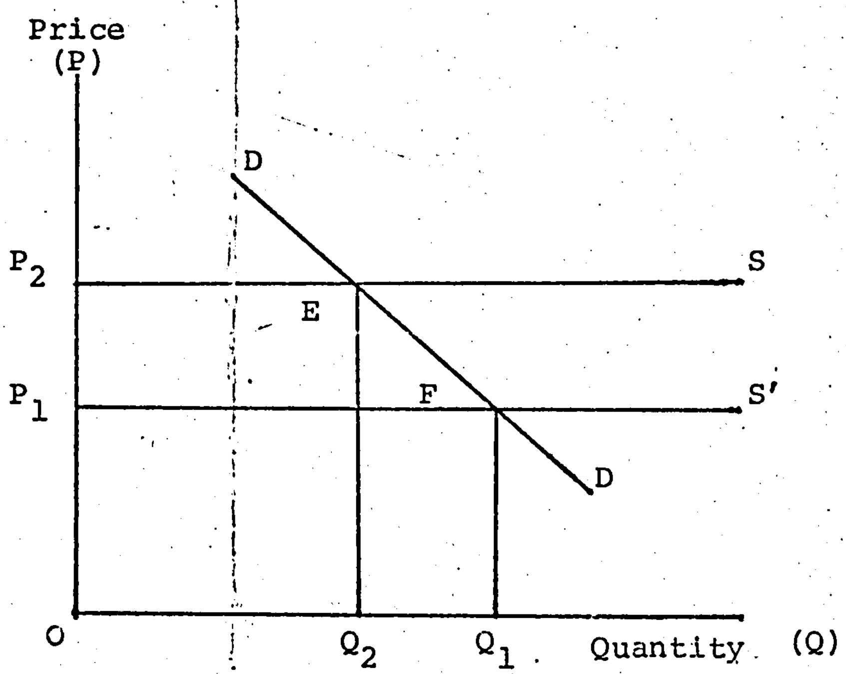
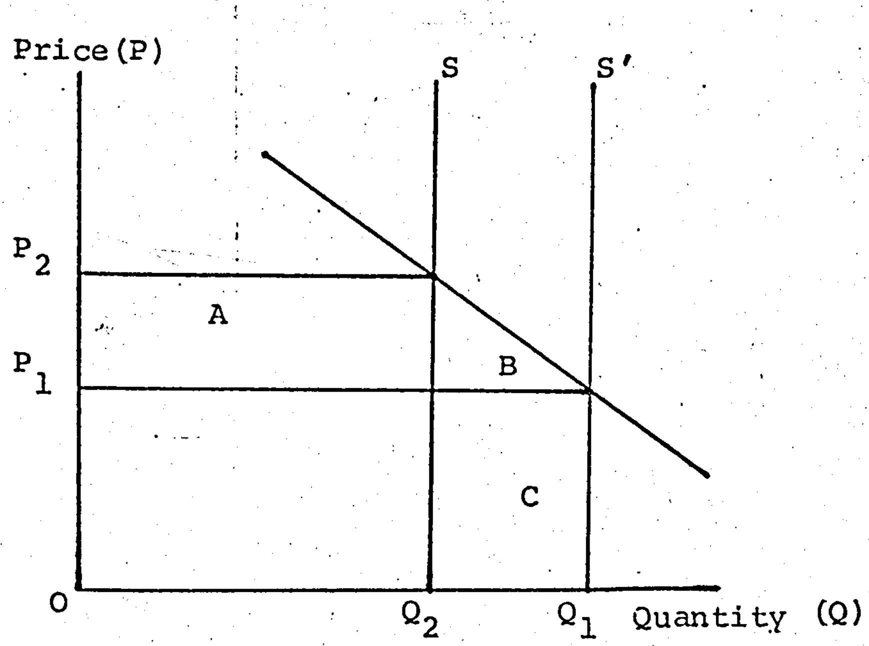


Figure 2.3: Measures of Consumer Surplus Under Assumption of Perfectly Inelastic Supply



+ I + J was approximately equal to I + J + K + L + E + G - D and used the following formula to estimate the area:

$$K\,Q_1P_1 + \frac{\frac{1}{2}K^2P_1Q_1}{n} - \tfrac{1}{2}Q_2\;K^2P_1\left(\frac{P_1}{P_2}\right)\left(\frac{en}{n+e}\right)\left(\frac{n-1}{n}\right)^2$$

where n = absolute value of the demand elasticity

e = supply elasticity

K = percentage shift in the supply curve $= \dfrac{Q_1 - Q_2'}{Q_1}$

If n = 1 and e = 0, the above formula reduces to $K\,Q_1P_1\ (1 + \frac{K}{2n})$.

Hertford and Schmitz provided the following formulae for estimating net social surplus when the supply and demand curves as represented in figure 2.4 are linear and the supply shift is parallel.[9]

$$\text{Consumers Surplus} = \frac{KP_1Q_1}{n+e}\left(1 - \tfrac{1}{2}\,\frac{Kn}{n+e}\right)$$

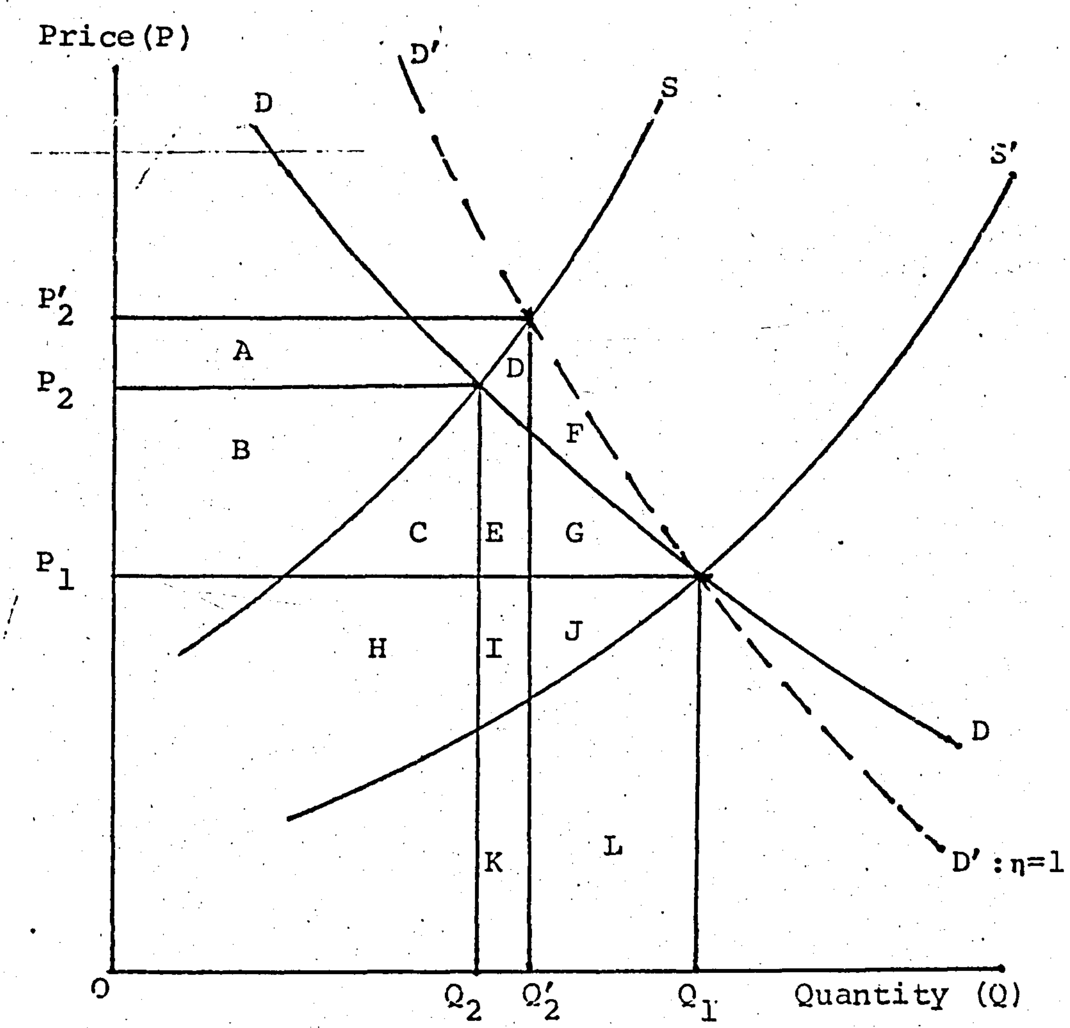
$$\text{Producers Surplus} = KP_1Q_1\left\{1 - \frac{1}{n+e}\left(1+\tfrac{1}{2}K\left(\frac{2n+e}{n+e}\right)\right)\right\}$$

$$\text{Total net Social Surplus} = KP_1Q_1\left(1+\tfrac{1}{2}\frac{K}{n+e}\right)$$

where K is defined as the horizontal distance between S and S'.

Schmitz and Seckler extended the model to the mechanical tomato harvester and took into account the labour displaced by the harvester.[10] They estimated benefits by Schultz's method of inputs saved, then estimated the hours of labour lost, multiplied this by the wage rate and subtracted this value from the benefits to get a measure of the net benefits. They calculated the benefits assuming unemployment of the freed labour and various levels of compensation of the labour, including zero compensation.

Figure 2.4: Estimation of Economic Surplus Under Supply Conditions Which Are Neither Perfectly Elastic Nor Perfectly Inelastic.



Ayer and Schuh modified the model by specifying a cobweb behavioural model for cotton production in Brazil.[11] Referring to figure 2.5, the change in social returns is given by (O A B C - O A H) - (O E F C - O E G). S represents cotton supply when unimproved varieties are planted, S' represents supply under improved varieties and D is the demand for cotton. The supply of cotton was assumed to depend on the previous years price, P_{t-1} and the demand and supply schedules were estimated to be represented as follows:

$$D = P - nQ^{\alpha}$$

$$S' = Q - mP^{\beta}_{t-1}$$

$$S = (1 - K)\ mP^{\beta}_{t-1}$$

where n = all parameters and variables influencing demand but excluded from the equation.

m = all parameters and variables influencing supply but excluded from the equation

K = Percent shift of the supply curve, determined by the difference in cotton fiber yield between the old and improved varieties and the proportion of new varities planted.

Net social returns were then estimated for each year as follows:

$$\int_{0}^{A} (D)\ d(Q) - \int_{0}^{A} (S')\ d(Q) - \int_{0}^{E} (D)\ dQ + \int_{0}^{E} (S)\ d(Q)$$

These returns were then compared with the estimated costs of the project and the internal rate of return calculated. Elasticity estimates and K values were varied to test the sensitivity of the results and the distribution of benefits between consumers and producers were examined.

Akino and Hayami used an approach similar to that used by Ayer and Schuh above but without the cobweb specification to estimate the social returns from plant breeding research in Japan.[12] They also considered the distributional effects from the research and looked at the effects of government rice import policies.

Their analysis is represented in figure 2.6. Assuming market equilibrium and no rice imports, the increase in suplusses is represented as follows:

Consumer Surplus: $P_n B C P_o + A B C$

Producer Surplus: $A O C - P_n B C P_o$

Net Surplus: $A B O$

However, if the government decided to maintain the price at P_o, the total surplus gain would be an increase in producer surplus of A O C. Without the increased research, Japan would have to import rice at a total value equivalent to the area $A C Q_n' Q_o$ to keep the price at P_o. Therefore the area $A C Q_n' Q_o$ represents a gain in foreign exchange due to the

Figure 2.5: Measures of Economic Surpluses Including a Cobweb Specification.

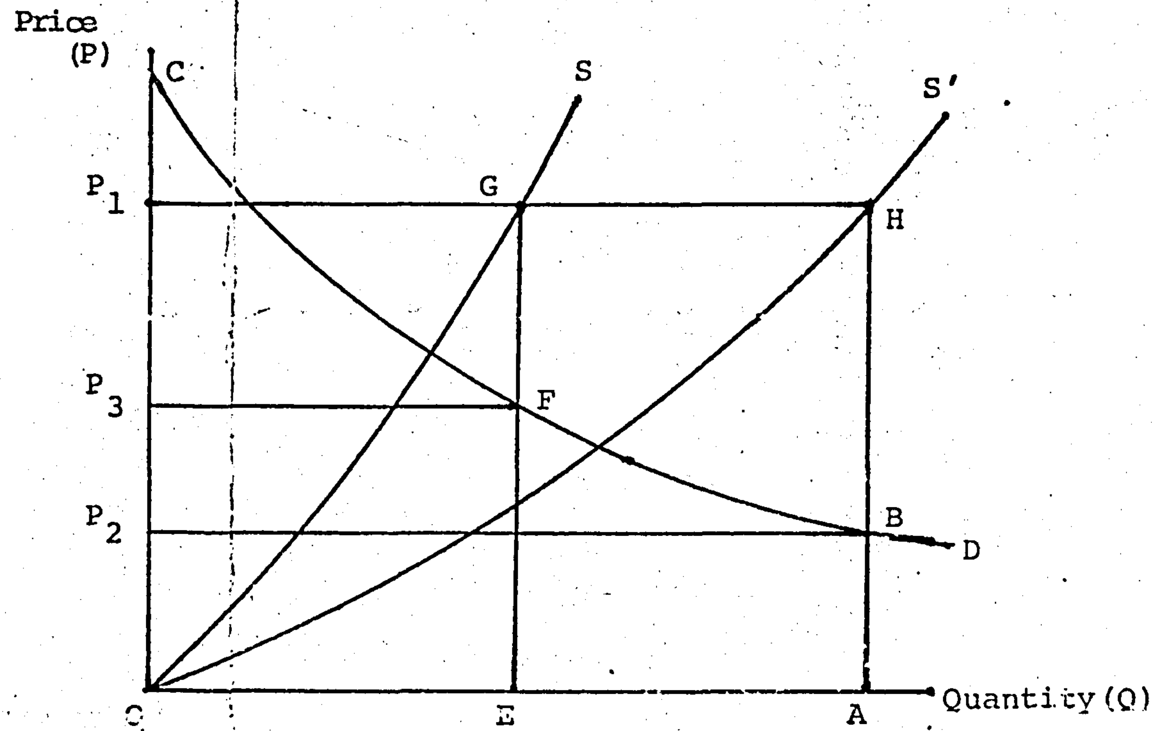
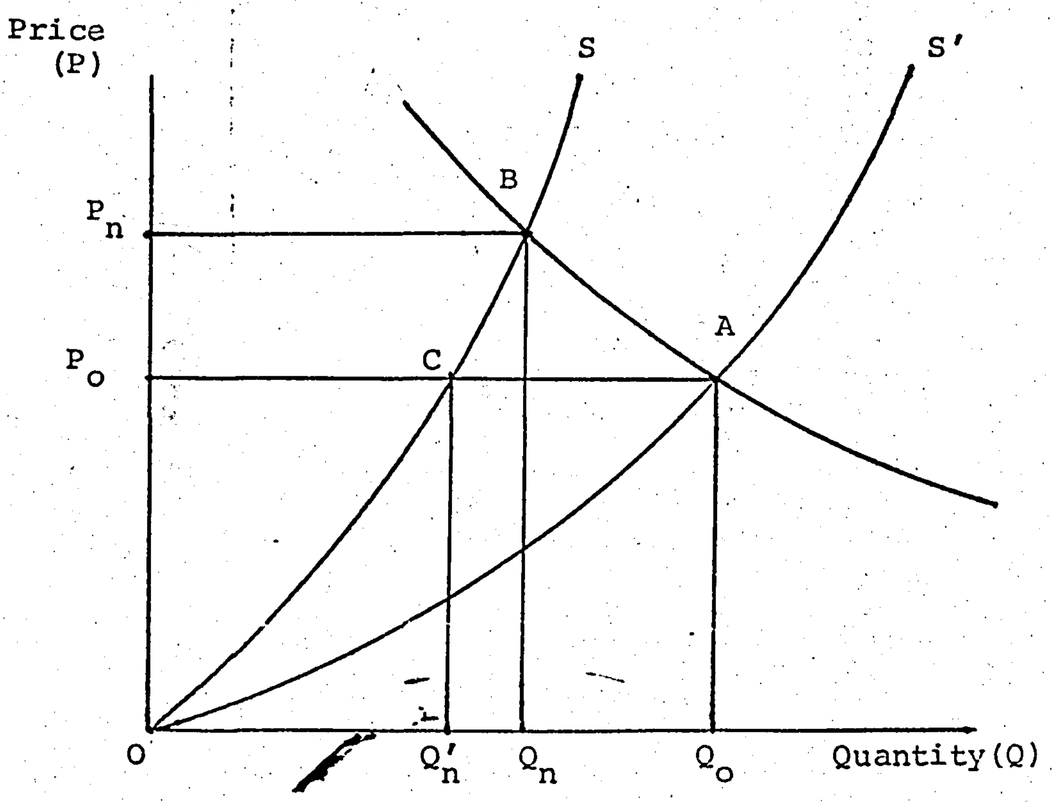


Figure 2.6: Measures of Economic Surpluses Taking Into Account Distributional Effects of Research and Government Import Policies, Assuming a Free Market.



research. They provided formulae for estimating P_n B C P_o, A B C, A O C and A C Q_n' Q_o as follows:

$$P_nB\ C\ P_o = P_oQ_o\ \frac{K(1+e)}{e+n}\{1-\frac{\frac{1}{2}K(1+e)n}{e+n} - \tfrac{1}{2}K(1+e)\}$$

$$A\ B\ C = \tfrac{1}{2}\ P_oQ_o\ \frac{(K\ (1+e))^2}{e+n}$$

$$A\ O\ C = K\ P_o\ Q_o$$

$$A\ C\ Q_n'\ Q_o = (1+e)\ K\ P_o\ Q_o$$

where K = The shift in the production function

n = Price elasticity of demand

e = Price elasticity of supply

They mention that the shift in the supply curve can be approximated by (1+e)K

Scobie and Posada used the consumer and producer surplus approach to study the impact of rice research on the distribution of income in Colombia.[13] They considered the incidence of research costs among upland producers, irrigated producers and consumers and subtracted this from the gross benefit for each group and obtained the net benefits for each group. Their analysis led to the conclusion that consumers benefited most, producers suffered losses but small producers lost the most.

Duncan used the consumer and producer surplus approach in new pasture technologies to estimate the benefit of research for a product with a derived demand.[14] In this case the product under consideration is an input into the production of another product. The increase in productivity of the input shifts its demand from D_1 to D_2 in Figure 2.7. The area A represents the gross welfare gains from increase in productivity of the input. He presented the following formula for the calculation of the area.

$$b(eP^{-Q_1/b} - eP^{-Q_2/b}) - P(Q_2 - Q_1)$$

where, b = the long run price elasticity of demand.

e = price elasticity of supply.

Norton and Davis note that <u>ex-post</u> cost-benefit analyses that have measured net benefits by estimating the increases in production and valuing this at a given constant price also fall into the consumer/producer surplus classification.[15]

For example, Kislev and Hoffman estimated returns to research on wheat in Israel by using this method and in effect estimated the area A B Q_2 Q_1 in figure 2.8.[16] Since Israel imports most of its wheat they assumed a perfectly elastic demand curve for wheat and evaluated the economic contribution of additional output at world prices. They used yield regressions to determine the yield increases due to new varieties, multiplied those increases by the area sown and multiplied this by the world price. The result was an estimate of the social surpluses as represented by area $A\ B\ Q_2\ Q_1$ in figure 2.8.

Lindner and Jarret have pointed out that it is important to recognise that the total level of annual social benefits from the adaption of an innovation is influenced by the nature of the shift in the supply curve.[17] They presented the hypotheses that certain types of innovations such as biological and chemical innovations are more likely to generate divergent supply shift while mechanical or organizational innovations will be more likely to produce a convergent shift or, possibly, a parallel shift. They went on to provide a generalised formula for measuring research benefits that avoids some of the biases that arise from varying assumptions about the supply shifts and elasticities.

Referring to figure 2.9, Lindner and Jarret provided the following formulae for estimating the benefits:

Change in Consumer Benefits:

$$= \tfrac{1}{2}\,(P_oQ_1 - P_1Q_o + P_oQ_o - P_1Q_1)$$

Change in Producer Benefits:

$$= \tfrac{1}{2}\,(Q_oA_o - Q_1A_1 - P_oQ_o + P_1Q_1)$$

Figure 2.7: Measures of Economic Surplus for a Product with a Derived Demand.

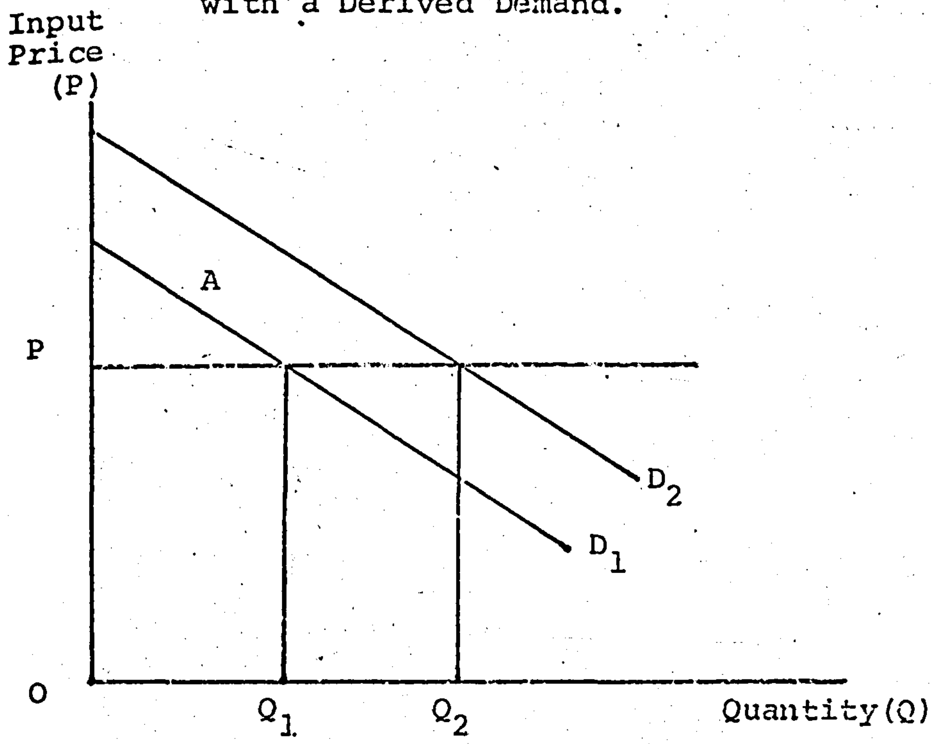
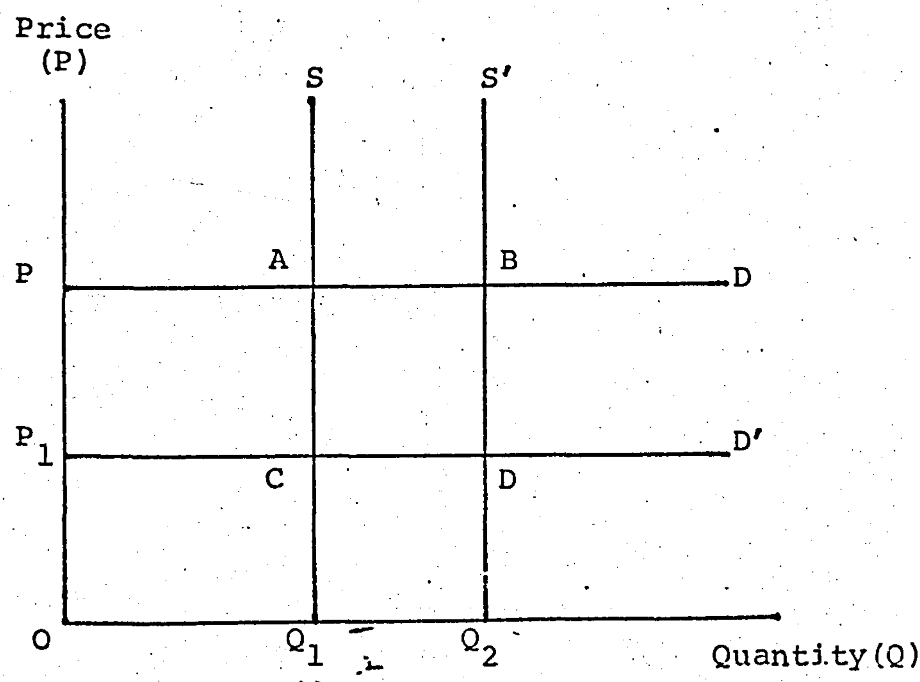


Figure 2.8: Economic Surpluses under Perfectly Elastic Demand Curve and Vertical Supply Curves.



Change in Total Benefits:

$$= A_1M_1M_oA_o = \tfrac{1}{2}\,(P_oQ_1 - P_1Q_o + Q_oA_o - Q_1A_1)$$

where P_o = Current price

Q_o = Current quantity

$P_1 = P_o\,(1 - \frac{ke}{e+n})$

$Q_1 = Q_o\,(1 + \frac{ken}{e+n})$

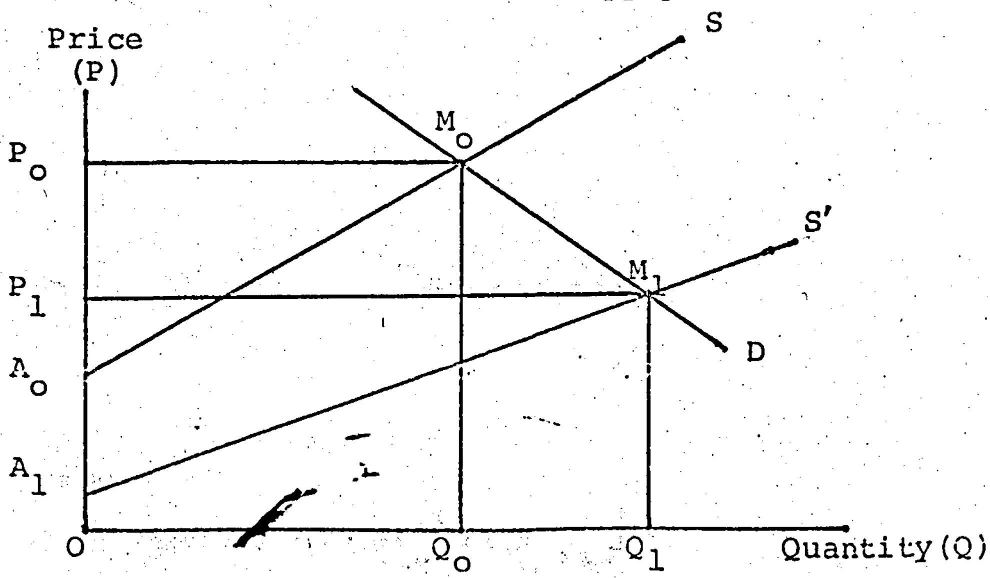
k = absolute cost reduction at Q_o divided by P_o

$A_1 = \frac{A_o}{1-k}$ for a proportional shift

$A_1 = A_o - R$, where R is the absolute reduction in average costs for all firms for a parallel shift.

$A_1 = A_o$ for a pivotal shift.

Figure 2.9: Measures of Economic Surpluses that Avoid Biases Arising from Varying Assumptions About Supply Shifts and Elasticities. (Linear Demand and Supply Curves Assumed).



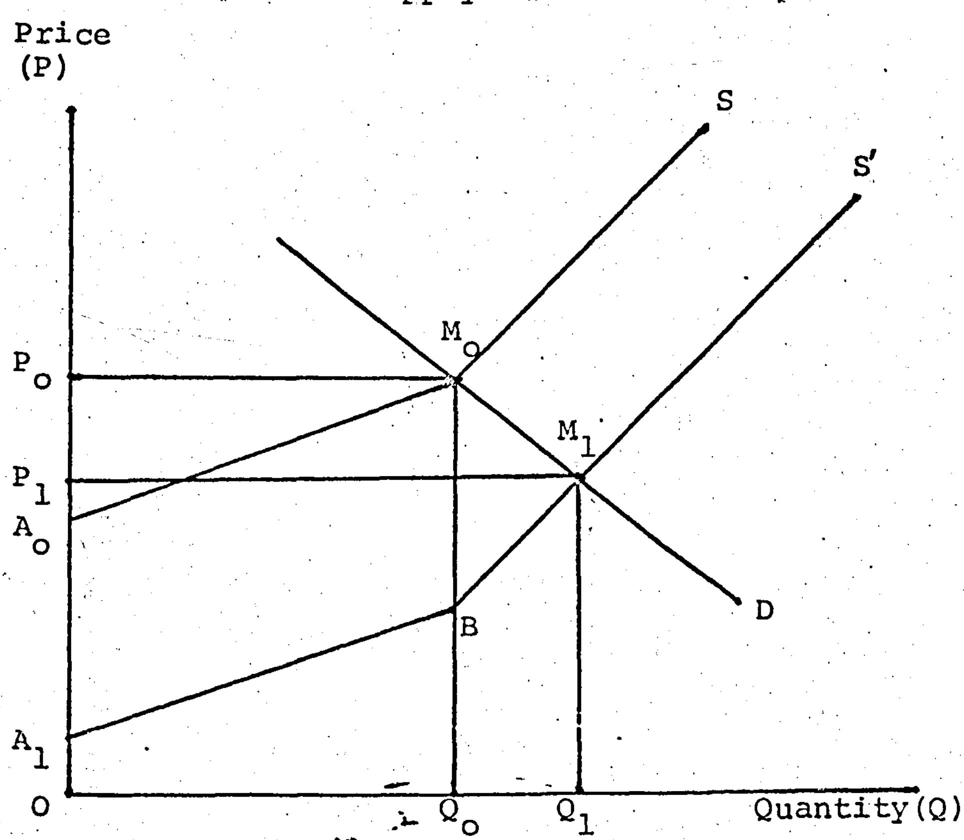
Lindner and Jarret pointed out that their formulae apply only when the supply and demand curves are linear. Rose[18] and Wise and Fell[19] suggest the inclusion of a kink in the S′ curve directly below M_o as shown in figure 2.10 and then provide the following formulae to estimate net social surplus:-

$$\tfrac{1}{2}\ Q_o\ (K\ P_o + A_o + A_1) + \tfrac{1}{2}K\ P_o(Q_o - Q_1)$$

If a parallel shift is assumed, the formula reduces to: $K\ P_oQ_o + \tfrac{1}{2}\ K\ P_o(Q_o - Q_1)$

If a pivotal shift is assumed, the formula reduces to: $\tfrac{1}{2}\ K\ P_oQ_o + \tfrac{1}{2}\ K\ P_o(Q_o - Q_1)$

Figure 2.10:—Measures of Economic Surpluses That Avoid Biases Arising From Varying Assumptions About Supply Shifts and Elasticities (Kinked Supply Curves Assumed).



A Critique of the Consumer/Producer Surplus Approach

It is apparent from the foregoing discussion that the consumer/producer surplus approach has a number of advantages. One of the most important advantage is that the approach provides a means of analysing how the benefits of the research are divided between consumers and producers. The only thing required of such an analysis is knowledge about the demand and supply curves. As is apparent from figure 2.1, producers can sustain losses from the change. All this requires is that area P_o A E P_1 be greater than area B E O. The importance of this distributive aspect is more enhanced if policy makers should have as a particular goal an improvement in the welfare of either consumers or producers.

The discussion has also showed that the approach can be used for a closed economy or an economy open to trade. The demand elasticities in an open economy may tend to be high, meaning that there will be small changes in price associated with the quantity supplied. In such a case, the technical change will result in most of the direct benefits accruing to the producers, unless there is government intervention. Consumers will benefit indirectly since the additional foreign exchange will help to finance a higher rate of growth of the economy. These indirect effects should be taken into account in calculating the benefits and costs of research.

We have also seen that the model can be modified to take into account price and trade policies as illustrated by Akino and Hayami in the case of rice breeding in Japan where they concluded that in the absence of trade Japanese producers would have been net loosers from agricultural research.[20]

Let us also look at some of the limitations of the model. The above discussion has also illustrated the extent to which studies using the approach have differed in their specification of supply and demand functions and in the nature of the supply function shifts. The various formulae which have been presented reflect these differences as well as the differences in the derivation of the shift parameter "K". Scobie has drawn attention to the dissimilar results that could be obtained by applying different formulae found in the literature to the same problem.[21]

For example Griliches assumes a parallel shift (horizontal or vertical); Peterson a proportional shift; Hertford and Schmitz a parallel shift; Akino and Hayami a pivoted shift, Lindner and Jarret and Rose four types of shifts. The type of shift assumed is important because divergent shifts result in fewer benefits in total to producers than parallel or convergent shifts.

Duncan and Tisdell have shown, for example, that returns to producers from research projects will be negative when research leads to a divergent supply shift and when demand is inelastic.[22] Lindner and Jarret point out that this set of assumptions was made by Akino and Hayami and therefore predetermined their conclusions about the distributional effects of the rice breeding research on Japanese agriculture.[23]

We have further seen that Griliches, Hertford and Schmitz, and Lindner and Jarret assume linear supply and demand curves. Peterson assumes a general specification while Akino and Hayami assume constant elasticity supply and demand curves. Rose assumes a linear kinked supply curve and a linear demand curve. However, Norton and Davies point out that these differences are likely to be of minor importance in measuring net benefits.[24] They emphasize that much more attention needs to be devoted in the evaluation of K because its size is a major determinant of net benefits.

Norton and Davies have pointed out that in some cases it is easier to measure K as an output effect (horizontal shift in the supply curve) and in others as the lowering of the supply curve. They add that this distinction between a horizontal and a vertical supply is really an artificial one because when yield increases due to technical change this also means that the same output can be produced at a lower price. They caution that when using a particular formula, one must be careful to use the type of K which corresponds to the formula. For example, the formula developed by Hertford and Schmitz includes K as a horizontal shifter of the supply curve while Lindner and Jarret and Rose use K as a vertical shifter. Akino and Hayami use K as a production function shifter and provide a formula for converting it into a horizontal supply shifter. Peterson measures K as the proportional change in equilibrium quantity following the supply shift, which is less than Schmitz's horizontal distance between the supply curves.

Thus there are differences in results for the various formulae due to differences in type of shifts, functional forms and K values.

Norton and Davies have also discussed the importance of the demand elasticity in the model. In general, the more inelastic the demand curve, the more likely producers will loose following technical change. Also, if the supply elasticity is larger than the demand elasticity, the consumer will tend to receive a larger share of the benefits than the producers. In addition, when accounting for secondary effects such as labour displacement resulting from technical change the size of the price-elasticity of demand is important.

If it is low even those technologies which do not directly displace labour can do so as a result of depressing prices of the product in the industry.

In summary, the consumer/producer surplus approach is flexible. It enables estimation of trade and price policy effects as well as distributional effects. To the extent that policy makers are interested in the distribution of benefits and costs from policies governing technical change and in trade implications, the model provides them a means of giving some important answers. Moreover, these answers are quite important in establishing research priorities and in managing the process of technical change for the good of all.

However, this feasibility of the model can also be a liability if the underlying relationships and policies are not accurately taken into account in the analysis. For example, if a parallel shift of the supply curve is assumed instead of a divergent shift, the estimated benefits will be too large. Or if a closed economy is assumed for a product when the country is a small producer of the product and exports it openly in the world market the analysis may wrongly imply less gain by the producers than the consumers. Thus there are differences in the consumer/producer surpluses formulae due to the assumptions about the type of the supply shift, functional form and how the shift 'K' is measured. These differences must be carefully taken into account in the analysis.

2.2.3 The Production Function Approach.

The second major approach used in measuring returns to agricultural research is the production function approach. The conventional production function includes only on-farm inputs. But inputs provided by the public sector such as research expenditures can be included in the production function.

The basic model used in this approach has been the Cobb-Douglas (log-linear) type of production function where:

$$Q = AR^{\alpha} \prod_{i=1}^{n} X_i^{\beta i} e^{\mu}$$

where Q = value of output

A = Constant which can be termed as a technological shift factor

R = expenditure on research

X_i = ith conventional production input

α = the production co-efficient of research

β_i = the production co-efficient of X_i

μ = the random error term

the marginal product of research is then given by $\frac{\alpha Q}{R}$

The response of output to research is not instantaneous and therefore studies using this approach have specified time lags in the model for the impact of research expenditure on output. The specification of the length and shape of the time lag has been a major source of variation among the studies in which this approach has been used. Griliches, who appears to have been among the first writers to use this method, used either a single years expenditure or an average of two years.[25] Evenson,[26] Fishelson[27] and Cline[28] have presented some empirical evidence which supports the use of an inverted 'V' or 'U' shaped distribution of the lag. These studies have also attempted to determine the appropriate length of this lag which the concensus suggests to be six to seven years for the United States.[29] The study by Evenson also threw some light on the time path of output response to increased research expenditures. He found that the returns increased and then decreased, with the high point occurring after about six years.

Researchers who have used the above type of the model have used mainly cross-sectional data. Some of the studies such as those by Griliches[30] and Kahlon et al[31] have used aggregate level of output as their unit of study while others have used the model for different commodities, such as the study by Bredahl and Peterson.[32] The latter study was concerned with comparing the productivity of research among cash grains, poultry, dairy and other livestock products and among states in the United States for the four different commodities. Using the above model, they were able to provide estimates of the marginal rate of return to incremental changes in the investment of research for each state and each commodity, and, were therefore able to indicate possibilities of increasing the overall rate of return by re-allocating some of the research investments from the low to the relatively high rate of return commodities among the different states.

Studies using time series data have adopted slightly different specification of the model as follows:

$$P = AR^{\alpha} \prod_{i=1}^{n} X_i^{\beta_i} E^{\varepsilon} W^{\gamma} e^{\mu}$$

where P = productivity index of agricultural output

A, R, α, X_i, β_i, μ = as defined above

E = other public expenditures such as extension, education, etc.

ε = productivity coefficient for E

W = weather index (usually rainfall)

γ = productivity coefficient for W

Evenson used this type of model to calculate the marginal product of research in the United States.[33]

Kahlon et al also used the same model for India.[34]

In the above two models there has been considerable variability in the items included in the expenditure figure. In some studies such as that of Bredahl only expenditures of state research stations were included.[35] On the other hand, Cline used total expenditures for US experimental stations, Department of Agriculture, extension, and soil conservation services.[36] Alternatively, Evenson and Kislev used the number of scientific publications in particular agricultural sciences as a proxy for research.[37] Their basic model amounted to regressing change in yield over a base period on a set of farm input variables plus a set of knowledge stock variables in form of scientific publications that are construed to be cumulated research investment. They estimated production functions for various countries and attempted to estimate the spillover effect of one country borrowing research from another region.

A Critique of the Production Function Approach

The consumer-producer surplus approach leading to a calculation of the cost-benefit ratio has the probable advantage that it is likely to be more appealing to decision makers in terms of translating its meaning into reality and understanding it. When public investments are analysed the cost-benefit approach is the one most often used and is therefore a more familiar analytical tool to the public decision and policy makers than the production functions.

However, the cost-benefit approach gives us the average productivity. The professional analyst may wish to assess the contribution of the important factors of production at the margin. For this kind of analysis, the production functions are used. The foregoing discussion has shown that the production function approach provides means of statistically isolating the effects of the various research programmes while at the same time controlling for the use of other inputs that are expected to influence output. The benefit of research can then be imputed to particular research programmes and allocation questions can be answered. In principle, increments in budgets would be allocated where the social rate of return is highest. Thus, Schuh and Tollini note that the production function is potentially as rich as the economic surplus approach, although its flexibility lies in somewhat different directions.[38]

However, the production functions as applied to R&D have come under considerable criticism, particularly with regard to the specification of the model.[39] Mansfield has cautioned that measures that have been done on the productivity of R & D are based on a number of highly simplified assumptions regarding the shape of the production function and that they are an incomplete estimation of the rate of return to R & D.[40] UNESCO, in the most recent work on "research on research" notes that the effectiveness of R & D is not a continuous linear function of output that might be obtained for example, in a manufacturing process, and that action of R & D on productivity has a more random nature and when these occur the output may be many fold the input.[41] This means that the production function may not only be shifted and its parameters altered but it may also be completely changed to a different form altogether.

We have already noted the variations arising from the type of lag assumed for research expenditures. Other difficulties with production functions arise from the high multicorrelation as well as serial correlation problems arising from time series data for conventional production inputs, and the general lack of sufficient time series data for the important conventional inputs such as fertilizers. The quality of the productivity indices are also, likewise, critical aspects of this approach.

We finally note that, despite the above criticisms attempts are being increasingly made to improve this approach and we may hope for refinements of the models by econometric researchers in the future. It should be noted that although the majority of studies have used the Cobb - Douglas specification as indicated in the above two equations, there have also been attempts such as those of Kahlon et al to fit the data into other specifications and see where the best fit is obtained.[42]

2.2.4 Impact of R & D on National Income Approach

Tweeten and Hines have employed a different approach in the evaluation of returns to agricultural research.[43] They calculate how much lower the national income would be if the percentage of people on farms was still the same as in 1910 and the resulting additional farmers had the income of today's farmers instead of today's non-farmers. This provides a measure of the benefits of research. They then estimate the costs of public and private research, education and federal programmes and use this to calculate a cost-benefit ratio. Thus their methodology is similar to the input-saving methodology and recognises that a contribution of new agricultural technology is the resources it releases to the non-farm sector. The larger the gap in earnings between the farm and non-farm workers and the higher the rate of migration off the farm, the higher the returns to agricultural research and extension as measured by this procedure. The improve this approach and we may hope for refinements of the models by econometric researchers in the future. It should be noted that although the majority of studies have used the Cobb - Douglas specification as indicated in the above two equations, there have also been attempts such as those of Kahlon et al to fit the data into other specifications and see where the best fit is obtained.[42]

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This approach provides only a crude approximation to the benefits of agricultural research and would not appear to be an approach with widespread applicability. Nevertheless, Tollini and Schuh contend that it does provide its results in a form understandable by policy workers and may be feasible when data is rather scarce.

2.2.5 Nutritional Impact Approach:

This approach has been developed by Pinstrup-Anderson, de Londono and Hoover.[44] The model raises the issue that goals such as nutrition, other than income can be important. The model estimates the nutritional impact of alternative commodity priorities in agricultural research and policy. The model estimates the distribution of supply increases of commodities among consumer groups, the related adjustments in total food consumption and implications for calorie and protein nutrition. This procedure permits a translation of increases in agricultural output to its impact on nutrition and by income groups. Hence equity and nutritional aspects can be analysed.

The model has two parts: The first involves estimating a price elasticity of demand matrix for each of a number of income strata and for the market as a whole. The second part deals with the distribution of a hypothetical supply increase of any one good among the income strata, the resulting consumption of all other goods and the impact on calories and protein nutrition. The model is demanding in terms of detailed knowledge of demand and consumption patterns. It does, however, provide information of considerable value in establishing research priorities if improved nutrition is the goal set for research.

2.3 Ex-ante Evaluations

Ex-ante evaluations are widely used in industrial and military R & D to improve decision-making with respect to research resources allocations. There exists a wide variety of methods that have been used in this area. These range from simple scoring exercises to more complicated mathematical models. The diversity of these models is partly the result of studies attempting to answer different questions and partly due to the way that uncertainty about the future has been handled. In this discussion, we shall mainly concern ourselves with those major models which have had a bearing on agricultural research.

However, before proceeding we should note that there are many pitfalls which could accompany decision-making about the future by use of quantitative methods and the efficiency of these methods has often been criticised. It is therefore benefitting to recall the words of Centron and Johnson at this stage.[45]

> We are all well aware of the many of the omisisions and weaknesses of these quantitative selection or resource-allocation techniques. It should be stressed again that they are not intended to yield decision, but rather information that would facilitate decision. Indeed, these techniques are merely thinking structures to force methodical, meticulous consideration of all factors involved in resource allocation. Data plus analysis yield information. Information plus judgement yield decisions .

Thus these models should be regarded mainly as important aids to decision-making. Cetron and Johnson go on to say

> It is wrong to say that one must select intuitive experience over analysis or minds over machines; really they are not alternatives; they complement each other. Used together, they yield results far better than if used individually .

In this discussion the different approaches to <u>ex-ante</u> evaluations are classified into four groups, namely,

- Pay-Back Period Approach
- Scoring Models
- <u>Ex-ante</u> Cost- Benefit Analysis
- Simulation and Mathematical Programming Models.

2.3.1 Pay-Back Period Approach

This method is a crude measure of returns to

R & D. However, despite its crudeness, Mansfield noted in 1968 that it was all that was available on a wide-spread scale for R & D in industry.[46] As the name suggests, the application of this method leads one to choose that project which recovers its investment in R & D in the shortest period. In this method, the expected annual costs of the project are calculated and subtracted from the expected cash flows of the project to obtain a net cash flow. The costs to be subtracted from the cash flows include all research, development and other investment costs. Once the un-discounted net cash flow has been determined the pay-back period is determined by dividing the cumulative R & D expenditures into the cumulative net cash flow. The R & D expenditures and the net cash flow may or may not be discounted by an appropriate discount rate before dividing.

The main difficulty with this method (whether discounted or not) is that it ignores the benefits accruing after the pay-back period has been realised. Thus a bias exists against long-lived projects having a low initial yield of benefits which gradually rise to a maximum.

2.3.2 Scoring Models:

Scoring models are fairly straightforward procedures used in the choice of a research portfolio.

Key evaluators, usually scientists themselves and other informed people, are called upon to express their evaluation of a given number of research projects. The evaluations are based on the potential contribution of each research project to a pre-specified goal or set of goals. The evaluations are expressed numerically. Where more than one goal is involved, the same or other evaluators have to establish a weighting scheme for the goals, that is, they will have to establish numerically the relative importance of each goal to society. Complementary goals can be reduced to one goal.

The models we shall review here are a simple generalised basic scoring model and those developed by Iowa State University, North Carolina Experimental Research Station and the US National Association of State Universities and Land Grant Colleges with the US Department of Agriculture (NASULGC-USDA).

a) A Basic (Generalised) Scoring Model:

The basic scoring model described here has been suggested by Frederick M. Scherer.[47] The proposed procedure is as follows. A panel of experts is selected and each expert is asked to rank through a paired comparison technique a large number of proposed R & D programmes. For each programme pair (there are n!/(n-2)!2! pairs for n R&D programmes) an expert is asked to select the programme which offers the greater long-term net benefits or value, taking into account the programmes' expected operational functions, the probable costs of executing those functions and the alternative means of accomplishing those functions. Factual information on the status and plans for each project are provided to the experts to be studied before the rankings are attempted.

By rank correlation methods the paired comparisons made by individual panelists can be aggregated to give an overall ranking of programmes from most valuable to least valuable.

Alternatively, the choices of individual panelists can also be aggregated by means of "scaling factors" into a group consensus ranking. For any given programme A the scaling factor is defined as:

$$\frac{\text{Number of time A is chosen over other programmes}}{\text{Total number of choices involving A}}$$

The scaling factor can vary from 0 (no choices in which A is preferred) to 1 (A is preferred in every choice). The programme with the highest scaling factor is assigned the highest rank and so on.

It may also be possible to go further than the group consensus ranking with the scaling factors: Suppose in the set of research programmes to be evaluated we include a subset of programmes whose benefits are known and quantified. It may be possible to exploit this information as follows to estimate the benefits of the rest of the programmes in the set whose actual benefits are not known:

Let F_i be the scaling factor for the i^{th} programme belonging to the subset for which benefit estimates are known. Let B_i be the benefit for that programme. Then by least square regression of the form:

$$B_i = f(F_i) + U_i,$$

we can obtain an estimate of the relationship between the scaling factors and the benefit estimates. The specification of the relationship would have to be established empirically although on a prior basis, B should be monotonically increasing with F. The equation is used to obtain benefits for the programmes for which we have only scaling factors.

This suggested scoring model is subject to the shortcomings of scoring models, a critique of which is given at the end of the discussion of scoring models. However, it is less labour intensive than the other scoring models to be described and incorporates a simple but ingenious way of estimating programme benefits indirectly.

b) <u>The Iowa Model</u>

Schuh and Tollini have reported a scoring l that was set up at Iowa State University in the A.[48] The primary purpose of the Iowa model was nsure the greatest return for the research expendi-s at the experimental station. In addition, how-, an increase in the value of research output was cted due to better evaluation and selection of ects and an increase in resources for research due n improved ability to demonstrate their efficient

The steps followed were first to get all the nistration and department heads together to set s. They decided on the goals of growth, equity security. Then the research was divided into e major areas, namely, commodity research, resource arch and agricultural management research. These s were divided into a total of 19 sub-areas and nel assigned to each.

The panels were asked to identify research rnatives within each area. Each panel member was ired to present a list of research projects that is opinion would represent a significant contri-on to knowledge and to the goals of growth, defined alue of resources saved and value of increased out- The panel then consolidated these individual ons into a list of suggested research activities. dition, for each alternative research project suggested by the panel, an estimate of the cost in science man-years and other supporting costs were estimated.

The lists of suggested research activities were then presented to another panel which evaluated these in terms of equity. This procedure was then repeated in order to take security into account.

Finally, a scoring procedure was used based on 10 criteria. Each project was given a grade on a given scale according to its contribution to growth, then to equity and to security. Uncertainty could be included by use of sensitivity analysis.

The Iowa model can be represented algebraically as follows:-

$$C_j = \Sigma^{i} W_i C_{ij}$$

where C_j = cost of given project $_j$

C_{ij} = input of resource i for project j

W_i = weighting factor for the input (price of the input)

<u>and</u>

$$Gj = \Sigma^{k} W_k g_{kj}$$

where Gj = growth contribution of the project j

g_{kj} = contribution of the project j to growth aspect k (resources saved, increase in output)

W_k = weighting factor representing relative importance of each growth aspect considered

<u>and</u>

$$E_j = \overset{h}{\Sigma} W_h e_{hj}$$

where E_j = contribution of the project j to the equity objectives

e_{hj} = contribution of the project j to equity aspect h (absolute and relative equity)

W_h = weighting factor representing the relative importance of each equity aspect considered.

<u>and</u>

$$S_j = \overset{r}{\Sigma} W_r s_{rj}$$

where S_j = contribution of the project j to security objectives.

s_{rj} = contribution of the project j to security aspect r (security of person, property, consumer health, nutrition, resource depletion, etc.)

W_r = weighting factor representing

the relative importance of each security aspect considered.

Then we have:

$$B_j = W^1G_j + W^2E_j + W^3S_j$$

where B_j = contribution of project j to overall goal of growth, equity and security

$W^t, t = 1,2,3,$ = weighting factors representing the relative importance of the goals of growth, equity and security.

(Note: B_j could also be defined in a multiplicative or an additive way).

Panel members as individuals and as a group had to define and provide estimates for c_{ij}, g_{kj}, e_{hj}, sr_j, W_i, W_k, W_h, W_r, and W^t.

Then C_j, G_j, E_j, S_j, and B_j were computed for each project as outlined above.

Then the growth-cost ratios G_j/C_j, equity-cost Ratios E_j/C_j and security-cost ratios S_j/C_j are computed for each project.

The total cost-effectiveness for each project is computed as B_j/C_j.

c) The NASULGC - USDA Model

In 1966, the US National Association of State Universities and Land Grant Colleges and the US Department of Agriculture (NASULGC - USDA) published the results of a study of agricultural and forestry research programmes in the USA.[49,50]

A task force classified research into three major headings and several subheadings. To each subheading a review panel was assigned consisting of people from the Universities, Government, private research organisations, producer groups, industry and members from the original group responsible for the study. The panels went into details of each sub-area, and evaluated the strengths and weaknesses in the sub-area, identified future research problems and recommended a level of public research investments for the next few years. A simple scoring model was used to determine the extent to which each research problem area met certain criteria which were numerically weighted according to mportance.

This model was used both for the evaluation of research and for developing an information storage and retrieval system. A major result of the study was the systematic classification of research areas that is used in the Current Research Information System (CRIS) of the USA Department of Agriculture.

d) <u>The North Carolina Agricultural Experimental Station Model</u>

Shumway and McCracken have reported on a model used at the North Carolina Agricultural Experimental Station in the USA to determine how much emphasis should be placed on each research problem area as defined by the CRIS classification of the USDA mentioned above.[51] A summary of the procedures used has been presented by Schuh and Tollini.[52]

The procedure involved 20 groups of interdisciplinary research and extension personnel plus 18 groups of external scientists and 23 academic departments. Groups of administrators from the experimental stations were also involved. The interdisciplinary teams of researchers and extension workers were allocated the following four research problem areas:- biological sciences and technology, animal and plants, environment and natural resources and food-fiber-people-economics. They reviewed the entire research programme and prepared recommendations on how and when human and monetary resources should be allocated. Then they rated each of their recommendations according to weighted criteria developed under NASULGC-USDA such as the extent to which research met state, experimental station, department and national goals; the urgency of the problem; cost; relevance; likelihood that research results would not be available elsewhere and potential contribution to knowledge.

Then the recommendations of the interdisciplinary teams were submitted to several smaller groups of the external scientists. After reviewing these recommendations the external groups of scientists developed their own set of recommendations for resource allocations within the research programme and rated the recommendations of the in-house teams. The recommendations of the interdisciplinary in-house teams were finally rated according to the criteria discussed above by each member of three groups; in-house scientists, external scientists and department heads. Scores for each research area were then computed by an algebraic formula, averaging over the criteria all the partial scores attributed to the recommended increase in resources in a given area. Weights representing the relative importance of each criteria were used to arrive at a weighted score. These scores represented the evaluation of individual scientists and administrators of the importance of the research area. The average score was computed for each research area. This average score was a numerical expression of the average opinion of in-house and external scientists, plus administrators, with respect to the relative worth of each research area, given the criteria that were developed independently.

Shumway and McCracken have noted that the major fault with the North Carolina model was that there was little consensus within or among groups of scorers because less attention had been given to setting goals precisely than with the Iowa Model.[53] Consequently, each scorer could have a different idea about the goals of the experimental station, the departments and the country.

A Critique of Scoring Models

Scoring models are very flexible not only with respect to the number of goals but also with respect to the type of goals considered. They have the advantage of forcing all people involved to spell out formally what they think each research effort will contribute to given goals while at the same time taking into account some restrictions. They thus pool information from a large number of experts. They also have the advantage of incorporating benefits that are difficult to quantify by most other procedures. Norton and Davis also note that although this has not been done in the past, theoretical shadow prices could be developed from the results which measure the opportunity cost of selecting one research area over another.[54]

However, although scoring models are conceptually simple, they are labour intensive. They require frequent meetings of a large number of people for whom the opportunity cost of time could be very high.

The scoring models will run into trouble if any of the following phenomena emerge:-

1. If the ranking of the subset of programmes for which benefits are known (in the case of the generalised scoring model discussed above) disagrees significantly with the ranking of the same programmes obtained by paired comparisons.

2. If there is significant evidence of intransitivity in the individual panelists' paired comparisons, that is, if panelists frequently indicate that A is better than B, B is better than C, but C is better than A. (This is also called the Arrow problem, named after the economist Kenneth Arrow).

3. If there is little agreement among the various panelists on the rankings of different programmes.

Pooling of a large number of people's opinion together may also do little more than pooling ignorance together if the panelists are not well selected according to the subject to be evaluated. Schuh and Tollini have noted that a question might arise as to whether the scoring models require too much guessing.[55] They note that the answer is probably yes, but they can be informed guesses, which tend to improve with repeated trials. A second question which they raise is whether this approach is better than no model at all. Again, their answer is probably yes, so long as scientists and decision-makers work together to improve it.

2.3.3 <u>Ex-Ante Cost-Benefit Analysis</u>

Several studies have evaluated returns to proposed agricultural research by calculating rates of return or cost-benefit ratios. These studies are analogous to the consumer-producer <u>ex-post</u> studies described earlier. However, the <u>ex-ante</u> studies have tended to focus on specific projects while <u>ex-post</u> studies have been more macro oriented.

Due to the stochastic nature of research results, it is difficult to predict the pay-off of research projects. Therefore one of the major differences among <u>ex-ante</u> cost-benefit studies is the manner in which costs and benefits are projected, as exemplified in the models described below:-

a) <u>The Minnesota (MARRAIS) Model</u>

This is a computerised model for collecting and processing information needed to evaluate research activities and select an efficient allocation of resources. The model called MARRAIS (Minnesota Agricultural Research Resources Allocation Information System) has been summarised by Schuh and Tollini.[56] It takes into account many of the uncertainties involved in the prediction of costs and benefits in research. Three major steps are involved in MARRAIS: Specification, estimation and analysis. A fourth step would be the selection of the research portfolio, but this is left to the decision-maker.

In the specification phase, the alternative research projects to be analysed and evaluated are defined under lines of administrative responsibility. In addition, the form of the research results and unit of measurement of these results is identified at this stage. MARRAIS uses percentages of total objective achievement as the unit of measurement. This is to take account of the fact that benefits may be derived from research efforts that do not fulfill their objectives. The source or persons to provide estimates is also identified at this stage.

The second phase is estimation. Basic estimation involves calculation of either present values of benefit-cost ratios and benefit minus costs or internal rates of return. All the estimates are made under alternative levels of average annual expenditures and expected time to complete the projects. MARRAIS recognises that a lot of uncertainties affect the discounted value of costs and benefits so that these are taken as stochastic variables with given probability distributions. Assuming 100% eventual adoption of the research results, the discounted benefits are taken to depend on the adoption patterns over time, the residual value of the research facilities at the end of the project and the so-called "process" value of research i.e. the increase in the value of participating scientists plus increased human capital from graduate training involved in the research effort. The discounted costs are hypothesized to depend on the average annual expenditure on research, the maximum annual expenditure on dissemination costs of research results and the time path of dissemination costs of research starting one period after the project is completed. The adoption patterns and the path of dissemination are functions of time.

To obtain the information needed, survey questionnaires are sent to several scientists in the field of study to provide estimates of average annual expenditures, time requirements and technical feasibility. Given the average annual expenditure on a project, groups of experts estimate the probability of the project being completed in alternative periods of time. Then, with the estimates of the mean time to complete the project and the average annual expenditure on the project, benefits are estimated. This results in a probability distribution of benefits from the project, funded at a given level of annual expenditure and given the mean expected time for completion. The probability distribution of benefits is weighted by the probability distribution of technical feasibility for each project and funding level. By a random sampling from the distributions of the stochastic variables involved plus single-value estimates of the non-stochastic variables, estimates are made of the distributions of the differences between costs and benefits, the cost-benefit ratios and of the internal rates of return.

It should be noted that the above mentioned distributions of costs and benefits generated for alternative levels of annual expenditure are subjective. However, this offers a good potential for sensitivity analysis in MARRAIS. Although MARRAIS is a well thought out and logical multi-dimensional ranking method that takes into account many of the uncertainties involved in the prediction of costs and benefits in research, Newton and Davis note that its complexity may lead to high costs in terms of time and effort than simpler methods.

b) de Castro and Schuh Model

de Castro and Schuh presented a model which

focused on the growth and distributional effects of technical change as well as the direct and indirect effects of research in Brazil.[57] They set four goals for the research programme, namely:-
to increase the net income of the agricultural sector, to increase employment and the income of workers in the agricultural sector, to increase consumer welfare through lower real food prices and to maximise the contribution of the agricultural sector to the growth of the overall economy.

They assumed a shift in the supply curve due to technological change for various crops and compared distributional effects on consumers and producers which resulted from the demand and supply elasticities. They looked at the trends in factor scarcity and the direction that research should take. They discussed the effects of technological change in the agricultural sector on the non-agricultural sector and the effects of economic policies on the social benefits and costs of research programmes.

The de Castro and Schuh model is not a formal mathematical model although it could be used as a starting point to build such a mathematical model. The important point to note is its focus on both the growth and distributional effects of technological change, and both the direct and indirect effects of research. The explicit consideration of distribution of benefits and losses between producers and consumers is a desirable character of this model. Also important is the follow-up of the effects and reactions of technological change in the agricultural sector into the non-agricultural sector.

Unlike the scoring models and other more complicated models, the de Castro and Schuh model minimises the burden on scientists and administrators in terms of the information necessary and in terms of the amount of difficult estimates and/or informed guesses required. The model depends primarily on secondary data and the burden of analysis rests with the analysts.

c) <u>The Easter and Norton Model and Others</u>

Schuh and Tollini have reported another <u>ex-ante</u> cost-benefit analysis by Easter and Norton.[58] Taking a somewhat different approach, Easter and Norton used estimates provided by scientists on the effect on costs and yield of different research lines and on the expected rate of adoption of new technologies and then applied cost-benefit analysis to research in maize and soya beans in the North Central region of the U.S.A. A 10% discount rate was used, harvested acreage was assumed constant and a specific set of prices was assumed. Product quality was also assumed unchanged or, if improving, not affecting the cost of livestock. Benefits were estimated for a 25 year period, ending in the year 2000.

An important aspect of the analysis was the sensitivity of the cost-benefit ratios to variations in the probabilities of success, the expected yield increases, the product prices and the length of the lags between research expenditures and the availability of the results to the farmers. These results provide decision makers with information on the relative importance of added precision in the estimation of the variables involved in the evaluation. Effects of the prices received by farmers, meat prices and the prices of fats and oils were estimated by making use of impact multipliers from another study. The effects on consumer surplus and gross farm income were then estimated.

Araji, Sim and Gardner carried out a similar type of analysis to evaluate research and extension programmes in sheep, fruits, vegetables, potatoes, cotton and rice in 1977 in the Western region of the U.S.A.[59] Personal interviews were conducted with agricultural researchers and extension scientists to determine initiation and termination dates of research projects, the probability of research success, the probability and rate of adoption of research results with and without extension and the resources required to implement and maintain new technology.

The yield, quality, cost and production changes resulting from the new technology were estimated, as were the flow of benefits and costs, the cost-benefit ratios and the internal rates of return from each research project. They also estimated the reduction in productivity that would result from eliminating maintainance research and they used different ratios derived from demand elasticities to determine the effects on prices and consumer expenditures for the commodities.

Another study reported by Norton and Davis was conducted by Eddleman and attempted to measure the secondary impacts of an increase in agricultural productivity on other aspects of the USA economy.[60] Eddleman made use of the multipliers from a national input-output analysis. Gross benefits were measured as changes in other sectors' output resulting from increased output in the agricultural sector. Net benefits were estimated as net wages resulting from expanded employment in each of the sectors plus net profit gains in each of the sectors.

Other ex-ante cost/benefit studies reported by Norton and Davis are studies conducted by Araji and Sparks for potato research in Idaho and by Barker for rice research in South and South-east Asia.[61] The latter study compared benefits for different types of environments under which rice is grown.

2.3.4 Simulation and Mathematical Programming Models

A number of researchers have constructed simulation and mathematical programming models for agricultural research evaluation. Simulation and mathematical programming lend themselves to a wide range of formulations. The MARRAIS model described previously could be described under this section. The Pinstrup-Andersen and Franklin model described here below is in a sense a formalised version of the de Castro and Schuh model described above with the former being much larger and more comprehensive, with subsystems for the demand side in terms of matrices of elasticities, etc.

a) The Pinstrup-Andersen and Franklin Model

These researchers described the basic components of a simulation model to assist in helping to predict the relative contributions and costs of alternative research activities in order to establish priorities and allocate research resources.[62] The model was developed in connection with the allocation of research resources in developing countries. A summary of the model has also been presented by Schuh and Tollini.[63]

There are seven stages involved in this model. The first step required is to establish overall goals. The second is an identification of changes in product supply, input demand and farm consumption necessary to achieve those goals. This is followed by identification of research problems and then identification of alternative technologies to solve the problems. The fifth step is to estimate the time, costs, and probabilities involved in research and farm adoption of the alternative technologies. This is followed by estimation of effects of alternatives on farm consumption, product demand and in-put supply. Finally, the technology to be developed and the scientists' working objectives are specified.

Pinstrup-Andersen and Franklin argue that after the identification of the changes in product supply, input demand and farm consumption necessary to attain the development goals, the identification of the research problems should be made independently of the alternative technologies that can contribute to the solution of the problem. They call this a "technology-free" specification of the problem since it does not presume _ex-ante_ a particular technological solution to the problem. This is an important aspect of the definition of the problem which draws attention for one not to jump from farm problem identification to research problem definition in terms of required technology without a careful evaluation of all technological possibilities available.

After the identification of the problems in a "technology-free" manner and of the alternative technologies available to solve each problem, it is necessary to estimate the time, costs and probabilities involved in research and in farm adoption for each alternative technology. The next step is to estimate the impact of research alternatives on farm consumption, product supply and input demand. These estimates are used to obtain an evaluation of the contribution of the alternative research approaches to the achievement of the stated development goals. This leads to a specification of the working objectives for the research and of the desired technology.

This approach tries to relate specific research problems to overall aspects of growth, equity and security through consideration of variables such as income distribution, nutrition, demand for labour and other services, farm consumption, capital formation, supplies and demands, net revenues, risk, etc. Its representation by mathematical equations is therefore not simple; an extensive amount of data is required and a number of mathematical relationships must be estimated. In view of this and given the paucity of data in developing countries, the model may not be applicable in many of these countries. However, it is a useful guide to the kind of information useful to the problem of research resources allocation. Indeed Schuh and Tollini note that some promising empirical results have been obtained with the model and add that it deserves further testing and development.[64]

b) <u>The Scobie Model</u>

Scobie developed a simulation model needed to determine the optimal level of investment in agricultural research.[65] His model included a production function, supply and demand function and a discounted cash flow analysis. In the absence of research, output was assumed to grow at a given minimum rate. As investment in research increased, the growth rate of output would increase but at a diminishing rate and become asymptotic to some maximum growth rate. Assumptions were also made about the length of the lag period following research before output would be realized and forms of the supply and demand equations. Several of the assumptions or parameters were varied and an estimation was made of annual levels of research investments that would generate various internal rates of return.

c) Other Simulation/Mathematical Programming Models

The relationship between research and extension expenditures and agricultural productivity growth were examined by Lu, Quance and Liu by use of the research and extension expenditures as the principle decision variable in a simulation model.[66] Productivity changes were attributed to lagged values of public agricultural research and extension investments, changes in farmers' education and the weather. Several coefficients in the model came from a previous similar model by Cline and Lu. They used the model to project agricultural productivity growth under three alternative research and extension investments growth rate scenarios and also to project growth due to a few specific new technologies. They also estimated cost-benefit ratios and internal rates of returns to the research and extension expenditures.

White, Havlicek and Otto analyzed investment patterns for agricultural research and extension that would result in optimal agricultural productivity growth.[67] They first estimated the effects on aggregate USA agricultural productivity in a manner similar to that of Lu, Quance and Liu. They then determined an optimal level and time path of research expenditures to attain a certain rate of increase in farm prices under selected conditions. They also examined the effects of a reduction in agricultural research funding including its net impact on consumer costs, that is, increased expenditures for food minus savings in taxes for funding the research.

Kislev and Rabiner built a simulation model of a breeding programme for increased milk production for Israel.[68] They defined an ideal breeding model and attempted to explain the gap between progress made in the actual breeding programme and the ideal system. They incorporated in the model principles of quantitative genetics and identified and quantified decision variables and natural constraints which limit the effectiveness of the selection process. This information is useful for ex-ante evaluation because it provides a guide as to which factors are most constraining in the research process. Also, to the extent that one can identify physical laws of nature governing the rate of technological change, the confidence in the projections made is improved.

Other simulation and mathematical programming models have been used by Knutson and Tweeten[69], Cartwright,[70] Atkinson and Bobis[71] and Russel[72]. In 1972, Souder estimated that more than one hundred models of research resource allocation had been built and that simulation procedures were an important component of many of these models.[73]

A Note on Simulation and Mathematical Programming Models

Simulation and mathematical programming models have the advantage of being flexible. They can be used to estimate optimal levels of research at the national, commodity or programme level. They can be used to determine the effects of research on prices, income, employment or the economic parameters involved.

However, much information and time is required to build these models and for this reason they have received more widespread use as an aid to research evaluation in the private industrial sector than for public agricultural research evaluation. Likewise, for the same reasons connected with data and skilled labour requirements, the models may not be appropriate for a large number of developing countries. However, some interesting and promising results have been obtained with these models and there is great potential for their improvement and future use.

2.4 Concluding Remarks on the Methods of Evaluating R & D

The evaluation of agricultural research presents the evaluator with a wide range of alternative approaches and methods. The literature indicates that the consumer-producer surplus approach, the production function and the ex-ante cost/benefit analysis have received the most widespread use in agricultural research evaluation.

A comparison of the major agricultural research evaluation techniques is given in Table 2.1. A look at the table indicates why the above three approaches have been used most.

The method chosen to evaluate R&D should depend on the availability of appropriate data. Often simple approaches which are less demanding in terms of data are more useful than more complicated procedures which have to be based on more precarious data.

The various ex-ante approaches are more appropriate in establishing priorities. Their advantage is that they provide a formal means of pooled and informed (presumably) judgement. These methods which depend on pooled judgement should be complemented as much as possible by hard data and historical studies.

The use of scoring and other ex-ante methods can be very demanding of highly qualified people: hence the use of such procedures should be used when initiating new programmes or following long intervals, or if not so, they must be substantially scaled down to simple procedures.

The various methods which attempt to use

Table 2.1: Comparison Among Major Agricultural Research Evaluation Techniques

Characteristic	Ex Post Techniques*		Ex Ante Techniques*			
	CS	PF	SM	BC	SI	MP
1. Requires explicit elicitation of goals.	no	no	usually	no	no	yes
2. Can determine distributional effects on consumers and producers at various income levels.	yes	no	no	yes	yes	no
3. Can determine effects on relative productivity of input categories.	no	yes	no	no	yes	no
4. Can consider secondary impacts of research on employment, environment, nutrition.	some	no	yes	some	yes	no
5. Can consider trade off among goals.	no	no	yes	no	yes	yes
6. Can consider economic policy and trade effects	yes	yes	yes	yes	yes	yes
7. Relative cost in researcher's time.	low	interm.	interm.	low	high	interm.
8. Relative cost in scientist's time.	low	low	high	interm.	interm.	interm.
9. Relative cost in administrator's time.	low	low	high	low	low	interm.
10. Relative data requirement.	low	high	low	low	variable	interm.
11. Can consider value of maintenance research.	yes	no	no	yes	yes	no
12. Can evaluate benefits to "aggregate" research.	yes	yes	no	yes	yes	no
13. Can evaluate benefits to "commodity" research.	yes	yes	yes	yes	yes	yes
14. Can evaluate benefits to research projects or program.	yes	no	yes	yes	yes	yes
15. Can evaluate benefits to "non-production" or "non-commodity" oriented research.	In some cases	no	yes	In some cases	In some cases	yes
16. Can provide ranking or research projects based on multiple goals.	no	no	yes	no	no	yes
17. Can handle uncertainty.	with sensitivity analysis	with difficulty	yes	yes	yes	yes
18. Can consider the lags involved in research and adoption.	yes	yes	yes	yes	yes	yes

Characteristic	Ex Post Techniques*		Ex Ante Techniques*			
	CS	PF	SM	BC	SI	MP
19. Can quantify public sector-private sector interaction.	no	no	no	no	no	no
20. Can quantify research-extension interaction.	no	some	no	no	some	no
21. Can quantify spillover effects.	no	yes	no	no	yes	no
22. Usually estimates marginal rate of return.	no	yes	no	no	some-times	no
23. Usually estimates average rate of return.	yes	no	no	yes	some-times	no
24. Calculates return while statistically holding non-research inputs constant.	no	yes	no	no	some-times	no
25. Usually require computer	no	yes	no	no	yes	yes
26. Can help identify or quantify factors most effecting progress in given research line.	no	no	yes	yes	yes	no
27. Can be used to evaluate basic research	no	some	some	no	some	no

*CS = Consumer-producer surplus approach; PF = production function approach, SM = scoring model approach, BC = *ex ante* benefit-cost approach; SI = simulation model approach; MP = mathematical programming approach.

Source: Norton, G.W. and J.S. Davis, 1981. "Review of Methods Used to Evaluate Returns to Agricultural Research". In G.W. Norton et al (eds.) Evaluation of Agricultural Research. Miscellaneous Publication No.8. University of Minnesota Agricultural Experiment Station. p.41.

historical data are best used in an attempt to understand the process of technical change and thereby provide guidance for improved policy making. The past can be a guide to the future and cost-benefit analyses and estimates of the social returns can indicate to the policy maker whether or not there has been an under or over-investment in R & D. Nevertheless, the future can be very different from the past. This is particularly so in R & D where the production function can change drastically in an "instant" or over time. Care should therefore be taken in extrapolating to an uncertain future. Thus uncertainty and the specification of the form of the production function are very important elements in R & D. While the models described can handle uncertainty in various ways, more research is indicated in the area of specification of the production functions in R & D.

Footnotes to Chapter Two

1. Schuh and Tollini, 1979, p.10.

2. Fishel, 1981. p.16

3. Schultz, 1953.

4. Schuh and Tollini, 1979, p. 25.

5. *ibid.*, pp. 26-33.

6. Norton and Davis, 1981. pp. 27-33.

7. Griliches, 1958. pp 419-31.

8. Peterson, 1967. pp 656-69.

9. Hertford and Schmitz, 1977, pp 148-67.

10. Schmitz and Seckler, 1970. pp 569-78.

11. Ayer and Schuh, 1972. pp 557-69.

12. Akino and Hayami, 1975. pp 1-10.

13. Scobie and Posada, 1978. pp 85-91.

14. Duncan, 1971. Cited in Norton and Davis, 1981 p. 30.

15. Norton and Davis, 1981. p. 30.

16. Kislev and Hoffman, 1978. pp 166-81.

17. Lindner and Jarret, 1978. pp 48-56.

18. Rose, 1980. pp. 834-37.

19. Wise and Fell, 1980. pp. 838-40.

20. Akino and Hayami, 1975. *op. cit*.

21. Scobie, 1976. Cited in Norton and Davis 1981. p. 32.

22. Duncan and Tisdell, 1971. Cited in Norton and Davis, 1981. p. 32.

23. Lindner and Jarret, 1978. pp 48-56

24. Norton and Davis, 1981. p. 32.

25. Griliches, 1964. pp 961-74.

26. Evenson, 1967. pp 1415-25.

27. Fishelson, 1971. pp 129-31.

28. Cline, 1975. Cited in Norton and Davis, 1981. p. 34.

29. Norton and Davis, 1981. p.34.

30. Griliches, 1964. op. cit.

31. Kahlon, et al, 1977. pp 124-47.

32. Bredahl and Peterson, 1976. pp 684-92.

33. Evenson, 1967. op. cit.

34. Kahlon, et al, 1977. op. cit.

35. Bredahl and Peterson, 1976. op. cit.

36. Cline, 1975. op. cit.

37. Evenson and Kislev, 1975. pp 58-77.

38. Schuh and Tollini, 1979. p. 34.

39. Heertje, 1977.

40. Mansfield, 1969. p. 170.

41. Andrews, 1979. p. 13.

42. Kahlon, et al, 1977. op. cit.

43. Tweeten and Hines, 1965. pp 40-45 Cited in Schuh and Tollini, 1979, p 34-35.

44. Pinstrup-Andersen, et al, 1976, pp 131-42.

45. Cetron and Johnson, 1971. Cited in Schuh and Tollini, 1979. p.36.

46. Mansfield, 1969. p. 169.

47. Scherer, 1965.

48. Schuh and Tollini, 1979. pp 38-40.

49. Norton and Davis, 1981. p. 36

50. Schuh and Tollini, 1979. pp. 41-43.

51. Shumway and McCraken, 1975. pp 714-18.

52. Schuh and Tollini, 1979. p. 40-41.

53. Schumway and McCraken, 1975. *op. cit*.

54. Norton and Davis, 1981. p. 36.

55. Schuh and Tollini, 1979. p. 53.

56. *ibid*., p. 43-44.

57. de Castro and Schuh, 1977. pp 478-97.

58. Schuh and Tollini, 1979. p. 49

59. Araji et al. 1978. pp 964-68.

60. Eddleman, 1977. Cited in Norton and Davis, 1981. p. 37.

61. Norton and Davis, 1981. p. 37.

62. Pinstrup-Andersen and Franklin, 1977 pp 416-35.

63. Schuh and Tollini, 1979. pp 44-46.

64. *ibid*. p. 46.

65. Scobie, 1979. pp 33-45.

66. Lu et al, 1978. pp 976-80.

67. White et al., 1978. Cited in Norton and Davis, 1981. p. 38.

68. Kislev and Rabiner, 1979. Cited in Norton and Davis, 1981. p. 38.

69. Knutson and Tweeten, 1979. pp 70-76.

70. Cartwright, 1971. Cited in Schuh and Tollini, 1979. pp 46-47.

71. Atkinson and Bobis, 1969. Cited in Schuh and Tollini, 1979. pp 50-52.

72. Russel, 1977. Cited in Norton and Davis, 1981. p. 39

73. Souder, 1972. Cited in Schuh and Tollini, 1979. p. 50.

CHAPTER THREE

SPECIFIC PROBLEMS INVOLVED IN EVALUATING R&D

3.1 Definition of Research and Development (R&D)

According to UNESCO, Research and Development (R&D) is defined as any creative systematic activity undertaken to increase the stock of scientific and technical knowledge and to devise new applications.[1] It includes three categories, namely, basic or fundamental research, applied research and experimental development work leading to new devices, products or processes. It excludes scientific and technical information, general purpose data collection, routine testing, standardisation and other technological activities related to production or use of established products or processes, as well as large-scale mineral and petroleum prospecting for exploitable deposits and not essentially for basic geological knowledge. In social sciences, it includes activities of a research nature related to the solution of economic or social problems, but excludes routine activities such as censuses, routine surveys, etc. In general, the criterion which disguishes R&D from non-R&D activities is the presence or absence of an appreciable element of novelty or innovation.

More specifically, the definitions of the three categories of R & D are as follows:

<u>Fundamental or basic research</u>: Any activity directed towards the increase of scientific knowledge or discovery of new fields of investigation without any specific practical objective.

<u>Applied research</u>: Any activity directed towards the increase of scientific knowledge but with a specific practical aim in view.

<u>Experimental development</u>: Systematic use of the results of fundamental and applied research and of empirical knowledge directed towards the introduction of new materials, products, devices, processes and methods, or the improvement of existing ones, including the development of prototypes and pilot plants.

These definitions are important for delineating R&D activities. For example, demonstration projects connected with the testing and evaluation of the applicability of new technologies are included in experimental development and therefore in R&D. It should also be noted that, in real life, as far as the categorisation of R&D activities is concerned, these activities do not necessarily fall into such sequential and distinct categories. The three types of activities may sometimes be carried out in the same centre by the same staff. Moreover, there may be movement in both directions. When an R&D project is at the applied research/development stage, for example, some funds may have to be spent on additional basic research that is needed before further progress can be made.

3.2 Definition of Outputs of R&D

In principle, the research process can be viewed just as any other production process. Inputs of various kinds are combined in particular ways to produce output. However, there arises a problem in knowing how to define the output. Because of the difficulties of measuring output, researchers attempting to evaluate research have used a number of different surrogates for the output of the research process. One of the most recent attempt was made by a UNESCO International Research Team composed of a group of investigators.[2] The Team analysed data from different types of institutions in both the private and the public sector, covering ten scientific fields, including agricultural sciences. Through various analyses, the Team came out with the following fairly orthogonal (but not totally unrelated) quantitative and qualitative measures of a research output and its effectiveness:

Output Measures: (The figures in brackets are weights).

(a) Published written output, represented by:

number of books published in the country (4)

Number of articles published abroad (3)

number of articles published within the country (2)

number of published reviews and bibliographies (1)

(b) Patents, prototypes, represented by:

number of patents abroad (4)

number of patents within the country (3)

number of prototype devices, instruments, etc (2)

number of experimental materials (1)

(c) Reports and algorithms, represented by:

number of internal reports on orginal R&D work (2.5)

~~number of algorithms~~ (2.5)

number of routine reports (1)

Effectiveness Measures:

(a) General contribution:

general contribution to science and technology

(b) Recognition accorded to the research group:

international reputation of the research group

demand of the project's publications and research materials

(c) Social effectiveness of the project:

social value of the project's work

usefulness of the project's work

(d) Training effectiveness of the project:

training effectiveness

(e) Administrative effectiveness of the project:

success in meeting schedules

success in staying within budgets

(f) R&D effectiveness of the project:

productiveness

innovativeness

R&D effectiveness

(g) Application effectiveness of the project (or extent of application):

application of research results

use made of development activities

These effectiveness measures are mainly subjective. They are computed from different types of questionnaires specially designed to be answered by the research head, the staff scientists and external evaluators.

The relationships of the UNESCO R&D performance measures are exhibited in Appendix 3.1 where it can be seen that many of them are orthogonal.

We make the following comments about the UNESCO R&D performance measures:

(a) They probably represent the most comprehensive measures developed for R&D.

(b) All the measures are not necessarily applicable, depending on the nature and goals of R&D being evaluated. For example, public agricultural R&D is usually not in the business of producing patents. The number of published articles is also a dubious measure for many developing countries (LDCs) in view of the limited outlets available to LDCs for article publication.

(c) The most commonly used output in R&D, that is increase in yield, is here measured in subjective terms such as general contribution of the project, R&D effectiveness and applications effectiveness. Externalities are also measured within these subjective terms.

(d) Being mainly subjective, these measures lend themselves best to the cost-effectiveness and social approach to project evaluation.

(e) Despite their comprehensiveness, these measures do not take into account the quality aspect of output, although the subjective measures might help in this regard. For example, "a report is taken as equal to a report". The problem of quality is however, a special problem in the measurement of R&D output whether on a quantitative or qualitative basis. The problem becomes more pronounced if we want to measure the quality and applicability of the knowledge generated by the project. For example, there are many research stations which produce a copious amount of paperwork in the form of annual reports and other types of reports, but the quality of the work reported in some of these reports may be questionable.

(f) The usefulness of the above measures is that they give a rich array of output measures from which to choose, even if one does not use the cost-effectiveness approach for which they are best suited. However, the vast majority of researchers evaluating agricultural R&D, particularly of the biological type, have used increase in yields as the measure of output of R&D and the rest of the benefits are described. Some researchers have used the number of publications in journals; others have used the number of patents generated, these being applied in industrial projects more than in other types of R&D. All these measures have their shortcomings, but we shall focus more closely on the use of yield as we intend to use this as our main measure of the output of the case study.

When yield is used to define the output of R&D there are important questions which arise. First, there is the question about the fact that, in addition to R&D, a number of factors such as rainfall, fertilizers, capital investments and total cropped area determine the yield. Therefore the total yield increase cannot be merely ascribed to R&D without identifying the share of the other factors. This problem has been dealt with in Chapter Two.

Secondly there is the problem of "negative results". Here we want to know how to handle the case whereby knowledge is generated which eliminates infeasible alternatives but does not attain the original explicit objective of the project, for example, increasing yield. This is a definite advance in knowledge and must be counted as a benefit of the research project. Further discussion of this problem is undertaken in section 3.9.5 below where we conclude that a cost-effectiveness/cost-minimisation approach would be best for this problem.

Thirdly we are also concerned with the quality change of products such as nutritional or keeping quality of the product. If such aspects cannot be quantified and internalised, they must be described to qualify the assessment by yield. Such issues relate to the side effects of technological change which are discussed in Section 3.9 below.

Fourthly, the effects of diffusion on the application of the R&D results, and therefore success of the R&D project, must be taken into account. This is discussed in Section 3.6 below.

3.3 Definition and Measurement of Inputs and Transferred Technology.

The definition and measurement of most inputs in R&D is straightforward. Such inputs include labour, buildings, fertilizers and pesticides. The major problem arises in the measurement of transfer of technology and in the costing of inputs. In the case of transfer of technology, the difficulty arises in measuring previous R&D and transferred R&D as an input into the R&D programme being evaluated. For example, Schuh and Tollini note that the very successful cotton research programme in Brazil had its start with lines from the USA.[3] Likewise, there was considerable research in the USA and Japan that was drawn on in producing Mexican wheats.[4] To what extent should the cost of production of the transferred R&D be considered in evaluating the cost-benefit ratio in Brazil and Mexico? In the case of Brazil, Schuh and Tollini report that the procedure followed by Ayer and Schuh was to treat the lines as a free good.[5] In another study, Evenson and Kislev included trasferred knowledge as part of the explanatory variables in the R&D production function.[6] The transferred knowledge was measured as the number of articles related to the research programme published by other units outside the research programme in question. These articles were given weight, depending on whether they were nationally or regionally or internationally published. A similar effort has been attempted by Evenson, Flores and Hayami.[7]

Despite such commendable effort to internalise the transferred technology, it still leaves out the consideration of transfer of technology at the researcher to researcher contact level. The "synergism" generated by contact among researchers can produce a considerable amount of input into the R&D process. This synergism could be measured in terms of conferences attended, exchange visits, correspondence between researchers, etc. But, for a practical exercise, such fine tuning in trying to internalise this synergism may not be necessary. One could simply note and describe and treat them as a free good. In any case, if one is measuring the R&D inputs in financial terms, the synergism is, to a certain extent, internalised, assuming that expenses of conferences, exchange visits, etc are included in the budget of the research programme.

In the case of the Wheat Research Programme in Kenya, there has been a considerable amount of technology transfer embodied in expatriate personnel and imported wheat breeding lines. In this case study, a simple procedure of internalising the costs of technology transfer will be followed: The expatriate, conference and other related costs will be taken as part of the normal costs of the Research Programme. In the case of breeding lines of wheat brought into Kenya from other countries, it should be noted that Kenya is part of the International Wheat Rust Testing Centres and the FAO Nurseries and has contributed significantly in terms of the reverse transfer of technology whereby Kenya-bred lines have been used extensively all over the world.[8] In this context, since Kenya is participating in a worldwide exchange of the technology in which she is both at the receiving and giving ends, these transfers will be described and noted but be assumed to cancel one another.

3.4 Ex-ante versus Ex-post evaluations

The issue of ex-post versus ex-ante analysis of R&D has been discussed in Section 2.1 of Chapter

Two where we saw that most analyses of agricultural R&D have been on an ex-post basis and that ex-ante analyses have been mostly applied to industrial R&D projects. We need not repeat the discussion here. Suffice it to say that they are an important consideration in the evaluation of R&D and that whether one chooses to use ex-post or ex-ante evaluations will depend on the objectives of the evaluation as discussed in Chapter Two.

3.5 Technological Decay

Technological decay results from the inability of the techology to maintain the efficiency of production commensurate with the particular type of technology. It is different from obsolescence in that while obsolescence is a relative phenomenon resulting from the introduction of more efficient technologies, decay results from the innate inability of the technology to achieve the objectives for which the technology has been developed.

Technological decay is most prevalent in biological technologies. Examples of technological decay are: increasing resistance of disease organisms and pests to drugs and pesticides, breakdown of plant varietal resistance to diseases such as, in the case of wheat, variety resistance to stem rust.

R&D concerned with maintaining production under very high technological decay has been termed as "maintenance research". Questions have been raised as to whether maintenance R&D should be regarded as true R&D since a lot of routine and repetitive work is involved. However, an application of our definition of R&D shows that this is true R&D, often at the experimental and development stage but also generating basic information to keep ahead of biological change. Indeed, productivity must not only be maintained, it must also be increased. Thus, where most of the work is involved in the mitigation of technological decay, this should by and large be regarded as R&D and evaluated like other R&D projects. However, the routine maintenance of varietal and clonal stocks for seed multiplication purposes should not be included in R&D.

The case of wheat varietal resistance to stem rust illustrates a case where the rate of technological decay is very high. The resistance of a new wheat variety in Kenya breaks down in about four years and this requires a vigilant R&D programme to contain the effect of highly virulent rust strains: To keep ahead of the battle against rust, two new varieties are required to be released each year. In terms of plant breeding programmes, that is a very demanding objective of the wheat research programme. We will see in the case study whether this has been possible.

3.6 Disentangling Research/Diffusion Effects

The problem of defining the output of R&D is tied up with the question of what is successful research. Is success achieved when results which meet the objective are obtained in the laboratory? There are those who would say yes. They argue that the rest is a problem of the diffusion process and the right government processes such as credit, incentives of the right type, extension, appropriate regulations, etc. They also argue that the diffusion process is affected by X-inefficiency and therefore increase in farmers' yields underestimates the benefits of the research process. There are also the "benefits of failure" whereby the results show that a certain approach is not feasible and therefore other methods (research or non-research) need to be tried. This cannot be measured in yields in the farmers' fields or producers' factories.

On the other hand, a rather populist view is that research has not succeeded unless the increased yields are reflected in the farmer's balance sheet. They claim that if the consumer or farmer does not accept the technology being offered or its products, the researcher did not do his work correctly. They say that "the results are good in the laboratory but they are useless or impracticable in the field". These people forget the diffusion process and blame the researcher directly. They forget that while the researcher may share some of the blame, the eventual use and consumption of the results also very much depends on how the diffusion process is managed.

Mansfield lists the following factors as influencing the rate of diffusion of a new product:[9]

(a) the extent of economic advantage of the innovation over older methods of production;

(b) the extent of the uncertainty associated with using the innovation when it first appears;

(c) the extent of resource commitment required to try out the innovation;

(d) the rate of reduction of the initial uncertainty regaring the innovation's performance - leading to the bandwagon effect;

(e) the frequency and extent of advertising and other promotional devices;

(f) the extent of new knowledge and new types of behaviour engendered by the new innovation;

(g) bottlenecks in the production of the new innovation;

(h) the easiness of explaining and demonstrating the new innovation;

(i) the extent to which the new innovation requires changes in socio-cultural values and behaviour patterns; and

(j) the policies adopted by labour unions.

To these factors listed by Mansfield, can be added government policies and institutional factors such as access to credit, legal environment such as land tenure and consolidation, extension services, incentives, interventions, etc. and the educational level and knowledge of the target group.

In the case of the Wheat Research Programme in Kenya, we make some a priori statements and proceed to make some conclusions on how to tackle the diffusion/research effects:

(a) The profitability associated with the use of new wheat varieties is very high: farmers know that if they do not use the new varieties they will definitely incur heavy losses.

(b) The farmers are accustomed to the technology produced by the Wheat Research Programme and therefore the acceptance level of the technology is very high.

(c) There is no additional resource commitment required to grow new varieties as they are produced.

(d) In general, no significant new changes are usually expected to plant new varieties and the farmers are quite knowledgeable about the need for planting recommended new varieties.

(e) Given the foregoing statements, the uncertainty associated by the farmers with the new varieties is low.

To these points, we add Mansfield's observations that some inventions constitute major departures from existing practice, whereas others are more routine "improvement" innovations. The Wheat Research Programme can be regarded as falling in the second category but this does not dismiss the programme from the status of a full-fledged R&D programme.

The *a priori* observations allow us to assume that the diffusion channels for the new varieties are well established and that farmers adopt new varieties as soon as they are released, and abandon the varieties as soon as their resistance to rust breaks down. Thus dynamic X-efficiency, that is, adoption of new technologies, in this case new varieties, is assumed to be high. This assumption will then allow us to use yield as the main measure of the impact of various inputs into wheat production, unaffected by diffusion inefficiencies as far as the adoption of new wheat varieties is concerned. If the diffusion rate for the new varieties were low, then yield would result in an underestimation of the impact of research. What then now remains is to determine R&D's share of this increase in yield, the other major contributing factors being rainfall, fertilizers, capital investments and total cropped area.

However, it should be noted that although on a priori basis we have made some statements which allow us to arrive at some assumptions, the position must be qualified by the following points:

(a) Our assumptions only apply to the established wheat growers who are mainly large scale farmers and ignores the recent objectives of spreading wheat production to small scale farmers.

(b) We do not know the effect of government policies, particularly credit and intervention policies, on the general diffusion process in wheat.

(c) We have also ignored the diffusion process with regard to other technologies and inputs such as fertilizers: the more fertilizers are used the more the potential productivity of the new varieties is realised up to certain limits. This fact is ignored in our analysis and the impact of the new varieties is evaluated, given the existing farming practices. The alternative, which takes into account the optimal use of the package of available wheat production technologies, would be to evaluate on the basis of yields in experimental plots. We have however, in this analysis taken production at the farm as the more practical assessment, although it results in a downward bias of the estimation of the impact of R&D on increased productivity. If one undertakes the evaluation by both approaches one would be able to assess the gap between the actual and potential yields on the farms if all the recommended farming practices were practised.

3.7 The Role of Economic Policy

Economic policy can affect the impact of R&D in a number of ways. First, prices can be distorted by various economic policies. This problem is specially discussed at length in section 3.8 below. This can result in misallocation of resources and failure to undertake socially worthwhile R&D projects.

Trade and marketing policies can also affect the impact of R&D. Where, for example, there are extensive government interventions in the marketing of agricultural commodities, there tends to arise rigidities which affect opportunities to take advantage of the results of research. The best example of this in Kenya is the case of maize where research has done an excellent job in producing varieties suited to different ecological zones. However, heavy government interventionist policies have sometimes played havoc with the production and distribution of this food crop: several commissions of inquiry and studies have confirmed this observation.[10]

Other economic policies which affect the output of R&D are credit facilities, infrastructure development, extension services and other policies which affect the distribution of income arising from the results of R&D by favouring some groups so that they are in a better position to take advantage of the results of research. For example, we have already noted elsewhere that Kenya's R&D system has been criticised for being biased mainly in favour of cash and export crops and failing to concern itself with the problems of the small farmers who are mainly involved in production for subsistence.[11] Also the case of the income maldistributive impact of the Green Revolution and its miracle grains has been extensively studied and is well known. The main beneficiaries throughout the world have been found to be the large land owners and the wealthy farmers because most of the new varieties required considerable complimentarities in productive assets such as irrigation facilities and fertilizers.[12] While many of these disparities arise because of underlying factors beyond the control of R&D, R&D policy could be formulated to focus on production of technologies which require less in terms of skills and resources. For example, drought resistant or escaping varieties would require less irrigation facilities. R&D could also be focussed on simple technologies of moisture conservation and retention. Other useful innovations for the small farmer would be to focus R&D on the use of natural and biological fertilizers, away from the emphasis on artificial fertilizers. Other economic policies affect the export/cash crop/food crop balance so that one receives more emphasis in R&D than the other. The economic policies must thus be examined and their impact as they relate to R&D evaluated.

3.8 Shadow Prices and Accounting Ratios

3.8.1 Introduction on Shadow Prices

There are three levels at which a public sector project can be analysed:

(a) Analysis at market prices, which is called financial analysis;

(b) analysis at efficiency prices, which is called economic analysis; and

(c) analysis at social prices, which is called social analysis.

In the three levels of project analysis, the first step is to identify the costs (inputs) and benefits (output) of the project. This step has been discussed in the foregoing sections. The next step involves finding the prices that will be used in valuing the costs and benefits. This task is our major concern in this section.

In the case of financial analysis, the ruling market prices are used, irrespective of the distortions which might exist in the market. These prices are fairly straightforward and easy to identify and we need not say more about them here, since our focus is on economic/social analysis.

A financial analysis is concerned with private returns to an investment; hence the use of the prevailing (or projected) market prices. However, in economic/social analysis, we are concerned with the value of contribution of the project to the country's basic economic objectives. Governments often have socio-political goals that may be only indirectly related to economic objectives and therefore market prices may bear little relation to real economic costs. Often prices such as minimum wage rates, ceiling commodity prices, etc are fixed for socio-political reasons. Therefore in economic/social analysis of projects market prices must be adjusted to reflect the true value of the costs and benefits to society. When we make these adjustments we obtain what are called shadow or accounting prices.

There are two levels of the price adjustments which lead to a distinction between economic analysis and social analysis of the project. When the market prices are adjusted to represent the opportunity cost of resources to society we obtain efficiency prices which result in an economic analysis of the project. When the efficiency prices are weighted to reflect income distribution or savings objectives, social prices are obtained which lead to a social analysis of the project.

In determining the efficiency prices, three main steps are used to adjust the financial prices:

(a) opportunity cost or willingness to pay adjustments;

(b) transfer payments adjustments; and,

(c) conversion into border or domestic prices.

These are discussed in the following sections.

3.8.2 Opportunity Cost and Willingness to Pay Adjustments

Opportunity cost is the value of a good or service in its next best alternative use. We use opportunity cost to value inputs and outputs which are used in the production of other goods or services. In the case of goods and services to which opportunity cost is not applicable we use the "willingness to pay" concept. This simply means the price the consumers are willing to pay for the good or service in the market place and usually applies to non-traded goods (since traded goods are valued at international trade prices - (see below)).

3.8.3 Transfer Payment Adjustments

Transfer payments are those costs which do not represent direct claims on the country's resources but merely reflect a transfer of the control of resources from one member of sector of society to another. They mainly include taxes, subsidies, repayment of principal and payment of interest on principal. Taxes are subtracted from the prices, subsidies are added back and loan and interest repayments are excluded from the stream of costs.

However, in the case of taxes, one needs to be careful in what to consider as necessary to subtract from the prices. The general rule is that if the tax is charged specifically to carry out service or provide goods for the project, then this is part of the economic project costs. If the tax is merely a transfer of some part of the project resources to society for general public use then this should be subtracted from the prices.

3.8.4 Conversion into Border or Domestic Prices

This conversion involves determining the value of foreign exchange as this is a major element in adjusting financial prices to reflect economic prices. In many countries the official exchange rate tends to overvalue domestic currency in relation to foreign exchange. This makes imports cheaper so that tariffs are required to raise the prices of imports or quotas are imposed to save foreign exchange. Conversely, the overvalued currency tends to make exports more expensive so that subsidies may be required. There are many reasons why a government may wish to overvalue a currency but whatever the reasons, we shall not go into them here. Suffice it to say that the overvaluation makes imports cheap and exports expensive and so the optimum exchange rate which removes these price distortions has to be used in efficiency pricing. This exchange rate is called the shadow exchange rate (SER).

Suppose the official exchange rate in Kenya is Kshs. X to 1 US dollar and we determine that the Kenya shilling is overvalued by r%, then the SER is given by $X(1 + \frac{r}{100})$. The question remains as to how to determine the extent of overvaluation. This is left to a later section below.

The SER can also be approximated by:[13]

$$\frac{M(I + t_m) + X(I - t_x)}{M + X}$$

where M and X are the c.i.f. value of imports and the f.o.b. value of exports respectively in the marginal consumption bundle of goods, and t_m and t_x are the average taxes on imports and exports respectively, which may be measured by the ratio of the revenue from trade and other taxes on consumption goods to the c.i.f. or f.o.b. value of those consumption goods. ....
The SER is then used to convert the c.i.f. and f.o.b. prices of traded imports and exports into domestic prices.

Traded goods are inputs or outputs which could enter into international trade, irrespective of whether they are actually purchased or sold abroad in the case of the project being evaluated. On the other hand, inputs or outputs which by their very nature cannot be traded abroad or which are subject to prohibitive restrictions are treated as non-traded. In that case, the opportunity cost of the traded good is its border price.

The approach whereby the efficiency prices of traded goods are obtained by converting the border prices into domestic currency equivalents by using the SER is called the UNIDO Guidelines approach.[14] This approach also uses the domestic prices adjusted for their opportunity costs and transfer payments as the efficiency prices for non-traded goods.

There is another approach for bringing international and domestic prices (or prices of traded and non-traded goods) at per, that is, converting all prices into border prices. This may be called the Little and Mirrlees/Squire and van der Tak approach (or LMST approach for short).[15] This approach has also been adopted by the OECD.[16]

The LMST method uses what is called the Standard Conversion Factor (SCF) and is actually a reciprocal of the SER. In the case of the SER, the effect is to make the tradable goods and services r% more expensive relative to the non-traded items. The LMST approach achieves this by reducing the values of the non-traded goods by r%. This is done by multiplying the opportunity cost of non-traded goods, at market prices, by the SCF, the SCF being given by the reciprical of $\frac{1+r}{100}$. In this method, the prices of traded inputs and outputs are the c.i.f. or f.o.b. prices multiplied by the official exchange rate.

We should also note that as we shall see later, although we say above that the SCF is the reciprocal of the SER the estimation of SCF is different from SER and the practical results are not exactly equal. Further we shall see later that there are different conversion factors for different types of goods, hence the use of the term Standard Conversion Factor which is a general conversion factor for all non-traded inputs or outputs.

The question arises as to which is the better method to use. Irvin has argued that the LMST approach should be a better tool because it takes into account the fact that everything produced and consumed locally has an impact on the balance of payments by decomposing non-traded goods into their traded goods components in terms of consumption of the traded goods or inputs into the production of the non-traded good.[17] This is also the main argument advanced by Little and Mirrlees in addition to the argument that comparability of goods is enhabced.[18] Irvin contends that to the extent that the UNIDO Guidelines do not decompose the non-traded goods it should, at best, be regarded as a 'rough and ready' variant of the LMST method rather than a formally equivalent alternative.

However, Mishan notes that these reasons would be more acceptable if there were no excise taxes or tariffs or if they were very low or if there were foreseeable possibilities of these trade restrictions being removed, given the relevant political constraints.[19] We may also add that the decomposition techniques require more work and expertise and would probably introduce a greater margin of error. For example, patterns of consumption of wage earners according to their income groups have to be determined; inputs into electricity production have to be determined and where there are non-traded goods in the input and consumption goods they have to be decomposed further. Indeed Scott, although favouring the LMST method, notes that once one allows for indirect foreign exchange effects one can stop nowhere.[20] And even after that, one may still expect to get a residual of non-traded effects. On the other hand, the SER can be estimated from data available in the national accounts statistics.

Gittinger has this to say about the LMST method.[21]

> Economists in developing countries, on the whole seem to be taking the attitude that the Little-Mirrlees (LMST) method is too complex in

> comparison to other methods of shadow pricing to justify the additional improvement in the quality of investment decisions it might bring. Few planning agencies are attempring to introduce the methods, although they are watching others' efforts to use it with considerable interest........... Among international agencies, although there has been considerable interest in the Little-Mirrlees proposal, there has been no attempt to introduce it, even on modified form, on a broad scale. In the World Bank, for instance, the system is not being used and, for the moment at least, it is not proposed to do so.

Gittinger notes that the major questions have revolved around the complexity of the LMST method, its requirement of highly trained manpower and whether the method would lead to different investment priorities to justify the amount of analytical work required. After all, much of the benefits from the economic analysis of projects comes simply from the discipline of preparing a project in sufficient detail to undertake the economic analysis. If so, a sophisticated requirement in the valuation of inputs and outputs may contribute only marginally to the usefulness of the analysis. Gittinger notes that some preliminary tests by the World Bank Staff have led to the conclusion that there would be very few, if any, changes in investment decisions were Little-Mirrlees system used.

Little and Mirrlees suggest that the problem could be resolved by having a central core of a small group of economists charged with working out accounting ratios which then could be used for all project evaluations. However, there are still the doubts as to whether the method would lead to better decisions.

On the basis of the data requirements and the amount of "fine tuning" and expert resources required for the LMST method, one would recommend the more traditional UNIDO approach for LDCs like Kenya.

3.8.5 Estimation of Shadow Prices

A detailed account of the derivation of shadow prices would take us far out of the mainstream of the scope of this paper. Here a clear but concise exposition of the derivation will be presented to enable us to have a glimpse of the issues and problems involved in public projects evaluations.

In the economic evaluation of R&D projects six main shadow prices need to be taken into account, namely, unskilled labour, skilled labour, land, capital, exchange rate and commodities. Each of these is briefly discussed below.

(a) Economic Shadow Wage Rate of Unskilled labour

Irvin defines the economic shadow wage rate as:[22]

$$EWR = m.AR_m$$

where m is the product foregone and AR_m is the conversion factor translating m (measured in market prices) into foreign exchange equivalent. This is the LMST method. The UNIDO method would omit AR_m. We shall concentrate on the estimation of m. Irvin identifies four categories of average unskilled wage rates to choose from:

W_m, the modern sector wage;

W_i, the informal sector wage;

W_a, the average agricultural sector wage

W_{ca}, the wage for casual agricultural labour.

Whichever rate is adopted really depends on where the labour is drawn from. In financial analysis, W_m is used. This assumes that labour is drawn from similar occupations in the modern sector and that there are no further migration effects. Harris and Todaro,[23] set $m = W_a$ and Lal[24] set it equal to W_m, since, according to all of them, the creation of an extra modern sector job induces more than one worker out of agriculture. Harberger set $m = W_i$, his argument being that the apparent difference between W_i and W_{ca} is illusory.[25] This means the extra worker is ultimately drawn from the rural areas. Others, such as Bruce, use W_{ca} and weight it by an estimate of the degree of seasonal under employment.[26]

Whichever approach one takes, it will differ according to country and even regions within each country. Ultimately, it is an empirical decision. The important points to note are the following:

(i) The next best alternative use is not the precise occupation from which the worker is hired but the occupation that ultimately loses a worker as a consequence of the chain of hiring and replacement set in motion when a new project is added on to an existing set of economic activities. So, the ultimate source of new workers must be established.

(ii) The number of workers attracted by one extra job in the modern sector must be established and their total opportunity cost taken as the shadow wage rate.

(iii) If the workers ultimately come from the rural areas, then the opportunity cost is the wage paid by farmers for hired workers, adjusted, where necessary, by the value of any subsistence crops the worker harvests for himself and any informal activities he may be engaged in.

(iv) Any extra consumption by the new workers arising from additional claims on public resources, such as social amenities or public utilities must be added on to the opportunity cost to arrive at the correct shadow wage rate.

Kalbermatten and others note that generally, the shadow factor for unskilled labour in developing countries (LDCs) is in the range of 0.5 to 1.0.[27]

(b) Economic Shadow Wage Rate of Skilled Labour

Here our discussion falls in line with the arguments of Roemer and Stern.[28] They define a skilled worker to include any worker who has received enough training so that (i) he receives a wage substantially above that for the average labourer and (ii) is unlikely under normal circumstances to compete for jobs that do not require such training. The skilled labour is divided into three categories: Local skilled labour whose training predates the project, skilled and semi-skilled workers trained by the project, and expatriates.

(i) Local Technicians and Managers

The supply of this labour is usually highly inelastic. A new project will have to take this category of labour from other employers and in this situation, the shadow price is equal to the demand price which is the gross salary before income taxes plus other benefits paid by the present employer. This gross salary plus fringe benefits is assumed to be equal to the marginal revenue product and hence the opportunity cost. Skilled people who work for the government may not be paid a fully competitive wage either because they are compensated in other ways (such as job security, pension, etc) or because they are bonded after having been educated at government expense. So, the shadow price should ideally be based on wages and salaries paid by the private sector, if estimates for comparable skills can be found.

(ii) Skilled and Semi-skilled Workers Trained by the Project

For these, the shadow wage rate should be the opportunity cost of unskilled labour. The training is a creation of human capital and should, in a sense, be treated as a benefit to society and if possible should be included in the calculations or at least described. (It should be mentioned that there are also private consumption benefits of the education per se, by the workers, but we shall not go into this aspect here).

(iii) Expatriate Technicians and Managers

The supply of foreign experts is assumed to be unlimited if countries are prepared to pay the going price for the expatriates. Hence, the shadow price for the expatriates is taken to be the salary of the expatriates minus the income taxes paid in the country in which they are employed. However, the portion of salary which is repatriated or spent on imported consumer items should be treated as foreign exchange and valued at the shadow exchange rate.

(c) Shadow Price of Land

The value of land depends on developments on or near the land such as: proximity to transportation facilities and service industries, the improvements on or near the land such as sewerage, the kind of surrounding neighbourhood and other physical characteristics. If there is a free (or near free) market for land it is expected that the market price or rent will reflect these considerations and hence this will reflect the value of the land in its next best use and hence the shadow price for land.

As often happens, the government land price is often below the market price especially in urban areas. The solution here would be to look for land with similar characteristics and use its market price as the shadow price for land.

In the case of agricultural land the opportunity cost is the value of the previous enterprise on the land minus the cost of production for that

The interest rates observed in the market are nominal, i.e.; they include inflation. However in our calcualtions we deal with real interest rates net of inflation because project evaluation is usually done in constant prices. If i_m is the normal rate of inflation, t_c is an average effective tax rate on capital earning and t_s is an average effective tax rate on savers incomes, then the investment rate of interest i_c and the savers' rate of interest i_s are obtained by:[29]

$$i_c = \frac{i_m}{1-t_c} - p \text{ and } i_s = i_m(1-t_s) - p$$

where p is the rate of inflation.

However, we should note that capital markets are highly segmented and there is no single uniform rate of interest either for investors or for savers. Separate account should be taken, where information is available, of the opportunity cost of capital in domestic commercial bank lending, foreign commercial loans, equity including small business and farms, savings accounts, corporate retained earnings, private equity, etc.

Ignoring the complications of credit rationing in imperfect markets, the above formulae are used to calculate the opportunity costs in each of these markets. The shadow interest rate is then computed as the total of the different opportunity costs weighted by their relative responses to changes in interest rates.

Before concluding this subsection on shadow interest rates we should discuss briefly a controversy which exists on the proper social discount rate. There are two distinct schools of thought which are divided into the social time preference (STP) approach and the social opportunity cost approach (SOC) which we have used here. In the STP approach it is argued that government investments result in public goods and market interest rates used on public projects are imperfect and do not allow for weighting consumption in favour of future generations. It is also argued that government interest may not coincide with those of individuals and therefore the time preference of individuals revealed in the private market is not necessarily the same as that of the government which represents public interests. Individuals are also said to be willing to forgo present consumption in favour of future generations only if other individuals are willing to do the same, and hence only collective or government action can correct this.

Based on the above arguments, it is then argued that there exists a social rate of discount lower than the private rate of interest which must be used to discount the returns from public investments. Such rate is viewed as the natural rate of interest that would prevail along the optimal path when the economy is growing at a steady rate.

The above argument implies that the optimal path of growth is obtained when marginal productivity of capital is equal to the natural rate of interest. This contention has been seriously challenged, and Arrow has shown that to maximize output (allocate resources optimally) the marginal productivity of capital does not have to be equal to the natural rate of interest.[30] Moreover, there is no unique natural rate since there exists a natural rate of interest for each level of economic growth. Indeed, this approach has by and large been discredited and the opportunity cost approach is now favoured by the majority.

However, the opportunity cost approach has got its own problems. As we have seen above, there exists an array of rates of interest instead of one unique one. The basic reasons for the existence of these different rates is said to be corporate income tax; and risk and uncertainty about the future returns on private investment.

With regard to corporate income tax, it is now generally agreed that before tax rate of return constitutes the opportunity cost of resources. The major controversy centers on whether or not to include a risk premium. The general view is that if the number of people who share the costs and benefits of the project is large and the investment yields public goods as well as beneficial externalities, we should use a risk-free (low) discount rate. If the situation is the other way round, a risky (high) rate should be used.

(e) Shadow Foreign Exchange Rates

In section 3.8.4 we discussed the use of the shadow exchange rate (SER). Here we discuss the estimation of the SER.

In most developing countries, there is high reliance on imports and foreign exchange becomes a factor of production because it represents ability to buy equipment, industrial and agricultural inputs as well as consumer necessities. The foreign exchange market is like any commodity market. For a given price for foreign exchange, that is, the exchange rate or value of local currency per unit of foreign currency, investors (in this case importers) demand a certain amount of foreign currency. Likewise, for the same price, suppliers (in this case exporters) supply or produce a certain amount of exports to generate a certain amount of foreign exchange. Under free market conditions there is therefore, just like any commodity market, an equilibrating foreign exchange rate for a given demand and supply of foreign exchange, taxes and subsidies excluded.

However, the typical situation in many LDCs is that the exchange rates are controlled by the authorities and usually the exchange rate is fixed, usually below market prices. We say then that the local currency is overvalued. Under these conditions, suppliers will supply the market foreign exchange commensurate with the fixed exchange rate r_o. This price is, however, below what the importers are willing to pay, r_x. The difference between the two prices, $r_x - r_o$, is called the foreign exchange scarcity premium and becomes a windfall profit for any importer lucky enough to get an import license which are usually controlled.

To calculate the economic exchange rate, that is, the equilibrating rate, we compute a weighted average of the exporters' rate, which is the official exchange rate, r_o, and the importers' willingness to pay rate, r_x. Since we know the official exchange rate, then what remains is for us to determine the scarcity premium which when added to the official exchange rate gives us the importers willingness to pay rate, r_x.

Since under fixed exchange rates demand for foreign exchange is higher than can be met by suppliers, stringent controls over imports and other foreign payments are usually instituted to avoid a severe balance of payments deficit. As demand grows without attendant devaluation, an active black market in foreign exchange as well as smuggling become rampant. The way to measure the premium on imports is to compare the c.i.f. and domestic market prices of individual commodity imports. Part of the difference between these prices is due to tariffs, banking charges, clearing costs, handling charges, transport and selling costs and the normal profits of importers, wholesellers and retailers. However, somewhere along the line a trader is apt to take advantage of this scarcity and raise his price above the level that can be explained by these costs. If there are price controls, this raising of prices may be done informally and far along the marketing chain. What is needed here is an astitute sample survey well designed and implemented to explain any difference between actual market price and anticipated costs. This difference can be taken as the scarcity premium of foreign exchange for imports.

The approach we have followed here is that followed by Roemer and Stern.[31] Other methods use the black market rate as an indicator of the premium on foreign exchange. The more fundamental differences from other approaches is that while the method we have explained above calculates the shadow foreign exchange rates taking into account tariffs, the other methods assumes removal or non-existence of tariffs. This results in a slightly higher shadow exchange rate. However, because these alternative methods assume the unlikely situation where there are no tariffs, we think the method followed here is the more practical of the two approaches.

The shadow foreign exchange rate can also be approximated by taking the domestic to border price (c.i.f. or f.o.b. prices for imports or exports at the official exchange rate) ratio of traded commodities weighted by the share of each commodity in a country's marginal trade bill, or by the formula given for the Shadow Exchange Rate (SER) in Section 3.8.4.

(f) Shadow Prices of Commodities

Commodities can be inputs or outputs. We deal with the case of commodities as inputs first. In dealing with commodities as inputs, there are two questions which point the way to estimate the shadow price: What are the alternative sources of the good? What is the social cost of the factors used to produce the commodity in these alternatives? In the case of an input which is wholly imported and there is no production of the commodity in the country, foreign exchange is the factor used to 'produce' the commodity and its shadow price is the c.i.f. price multiplied by the shadow foreign exchange rate. In the case where the input is being produced locally but is also being imported despite local production, the shadow price is also the c.i.f. price multiplied by the shadow foreign exchange rate because, at the margin, the new project will result in an additional claim on foreign exchange unless investment is foregone elsewhere. In the case where investment is foregone elsewhere, perhaps because of an import ban, the social value of the commodity in its previous production should be used.

If it is possible to produce the commodity locally without requiring investment to be given up elsewhere, then the cost of producing the commodity should be used, the factors of production being valued at shadow prices. However, there are two points to note here: If the additional goods can be produced by use of existing excess capacity, only the raw materials and other variable or marginal costs should be used to calculate the shadow value. In this case capital charges and administrative overheads are not part of the social costs because they are fixed and would be incurred whether or not the additional input for the project is produced; market prices must therefore be adjusted accordingly because they embody components of fixed costs. On the other hand, where expansion of existing capacity or additional administrative costs or a completely new investment is required to produce the input, then the full costs of the production of the input must be used.

When inputs are produced locally by monopolies or when prices are controlled by the government, the market price is likely to differ from the social cost of production. In that case, it will be necessary to analyse the production costs of the supplier to determine the shadow price. The imported contents of production are then valued at c.i.f. prices converted into the local currency at the shadow rate of foreign exchange.

In the case of outputs, the principle is similar to that for inputs. If the commodity is imported, the project's products are saving foreign exchange and its value is the c.i.f. cost of the competing import valued at the shadow exchange rate. However, if the output is protected by a ban or prohibitively high tariffs, then the shadow price is the measure of the consumer's willingness to pay, which is the market price, taxes included.

3.8.6 Estimation of Accounting Ratios (or Conversion Factors)

We saw earlier that the basic difference between the UNIDO approach and the LMST method of evaluation of projects is that in the former all prices are converted into domestic prices, while in the latter all prices are converted into border prices. In formal terms, the difference is in the numeraire or unit of measurement used: In the former, the numeraire is the domestic prices, while in the latter, the numeraire is the border prices. We should, however, note that in both cases, the prices are expressed in domestic currency.

In practical terms, what this means is that in the UNIDO approach, the prices of traded goods are converted into domestic currency by multiplying the c.i.f. or f.o.b. prices by the shadow foreign exchange rate; while for the non-traded goods, the market prices are adjusted for their opportunity costs and transfer payments only to obtain the shadow prices as already described in the text above. In the case of the LMST method, the prices of traded goods are converted into border prices by multiplying the c.i.f. or f.o.b. prices by the official exchange rate; while the non-traded goods are converted into border prices by what are called accounting ratios or conversion factors. In the following discussion we turn to the explanation and estimation of the accounting ratios.

The basic first step in determining the accounting ratio for a given good is that of decomposing or breaking down the good into what are called the primary inputs of production. The choice of the primary inputs of production is a matter of choice and convenience but now the generally agreed categories of primary inputs are foreign exchange, labour, profits of producers and traders, and residuals comprised mainly of taxes and subsidies.

The foreign exchange input is really the c.i.f. or f.o.b. price of the traded inputs used in the production of the non-traded goods. This price is multiplied by the official exchange rate to obtain the accounting price for the foreign exchange input.

The case of labour and profits is more complicated. A determination has to be made of the consumption pattern from the income accruing from the project, particularly with regard to the direct and indirect foreign exchange bundle of goods consumed. This bundle of goods is then valued at border prices to determine the border prices for labour or profits. If in this bandle of goods there are non-traded goods, they are further decomposed, etc. Hence, Scott's statement noted before that once we allow for indirect effects, this decomposition can end nowhere.[32] For example, we may find out that the consumption bundle for labour is composed of:

Food - which is produced locally

Textiles - which are imported

Appliances - which are imported.

Since the textiles and appliances are imported, we value them at c.i.f. prices multiplied by the official exchange rate to obtain their border prices. The food component has to be decomposed further and we may find out that the food bundle is composed of maize, beans, sugar and others. We may find out that maize and sugar are exportable. We therefore value them at the f.o.b. prices converted to local currency at the official exchange rate to give us their border prices value. On the other hand, beans may be a non-traded good. The price of beans has then to be decomposed into costs of inputs of production and similar calculations made, etc, etc. If the components of 'others' is small, an approximation of the border price can be made by an adjustment for imperfections and taxes in the market price or by an 'informed' guess since presumably this remnant of 'others' would be so small as not to affect the result.

The above procedure used for labour inputs is used for profits. However, it should be noted that incomes in wages and profits accrue to different people in different income groups. This complicates the procedure further in that different income groups have different consumption patterns. Further, we may wish to weight the prices in favour of different income groups - but we leave this consideration to section 3.9.2. Suffice it here to say that this requirement of long chains of decomposition and the consideration of different income groups in determining patterns of consumption make the LMST method complicated and time and resource consuming.

An alternative method for valuing labour is to determine the accounting price of the foregone marginal product in the previous employment of the labour. If the product foregone is a traded good, then the problem is straightforward and we calculate the accounting price of labour as the c.i.f. or f.o.b. price of that good converted into domestic currency by the official exchange rate. If the good is non-traded then the original problem recurs and we have to go through the problem of decompositions.

Finally, the Residuals of taxes and subsidies is valued at zero since they have no social cost or bebefit respectively.

Once the accounting prices are worked out for each primary input, they are then added up to give the accounting price for the good being valued. The accounting ratio (conversion factor) is then calculated as the ratio of the accounting price to the domestic market price.

In the case where many accounting ratios (ARs) have to be measured, it would be useful to use summary ARs. In this case, the central tendency and the dispersion are measured and where the later is found to be small, the central tendency value is taken as a summary AR and used for all goods and services for that particular category. For example, work done by Scott in Kenya for the million acre settlement scheme resulted in AR values of 1.00 for exports and 0.86 for imports, with what were considered to be large standard deviations of 0.25. The AR for nontradables was 0.77 and, for urban consumer goods and services, it was 0.80, with small standard deviations, the latter being 0.06 for the non-tradables.[33] Hence if one is using the LMST method in Kenya it might be safer to estimate ARs individually for exports and imports but one may not go far wrong if one were to use an AR of 0.77 for non-tradables and 0.80 for labour and miscellaneous other small items to cover both tradables and non-tradables.

One important point needs to be mentioned here before we conclude this sub-section. Previously, we noted that the Standard Conversion Factor (SCF) is the reciprical of the shadow exchange rate. There is a practical difference in the application of the SCF and the commodity ARs discussed here. The SCF is applied to the market prices after they have been adjusted for opportunity cost. The ARs discussed here have already been adjusted for transfer payments and opportunity costs and therefore in using them, they are applied directly to market prices to obtain the accounting prices.

3.8.7 Economic Import and Export Parity Prices

In calculating the economic import and export parity prices, the costs of storage, transportation and distribution are valued in the same way as for any other goods, as described above, to obtain the relevant shadow prices which are added or subtracted to the c.i.f. or f.o.b. prices as the case may be.

3.8.8. The Treatment of Inflation

The matter of inflation was mentioned earlier in the discussion on capital where we said that interest rates should be based on real interest rates, net of inflation. However, in social cost-benefit analysis, changes in prices, or inflation, can be included in the appraisal so long as those changes are handled consistently; or the evaluation can be done in constant prices: either approach is possible. Then if the prices are inflated, the nominal rate of interest must be used. However, if some prices are expected to rise at a different rate than others, then this inflation must be taken into account. Where this is the case, using constant price approach, prices which rise faster than others should be deflated by the difference between their inflation rate and the general inflation rate.

3.9 The Side Effects of Technological Change.

3.9.1 Introduction on Side Effects

Side effects is an abbreviation for external economies and diseconomies. These are also variously referred to as external effects, neighbourhood effects, joint outputs or simply spillovers. Side effects are neatly and simply defined by Davis and Kamien as effects on persons not associated with specific purchases or activities.[34] This definition reflects the element of interdependence, that is, that the economic welfare of one individual is dependent on the activities of other individuals. There are two types of side effects: pecuniary and technological.

Pecuniary side effects arise when prices of inputs or products change due to their increased supply or demand. For example, if certain technological change brings about economies of scale in the production of a certain good we expect the price of that good to fall in a free market economy. The fall in price is a gain to the consumers of this good. On the other hand, if there is an expansion of the demand for a certain input, then we expect the price for that input to rise.

Pecuniary side effects do not cause serious difficulties in a market economy where changing demands and supplies cause prices to rise and fall. Indeed these form the basis of the consumer and producer surplus approach to the analysis of the benefits of research and technological change discussed in Chapter Two. We therefore shall not go into details of these here. Moreover, where the prices do not reflect the prices of a free market economy, methods of adjusting such prices are discussed in the previous section. This section will therefore concentrate on technological side effects.

A technological side effect can be viewed as either an economic gain or loss not reflected in the market price. These refer to direct effects, other than price changes, that one decision unit may impose on another. Technological side effects do in many instances prevent the market mechanism from functioning efficiently, that is, giving rise to a Pareto optimal allocations. In such cases there exists a possibility of bettering society's welfare, that is bettering one individual's welfare but not at the expense of another.

Here we will deal with the three well recognised main types of technological side effects, that is:-

Income distribution consequences

Employment effects

Environmental consequences

Other types will also be mentioned.

There are two main ways of handling side effects: by describing them or by internalizing them. The basic idea behind internalizing is that of transforming the side effect into a product that can be priced on the market and treated as a cost to the project (in case of a bad side effect) and as a return to the project (in case of a good side effect). Methods of internalizing the above three main side effects will be discussed under each respective heading below. It should, however, be kept in mind that the number of side effects that can be successfully internalised into the pricing mechanism or the costing systems of projects is indeed quite limited. Many side effects have to be handled simply by description.

3.9.2 Income Distribution Side Effects

The Green Revolution which brought about new high yielding grain varieties in the 1960's has been probably the most spectacular success in research in agriculture. It was heralded as the solution to the Malthusian dilemma, particularly in the developing countries where rapidly growing populations threatened to precipitate massive starvation. The Green Revolution did indeed contribute considerably to the food production of many countries which were faced with imminent severe food shortages. Some food deficit countries became even exporters of food grains.

However, the Green Revolution was not destined to achieve its total potential and in certain aspects it had serious external diseconomices. Due to its great promise, the Green Revolution attracted attention from highly enthusiastic optimists to cautious observers. By the end of the 1960's some keen observers were beginning to caution that it could only be seen as a stop-gap measure - some kind of holding ground in the long run because there were serious obstacles to realising its potential. Furthermore, serious income maldistribution consequences were singled out as one of the most serious diseconomies likely to be precipitated by it. In an article written to assess the impact of the Green Revolution on international relations, Wharton summarises very well the reasons why it would not attain its potential, which reasons also embody the issues which would result in a worsening of the income distribution in the countries involved.[35] His words are quoted here below at length because they apply not only to the Green Revolution but also to other agricultural technologies in one way or another.

> The reasons for believing that the new technology will not in fact spread nearly as widely or as rapidly as supposed and predicted include, first, the fact that the availability of irrigated land imposes at least a short-run limit to the spread of the new high-yield varieties. Most of these require irrigation and careful water control throughout the growing cycle. In most Asian countries about one-fourth to one-half of the rice lands are irrigated; the remainder are dependent upon monsoons and seasonal rains. The speed with which additional land can be converted to the new technology depends on the rapidity with which new irrigation facilities can be constructed; and here the high capital costs are likely to be a retarding factor. Large-scale irrigation projects can seriously strain the investment capacity of developing nations. For example, the massive Mekong River development scheme, involving Laos, Cambodia, Viet Nam and Thailand, has been estimated to require a capital investment over the next 20 years of about $2 billion, roughly 35 percent of the annual national income of the four countries involved and exceeding the annual net new investment of all the countries of Southeast Asia combined. Further, significant additional costs are involved in converting existing irrigation systems to the requirements of modern agriculture. Many of the old gravity irrigation systems were not designed to provide the sophisticated water controls demanded by the new varieties. (For example, each plot must be controlled separately throughout the growing season).

Second there are doubts about the ability of existing markets to handle the increased product. Storage facilities and transport are inadequate and crop grading often deficient. Not only must the market system be expanded to handle a larger output; there also is an increased need for farm supplies and equipment. Fertilizers, pesticides and insecticides must be available in the right quantities, at the right times, and in the right places. Given the inadequacy of the agricultural infrastructure, the need to expand and modernize marketing systems is likely to reduce the pace of the Revolution. Because many of the new varieties, especially rice, do not appeal to the tastes of most conumers, it is difficult to calculate the size of the market. Some argue that until newer varieties which are closer to popular tastes are developed, the market will be limited.

Third, the adoption of the new technology is likely to be much slower where the crop is a basic food staple, grown by a farmer for family consumption. Such farmers are understandably reluctant to experiment with the very survival of their families. Peasant producers are obviously far more numerous in the developing world than are commercial farmers and the task of converting them to a more modern technology is considerably more difficult. So far, spectacular results have been achieved primarily among the relatively large commercial farmers. Some semi-subsistence farmers have begun to grow the new varieties, but the rate at which they adopt them may be slower.

Fourth, farmers must learn new farming skills and expertise of a higher order than was needed in traditional methods of cultivation. The new agronomic requirements are quite different as regards planting dates and planting depths; fertilizer rates and timing; insecticide, pesticide and fungicide applications; watering and many others. Unless appropriate extension measures are taken to educate farmers with respect to these new farming complexities the higher yields will not be obtained.

Fifth, many of the new varieties are non-photosensitive and the shorter term will allow two or three crops per year instead of one. Multiple cropping is good, but there may be difficulties if the new harvest comes during the wet season without provision having been made for mechanical drying of the crop to replace the traditional sun drying. In addition there may be resistance if the new harvest pattern conflicts with religious or traditional holidays which have grown up around the customary agricultural cycles.

Sixth, failure to make significant institutional reforms may well be a handicap. There is evidence in several Latin American countries that a failure to make needed changes in policies now detrimental to agriculture or a reluctance to effectuate the institutional reforms required to give real economic incentives to small farmers and tenants, has been primarily responsible for the very slow spread of Mexico's success with new varieties of wheat and corn to its neighbours to the south.

From all this one may deduce that the "first" or "early" adopters of the new technology will be in regions which are already more advanced, literate, responsive and progressive and which have better soil, better water management, closer access to roads and markets - in sum, the wealthier, more modern farmers. For them, it is easier to adopt the new higher-yield varieties since the financial risk is less and they already have better managerial skill. When they do adopt them, the doubling and trebling of yields mean a corresponding increase in their incomes. One indication of this is the large number of new private farm management consultant firms in the Philippines which are advising large landlords on the use of the new seed varieties and making handsome profits out of their share of the increased output.

As a result of different rates in the diffusion of the new technology, the richer farmers will become richer. In fact, it may be possible that the more progressive farmers will capture food markets previously served by the smaller semi-subsistence producer. In India, only 20 percent of the total area planted to wheat in 1967-68 consisted of the new dwarf wheats, but they contributed 34 percent of the total production. Such a development could well lead to a net reduction in the income of the smaller, poorer and less venturesome farmers. This raises massive problems of welfare and equity. If only a small fraction of the rural population moves into the modern century while the bulk remains behind, or perhaps even goes backward, the situation will be highly explosive. For example, Tanjore district in Madras, India, has been one of the prize areas where the new high-yield varieties have been successfully promoted. Yet one day last

December (1968), 43 persons were killed in a clash there between the landlords and their landless workers, who felt that they were not receiving their proper share, of the increased prosperity brought by the Green Revolution.

Such issues as described above have to be looked into in assessing the impact of a new technology.

Having shown that technology can have serious income distribution consequences how do we go about handling such externalities? First of all we can describe these and make decisions on the basis of informed opinion. This is often done in public decision making. Alternatively, we can internalise these by giving weights to the various benefits accruing to different income groups as described below.

In many project analyses, there are implicit assumptions about the weighting of project benefits. Often the assumption is that all benefits count equally irrespective of whom they accrue to. The implication is that all benefits are given a weight of unity whether they accrue to Government, firms, rich or poor individuals. The distribution of benefits does, however, raise issues which go back to early days of the neo-classical theories in economics. The marginalist approach assumes that the more one has of one good, the less utility one derives from an additional unit. It follows then that total welfare can be increased by redistributing marginal units of a good from those who have a good deal of it to those with very little, that is, by moving towards a fully egalitarian distribution of income. However, this assumes that all persons have identical and declining marginal utility functions and that interpersonal utility comparisons are possible. Irvin notes that while Marshall appears to have accepted the possibility of interpersonal comparisons, others such as Jevons, Edgeworth, Pareto and later Robins denied the possibility of doing so.[36]

In weighting benefits, various suggestions have been made. Krutila & Eckstein have suggested using the reciprocals of marginal tax rates as weights assuming a progressive tax structure.[37] Foster suggested a modern elasticity approach seting the rate at which utility increases relative to a unit rate of increase in consumption, i.e. elasticity of marginal utility, equal to unity[38] (see below). Other suggestions for deriving weights implicitly from planners choice of project mix have been suggested by Marglin Weisbrod and McGuire and Garn.[39]

The essential principles of a weighting scheme have been outlined by Irvin:[40] Let d_i be the weight associated with an extra shilling worth of benefit going to i^{th} group presently enjoying level C_i of income. Let $\bar{C}$ be the average (per capita) income level. Let e be the elasticity of marginal utility, that is, the rate at which the utility increases relative to a unit rate of increase in income.

$$\text{Then,} \quad d_i = (\bar{C}/C_i)^e$$

This means that so long as e is greater than zero the unit of benefit accruing to an income group whose present income, C_i, is greater than the average per capita income, $\bar{C}$, will receive a weight of less than unity and vice versa. The value of d_i will therefore depend on how rich group i is relative to a reference level of consumption and the value chosen for e. $\bar{C}$ and C_i can be determined from national statistics. e is not easy to determine but some writers such as Foster have assumed it to be unity.[41] The d_is are then computed for each income group. What then remains is to determine the amount of benefits likely to accrue to each income group and weight these with the d_is and sum up to get the total weighted benefits i.e.

$$B_W = \sum_1^n d_i B_i$$

where:

B_W = total benefits weighted for income distribution

d_i = income distribution weight for income group i determined as above

B_i = unweighted benefits estimated as accruing to income group i.

n = number of income groups involved.

The approach can also be used for regional and other forms of income distribution.

3.9.3 Employment Effects

When technological change, particularly in industry, is mentioned many people think of unemployment. Mansfield notes that the fear of technological unemployment is by no means new.[42] He gives the example of the mid-1700's when a mob of worried English spinners smashed into a Mr. James Hargreave's mill and destroyed the first workable multi-spindle frames. Similar forms of labour resistance to the adoption of new technologies can be found in the history of most nations. Moreover, although new technologies often result in the replacement of unskilled labour, there are many cases whereby skilled labour is similarly affected. For example, the introduction of automatic glass-blowing machines largely destroyed the glass-blowers craft.[43].

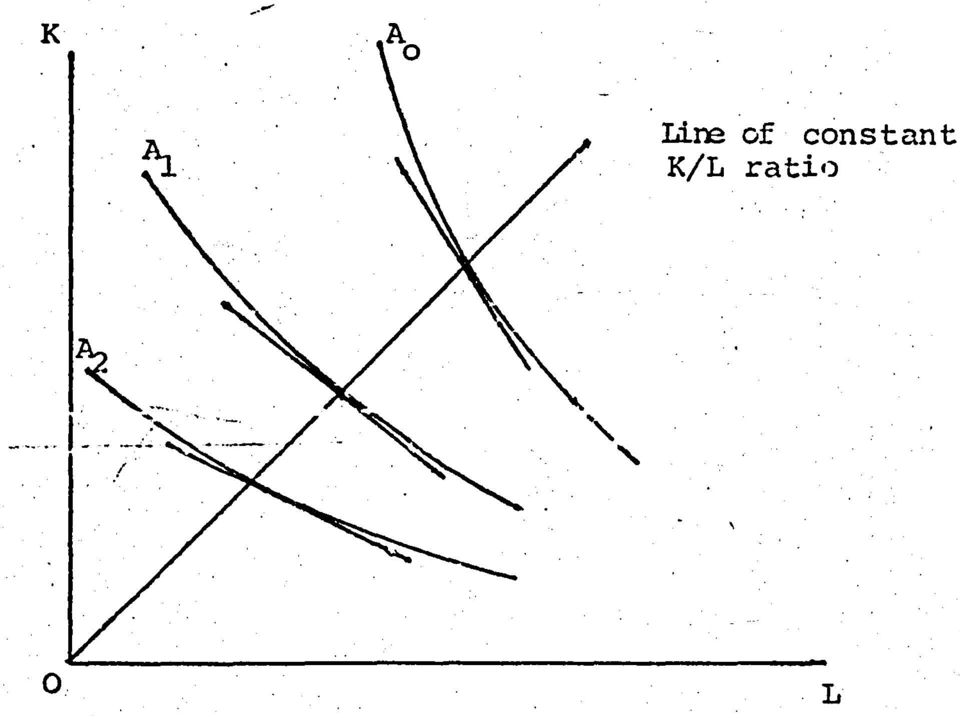
In more recent times the fear of technologically induced unemployment has been embodied in the word "automation". For example, Professor Crossman of Oxford University, addressing an international conference in 1964, predicted that automation would grow steadily in the following decades or centuries and in the end it would reach a very high figure, say 90% of the labour force, unless radical changes were made in contemporary patterns of working.[44] Mansfield has given an interesting exposition of the various responses of workers, labour unions and firms to automation.[45] However, such considerations are out of the scope of this work and we will not concern ourselves with such issues here. Suffice it to state that as noted earlier in Section 3.6, the policies adopted by labour unions do affect the rate of diffusion of a new technology.

Despite the dread of automation as far as employment is concerned, not all technological change is bound to increase unemployment mainly for two reasons : Firstly not all technological change is labour saving. Furthermore, as we shall see below, there exists considerable scope for labour/capital substitution in seemingly highly automated processes. Secondly, due to secondary effects arising out of forward and backward linkages and savings and re-investment ratios, the aggregate impact on national employment levels may not necessarily be negative. Let us look more closely at these issues.

Hicks has distinguished three types of technological progress, depending on its effect on the rate of substitution of labour and capital: These are capital-deepening, labour-deepening and neutral technological progress.[46]

To illustrate the capital deepening technological change, we refer to figure 3.1

<u>Figure 3.1: Capital-Deepening Technological Change.</u>



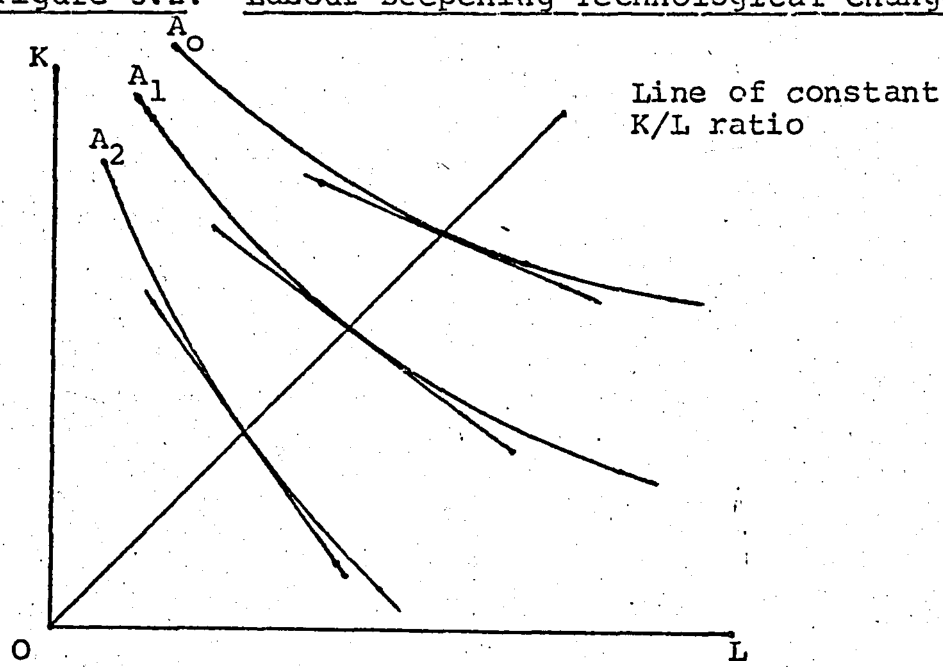
Technological change occurs when the isoquant is shifted downwards from A_o to A_1 or A_2. Such a change is capital-deepening (or capital-using) if, along a line on which the capital/labour ratio (K/L) is constant, the marginal rate of substitution of labour for capital ($MRS_{L,K}$) decreases in absolute value (or increases if the minus sign is taken into account).

$MRS_{L,K} = (\partial X/\partial L)/(\partial X/\partial K)$ = slope of the isoquant.

This means that technological progress increases the marginal product of capital (MP_K) by more than the marginal product of labour (MP_L) and that the slope of the shifting isoquant becomes less steep along any given radius.

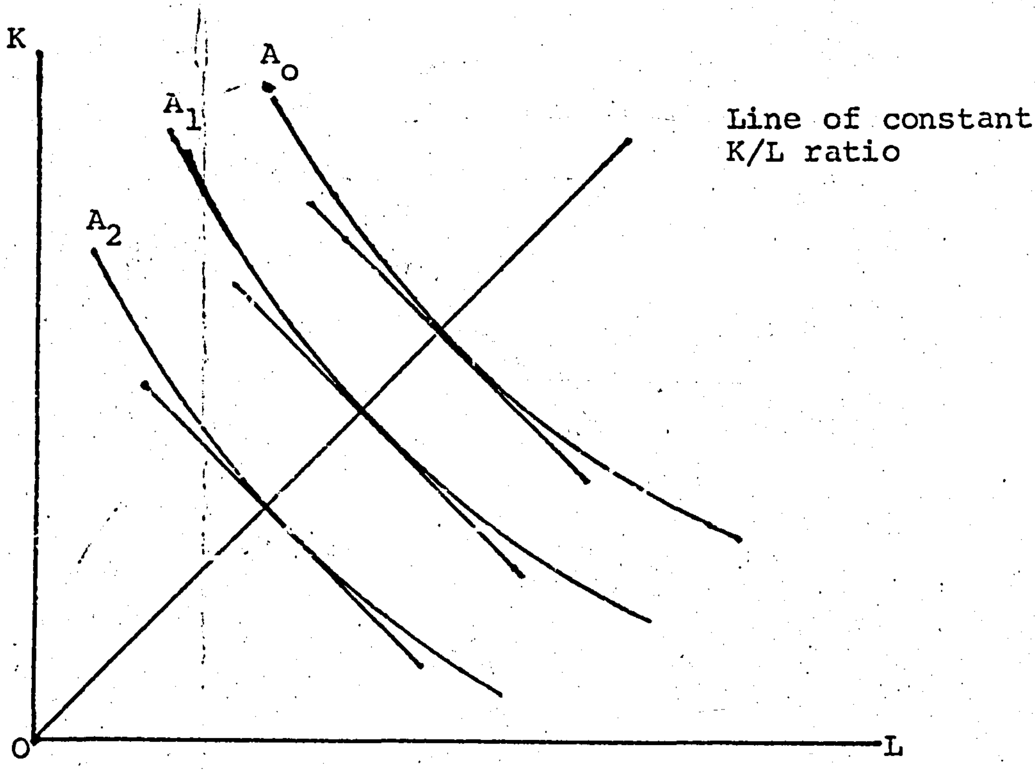
On the other hand, technological change is labour-deepening (or labour-using) if the $MRS_{L,K}$ increases in absolute value (or decreases if the minus sign is taken into account). Thus the MP_L increases faster than the MP_K and the slope of the shifting isoquant becomes steeper along any given radius. Labour-deepening technological progress is depicted in figure 3.2 below.

Figure 3.2: Labour-Deepening Technological Change



Technological progress is neutral if it increases the marginal product of both labour and capital by the same percentage so that $MRS_{L,K}$ along any radius remains constant. The isoquant shifts downwards parallel to itself. This is illustrated in figure 3.3 below.

Figure 3.3: Neutral Technological Change



It is the capital-deepening technological change that is feared most by workers and labour unions. However, the other types of technological change can also cause worker destabilisation by, for example, requiring different skills other than those possessed by the incumbent employees.

It should also be noted that the above description of various types of technological change is drawn independently of prices of the factors of production. It does not imply any actual choice based on the prices of the factors. The illustration describes the technologically possible paths of expanding output. What path will actually be chosen by the firm will depend on the prices of the factors; various considerations such as the firm attitudes towards labour and mechanization; and, the possibilities of varying the K/L ratio within the same production technology i.e. along the same isoquant or, in other word, using different techniques within the same technology.

Various studies have shown that there exists some although limited possibilities of varying the K/L ratio for each technology and therefore the possibility for ameliorating the labour displacing impact of new technology. Such evidence is very briefly reviewed below. A full review of the evidence, including the causes of adopting inappropriate technologies, is given by White.[47]

A number of studies have used developing countries data from industrial censuses to estimate the degree of substitutability between capital and labour within various technologies. All of the studies involve measurement of the elasticity of substitution in a constant elasticity of substitution (CES) production function involving labour and capital. Since the CES production function is nonlinear and cannot be estimated through ordinary least squares estimation techniques, and since data on capital is frequently not available or not considered reliable, an indirect method is used. Most studies regress the logarithm of output or usually value added per worker against the logarithm of the wage with the coefficient of the latter variable being taken as the elasticity of substitution.

The elasticity of substitution estimates have been made in about 25 developing countries for the whole of the manufacturing sector in single countries and individual sectors within manufacturing for both time series and cross sections for sectors and across countries.[48] The estimates obtained are positive, indicating that efficient factor substitutability is possible and that the fixed proportions view of given techniques may be incorrect. The estimates tend to clamp between 0.5 and 1.2 but some studies find values, appreciably above or below these values. Cross-section studies tend to find higher elasticities than do time series.

In Kenya, House obtained elasticities which were above unity;[49] Mureithi obtained elasticities of 1.20 to 1.27 in a study of firms of different sizes;[50] Maitha obtained elasticities ranging from zero to 1 but the majority were not significantly different from unity;[51] and, Harris and Todaro obtained estimates ranging from 0.234 to 1.03 but generally falling between 0.5 and 0.9.[52] Harris and Todaro note that their regression results are consistent with those obtained by other researchers for Puerto Rico, Brazil, Mexico and Uganda. In Nigeria, Oleyabi obtained elasticities ranging from 0.747 to 1.802.[53]

These studies have been seriously and severely criticised because of problems arising out of economic concepts, the data and econometric problems (see Gaude;[54] Morawetz[55]). The data is said to be bad, the CES form may not be the correct one, the time series studies may not include lags properly, the profit-maximisation assumption is questionable, the assumption of competitive markets is usually not true, all firms may not be using the same technology, the cross-country studies may not use the correct exchange rates, the cross-section studies may not be using comparable industries, the level of capital utilization is usually not held constant, labour and capital are assumed to be the only factors of production, and there are said to be problems of multicollinearity and simultaneous equation bias.

Leaving aside the data and econometric problems, one's evaluation of the usefulness of the regressions would very much depend on how one views the causation between wages and capital-labour ratios. If one believes that capital-labour ratios are efficiently flexible and that entrepreneurs do respond to factor price incentives, then the results of the regressions provide additional support for this view: that making labour more expensive and capital cheaper tends to cause factor substitution towards greater capital intensity and vice versa. On the other hand, if one believes that factor proportions are more or less fixed and that observed differences are largely due to other elements such as pressure for increased employment or that wages respond to higher levels of productivity, then the regressions may not support the claim of substitutability. In my view, both effects are probably occuring and the econometric evidence does give some support to the position that capital-labour substitution is possible and therefore the contention of fixed factor proportions as espoused by Eckaus[56] and others cannot be entirely supported. There exists, for example, considerable possibilities for factor substitution in peripheral activities such as handling, packaging and transportation and also within other processes of a given technology - given the willingness of the firm to substitute labour for capital.

We have so far dealt with the direct impact of technological change on employment which is more or less looking at the impact of technological change on employment at the microeconomic or firm level., When we look at the indirect or secondary effects of technological change and the associated multiplier effects we find that contrary to popular opinion, technological change need not necessarily result in aggregate unemployment. Changes in aggregate unemployment are governed by the growth in the aggregate demand for goods and services, the growth in the labour force as well as the growth in the output per man-hour. These factors are affected by technological change. If the rate of increase of aggregate demand equals the rate of increase in productivity plus the rate of increase of the labour force, there will be no increase in the aggregate unemployment, regardless of how high the rate of increase in labour productivity may be. There will be increases in some types of jobs and decreases in others but the total number of unemployed will not be affected. Some technological changes will stimulate strong backward linkages whereby use of the inputs for the new techology is increased and therefore employment in the industries producing the inputs will be increased and so on and so forth. On the other hand the new technology may result in an overall reduction in the prices of its products and these benefits will accrue to the consumers of the product - both households and industries using the product as an input. Hence aggregate demand and therefore employment may be increased.

How do we internalise the side effects of technological change on unemployment? Often this is done by simply describing the effects after calculating the rates of return for the project. These descriptions qualify the decision made on the basis of the rates of return and can modify policy decisions on the project considerably depending on whether the project is expected to generate high employment directly or indirectly and vice versa.

On a more quantitative approach, if the project is expected to generate strong and specific linkages with high employment rates, these linkages are incorporated as part of the technology being evaluated with the costs and benefits of the linkage projects being treated in the normal ways of project analysis. Payment to labour is treated as a benefit. For example, suppose a new crop variety is expected to generate high incomes for many small farmers in an economically depressed area (so that the benefits far outweigh the incomes foregone from existing activities) then the incomes of the small farms should be included as benefits of that research project for the crop. Of course the costs for the farmers are also taken into account. Thus the small farms enterprise becomes integrated into the evaluation of the technology.

Obviously one cannot quantify all the possible ramifications of the impacts of technology on employment. Usually where quantitative analysis is used, only the direct and immediate secondary effects are taken into account. Tertiary effects are usually described. However, a few sophisticated methods using simulation/mathematical programme techniques have attempted to take into account a considerable amount of ramifications. (For example see the study by Eddleman described in Chapter Two, Section 2.3.3(c)). Such techniques are highly demanding of data and analytical sophistication and have not yet found widespread use although as the data base becomes more adequate and as the methods are further developed, such tools may eventually be available on a "plug-in" basis.

3.9.4 Environmental Side Effects of Technological Change

Another category of side effects associated with technological progress is the effects on the environment. Some of the effects are positive, such as reduction of soil erosion. Others such as pollution of the biosphere with fertilizer and pesticide runoff may be negative. The various effects can be quite sizeable and when they are positive they should be charged to the benefit side of the project; if negative they should be charged to the cost side of the project.

However, in practise, it is not really easy to quantify the environmental effects and internalise them. Usually a description of the side effects is given as a qualification to the quantitative analysis of the project because the number of environmental side effects that can be internalized into the pricing mechanism or the costing systems of firms is quite limited. Among those that cannot be internalised are the by-products of modern industry such as traffic noise, various forms of pollution arising from the spread of sewerage and garbage and chemical wastes and various diseases of the nerves, heart and stomach arising from the pressures engendered by high technological advancement. The main reason why such effects cannot be internalised is because they are a "public bad" (along the same lines as the concept of a public good). The potential victims do not have property rights over the air space so that if they enjoyed clean conditions in their piece of air space they could sell the rights of enjoying such air to others. Secondly, they cannot demarcate such territory around themselves so that intrusion by others can be identified and appropriate legal action taken. Therefore, there exists no direct pricing mechanism for the "bad".

Attempts to quantify environmental side effects usually revolve around indirect methods such as computing how much it would cost to install antipollution devices or calculating the cost of treating individuals affected by diseases associated with certain side effects plus the output lost due to incapacitation of the individuals. Most controversy on the environmental side effects of technological change surrounds the negative side effects. It should be noted, however, that the existence of the negative side effects should not necessarily result in abandoning the new technology, as is often implied. The net benefits may be sufficiently large to compensate those who are harmed and still leave a surplus. Also with appropriate policies, the effects may be minimised or eliminated.

3.9.5 Other Side Effects of Technological Change

Other side effects of technological change include technology transfer to other countries in the form of books, articles, conferences/seminars and personnel associated with the research project. Training and manpower development are also important spin-offs of technological change. Workers learn and perfect new skills and accumulate knowledge which improves their efficiency. In some institutions, particularly higher institutions of learning, research and training go together so that the benefits of R&D are passed simultaneously to manpower development programmes. Other side effects also include the quality of goods and services offered such as better and more food leading to improvement of the nutritional and health status of the people.

All these side effects should be noted and described. However, in some cases, attempts have been made to internalise them quantitatively (For example see the Nutritional Impact approach to evaluating R&D described in Chapter Two, Section 2.2.5).

There is also a special aspect of the output of R&D which is sometimes referred to as "the benefits of failure". Investments can be put into R&D for many years but without achieving the objectives of the programme. However, knowledge is generated and even alternatives which cannot work are eliminated although the successful alternative is not yet achieved. Clearly in this case, some knowledge has been generated. Then there arises the problem of how to treat such results which may be called negative results or the benefits of failure. Such benefits must be taken into account. The best way to handle such benefits is by the cost-effective approach whereby a descriptive or cost-minimisation approach is used.

Footnotes to Chapter Three

1. UNESCO, 1980. p. 742; OECD, 1976. pp. 19-32.

2. Andrews, 1979. pp. 45-7.

3. Schuh and Tollini, 1979. p.8.

4. *ibid.*, p.8.

5. *ibid.*, p.8.

6. Evenson and Kislev, 1975. pp 58-77.

7. Flores - Moya, Evenson and Hayami, 1978. pp.591-607.

8. Dixon, 1960. pp 209-21.

9. Mansfield, 1968b. p. 119.

10. See, for example, Heyer, 1976. pp 323-7; Gsaenger and Schmidt, 1977; Schmidt, 1979; and Republic of Kenya 1966 and 1973 Reports on the Commissions of Enquiry on Maize.

11. Heyer and Waweru, 1976. pp 202-5.

12. Scobie, 1979. p. (ii); Wharton, 1979. pp 464-76.

13. Squire and van der Tak, 1975. p 59.

14. UNIDO, 1972.

15. Little and Mirrlees, 1974; Squire van der Tak, 1975.

16. OECD, 1968.

17. Irvin, 1978. p. 87.

18. OECD, 1968.

19. Mishan, 1975. pp 84-5.

20. Scott, 1974. p. 170.

21. Gittinger, 1972. p. 46.

22. Irvin, 1978. p. 121.

23. Harris and Todaro, 1970. pp. 126-42.

24. Lal, 1973. pp. 122-26.

25. Harberger, 1971. pp. 559-79.

26. Cited in Irvin, 1978. p. 122.

27. Kalbermatten et al, 1980.

28. Roemer and Stern, 1975. pp 68-70.

29. *ibid.*, p. 57.

30. Arrow, 1965; Arrow and Kurz, 1970.

31. Roemer and Stern, 1975. pp 52-3.

32. Scott, 1974. p. 170.

33. *ibid.*, p. 171.

34. Davis and Kamien, 1977. p. 155.

35. Wharton, 1969. pp 464-76.

36. Irvin, 1978. p. 140.

37. Cited in Irvin, *op. cit.*, p. 141.

38. *ibid.*, p. 141.

39. *ibid.*, p. 141.

40. *ibid.*, p. 142-3.

41. *ibid.*, p. 141.

42. Mansfield, 1968b. p.134.

43. *ibid.*, p. 134.

44. *ibid.*, p. 135.

45. *ibid.*, pp.134 - 161.

46. Hicks, 1946.

47. White, 1978. pp 27-59.

48. *ibid.*, pp 32-3.

49. House, 1973. pp 75-78.

50. Mureithi, 1974. p. 11.

51. Maitha, 1973. pp 43-52.

52. Harris and Todaro, 1969. pp 29-46.

53. Gaude, 1975. p. 144.

54. <u>ibid.</u>, pp 35-58.

55. Morawetz, 1976. pp 11-15.

56. Eckaus, 1955. pp 539-65.

APPENDIX 3.1

RELATIONSHIPS AMONG THE UNESCO R & D PERFORMANCE MEASURES[a]

	A	B	C	D	E	F	G	H	I	J
A. Published output										
B. Patents & prototypes	-.02[b]									
	.16									
C. Reports & Algorithms	-.06	.34								
	.16	.21								
D. General contribution	.30	.08	.02							
	.29	.17	.09							
E. Recognition	.51	-.04	-.11	.55						
	.45	.11	.08	.56						
F. Social effectiveness	.10	.05	.14	.32	.09					
	.14	.07	.12	.35	.16					
G. Training effectiveness	.26	-.10	-.16	.30	.35	.09				
	.14	.05	.04	.31	.24	.19				
H. Administrative effectiveness	.07	-.05	-.06	.25	.15	.19	.12			
	.06	-.02	-.05	.24	.15	.17	.13			
I. R & D effectiveness	.17	.22	.10	.67	.44	.29	.33	.21		
	.21	.22	.10	.68	.48	.33	.40	.21		
J. Applications effectiveness	-.18	.17	.23	.13	-.04	.26	-.08	.08	.32	
	-.03	.06	.08	.17	.10	.24	.10	.09	.33	
K. General R&D effectiveness	.22	.20	.09	.82	.51	.32	.35	.24	.97	.29
	.25	.22	.10	.82	.54	.36	.41	.24	.97	.31

[a] All measures in the exhibit are composites; measures D-K combine information from unit heads, staff scientitsts, and external evaluators

[b] Figures show Pearson rs. Upper figure is based on unadjusted measures; lower figure, on measures adjusted to remove effects attributable to type of unit.

Source: Andrews, F.M. (ed.) 1980. Scientific Productivity: The Effectiveness of Research Groups in Six countries. London, Cambridge University Press. Exhibit 2.4, p. 46.

CHAPTER FOUR

THE EMPIRICAL INVESTIGATIONS

4.1 Methodology and Data

In our analysis we use the production function approach which was discussed in Chapter Two, coupled with a computation of a stream of net benefits and the internal rate of return. Later, a discussion on externalities is undertaken.

Two forms of production functions are used, namely, the Cobb-Douglas (log-linear) and the linear types of production functions and a comparison is made on which production function fits the data best. These forms of production functions lend themselves to easy manipulation and interpretation. Real research expenditure lags of up to 15 years are included. The coefficients of the research expenditure variable in the functions can be interpreted as indicating the percentage return to a 1 percent increase in R & D expenditures or the elasticity of production with respect to research expenditures for a log-linear production function, and the return to one pound invested in wheat R&D for a linear function. This allows us to compute the research expenditure share of the wheat produced annually and therefore the stream of gross benefits arising from research. The gross benefits minus the research expenditures gives us the stream of net benefits or net cash flow. Then by iteration and interpolation, we can compute the Internal Rate of Return, that is, that rate of return that will reduce the stream of net benefits to a zero Net Present Value.

The specific variables used in the study are land area in hectares, rainfall in decimetres (millimetres/100) and deflated (real) research expenditures in Kenya Pounds regressed on wheat production in tonnes. The rainfall is given in decimetres rather than millimetres because in the preliminary run of the data it was found that by using multiples of 100 in the log-linear analysis it would be possible to increase the number of significant figures in the rainfall coefficient from 1 to 4 significant figures. This makes it possible to see changes in the coefficient that would be hidden in rounding one significant figure. All data is given on a yearly basis although it would be interesting to investigate the outcome of the results using rainfall figures for the wheat growing months only.

It would have been desirable to include fertilizers as one of the explanatory variables but the relevant data was lacking. While information on total national fertilizer consumption is fairly easily available, no information is available on fertilizer consumption by crop. Discussions with the older wheat farmers in the field indicated that the use of fertilizers in wheat started around 1949 with the use of cotton seed ash. Shortly afterwards, the use of cotton seed ash was abandoned as it was found to introduce undesirable weeds into the wheat fields. Cotton seed ash was then replaced by the use of rock phosphate from Tororo, Uganda which was also phased out fairly quickly by the use of commercial fertilizers which were introduced into wheat growing in the early fifties. Looking at the trend of the data in yields per hectare in Table 4.1 and Figure 4.3, we notice a steady rise throughout the series we are considering. There is no indication that there was a singularly spectacular change in the general trend of rising yields per hectare from 1949 onwards when fertilizer use started. Given the lack of data, this observation and the fact that fertilizer use would be of relevance to only about half the series we are considering, minimises the effect of fertilizer as an omitted variable and allows us to assume that any fertilizer effect will be caught in the residual. See also the discussion in Section 4.2.2 on the possibility that the fertilizer effect and other inputs into land might further be caught in the area (land) coefficient, thus further minimising the consequences of the omission of fertilizer as a variable.

Various data sources were used to arrive at the values for the different variables used. The most important sources and how the values were arrived at are indicated below. However, in presenting the data in this section, it should be noted that an extensive discussion is required on how the Research Expenditures and the Capital Formation Deflator were arrived at. It has therefore been decided that in order to keep this Chapter precise and compact, the discussion on these two variables should be presented in the appendix. Therefore, for a full treatment of these two variables, the reader is referred to Appendix 4.1 for Research Expenditures and Appendix 4.2 for the Capital Formation Deflator (CFD). Only an outline of the methods used with regard to these two variables is included here below.

Wheat Production and Area Planted

Yearly wheat production data and area planted with wheat was obtained from the article by Pinto and Hurd,[1] Annual Reports of the former Kenya Wheat Board and the current records of the National Cereals and Produce Board. Gaps for the war years 1939 and 1940 were filled with estimates from the Kenya Statistical Abstracts on production and records of correspondences in the Kenya National Archives on yields per acre.

Rainfall

The Njoro area was assumed to be reasonably representative of the wheat growing areas and therefore rainfall figures for the Njoro area were used. These figures were supplied by the National Plant Breeding Station (NPBS), Njoro for the rainfall station at the NPBS for the years 1930 to 1982. There were no figures available for the NPBS before 1930 and therefore, for the years 1922 to 1930, figures were used for another station at Olgilgei in the Njoro area. These figures were supplied by the Kenya Meteorological Department. For the year 1921, the rainfall figure for Nakuru Railway Station (15 km from the NPBS) was used, also supplied by the Kenya Meteorological Department.

Research Expenditures

Research Expenditures were determined from the following main sources and the best likely figures chosen:

(i) Kenya Department of Agriculture Annual Reports: 1921 to 1937. The annual reports stopped reporting on expenditures from 1938 onwards.

(ii) Colony and Protectorate of Kenya Estimates of Revenue and Expenditure: 1926 to 1954. From 1955 on wards expenditures for Plant Breeding Services and hence wheat research expenditures were not recorded separately in the estimates.

(iii) Development and Reconstruction Authority (DARA) Annual Reports: 1945 to 1951. This was an authority started in 1945 after the Second World War for reconstruction against the effects of the war. Apparently it disappeared around 1951 after it outlived its usefulness.

(iv) The Colony Development and Welfare Fund (CD&WF) Annual Reports and correspondences in files at the Kenya National Archives: 1954 - 1956.

(v) NPBS, Njoro records of expenditure and AIEs (Authority to Incure Expenditure): 1957 - 1980. It is reported in archival records that there was a fire outbreak at the NPBS, Njoro in 1953/54 and therefore the records at the station before 1955 were destroyed.

(vi) Wheat Board of Kenya Annual Reports: 1963-1976.

(vii) End of Year Ledgers of the Ministry of Agriculture: 1974 to 1982. It is unfortunate that these Ledgers are destroyed after every few years: they contain accurate information on the actual expenditures of every research station under the Ministry. It is not possible to get such accurate information from the stations themselves because they control only part of their budget, the rest of the budget on salaries and allowances being controlled at the Ministry Headquarters. Such information is easily lost after a few years when the Ledgers are destroyed.

(viii) DANIDA, CIDA, NPBS Njoro records and the 1976 UNDP Compedium on Development Assistance to Kenya.

(ix) Kenya Government Appropriation Accounts and Audit Reports.
See Appendix 4.1 on the full determination of the Research Expenditures.

The Deflator

A capital formation deflator was used to calculate the real research expenditures (1976 = 1.000). The deflator was calculated by first computing a cost of living index (CLI) from 1921 to 1982 from data from Cowen,[2] Kenya Statistical Abstracts and the East African

Economic and Statistical Reviews. The CLI was then regressed on a Capital Formation Deflator (CFD) for 1952-1979 obtained from unpublished papers by Ryan.[3] The regression equation was then used to estimate the CFD for the other years i.e. 1921 to 1951 and 1980 to 1982. See Appendix 4.2 on the full determination of the CFD.

The CFD was chosen over other possible types of deflators because Research Expenditures are here regarded as capital investments.

Social Prices

Before proceeding to the analysis of the data, the practical aspects of the attempts which were made to apply social prices to this project are discussed. A fairly extensive exposition on the theory of social pricing of projects (Shadow Prices and Accounting Ratios) was given in Chapter Three, Section 3.8. However, despite the fairly clear knowledge of the theoretical aspects of social pricing, the practical problems of applying social pricing are enormous especially for projects involving long time series data such as this one under consideration. This is because of various reasons.

First it is clear from the theoretical discussion that social prices can only be determined within the context of prevailing economic conditions. The conversion factors therefore change over time. This would require that either the conversion factors have been worked out by someone or an agency over the years as time progresses or that the economic data for those years is available in sufficient accuracy to be able to compute the conversion factors at any one time. We find that either case is not tenable especially in developing countries, Kenya included. For one, the amount and accuracy of economic data that would be required to compute meaningful conversion factors is such that it is either simply not available or it would require a major research undertaking to generate. In the case of Kenya, an attempt was made in 1978 to compute Accounting Price Ratios for social pricing.[4] While such conversion ratios could be applied to prices for the last one decade it may not make sense to extend their use beyond that period.

Secondly, the use of social prices is a fairly recent phenomenon and, in practical terms, it has not yet found widespread acceptance in the practical planning and management of economies. For example, in Kenya, the Ministry of Finance and Economic Planning does not use social pricing in its projects appraisal. Usually, a description of the externalities is undertaken and no attempt is made to internalise these by social pricing.

For these reasons, particularly the first one, it was therefore found that it would be meaningless or impracticable to try to apply social pricing to data stretching from 1921 to 1982 within the Kenyan situation. Instead, a description of the externalities is undertaken in Section 4.3 below. However, we note that social pricing can certainly be developed now for current and future use as well as for the immediate past, but it hardly lends itself for application to earlier years within the Kenyan context.

The basic data is presented in table 4.1 and its analysis follows.

4.2 Estimation of the Production Functions and Rates of Return to Research Expenditures.

4.2.1 The General Data Trend

The general trend of the data is exhibited in figures 4.1 to 4.9 where the various variables are presented in Bar Charts as well as scatter diagrams to give a visual indication of the relationships between these variables. Figures 4.1 and 4.2 respectively indicate that total wheat production and total area have been rising steadily over the years. And so has the yield in tonnes per hectare as indicated in figure 4.3. Therefore apart from increases in total production due to mere increases in area there have been other factors contributing to the increase in total production through increases in the wheat yields per hectare.

When we look at the general trend in research expenditures we note that like the production, area and yield/hectare, the research expenditures have been rising but with notable reductions around 1963 and 1975/6/7 in real research expenditures. (Fig. 4.5 and 4.6). For 1963 this could be explained by the fact that this was a transition stage from the colonial administration to an independent Kenya. Records indicate that before 1954 capital developments at the NPBS Njoro were minimal.[5] Heavy investments in Njoro started in 1953/54 but this investment momentum seems to have been checked at independence. However there was a fairly quick recovery until 1975 when the situation suddenly changed. This change which resulted in sudden reduction of real research expenditures could be explained by the fact that 1975/6/7 were the years immediately after the oil price crisis of 1974. Apparently the research expenditures have not recovered fully in the inflation - ridden post-1974 period.

The scatter diagrams in figures 4.7 and 4.8 respectively indicate that there is an increasing relationship between yield per hectare and the current and deflated research expenditures. However, while the diagrams indicate this relationship to be more

Table 4.1: Data Li

Case No.	Year	Wheat Prod. (Tonnes)	Yield (Tonnes/Ha)
1	1921	3357.69	0.61
2	1922	3362.32	0.54
3	1923	5297.18	0.63
4	1924	5534.26	0.57
5	1925	7258.19	0.59
6	1926	10959.29	0.58
7	1927	15820.72	0.52
8	1928	20712.84	0.62
9	1929	26634.09	1.04
10	1930	17629.73	0.63
11	1931	7878.53	0.45
12	1932	5742.10	0.47
13	1933	13061.94	0.92
14	1934	16235.58	0.92
15	1935	13775.54	0.65
16	1936	14074.64	0.61
17	1937	16664.43	0.72
18	1938	17246.28	0.96
19	1939	20360.00	0.90
20	1940	20360.00	0.90
21	1941	21604.04	0.52
22	1942	37652.22	0.76
23	1943	64725.96	1.14
24	1944	53870.37	0.83
25	1945	76366.07	1.06
26	1946	74283.66	0.94
27	1947	63289.51	0.81
28	1948	94559.30	1.17

isting

Area (Ha)	Rainfall (mm/100)	Current Research Exp. (K£)	Deflator	Deflated Res. Exp. (K£)
5547	0.6507	1675.	0.4820	3475.
6249	0.7665	1538.	0.4586	3354.
8468	1.1354	2545.	0.4399	5785.
9718	0.8051	1597.	0.4212	3792.
12404	1.0027	2218.	0.4212	5266.
18873	1.1918	3129.	0.4165	7513.
30416	0.7165	1999.	0.3838	5208.
33595	0.7315	2511.	0.3510	7154.
25603	0.6653	2472.	0.3042	8126.
27885	1.2812	2699.	0.2621	10298.
17483	0.8245	2500.	0.2527	9893.
12196	1.0502	2435.	0.2434	10004.
14175	0.7671	2320.	0.2293	10118.
17619	0.5294	2354.	0.1966	11974.
21115	0.8703	2290.	0.1872	12233.
23251	1.0760	2347.	0.1732	13551.
23155	1.1286	1769.	0.1778	9949.
17922	0.8480	1831.	0.1732	10572.
22670	0.6241	2166.	0.1919	11287.
22670	0.9150	2048.	0.1872	10940.
41715	1.1701	1991.	0.2012	9896.
49540	1.0575	2192.	0.2200	9964.
56661	0.8819	2206.	0.2246	9822.
64869	0.8302	2540.	0.2293	11077.
72067	0.8859	3619.	0.2340	15466.
78949	0.8571	2680.	0.2340	11453.
78352	1.2902	2459.	0.2434	10103.
80625	0.8404	2196.	0.2527	8690.

Case No.	Year	Wheat Prod. (Tonnes)	Yield (Tonnes/Ha)	Area (Ha)	Rainfall (mm/100)	Current Research Exp. (K£)	Deflator	Deflated Res. Exp. (K£)
29	1949	103569.02	1.15	90179.	0.7599	3220.	0.2668	12069.
30	1950	130588.20	1.24	105734.	0.7184	2981.	0.2714	10984.
31	1951	117355.55	0.96	121870.	1.2780	4100.	0.3136	13074.
32	1952	111653.03	0.96	116484.	0.6343	5449.	0.2499	21805.
33	1953	119511.60	1.02	117057.	0.6071	5731.	0.3583	15995.
34	1954	138507.14	1.18	117543.	1.0805	20715.	0.2697	76808.
35	1955	111987.64	0.80	140196.	1.0318	15921.	0.2864	55590.
36	1956	114927.83	0.95	121611.	1.1885	15043.	0.2905	51783.
37	1957	100797.44	0.99	101680.	0.8076	31714.	0.2999	105749.
38	1958	96827.76	0.98	98959.	1.3136	29652.	0.2999	98873.
39	1959	128204.88	1.22	105221.	0.8839	50496.	0.3020	167205.
40	1960	109497.90	1.06	102853.	0.8202	50769.	0.3041	166948.
41	1961	84356.29	0.90	93370.	1.2369	39929.	0.3114	128224.
42	1962	119788.90	1.15	104224.	1.1059	28204.	0.3280	85988.
43	1963	130088.98	1.10	118126.	1.0614	13185.	0.3374	39078.
44	1964	144257.50	1.19	121217.	0.9613	13339.	0.3374	39535.
45	1965	133312.74	1.01	131396.	0.5529	15910.	0.3520	45199.
46	1966	180652.50	1.31	137872.	0.9503	46889.	0.3675	127589.
47	1967	240969.58	1.59	151771.	0.6987	52562.	0.4047	129879.
48	1968	224528.61	1.34	167392.	1.1624	51491.	0.4105	125435.
49	1969	217436.49	1.32	164609.	0.8002	61001.	0.4191	145552.
50	1970	178443.61	1.39	128103.	1.1445	72496.	0.4439	163316.
51	1971	170316.18	1.48	115188.	0.9142	76082.	0.4613	164930.
52	1972	149585.76	1.43	104494.	0.8382	82151.	0.5050	162675.
53	1973	137884.32	1.28	107427.	0.7413	75423.	0.5804	129950.
54	1974	157832.73	1.50	105183.	1.0764	72756.	0.7276	99995.
55	1975	175709.07	1.50	117333.	1.1932	52338.	0.8506	61531.
56	1976	175930.38	1.47	119746.	0.6986	55062.	1.0000	55062.
57	1977	170865.27	1.24	137871.	1.1203	61303.	1.0848	56511.

Case No.	Year	Wheat Prod. (Tonnes)	Yield (Tonnes/Ha)	Area (Ha)	Rainfall (mm/100)	Current Research Exp. (K£)	Deflator	Deflated Res. Exp. (K£)
58	1978	165271.59	1.39	119062.	1.2730	141303.	1.2084	116934.
59	1979	114707.52	1.74	65862.	0.9093	147139.	1.3605	108151.
60	1980	204498.09	2.05	99991.	0.9093	163649.	1.5959	102543.
61	1981	234546.21	2.25	104401.	0.9393	187371.	1.9328	96943.
62	1982	227628.45	2.02	112952.	0.9566	231109.	2.2183	104183.
MEAN		94683.15	1.05	78400.	0.9316	32916.		53920.
ST.DEV.		71925.89	0.40	47784.	0.2059	49679.		54979.

Source: See Section 4.1 on sources.

Figure 4.1: Time Series Chart for Wheat Production (Tonnes)

re 4.2: Time Series Chart for Area Under Wheat (Hactares)

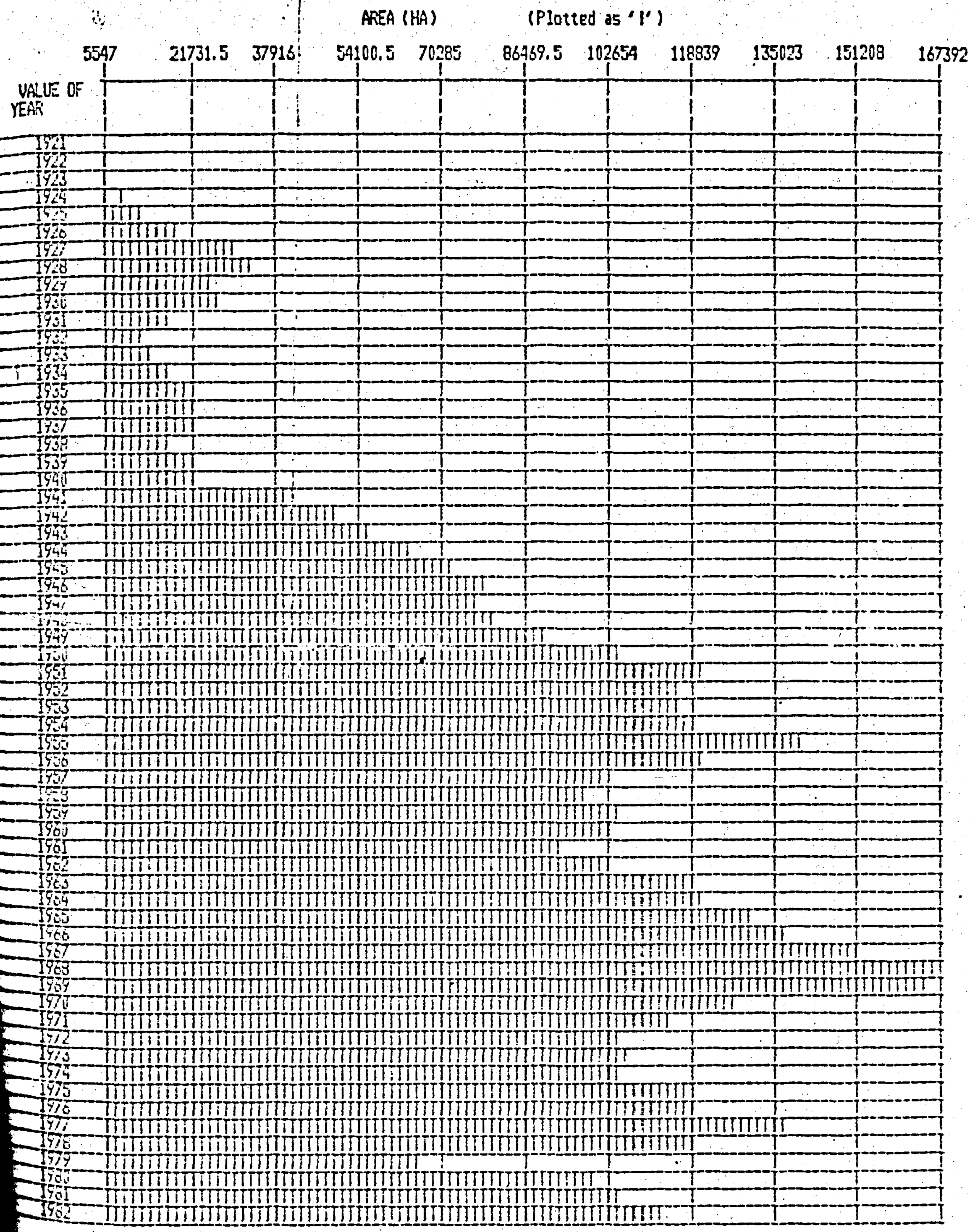


Figure 4.3: Time Series Chart for Wheat Yields per Hectare (Tonnes/Ha)

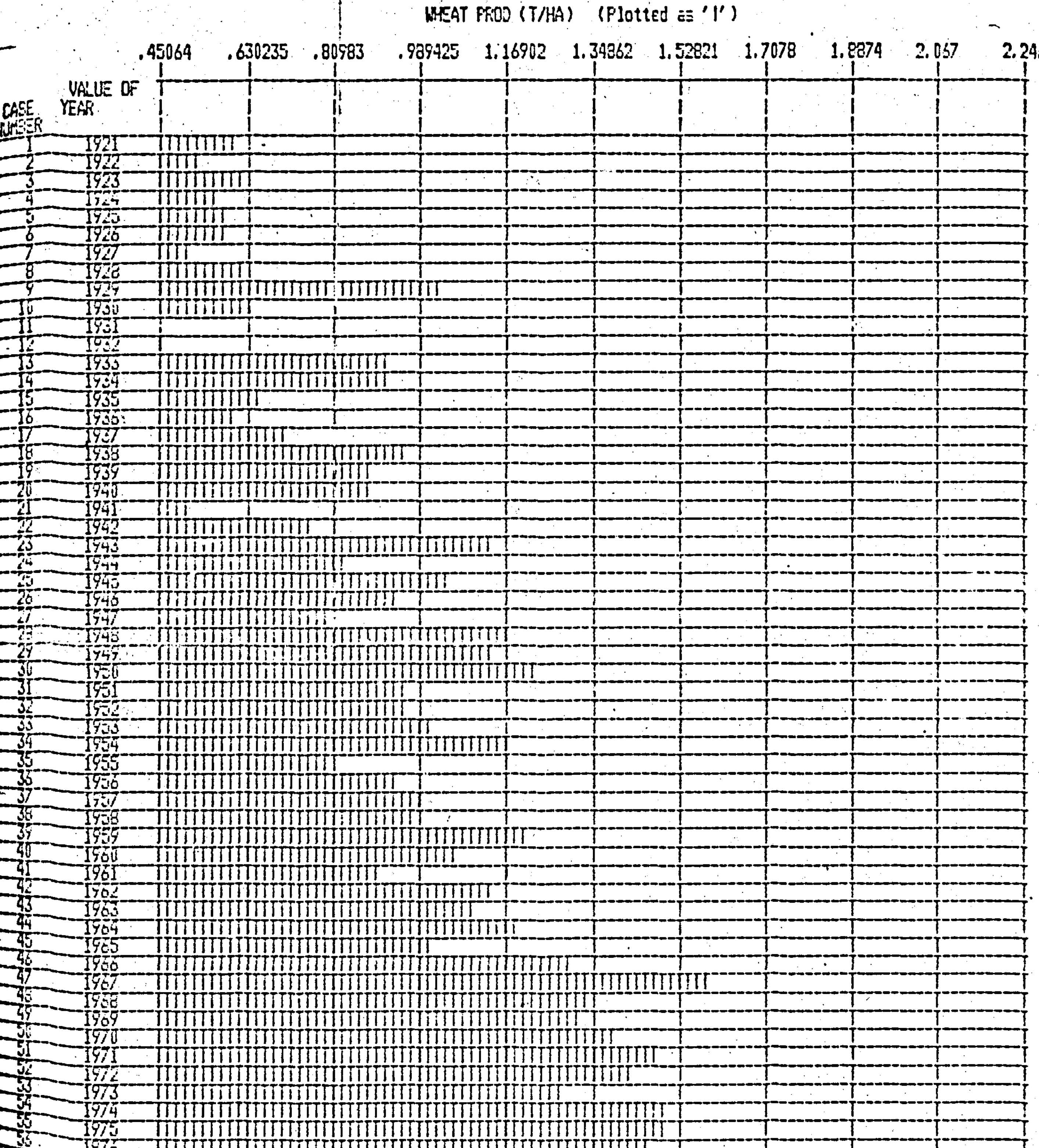
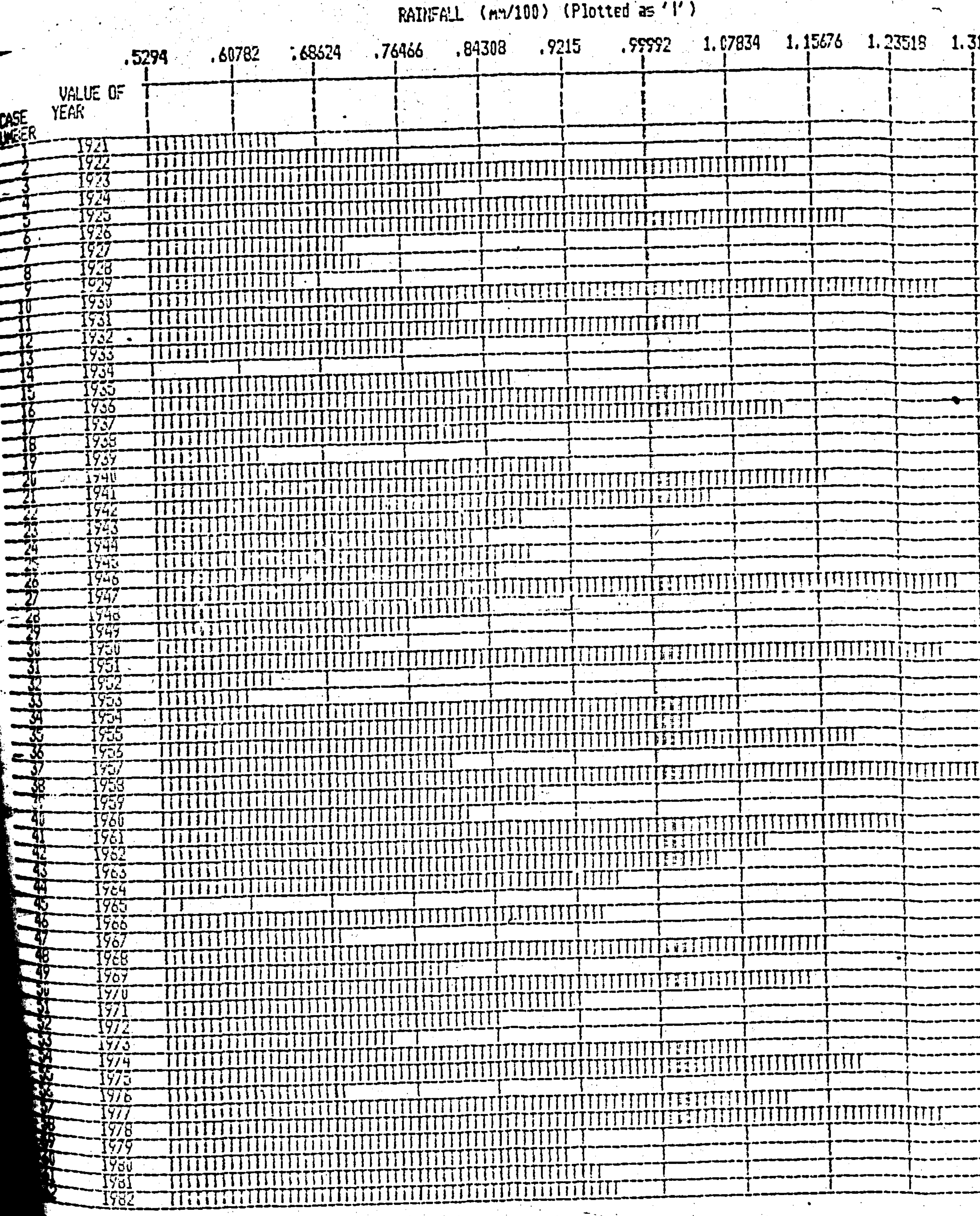


Figure 4.4: Time Series Chart for Rainfall (mm/100)



igure 4.5: Time Series Chart for Current Expenditures on Wheat Research (K£)

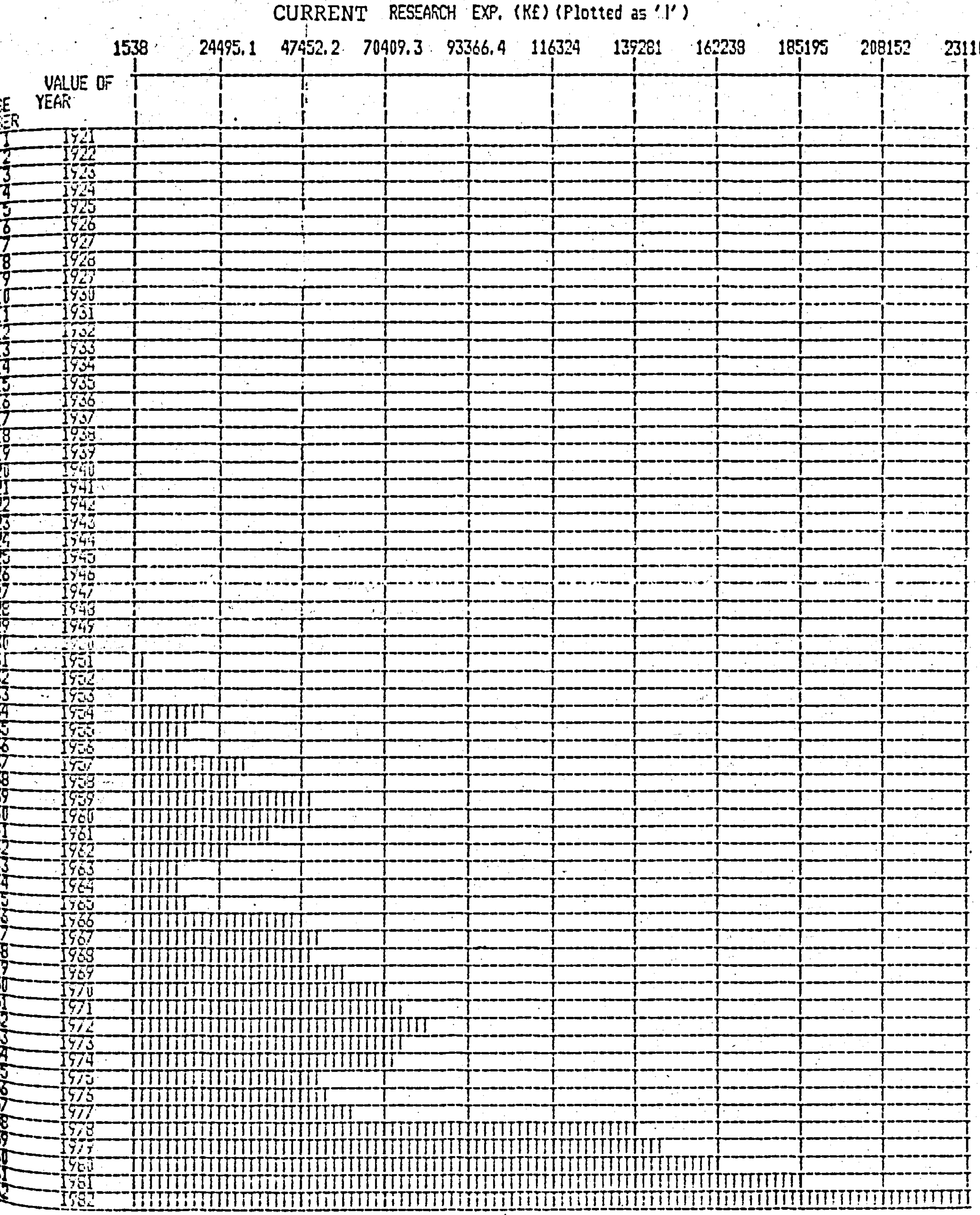


Figure 4.6: Time Series Chart for Real (Deflated) Expenditures on Wheat Research

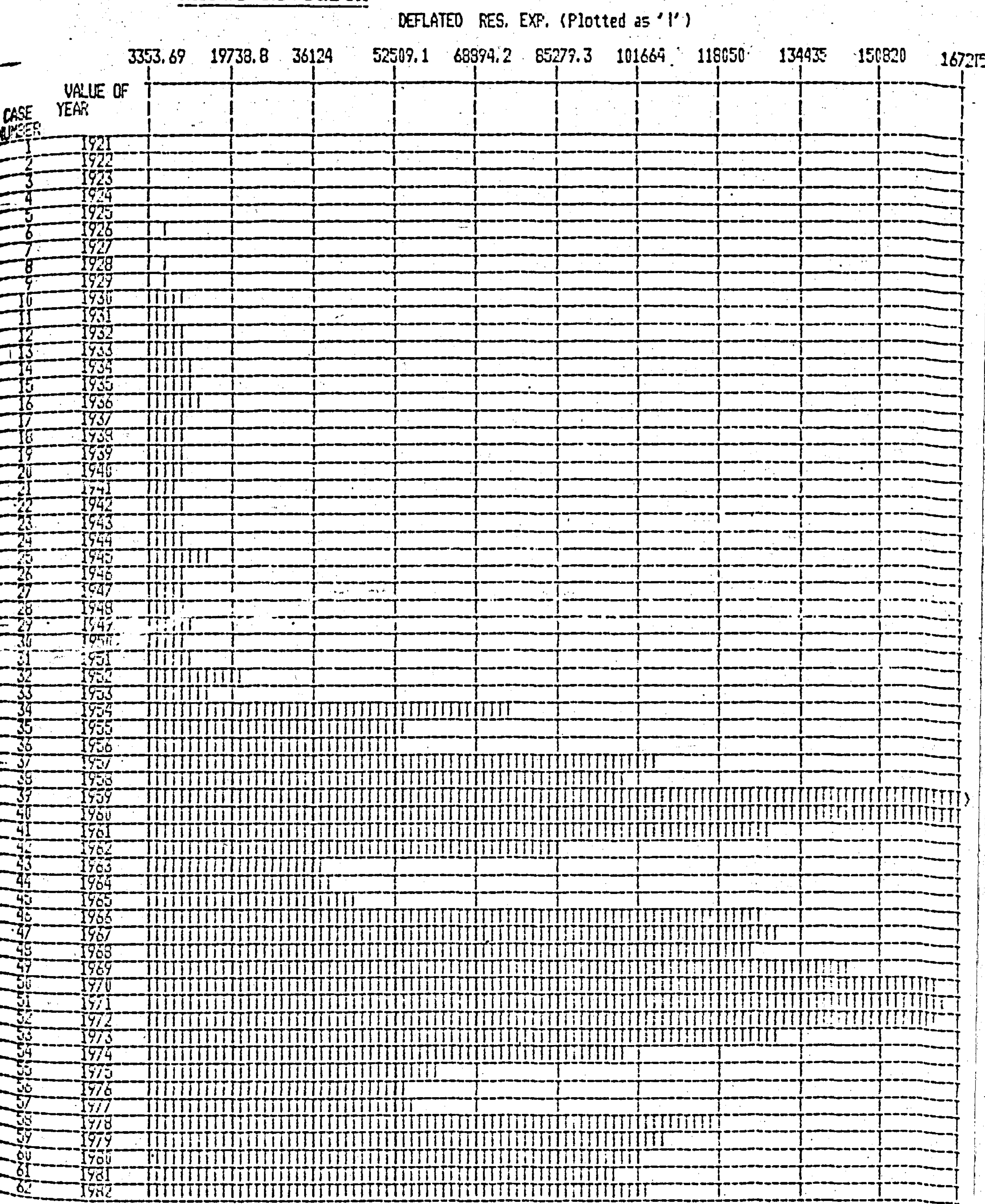


Fig. 4.7: Scatter Diagram: Yield per Ha vs. Current Research Expenditures

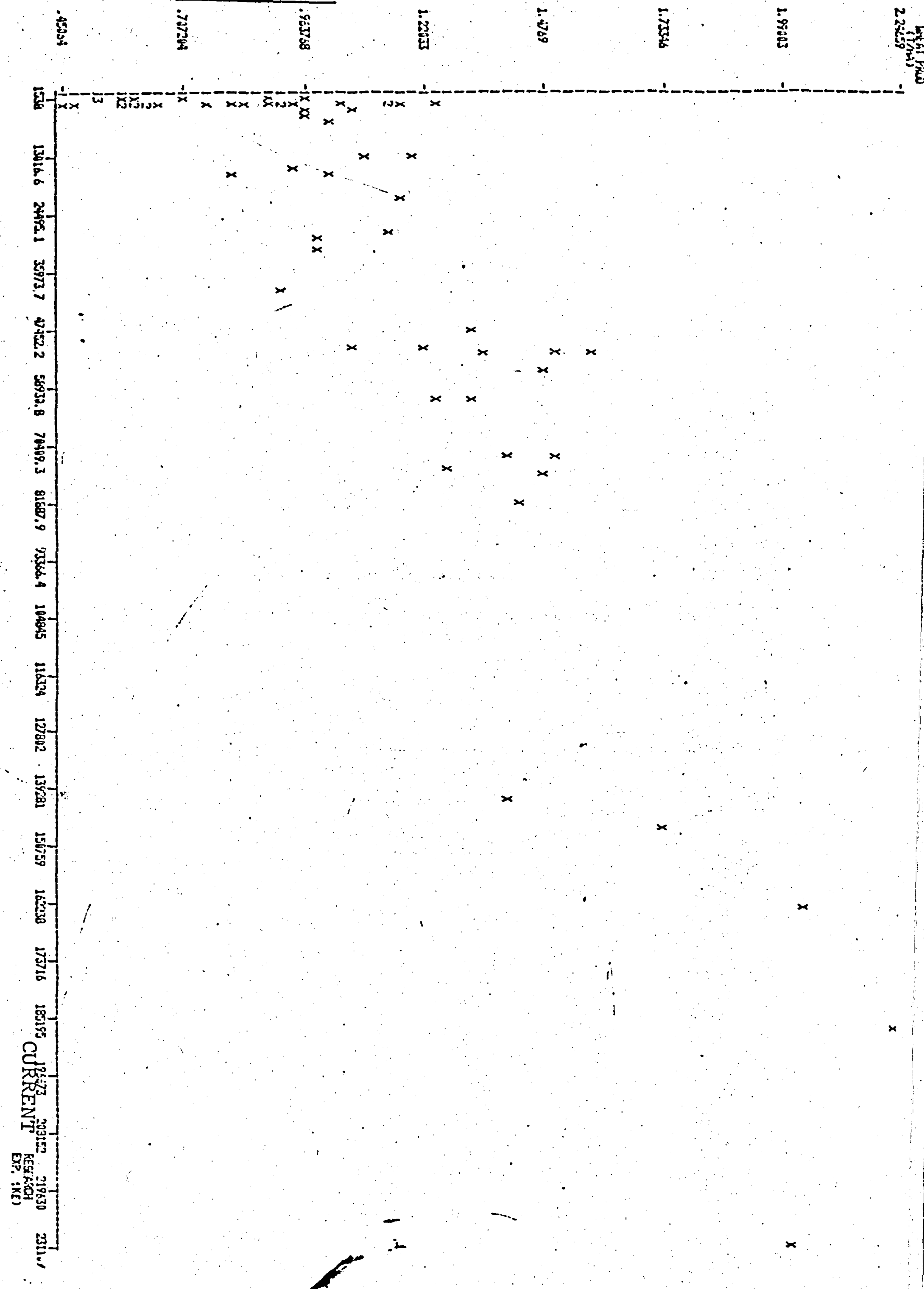


Figure 4.8: Scatter Diagram: Yield per Ha vs. Real (Deflated) Research Expenditures

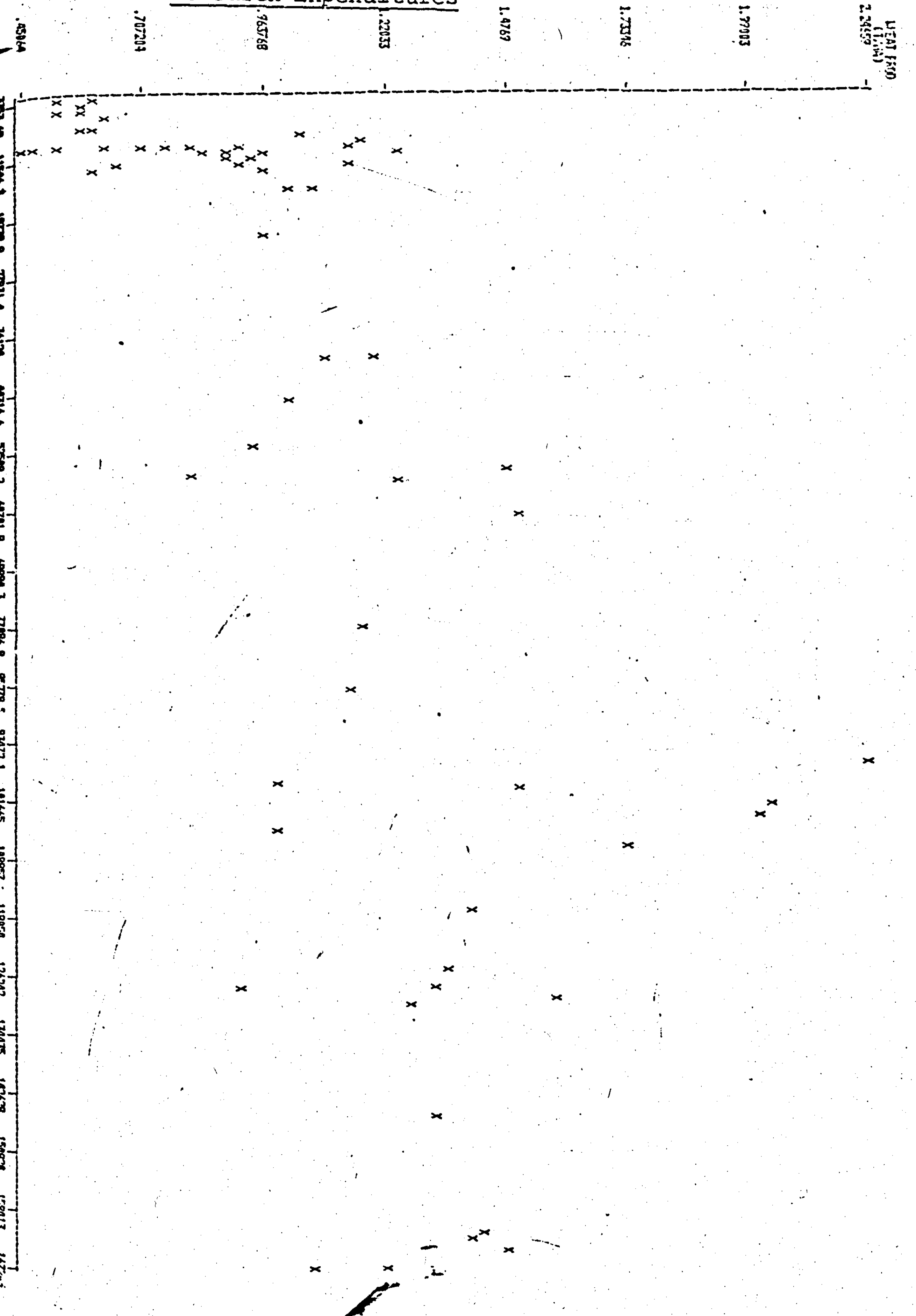
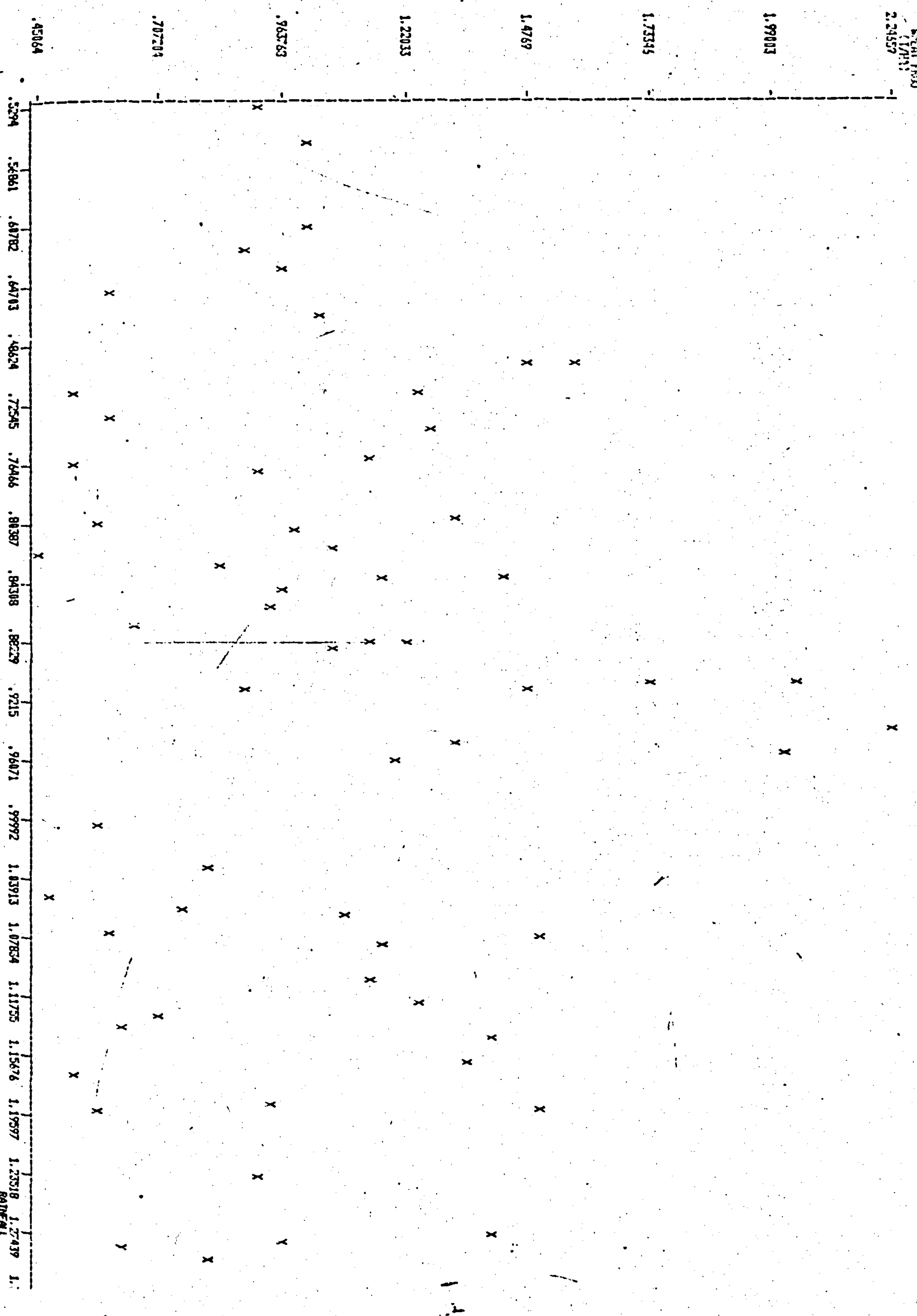


Figure 4.9: Scatter Diagram: Yield per Ha vs. Rainfall



linear for the current expenditures, a straightforward linear relationship is not indicated for real expenditures. Since we shall be working with deflated research expenditures this will require us to explore later the relationship on the basis of other models, specifically on a log-linear basis in our regression analysis.

We then explore through another scatter diagram 4.9 the relationship between yields i.e. tonnes per hectare and rainfall. This relationship is not clear in the scatter diagram but there is an indication that the yields could first be rising and then falling at the higher levels of rainfall. The scatter diagram indicates that the decline in yields commences at about 950 mm rainfall. The possible reasons for this will be discussed later but meanwhile we note that this means there will be need to look at other models other than linear for this relationship, again such as the log-linear realtionship.

4.2.2 <u>The Log-Linear Analysis</u>

The results of estimating the log-linear production function are shown in Table 4.2 which shows the log-linear parameter estimates for functions incorporating various research expenditure lags of up to 15 years. The production coefficients, the standard errors (in brackets), and the multiple coefficients of determination (R^2) are presented. The latter two are adjusted for the degrees of freedom (DF). The significance of the production coefficients at the 1 and 5 percent levels are indicated.

Turning to the coefficients, we notice that there is a general rise and then a tendency to fall as one proceeds from lag 1 to lag 15. The area and research coefficients are indicated to be strongly significant throughout while the significance of the rainfall coefficients is generally low. The research expenditure coefficients look reasonable in magnitude and sign. However, the area and rain coefficients need some further considerations.

The area coefficient is greater than unity, indicating that there could be increasing returns to scale to the area variable. It is not clear why this is so but it could indicate use of better technology over time as more land is put into wheat production over the years. The opening up of larger pieces of land could also be associated with the wealthier and more progressive farmers who may be using better technology in farming practices and inputs. In other words, if we assume that land (or area) includes all the investments put into it as Hayami and Ruttan do,[6] such as clearing, reclamation, drainage, fencing, tillage and even fertilization and other developments,

Table 4.2 The Log-Linear Regression Parameter Estimates

Lags of Res. Exp.	Constant	Log Area Coefficient	Log Rainfall Coefficient	Log Res. Exp. Coefficient	R^2	Degrees of Freedom(DF)
0	-3.288	1.155xx (.050)	-0.304 x (.129)	.151xx (.038)	.969	58
1	-3.359	1.178xx (.051)	-0.287x (.134)	.134xx (.037)	.965	57
2	-3.356	1.166xx (.051)	- .329x (.138)	.147xx (.035)	963	56
3	-3.474	1.183xx (.051)	- .276x (.132)	.140xx (.034)	.961	55
4	-3.472	1.183xx (.053)	- .301x (.133)	.142xx (.034)	.958	54
5	-3.457	1.188xx (.055)	- .245 (.135)	.134xx (.034)	.954	53
6	-3.412	1.180xx (.056)	- .259 (.137)	.140xx (.033)	.952	52
7	-3.227	1.151xx (.052)	- .307x (.129)	.155xx (.031)	.958	51
8	-3.050	1.128xx (.050)	- .275x (.122)	.166xx (.030)	.962	50
9	-3.122	1.120xx (.047)	- .293x (.117)	.181xx (.028)	.966	49
10	-3.058	1.114xx (.048)	- .237x (.120)	.183xx (.028)	.965	48
11	-2.809	1.101xx (.049)	- .260x (.120)	.175xx (.029)	.962	47
12	-2.512	1.060xx (.045)	- .258x (.107)	.193xx (.025)	.965	46
13	-2.694	1.075xx (.047)	- .202 (.105)	.196xx (.025)	.964	45
14	-2.767	1.079xx (.050)	- .201 (.112)	.200xx (.026)	.960	44
15	-2.626	1.079xx (.058)	- .212 (.124)	.188xx (.029)	.946	43

x Significant at 5 per cent level
xx Significant at 1 per cent level
Note: Figures in brackets are standard errors of respective coefficients.

then our conclusion here with regard to the magnitude of the area coefficient may be correct. Hence our earlier hint that some of the fertilizer effect might be occuring in the area coefficient and thus minimising its (fertilizer's) importance as a separate variable may be correct. However, the magnitudes of the coefficients indicate that the returns to scale would be on the low side.

The rainfall coefficient is interesting in that it is negative. This should not be surprising given our observation in the previous section that figure 4.9 indicates a tendency for lower yields per hectare against high levels of rainfall, particularly above 950 mm of rainfall. The main cause for this is wheat lodging at higher levels of rainfall, damage to wheat which is ready for harvesting by prolonged rainfall which impedes harvesting and drying, and increased virulence of the wheat disease pests at higher humidities. Given this observation and the fact that we are dealing with the higher ranges of the rainfall variable (mean 932 mm; standard deviation 206 mm), then the negative coefficients are expected. In a similar study in India, Kahlon and others also obtained negative coefficients for the rainfall variable.[7] Nevertheless, as noted above, the significance in both our study and Kahlon's is low relative to the coefficients of the other variables as would be expected. Indeed if we were considering the lower ranges of the rainfall variable we would expect the reverse, that is, positive and highly significant coefficients. As it happens, our data falls in the higher rainfall ranges where declining returns to rainfall have started to set in due to the effect of the rainfall as described above. Hence the negative but weakly significant rainfall coefficients.

We should now consider the effect of the research expenditure lags included in the function. For this analysis, we turn to the standard errors and the multiple coefficients of determination(R^2). These indicate how much of the variation in output is explained by the inputs. Low standard errors and high coefficients of determination indicate a strong explanatory power of the function or goodness of fit and vice versa. When we look at Table 4.2 we find that the standard errors are generally high at both ends of the lag range. They are lowest between lag 9 and 13. In addition, the distribution of the higher levels of R^2 seems to clamp around these lags. This leads us to conclude that the best goodness of fit occurs at between lag 9 and 13. On having a closer look at these lags, we find that considering the significance of the coefficients, the standard errors and the R^2, the best goodness of fit would appear to be located at lag 12. We therefore take this as indicating that there is a twelve year lag between research expenditures and returns. The following equation incorporating the expenditure variable with a twelve year lag is therefore taken as the best log-linear equation for estimating wheat production and returns to wheat investments in Kenya.

$$\text{Log } Y = \underset{}{-2.512} + \underset{(0.045)}{1.060} \ \ell n \ A^{xx} \ \underset{(0.107)}{-0.258} \ \ell n \ RF^{x} \ \underset{(0.025)}{+0.193} \ \ell n \ RE^{xx}_{t-12}$$

$R^2 = 0.965$

x Significant at 5 per cent level.

xx Significant at 1 per cent level.

Note: Figures in brackets are standard errors of the respective coefficients.

where Y = Annual wheat production in tonnes.

A = Annual area planted with wheat in hectares

RF = Rainfall in mm/100

RE_{t-12} = Deflated research expenditures with 12 year lags in pounds.

Note that lags 0 and 1 have some explanatory powers but their standard errors are comparatively too high. Also , although they have comparatively high R^2 some of this could simply be because of the effect of a larger number of degrees of freedom which does not indicate superiority over lags with less degrees of freedom but nearly the same R^2. Hence the equation with lag of 12 years is superior to the 0 and 1 year lag specifications.

Hence the marginal rate of return on real research expenditures is

$$\frac{0.193\ Y}{RE_{t-12}}$$

with a twelve year lag between expenditures and returns. At 1982 wheat prices (column 4, Table 4.3) this translates into

$$£\ \frac{0.193 \times 227628.45}{163,316} \times \frac{1000}{100} \times \frac{173.60}{20}$$

$$= £23 = £10 \text{ real returns (Deflator, 1982=2.2183)}$$

We can also calculate the stream of gross and therefore net benefits using the above formula, a task we shall turn to below:

4.2.3 Calculation of the Internal Rate of Return Using the Log-Linear Parameter Estimates

Using the parameter estimate of 0.193 for real research expenditures with 12 year lags, we are able to calculate an Internal Rate of Return as exhibited in Table 4.3. Referring to the table we start with column (2) in which is indicated the annual wheat production data with a 12 year lag in relation to the research expenditures. We then multiply column (2) with the research coefficient of 0.193 to get the research expenditure total share of the output which is given in column (3). These are then multiplied by the current wheat price as shown in column (4) to give the current value of research expenditure share of the production as exhibited in column (5). In column (6) we recapitulate from Table 5.1 the current research expenditures. We then subtract column (6) from column (5) to get the net cash flow in column (7).

In calculating the IRR, we took the year 1924 as our year zero because we were able to generate relaible data for wheat prices up to 1934 only. For a twelve year lag this would mean our year zero should actually be 1922. However, we start at 1924 so as to carry out our analysis over the same comparable period as in the analysis of returns under the linear model in the next section where a lag of 10 years, and not 12, is indicated, and which therefore limits us to starting in the year 1924 as our year zero.

In the 12 year period, there are no returns to research expenditures and hence in Table 4.3 there are no returns to R&D from year 0 to 11 as shown in column (5). Hence the net cash flow for that period is negative. The IRR is calculated on the basis of

Table 4.3: Calculation of the Net Cash Flow Arising from Research Expenditures Using the Log-Linear Parameter Estimates

YEAR (1)	12 Year Lag Wheat Production (Tonnes) (2)	Col. (2) x0.193 (3)	Wheat Prices (Shs/100kg) (4)	Gross Benefits (£) Col. (3) x Col. (4) (5)	Current Research Expenditure (£) (6)	Net Benefits (£) Col. (5) - Col. (6) (7)
1924 (0)					1597	-1597
1925 (1)					2218	-2218
1926 (2)					3129	-3129
1927 (3)					1999	-1999
1928 (4)					2511	-2511
1929 (5)					2472	-2472
1930 (6)					2699	-2699
1931 (7)					2500	-2500
1932 (8)					2435	-2435
1933 (9)					2320	-2320
1934 (10)					2354	-2354
1935 (11)					2290	-2290
1936 (12)	14074.64	2716	16.70	22679	2347	20332
1937 (13)	16664.43	3216	17.05	27416	1769	25647
1938 (14)	17246.28	3329	19.05	31709	1831	29878
1939 (15)	20360.00	3929	19.84	38976	2166	36810
1940 (16)	20360.00	3929	22.59	44378	2048	42330

(1)		(2)	(3)
1941	(17)	21604.04	4170
1942	(18)	37652.22	7267
1943	(19)	64725.91	12492
1944	(20)	53870.37	10397
1945	(21)	76366.07	14739
1946	(22)	74283.66	14337
1947	(23)	63289.51	12215
1948	(24)	94559.30	18250
1949	(25)	103569.02	19989
1950	(26)	130588.20	25204
1951	(27)	117355.55	22650
1952	(28)	111653.03	21549
1953	(29)	119511.60	23066
1954	(30)	138507.14	26732
1955	(31)	111987.64	21614
1956	(32)	114927.83	22181
1957	(33)	100797.41	19454
1958	(34)	96827.76	18688
1959	(35)	128204.88	24744
1960	(36)	109497.90	21133
1961	(37)	84356.29	16281
1962	(38)	119788.90	23119

(4)	(5)	(6)	(7)
27.50	57338	1991	55347
27.50	99921	2129	97792
29.70	185506	2206	183300
30.25	157255	2540	154715
30.25	222927	3619	219308
30.64	219643	2680	216963
30.65	187195	2459	184736
36.02	328682	2196	326486
36.02	360002	2220	357782
43.78	551716	2981	548735
50.96	577122	4100	573022
57.27	617056	5449	611607
57.75	666031	5731	660300
57.70	771218	20715	765487
56.10	606273	15921	590352
57.93	642473	15043	627430
56.85	552980	31714	521266
57.56	537841	29652	508189
53.48	661655	50496	611159
51.28	541850	50769	491081
51.62	420213	39929	380284
53.54	618896	28204	590692

(1)	(2)	(3)	(4)	(5)	(6)	(7)
1963 (39)	130088.98	25107	53.54	672114	13155	658959
1964 (40)	144257.50	27842	53.54	745330	13339	731991
1965 (41)	133312.74	25729	53.54	688765	15910	672855
1966 (42)	180652.50	34866	56.84	990892	46889	944003
1967 (43)	240969.58	46507	56.78	1320334	52562	1267772
1968 (44)	224528.61	43334	56.26	1218985	51491	1167494
1969 (45)	217436.49	41965	54.51	1143756	61001	1082755
1970 (46)	178443.61	34440	45.10	776622	72496	704126
1971 (47)	170316.18	32871	50.61	831801	76082	755719
1972 (48)	149585.76	28870	50.61	730555	82151	648404
1973 (49)	137884.32	26617	56.72	754858	75423	679435
1974 (50)	157832.73	30462	80.36	1223963	72756	1151207
1975	175709.07	33912	104.71	1775463	52338	1723125
1976	175930.38	33955	120.30	2042393	55062	1987331
1977	170865.27	32977	133.33	2198412	61303	2137109
1978	165271.59	31897	133.33	2126414	141303	1985111
1979	114707.52	22139	143.64	1590023	147139	1442884
1980	204498.09	39468	163.86	3233613	162649	3070964
1981	234546.21	45267	166.67	3772325	187371	3584954
1982	227628.45	43932	173.60	3813298	231109	3582189

Source: Column (2): From Table 5.1
Column (4): Kenya Statistical Abstracts, Kenya Wheat Board Annual Reports Correspondences in the Kenya National Archives.
Column (6): Table 5.1.

a 50 year period stretching from 1924 to 1974. Beyond that, the present values become so small that they make no significant differences to the estimated IRR value.

By iteration and interpolation, we find that the discount rate that reduces the net cash flow to zero Net Present Value is 33%. This is our estimated Internal Rate of Return to wheat research in Kenya using the log-linear parameter estimates.

4.2.4 The Linear Analysis

The results of the linear analysis are presented in Table 4.4. The standard errors and the multiple coefficients of determination indicate that the log-linear model is superior to the linear model where those indicators are larger and smaller, respectively, than in the log-linear model. However, the behaviour of the coefficients is similar in both models and the discussion on this aspect of the coefficients need not be repeated here. The research expenditures lag with the highest explanatory power, however, appears to be lag 10 as it is indicated to have the highest value of R^2 with the lowest standard errors for the more significant variables of area and research expenditures. Our empirical linear production function is then indicated to be:

Table 4.4: The Linear Regression Parameter Estimates

Lags of Research Expenditure	Constant	Area (A) Coefficient	Rain (RF) Coefficient	Research Expenditure (RE) Coefficient	R^2	Degrees of Freedom (DF)
0	4509.859	1.160^{xx} (.096)	-18177.961 (16497.138)	$.300^{xx}$ (.083)	.874	58
1	5016.145	1.198^{xx} (.094)	-19884.538 (17080.387)	$.272^{xx}$ (.081)	.867	57
2	7649.305	1.199^{xx} (.093)	-23141.853 (17187.902)	$.285^{xx}$ (.080)	.867	56
3	1658.044	1.237^{xx} (.096)	-17639.235 (17751.402)	$.245^{xx}$ (.080)	.856	55
4	2788.820	1.265^{xx} (.099)	-19345.201 (18349.280)	$.216^{xx}$ (.082)	.846	54
5	-3213.195	1.268^{xx} (.103)	-12753.715 (18488.437)	$.213^{xx}$ (.083)	.841	53
6	-2259.963	1.234^{xx} (.104)	-12904.328 (18478.085)	$.259^{xx}$ (.082)	.845	52
7	4793.644	1.145^{xx} (.095)	-17517.682 (16820.645)	$.369^{xx}$ (.075)	.872	51
8	10540.934	1.054^{xx} (.082)	-19970.459 (14293.299)	$.473^{xx}$ (.064)	.908	50
9	15560.066	1.037^{xx} (.074)	-24725.727 (13072.992)	$.512^{xx}$ (.057)	.925	49
10	3356.823	1.066^{xx} (.072)	-13154.703 (13339.914)	$.510^{xx}$ (.055)	.925	48
11	7121.675	1.128^{xx} (.080)	-19967.406 (14947.721)	$.480^{xx}$ (.062)	.904	47
12	-875.782	1.178^{xx} (.080)	-15494.726 (14903.232)	$.494^{xx}$ (.063)	.903	46
13	-7486.124	1.221^{xx} (.083)	-11685.019 (15463.504)	$.504^{xx}$ (.067)	.893	45
14	-1988.003	1.220^{xx} (.092)	-16146.743 (17081.206)	$.510^{xx}$ (.076)	.876	44
15	1771.022	1.238^{xx} (.106)	-19350.853 (18900.370)	.477 (.087)	.842	43

^{x}Significant at 5 percent level

^{xx}Significant at 1 percent
Note: Figures in brackets are standard errors of respective coefficients.

$$Y = 3356.823 + 1.066A^{xx} - 13154.703RF + 0.510RE^{xx}_{t-10}$$
$$\quad (0.072) \quad (13339.914) \quad (0.055)$$

$R^2 = 0.925$

^{x}Significant at 5 percent level

^{xx}Significant at 1 percent level

Note: Figures in brackets are standard errors for the respective coefficients.

The indication from this equation is that the research expenditures share of the output is at the rate of 0.510 tonnes of wheat for every one pound of real research expenditures, with a ten year lag. From this information we are able to calculate an internal rate of return to research expenditures similarly as done for the log-linear model in the previous section.

4.2.5. Calculation of Internal Rate of Return Using the Linear Parameter Estimates

The calculation of the Internal Rate of Return using the Linear Parameter Estimates is exhibited in Table 4.5. We start with column (2) which shows real research expenditures with a ten-year lag so that the expenditure incurred in 1924 is actually shown against 1934, that of 1925 against 1935, etc. These expenditures are then multiplied with the coefficient 0.510 to give the research expenditure annual share of the wheat production, as exhibited in column (3). From

Table 4.5: Calculation of the Net Cash Flow Arising from Research Expenditures Using the Linear Parameter Estimates

Year (1)	10 Year Lag Real Res. Exp. (2) £s	10 Year Lag Real Res. Exp. x .510 (3) Tonnes	Wheat Prices Shs/100 kg (4)	Current Value of (3) (3)x(4)=(5) £	Current Res. Exp. (6) £	Net Cash Flow (5)-(6)=(7) £
1924(0)		-		0	1597	-1597
1925(1)				0	2218	-2218
1926(2)				0	3129	-3129
1927(3)		-		0	1999	-1999
1928(4)		-		0	2511	-2511
1929(5)		-		0	2472	-2472
1930(6)		-		0	2699	-2699
1931(7)		-		0	2500	-2500
1932(8)		-		0	2435	-2435
1933(9)		-		0	2320	-2320
1934(10)	3792	1934	11.00	10637	2354	8283
1935(11)	5266	2686	12.65	16988.95	2290	14699
1936(12)	7513	3832	16.70	31997.2	2347	29650
1937(13)	5208	2656	17.05	22642.4	1769	20873
1938(14)	7154	3649	19.05	34756.73	1831	32926
1939(15)	8126	4144	19.84	41108.48	2166	38942
1940(16)	10298	5252	22.59	59321.34	2048	57273
1941(17)	9893	5045	27.50	69368.75	1991	67378

Year (1)	10 Year Lag Real Res. Exp. (2) £s	10 Year Lag Real Res. Exp. x .510 (3) Tonnes	Wheat Prices Shs/100 kg (4)
1942(18)	10004	5102	27.50
1943(19)	10118	5160	29.70
1944(20)	11974	5107	30.25
1945(21)	12233	6239	30.25
1946(22)	13551	6911	30.64
1947(23)	9949	5074	30.65
1948(24)	10572	5392	36.02
1949(25)	11287	5756	36.02
1950(26)	10940	5579	43.78
1951(27)	9896	5047	50.96
1952(28)	9964	5082	57.27
1953(29)	9822	5009	57.75
1954(30)	11077	5649	57.70
1955(31)	15466	7684	56.10
1956(32)	11453	5841	57.93
1957(33)	10103	5153	56.85
1958(34)	8690	4432	57.56
1959(35)	12069	6155	53.48
1960(36)	10984	5602	51.28

Current Value of (3) (3)x(4)=(5)£	Current Res. Exp. (6)£	Net Cash Flow (5)-(6)=(7)£
70152.5	2192	67960
76626.0	2206	74420
92368.375	2540	89828
94364.875	3619	90746
105876.52	2680	103197
77759.05	2459	75300
97109.92	2196	94914
103665.56	2220	101446
122124.31	2981	119143
128597.56	4100	124498
145523.07	5449	140074
144634.875	5731	138904
161561.4	20715	140846
215536.2	15921	199615
169184.565	15043	154142
146474.025	31714	114760
127552.96	29652	97901
164584.7	50496	114089
143635.28	50769	72866

Year (1)	10 Year Lag Real Res. Exp. (2) £s	10 Year Lag Real Res. Exp. x .510 (3) Tonnes	Wheat Prices Shs/100 kg (4)	Current Value of (3) (3)x(4)=(5)£	Current Res. Exp. (6)£	Net Cash Flow (5)-(6)=(7)£
1961(37)	13074	6668	51.62	172101.08	39929	132172
1962(38)	21805	11121	53.54	297709.17	28204	269505
1963(39)	15995	8157	53.54	218362.89	13155	205208
1964(40)	76808	39172	53.54	1048634.4	13339	1035295
1965(41)	55590	28351	53.54	758956.27	15910	743046
1966(42)	51783	26409	56.84	750543.78	46889	703655
1967(43)	105749	53932	56.78	1531129.48	52562	1478567
1968(44)	98873	50425	56.26	1418455.25	51491	1366964
1969(45)	167205	85275	54.51	2324170.12	61001	2263169
1970(46)	166948	85143	45.10	1919974.65	72496	1847479
1971(47)	128224	65394	50.61	1654795.17	76082	1578713
1972(48)	85988	43854	50.61	1109725.47	82151	1027574
1973(49)	39078	19930	56.72	565214.8	75423	499791
1974(50)	39535	20163	80.36	810149.	72756	737393
1975 [illegible]	45199	23051	104.71	1206835	52338	1154497
1976 [illegible]	127589	65070	120.30	3913960	55062	3858899
1977	129879	66238	133.33	4415756	61303	4354453
1978	125435	63972	133.33	4263734	141303	4122431
1979	145552	74232	143.64	5331342	147139	5184203
1980	163316	83291	163.86	6824032	162649	6661383
1981	164930	84114	166.67	7009640	187371	6822269
1982	162675	82964	173.60	7201275	231109	6970166

Source:	Column (2):	From Table 5.1
	Column (4):	Kenya Statistical Abstracts, Kenya Wheat Board Annual Reports and Correspondences on wheat in the Kenya National Archives
	Column (6):	Table 5.1

there on we proceed exactly as for Table 4.3 as explained in the previous section and calculate the Internal Rate of Return which is found to be 31%. This compares very well with the internal rate of return of 33% calculated under the log-linear model. However, we adopt the log-linear results for our discussion because as noted earlier, the log-linear model gave the better fit for the data.

4.2.6 Implications of the Estimates

Thus the returns to wheat are indicated to be quite high in both the log-linear and linear analysis. The marginal rate of return (MRR) of £10 to £1 of real research expenditure and the internal rate of return of 33% indicates that there is considerable scope for further investments in wheat research before negative returns start to set in. A study sponsored by the Kenya National Council for Science and Technology on

Kenya's agricultural research system found laboratory and office facilities at the NPBS to be inadequate.[8] The high returns indicate that considerable investments in such facilities could be carried out at a favourable cost/benefit ratio resulting in the increase of the total net benefits from wheat research.

The internal rate of return compares very well with results from other countries as illustrated in Appendix 1.2. This figure is also generally above the rates of return to conventional projects as shown in Appendix 1.3, meaning research could be a more attractive public investment than such conventional development projects, at least as far as direct returns are concerned.

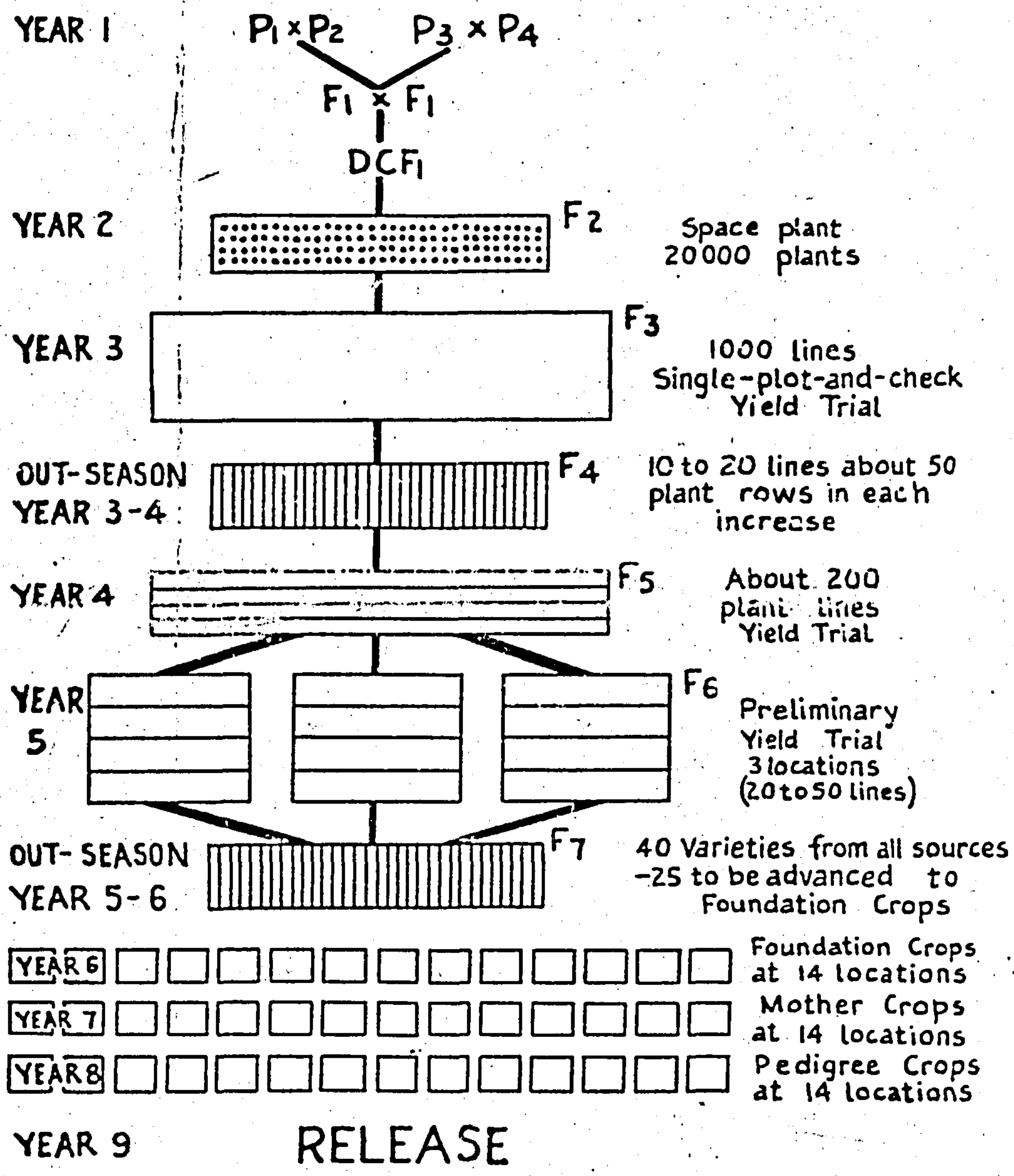
In the evaluation of returns to R&D some studies include extension services expenditures; others do not for various reasons. If in our case we were to include extension services expenditures the rates of return would certainly be lower. However, we have assumed that without research there would be no wheat to grow and have ascribed the benefits to wheat research. Also the wheat grower in Kenya has mainly been the large scale and more knowledgeable farmer requiring fairly low inputs in extension services compared to other types of crops and farmers, although in more recent times there has been some significant extension inputs in the form of intensified seed inspection services and extension services from the increased field personnel of the Kenya Wheat Board, particularly to upcoming new wheat growers. The staff of the NPBS, Njoro also carry out some field services and hold field days and the expenses for such activities are included in our research expenditure data. Indeed in the earlier days such services as seed inspection and advice to the farmers were given by the plant breeding research services. It would also be true to say that today the average wheat farmer would be more likely to seek technical advice from the research station than from the conventional extension officer whose attention is also divided among many other crops. Given these observations of an expected lower than average inputs in conventional extension services and the fact that a great portion of such expenditures are already internalised in our research expenditures, the errors that would be introduced in the difficult task of trying to apportion extension expenditures to wheat from 1921 to 1982 may not be worth the effort. So we note that such extension expenditures which are not already internalised in our research expenditures, although more significant in recent periods, have been assumed away and this could lead to a slight overestimation of the returns. The internal rate of return would not actually be affected much because the Net Present Value for the more recent periods when the uninternalised extension expenditures have risen would be very small and therefore make little difference to the IRR.

With regard to the behaviour of the lags, the 10 and 12 year lags obtained for the linear and log-linear regressions respectively should not be surprising when we consider that it takes 9 to 12 years to produce a new variety of wheat as exhibited in figure 4.10. However, we lack knowledge on the lag structures and it would be naive to assume that the lags are as simple as presented in our study case. However, a look at the values for R^2 shows that the distribution of the lags could be an oscillating but declining sine/cosine or 3rd degree polynomial (cubic) type of distribution. This is an area which could be investigated with more refined and sophisticated statistical/econometrics approaches. The results in this case study are sufficiently promising to arouse an interest in this type of study.

We also note that the regressions could be improved by inclusion of more variables. Notably we have already pointed out that we would have liked to include fertilizers but no data exists in Kenya on fertilizer consumption per crop. The same also applies for most of the other inputs. The task of trying to estimate the inputs per crop or activity over a long period of time would be a momentous one but could be instituted so that the current information can be collected on a regular basis by statistical or/and extension officers. It is hoped that the effect of other inputs as are excluded from the regressions is caught in the residual. We did also discover in our analysis that it might be possible that some of the effect of some of the land-improving inputs such as fertilizers might have been caught in the area coefficient and that therefore in the analysis of wheat R&D in Kenya, the omission of fertilizer as a variable may not, after all, be so serious as long as the land (area) variable is included.

Another area requiring attention as noted earlier in Chapter Two is that of the model specification. In this case study we have seen that the Cobb-Douglas type of production function is an improvement over the linear model. Hayami and Ruttan have espoused the idea of a metaproduction function in the long run covering a series of short-run production functions.[9] However, they do not attempt to specify what form that production function would take. Most of the major R&D studies discussed in Chapter Two under the production function approach have used the Cobb-Douglas production function with slight variation here and there.

Figure 4.10: Wheat Breeding Stages in Kenya



Source: Pinto, F.F. and E.A.Hurd, 1970 'Seventy Years with Wheat in Kenya'. East African Agricultural and Forestry Journal. xxxvi, Special Issue. p.16.

This is an area requiring research to enlighten investors in R&D on the path along which they may expect a research production function to move. This is a difficult area because there can be spectacular changes of the functions due to major breakthroughs in R & D. Nevertheless, the results of most of the world's R&D are mainly gradual marginal additions to knowledge and therefore Hayami and Ruttan's suggestion of a longrun metaproduction function which could be investigated is a useful idea.

4.3 Externalities

In our discussion in Chapter Two on the externalities or side effects of technological change we identified the following issues as requiring attention:

Income Distribution Effects.
Employment Effects.
Environmental Consequences.
Technology Transfer and Manpower Development.
Nutritional Impact.
Foreign Exchange Effects.

Each of these will be considered with regard to the Wheat Research Programme. In dealing with side effects we should, however, recall what we observed in Chapter Two: that it should be kept in mind that the number of side effects that can be successfully internalised are indeed quite limited. Many side effects have therefore to be handled by discription as we intend to do in this section.

4.3.1 Income Distribution Side Effects

Kenya's research in agriculture has been criticised in the past for having been biased towards certain crops and the large farmers. Heyer and Waweru have noted that given the high priority attached to agricultural research in Kenya, the results for small farmers have been disappointing.[10] They add that research has been concentrated on the high value cash crops rather than food, with the exception of maize, wheat and dairy products which were the mainstay of the European mixed farms and that research still tended to emphasize larger rather than small farm needs.

A survey commissioned by the National Council for Science and Technology as recently as 1981, concluded that there was no convincing evidence that major emphasis is being placed on the development of production technologies for the small holder farmers.[11] They note that the earlier research workers were aiming at high potential areas under large scale farming; they were able to draw on a great world-wide wealth of relevant technology that could be applied with relatively little modification. They add that there is much less world knowledge available for production systems for small farmers or on how to get information to a large number of low-capital farms and that there is great need for critical reassessment, interpretation and development of technologies and systems for small farms.

The implication of these criticisms is that past research in agriculture has tended to favour the wealthier farmer and therefore worsen the income distribution. On the other hand there is now indication that these issues are receiving attention from Government planners as is apparent throughout the Kenya Development Plans 1978/83 and 1984/88. In these plans there is clear emphasis on the creation of technologies which are labour intensive and suitable for small farms and marginal areas.

How has the wheat research programme faired under this self searching criticism of the agricultural research system in Kenya? We begin by examining table 4.6 which shows the percentage contribution of small scale and large scale farms to wheat production in 1975.

Table 4.7 shows that small scale farmers contributed only 8% of the wheat produced in 1975.

Table 4.6: Comparison of Large Scale and Small Scale Farms Contribution to Wheat Production in 1975 in Kenya

% Large Scale	% Small Scale (Under 20 Ha)	No. of Small Scale Farms Farms	Total area Under Small Scale (Ha)	Average Area under Small Scale (Ha)
92%	8%	856	12,134	14

Source: Kenya Wheat Board, 1976: Annual Report, Appendix 9, 10, pp. 24-5.

However, that is not the whole story. The table shows that what the Kenya Wheat Board classifies as small farms are farms under 20 hectares of wheat and that the actual average area under this category was 14 hectares. The ILO Report on employment in Kenya identified 8 hectares as the acreage beyond which returns start to decline markedly under small scale production in settlement schemes of medium potential conditions as are found in the main wheat growing areas.[12] Assuming this figure of 8 hectares and under to define the small scale farmer, then the small farmer as defined by the Wheat Board is nearly twice the figure of 8 hectares and therefore he is not really a small farmer. We therefore conclude that the wheat farmers are predominantly large scale and that in reality there are no small scale farmers of significant importance.

Indeed wheat farming as practised today is a highly mechanised operation as we shall see in the discussion under employment effects and requires large acreages to utilise the full capacity of the machinery involved. This effectively excludes the really small scale farmers, most of whom have farms which are even smaller than the above stated size of 8 hectares. In fact, Heyer and Waweru note that the majority of the small scale farms are less than 2 hectares and that very few exceed 5 hectares, excluding the pastoral areas.[13]

In view of the above discussion, we conclude that wheat research has by and large benefited the wealthier large scale capital-owning farmer and therefore has had the side effect of worsening the distribution of income. This conclusion is further re-inforced by the data in Table 4.7 which shows the number of families supported by one hectare of land in large and small scale farms.

Table 4.7: Number of Families Supported by an Hectare of Land in Large Scale and Small Scale Farms in 1974 in Kenya

	Large Farms[a]	Small Farms[b]
Cultivated Acreage ('000 Ha)	460.4	1281.9
Number of families ('000)	22.9	1347.5
Families per Ha	0.5	1.1

Source: a) Kenya Statistical Abstracts, 1977, Table 32(b) (The figures on families includes squatter families).

b) Computed from Kenya Statistical Abstracts, 1977. Tables 5.1, 5.7, 6.1, 7.5. The figures have been adjusted to exclude families engaged in non-farm work.

It is evidently implicit in Table 4.7 that concentration of wheat growing in large farms will tend to concentrate incomes into the hands of fewer people.

We shall also see later that the nutritional impact also tends to favour the higher income groups. Our conclusions above would be mitigated if wheat production was highly labour-intensive but as we shall see below on employment side effects, this appears not to be so.

Before concluding this section however, we note that one of the stated aims of the NPBS is to de-regionalise wheat growing and take it to the small farmer. We have also stated the Government aims in the Development Plans to give more emphasis to the small farmer. There are also credit schemes administered mainly by the Agricultural Finance Corporation which mainly assist the upcoming African and small farmer. It is expected that this effort will yield results in the right direction.

4.3.2 Employment Effects

The employment effects are related to the question of income distribution effects discussed above because if more small scale farmers are involved in the production of wheat, a greater number of people are likely to be involved in the activity than under a predominantly large scale production system. This observation is evident in Table 4.7 above if we use the number of families supported by one hectare of land as a proxy for the labour intensity of the enterprise. Further direct evidence on this observation is borne out in Table 4.8 below.

Mureithi reports that small farms are more labour intensive than large farms as revealed in Table 4.8 which shows that small farms use more men equivalents per 1,000 acres than do large farms.[14] He further notes that small scale farms are less dependent on machinery for cultivation as implied by the expenditure on machinery cultivation in Table 4.8 and that promotion of production on small scale basis would be in line with the promotion of labour intensive technologies. He also points out that the case for small farms becomes stronger when it is observed that gross output per acre is, by and large, higher for small size farms - an observation which has obvious implications for income distribution.

Table 4.8: Output, Employment and Farm Size

Farm Size (acres)	Gross Output (Shs/Acre)	Labour Inputs (Men equivalents) per 1000 acres	Expenditure on Machinery Cultivation (Shs./acre)
10 or less	635	808	6
10 - 9.9	250	399	11
20 - 29.9	156	234	9
30 - 39.9	161	159	28
40 - 49.9	113	124	21
50 - 59.9	98	111	19
60 - 69.9	98	109	12
70 or more	111	70	10
All Small Farms (1967/8)	156	190	14
250 or less	248	93	135
250 - 499	161	62	140
500 - 749	133	43	136
750 - 999	113	44	146
1,000-1,249	89	34	119
1,250-1,499	149	46	167
1,500-1,999	128	28	155
2,000 or more	65	14	131
All Large Farms (1970/1)	117	36	143

Source: Kenya Statistical Digest 1972 X (1), cited in Mureithi, L.P. 1979. "Scope and Salient Features of Rural Development in Kenya." Israel Journal of Development 5 (2), pp 14-20.

Further and more direct evidence as far as wheat is concerned is provided in Table 4.9 on the land/labour coefficients for various farm enterprises. The coefficients are the labour inputs in man days per acre. Table 4.9 indicates that some crops and livestock farming activities in Kenya are more labour intensive than others. Wheat is indicated to have comparatively very low labour intensity which is about 15 times less than the next lowest crop in Nyandarua. This could be explained by the fact that wheat is grown on large farms which we have seen to be generally less labour intensive than small farms and tends to depend more on machinery than small farms.

Further evidence on the overall employment impact would need to be generated on the linkage effects of wheat production such as on the input supply industries, the wheat processing industries and the transportation and distribution sector. But assuming that other crops and farming activities are also generating employment in these secondary and tertiary industries, it would appear from the evidence above that wheat growing in Kenya has a higher opportunity cost per unit area than other main crops in terms of employment generating possibilities.

4.3.3 Environmental Effects

We have very little hard data to allow us to make definitive conclusions on the environmental effects

Table 4.9: Land/Labour Coefficients for Individual Farming Enterprises - 1969/70

Enterprise	Mean Annual Labour Input (Man-Days per Acre)			
	Nyeri	Kiambu	Nandi	Nyandarua
Coffee	190.7	105.5	-	-
Mature Tea Unimproved	187.6	-	193.2	-
Dairy Cattle Improved	178.8	69.4	-	-
Dairy Cattle other	144.7	50.1	10.4	18.4
Livestock	135.3	51.1	-	13.0
Pyrethrum	80.8	55.6	-	65.5
Maize	49.3	76.8	36.2	63.0
Hybrid Maize	-	12.8	24.7	61.7
Wheat	-	-	-	4.9

Source: Mureithi, 1979, op. cit., Table 2.

of wheat research and production. However a qualitative analysis is attempted.

Most wheat growing in Kenya has been generally confined to flat lands (with the exception of areas such as Timau) where soil erosion is low. Furthermore the plant population densities in wheat farming is such that direct rain drops destruction of the soil surface, which is one of the major factors governing heavy soil erosion, is mitigated when the force of the falling rain drops is broken by the plants. The high density of the plant population also reduces the soil dislodging and carrying effects of the flowing water by holding the soil together with its root system as well as by acting as a natural sieve. In addition, terracing against soil erosion in the more slopy wheat growing areas is practised at a fairly sophisticated level so that the soil conservation effects are enhanced.

However, wheat production requires a fine bed and this results in considerable pulverization of the soil. Given that wheat production in Kenya is a machinery intensive activity, the pulverization of the soil is even more intense due to the excess reliance on machines, thus enhancing the possibilities of erosion. In addition, the removal of the straw from the fields may cause nutrient mining out of the fields but we do not know to what levels, although most of this may be replaced where fertilizer is used, particularly in conjunction with diagnostic soil analysis.

We nevertheless conclude that on the overall, although we do not have definitive data, the consequences of wheat growing on soil conservation and erosion appear to be on the balance less severe than in other crop activities and the non-wheat growing areas of the country. However, this situation could change as we move to more sloppy lands and a new type of farmer and therefore the situation needs to be monitored closely as, indeed, should be with all other activities on the land. This calls for enhanced agronomic research on appropriate tillage techniques such as the minimal tillage approach to farming which has received considerable attention in various parts of the world.

Other environmental consequences involve the use of fertilizers and plant protection chemicals. This is an area in which research has made considerable positive contribution for the following two reasons:

First, the breeding research programme has eliminated the need to spray against rust. If the breeding programme was not there, it would require an intensive chemical spraying programmes for the wheat industry to survive. Apart from the costs saved, the elimination of use of chemicals against rust represents substantial benefits in environmental pollution control. It should also be noted that if one were to use the costs saved approach in the evaluation of R&D, the value of the savings in chemicals for spraying against rust should represent a quick evaluation of the benefits of research.

Secondly, research investigations have shown that two of the most important agricultural chemicals in environmental pollution are not necessary in wheat production or are required only in small quantities and only in few situations. These are nitrogenous fertilizers and organochloride insecticides.

We therefore conclude the discussion on environmental consequences by observing that although research is mainly geared to the increase in yields, it has also has had the side effect of making considerable positive contributions in the reduction of environmental pollution in wheat production.

4.3.4 Technology Transfer, Training and Manpower Development

There has been a considerable exchange of technology throughout the history of wheat breeding in Kenya both to the NPBS and from the NPBS to other parts of the world. The NPBS is world re-known for its work and hosts one of the world-wide network of the International Wheat Rust Testing Centres. While the NPBS has received many wheat breeding lines and potential varieties it has also supplied similar material to various parts of the world.

The NPBS has also contributed considerably to the world wide knowledge on wheat and the transfer of the technology through publication. For example, over the period 1948-1968 Kenya published a total of 54 internationally recognised articles on wheat. Table 4.10 shows that this was 33% of the average for 64 countries. This, for a developing country is a highly commendable performance and represents a considerable participation in the world-wide transfer of knowledge.

Table 4.10: World Publications on Wheat (64 countries): 1948 - 68

	No of Countries	Total Articles	Average per country	Kenya	World Range
Plant Breeding Articles	64	6,871	107	39	0-1634
Field Articles	64	3,774	59	15	0-533
Total	64	10,645	166	54	0-2167

Source: Evenson, R.E. and Y. Kislev, 1975. Agricultural Research and Productivity, London, Yale University Press, Appendix 2, pp 170-1.

We have seen in Chapter Three on the definition of outputs of R&D that in one approach to the evaluation of R&D, transferred knowledge has been taken as an input into R&D by some workers and used as the explanatory variable in the R&D production function. Of particular note in this area is the extensive work of Evenson and Kislev.[15] They measured the transferred knowledge as the number of articles related to the research programme and gave them weight depending on whether they were nationally or regionally or internationally published and used them as part of the explanatory variables. However, this approach has got severe limitations because of the quality of reports/articles, their applicability and the problem of access to publication in reputable journals. So we handle this as a side effect of R&D and note that the publications from Kenya represent a considerable impact on the transfer of technology.

In addition, Kenyan wheat research workers have contributed to world and local knowledge through other various means such as seminars, workshops, conferences, exchange of notes, information pamphlets, annual field days and field diagnostic services.

On the other hand, there has been considerable gain in manpower development for the NPBS and the nation as a whole as well as in research infrastructure development through local and foreign efforts. This has been in the form of sponsorship for training, seminars, conferences as well as on-the-job learning and training from more experienced local and foreign scientists leading to the enhancement of the total human capital available in the country.

Table 4.11 shows the growth in the number of research scientists of the NPBS by degrees status from 1963 to 1978. The table shows that the research capability of the Kenyan staff at the NPBS rose from RE4 (RE=Research equivalents: See explanatory notes for table 4.11) in 1963 to RE 79 in 1978 while that of the expartriates rose from RE 13 in 1963 to a maximum of RE 76 in 1971 and then to zero from 1976 onwards. This represents an interesting symbiosis between foreign and local researchers during which period Kenyan researchers were recruited and trained over a period of about 10 years (1966 to 1975) to take over completely the running of the NPBS programmes. Of particular note here among the foreign assistance donors is the Canadian International Development Agency (CIDA) which provided opportunities for the Kenyan scientists for postgraduate training in Canada as well as expartriate staff both to run local programmes while the Kenyans were on study leave abroad as well as to provide local on-the-job training particularly for younger less experienced researchers.

In the case of infrastructure development, considerable research capability exists in equipment, laboratory space, administration facilities, green houses and staff quarters. However, the NCST sponsored evaluation on agricultural research in Kenya found the laboratory and office facilities inadequate and therefore there is need for improvement in such facilities.[16]

In conclusion, we note that there has been considerable two-way transfer of technology and commendable training benefits leading to the full and effective manning of the NPBS by Kenyan staff. Staff turnover of the Kenyan personnel as indicated by the Ph D column in Table 4.11 cannot be counted as a loss so long as the personnel remain in Kenya or work on programmes for the benefit of Kenya (that is, assuming that there is no brain drain) because whatever new organisations or activities they enter into will be contributing to the Kenyan economy in its totality.

4.3.5 Nutritional Impact and Competition with Traditional Foods

We recall that in Chapter Two we outlined a model

Table 4.11: Number of Research Scientists at the NPBS by Degree Status, 1963 to 1978

	No. of Kenyan staff			No. of Expatriate staff			REs	
Year	KBS	KMS	KPD	EBS	EMS	EPD	KRE	ERE
1963	1	0	0	1	0	1	4	13
1964	1	0	0	0	0	1	4	9
1965	1	0	0	0	0	1	4	9
1966	1	0	0	0	1	3	4	31
1967	2	2	1	1	1	0	29	10
1968	2	1	1	0	1	0	23	6
1969	2	1	1	0	2	2	23	30
1970	2	1	1	0	1	2	23	24
1971	4	2	2	1	3	6	46	76
1972	5	3	2	0	4	4	56	60
1973	6	2	3	0	2	5	63	57
1974	5	4	3	0	0	4	71	36
1975	5	5	3	0	0	3	77	27
1976	2	7	1	0	0	0	59	0
1977	2	7	1	0	0	0	59	0
1978	7	7	1	0	0	0	79	0

Key: NPBS = National Plant Breeding Station, Njoro

KBS = number of Kenyans with BSc degree

KMS = number of Kenyans with MSc degree

KPS = number of Kenyans with PhD degree

EBS = number of expatriates with BSc degree

EMS = number of expatriates with MSc degree

EPS = number of expatriates with PhD degree

KRE = Kenyan Research Equivalents

ERE = Expatriate Research Equivalents

RE = measure of research equivalent for research staff =(4xKBS)+(6xKMS)+(9xKPD)+(4xEBS)+ (6xEMS)+(9xEPD)

Source: Jamieson, B.M., 1981. Research Allocation to Agricultural Research in Kenya from 1963 to 1978. Ph D Thesis, University of Toronto, Canada.

by Pinstrup - Anderson, de Londono and Hoover which measures the nutritional impact of alternative commodity priorities in agricultural research and policy.[17] We noted that the model measures the distribution of supply increases of commodities among consumer groups, the related adjustments in total food consumptions and implications for calorie and protein nutrition. This procedure permits a translation of increases in agricultural output to its impact on nutrition by income groups. Thus equity and nutritional aspects can be analysed.

The model is demanding in terms of detailed knowledge of demand and consumption patterns and we cannot possibly go into such analysis here. However, we can look at the issue here in simpler terms.

The question of the comparative impact of wheat and its products on nutrition in Kenya has received some critical probing by Kaplinsky.[18] Looking at Table 4.12 below, we find that the cost of nutrients in wheat flour and bread is generally far in excess of the cost of similar nutrients in maize flour.

Thus wheat and wheat products are a very expensive way of providing basic nutrients compared to more traditional foods such as maize and maize meal. Therefore wheat and wheat products tend to be food for people in the high income brackets. This observation is collaborated by the work of a team which was sponsored by the Kenya Ministry of Health, WHO, FAO and UNICEF to conduct a nutritional survey in Kenya in 1964-68.[19] In a fairly detailed study covering 8 major tribes in Kenya representing 79.53% of the population, the team found that consumption of cereals such as maize, sorghum and millet in the rural areas was far ahead of wheat consumption. Although one could criticise this report as outdated, eating habits change slowly and the more recent data in Table 4.13 below tends to confirm this observation further.

From Table 4.13 we see that only 17% worth of wheat and wheat products is indicated to be consumed by the lower income group which forms the majority of

Table 4.12: Unit Nutrient Costs of Different Breakfast Foods (Gm per Sh)

	Carbo-hydrate	Protein	Fat	Ash	Fibre	Calo-ries	Vitamines (Mgs per Sh.)		
							Thiamine	Ribo-flavin	Niacin
a) TRADITIONAL									
- Maize flour 100% Extraction	710	100	45	115	20	3630	3.5	1.3	20
- Maize flour 60% Extraction (sifted)	453	47.1	8.8	68.8	4.1	2082	0.3	0.2	3.5
b) MODERN									
Wheat flour 85% Extraction (Atta)	288	44	6.4	94	4	1384	13.2	0.3	8
Bread	168	29	10.7	6.7	NA	900	1.5	1.0	14.6

Source: Kaplinsky, R.M. 1978. "Inappropriate Products and Techniques in UDC's: The Case of Breakfast Foods in Kenya." Working-Paper No. 335. IDS, University of Nairobi.

the population. The rest 83% is consumed by the upper and middle income groups with the upper consuming the highly disproportionate share of 54%.

From the foregoing review, we thus conclude that compared to more traditional foods, wheat and its products are an expensive way of feeding and has mainly benefited those with the higher incomes to afford such foods. Kaplinsky notes that aggressive marketing techniques have ensured that the tastes for such high income foods are quickly and permanently acquired by the elite.[20] In turn, the demonstration effect from such elite communities ensures the trickling and permeation of the taste to the rest of the population. Thus foods such as wheat and wheat products which were the mainstay of the colonising European community have taken perhaps an irreversible place in the diet of the local population in place of more nutritious foods per unit cost such as maize, sorghum, millet, etc. especially in the upper income groups. Seen in this light then, the nutritional impact can only be assessed as having been negative.

Moreover, Kaplinsky adds that products such as wheat and its products require either to have sugar directly added to them or to be taken with beverages containing sugar such as tea, coffee, soda, etc. in constrast with other cereals products such as "ugali" which does not require sugar.[21] This sugar is harmful to teeth and to the body in other ways. He adds that the harm to the teeth is much more, if the products tend to stick to the teeth as is the case with many wheat products.

Table 4.13: Average Monthly Expenditure on Wheat and Wheat Products by Different Income Groups Before 1971 (Old Index) and After 1971 (New Index)

(1)		% of Income Spent on Wheat Products (2)	Lower Limit of Income Range (Shs/month) (3)	Amount Spent on Wheat Products (Shs/month) $(4)=\frac{(2)\times(3)}{100}$
Upper Income Group	Before 1971	2.7	1400	38
	After 1971	1.6	2500	40
Middle Income Group	Before 1971	4.6	400	18
	After 1971	3.2	700	22
Lower Income Group	Before 1971	5.4	200*	11
	After 1971	3.8	350*	13

* Since the lower limit of the income of the lower income group is not given in the Abstracts, the median figure rather than the zero is used here.

Source: Computed from Kenya Statistical Abstracts, 1982. Tables on Retail Prices and Consumer Expenditures, pp. 276-280.

Kaplinsky further notes that high income foods, such as wheat products, tend to be produced with inappropriate technologies because of the excessive processing, refining, packaging etc. they have to undergo to appeal to the sensory (rather than nutritional) tastes of the client. The technologies are inappropriate because often they tend to reduce the nutritional value of food (unless artificial fortifying is done) and they tend to be capital-intensive. For example in another paper in 1974, Kaplinsky indicates that wheat processing was one of the most concentrated industries in the food processing industry in Kenya, with only 7 firms being in control of the industry.[22] Smaller and probably more labour-intensive entrepreneurs found it difficult to penetrate the market effectively.

We thus conclude that although wheat products seem to have come to stay as part of our staple foods, they are indicated to be less efficient nutritionally than more traditional foods such as maize. However, there are research efforts being made at the Kenya Industrial Research and Development Institute to incorporate more traditional foods such as sorghum into wheat and bread. Moreover a lot depends on the processing process and if people are encouraged to eat more of the whole wheat products than the more refined wheat products the situation may not be so bad.

4.3.6 Foreign Exchange Impact

A suitable way to analyse the foreign exchange impact is to use the Domestic Resource Cost (DRC) approach. DRC is defined as the cost of domestic resources used per unit of net foreign exchange saved or earned by the project and is given by:

$$DRC_j = \frac{\Sigma f_{sj} V_s + \Sigma d_{tj} V_t}{u_j - (mj + r_j)}$$

where DRC_j = domestic resource cost per unit of net foreign exchange saved or earned by project j.

f_{sj} = quantity of the s^{th} factor of production used in the production process of project j.

V_s = the unit value of S.

d_{tj} = quantity of the t^{th} input of domestically produced materials or services.

V_t = unit value of t.

u_j = gross value of foreign exchange earnings or savings of project j.

m_j - value of imported goods or services used in the production process of project j.

r_j = value of repatriated earnings of foreign factors of production employed by the project j: e.g. repatriation of profits, interests, salaries, etc.

All the above values are expressed in local currency. Foreign exchange values are converted at the official exchange rate and, where desired, the calculated DRC is adjusted for the shadow exchange rate. If the DRC is less than 1, the project is an efficient foreign exchange earner and vice versa. However if the DRC is close to 1, the project is marginal in either case.

As is evident from the above theoretical exposition, considerable data is required for a DRC analysis and therefore we shall, again, as in the rest of the analysis of the side effects, follow a descriptive approach to the foreign exchange impact.

We now turn to Table 4.14 which shows the major fungus diseases of bread wheat in developing countries. In the table, Kenya is shown to be one of the hot spots, that is, areas where the disease is most severe, for one of the diseases, stem rust, which is indicated to cause 40% yield losses in endemic areas and 100% losses in conditions of epidemic. It is doubtful whether under such losses any farmer will be able to break even and make some profits. This therefore leads us to conclude that if there was no research on wheat in Kenya, there would be no wheat industry because of wheat diseases unless the wheat is imported. This means that the value of foreign exchange saved by the research programme is all the wheat produced in Kenya valued at the c.i.f. prices at Kilindini at the appropriate exchange rates. The magnitude of these values are indicated for the years 1971 to 1981 in Table 4.15. The table shows that the value of savings in Kenya currency ranged from over £3 million in 1971 to over £21 million in 1981 at an average of nearly £12 million per year. These are really very substantial savings of foreing exchange. However, they are only indicative figures because for a full analysis one must substract all the foreign exchange input components such as fertilizers, insecticides, machinery, laboratory equipment, expatriate personnel repatriations, foreign travel, etc. Thus a rigorous analysis such as using the DRC approach may find that the foreign exchange savings are really not as high as a casual perusal of the issues might indicate.

Another way of looking at the foreign exchange

Table 4.14: Major Fungus Diseases of Bread Wheat in Developing Countries (Estimates by CIMMYT)

Common name and pathogen	Yield loss, susceptible Varieties (%): Average, in endemic area	Yield loss, susceptible Varieties (%): In epidemic	Endemic areas as a proportion of total wheat area (%)	Hot spots-areas where disease is most severe
Stem rust *Puccinia graminis* f. sp. *tritici*	40	up to 100	50	Highlands of Kenya and Ethiopia; Parana State, Brazil; South India
Leaf rust *Puccinia recondita* f. sp. *tritici*	15-20	up to 50	90	Mexico, India, Pakistan, Bangladesh, China
Stripe rust *Puccinia striiformis* f. sp. *tritici*	40	up to 100	33	Highlands of South America and East Africa; North Africa; Middleast; Indo-Gangetic Plain of India and Pakistan
Septoria (leaf and glume blotch) *Septoria tritici* and *S. nodorum*	20-30	up to 100	20	Argentina, Brazil, Chile, Mediterranean coast, Ethiopia, Central America
Scab (head blight) *Fusarium* spp.	10-15	50-100	30-40	China, Argentina, Brazil
Helminthosporium (common root rot, seedling blight, leaf blight) *Helminthosporium sativum*	5-10	up to 100	10 - 15	Eastern India, Nepal, Bangladesh, Zambia

Common name and pathogen	Yield loss, susceptible Varieties (%)		Endemic areas as a proportion of total wheat area (%)	Hot spots-areas where disease is most severe
	Average, in endemic area	In epidemic		
Powdery mildew *Erysiphe graminis* f. sp. *tritici*	30	up to 100	10	China, Chile, Iran Mediterranean coast
Bunt *Tilletia* spp.	5-10	up to 50	10 - 15	Turkey, Mideast, Himalayan highlands of India and Pakistan
Loose smut *Ustilago tritici*	1-10	up to 30	30	Argentina, Indo-Gangetic Plain of India and Pakistan, Turkey, Mid-east

Source: Hanson, H., N.E. Borlaug and R.G. Anderson, 1982. *Wheat in the Third World.* Boulder, Colorado, Westview Press. pp 120-21.

Table 4.15: Value of Kenyan Grown Wheat Valued at c.i.f. Prices at Kilindini, 1971 to 1981

Year	Tonnes[a]	c.i.f.price[b] per tonne (£)	Total c.i.f. value (£)
1971	170,316	22.85	3,891,721
1972	149,586	23.15	3,462,916
1973	137,884	46.67	6,407,469
1974	157,833	71.01	11,207,721
1975	175,709	50.83	8,931,288
1976	175,930	120.00	21,111,600
1977	170,865	59.60	10,183,554
1978	165,272	64.90	10,726,153
1979	114,708	115.40	13,237,303
1980	204,498	103.09	21,081,699
1981	234,546	90.74	21,282,704

Source: a) Table 5.1

b) Estimated from Kenya Statistical Abstracts, 1976 and 1982 Import Tables.

impact is to use the inputs saved approach. We have already seen that the wheat breeding research programme has resulted in eliminating spraying against wheat rust. The foreign exchange savings in chemicals, spray equipment, etc. can be assessed and accredited to the research programme minus foreign exchange expenditure components in the research programme. In addition, one could include savings of other inputs, such as fertilizers, arising from optimal use of the inputs as revealed by research.

4.4 Conclusions

Rusts are the most destructive diseases of wheat. The fungi that cause rusts mutate readily, enabling them to rapidly develop new races (strains) that can attack wheat varieties that were resistant to previous rust races. The rusts can also spread far and fast because air currents carry the spores long distances. The wheat breeder fights back by testing large numbers of wheat varieties to identify ones that have genetic resistance to a broad spectrum of the races of a fungus. Resistant varieties are then used in crosses to develop even greater concentrations of genes for disease resistance. Since the pathogens are constantly mutating and also reproducing sexually, the creation and release of resistant wheat varieties through dynamic breeding programmes is the only reliable safeguard against epidemics. Hence our earlier observation in Section 4.3.6 that without the Wheat Breeding Programme in Kenya there would be no wheat industry without imports.

The success of wheat research in Kenya as revealed in our analysis is reflected in the number of wheat varieties released at the NPBS, Njoro. 143 varieties were released between 1920 and 1982 as exhibited in Appendix 4.3. This gives an average of more than two varieties a year. In terms of a breeding programme, such performance is quite demanding and reflects considerable effort and commitment on those concerned. As a result, our analysis has shown that direct returns to wheat research have been high owing to the continuous and successful battle to keep ahead of biological change in rust pathogens. The returns have been comparable to, or even better than, returns to various forms of conventional development projects. Further investments in wheat research could therefore be profitably made.

However, the balance sheet for the side effects is not clear because there are both adverse effects and positive ones. The very notable positive effects are the environmental consequences in which research has eliminated the need to use harmful chemicals such as fungicides and high levels of fertilizer; technology transfer in the form of breeding material and R&D capacity transfer both to and out of Kenya; human capital development; and, foreign exchange savings. The negative effects are low labour intensity in wheat production compared to other farming activities; less efficient of cost-effective nutritional impact compared with traditional foods; and, an unfavourable effect on income distribution. If we had a justifiable way of quantifying or internalising these side effects then their effects would be included in the estimated rates of run. However, in the qualitative presentation, they are still a very important rider to the calculated rates of return when making decisions. The decisions will depend on the weighting given to the various effects, depending on existing public policy and on who is making that decision.

Finally in our conclusion, we note that there is need for more research towards a better specification of the analytical model. There is also need to improve the data base, such as data on inputs consumption according to crop or a given activity, research expenditures per activity, etc. so that these can be used for a regular and comprehensive analysis of the various research activities. This would require some reorganisation in the method of recording and preserving records in various organisations. However, the results of this study are encouraging enough to continue with evaluation of research work with the available data with the objective of improving resource allocation in research. In this regard there is need to try and apply the various models which have been discussed in earlier chapters to see which fit better to analytical requirements, while at the same time improving the data base and other new approaches to the analysis of R&D.

Footnotes to Chapter Four

1. Pinto and Hurd, 1970. p.2.
2. Cowen, 1978.
3. Ryan, 1983.
4. Kenya, Ministry of Finance & Planning, 1978.
5. Kenya, Ministry of Agriculture, 1963.
6. Hayami and Ruttan, 1971, p.88.
7. Kahlon et al, 1977, pp. 124-47.
8. International Service for National Agricultural Research (ISNAR), 1981. p. 120.
9. Hayami and Ruttan, 1971. p. 88.
10. Heyer and Waweru, 1971. pp. 202-5.
11. ISNAR, *op. cit.* pp. (xi), 20.
12. ILO, 1972, pp. 166, 171.
13. Heyer and Waweru, *op.cit.*, p. 187.
14. Mureithi, 1979, pp. 14-20.
15. Evenson and Kislev, 1975, p. 58-77.
16. ISNAR, *op. cit.*, p. 120.
17. Pinstrup - Andersen et al, 1976.
18. Kaplinsky, 1978.
19. Bohndal et al, 1968.
20. Kaplinsky, 1978.
21. *ibid.*
22. Kaplinsky, 1974.

APPENDIX 4.1

DETERMINATION OF THE RESEARCH EXPENDITURES

In section 4.1 we outlined the major sources of data on research expenditures. In this appendix we look in more details at the way the research expenditures were arrived at. The details of expenditures are shown in Table 4.16.

It is important to note at the outset that there is no separate data available on wheat research alone. As we shall see, most of the data available is on expenditures for Plant Breeding Services in the period before 1963 and on the National Plant Breeding Station (NPBS) at Njoro. These two encompass wheat and other crops research so that for the research expenditure under these two headings one has to determine the portion attributable to wheat research.

Table 4.16 show the various data as contained in the various sources as outlined in section 4.1 of the main text - with the exception of the Personal Emoluments (P.E. = salaries plus allowances) which had to be estimated for the years 1963 to 1976. Unfortunately, there are no reliable figures available anywhere for those years for Personal Emoluments. The estimation was done using the figures for 1977 to 1982 which are the most accurate figures available on Personal Emoluments and which appear best related to the period 1963-1976 which was the post-independence period. A linear and log-linear regression was run for these years and the equation giving the best fit was used to provide the estimates. This was the log-linear equation as is evident here below:

Linear:

P.E. = 89,338 + 11,472 X, 1979/80 = 0.

$r^2 = 0.801$

Log Linear:

Log P.E. = 4.933 + 0.0545 log X, 1979/80 = 0.

$r^2 = 0.912$

where P.E. = Personal Emoluments expenditures.
The estimates obtained are contained in Table 14.16 column 2 for years 1963 to 1976.

Columns 5 to 9 contain the donor assistance to the National Plant Breeding Station Njoro. The foreign donor assistance was converted to the Kenya pound at the official exchange rates as contained in the International Finance Statistics publications and the Central Bank of Kenya Financial and Statistical Reports.

Columns 2,3,4,6,7 and 8 were added together and columns 9 subtracted to get the expenditure for Plant Breeding Serivces (1921 - 1962) and the NPBS (1963 - 1982) which figure is contained in column 10. Column 5 (Kenya Wheat Board) was ommitted because it is already part of column 4 as appropriations -in-aid. Column 9 is also already included in column 4 but was subtracted from the final figure because the Rockefeller funds were funding an activity which was serving international interests separate from the NPBS national work.

As noted earlier, the total in column 10 had to be adjusted to arrive at research expenditure attributable to wheat. Conversion factors were worked out for this purpose. These conversion factors were:

Period	Conversion Factor
1921-1947	0.75
1948-1962	0.67
1963-1973	0.75
1974-1982	0.63

These conversion factors are based on an analysis for various expenditures for Plant Breeding Services for the years 1956 to 1962 which were obtained from various files of the NPBS, Njoro.

The analysis showed that wheat was taking an average of 66.94% of the expenditure which was rounded to 67% to give a conversion factor of 0.67 for the period 1948 - 1962. This conversion figure can be said to be the most objective of the conversion factors. For the other periods, it was not possible to get expenditure figures broken to sufficient details for a similar calculation of the conversion factors. However, using the 1948-1962 period as a base, estimates were made for the other periods as explained below.

Annual reports of the Department of Agriculture show that Plant Breeding Services were heavily in favour of wheat during the pre-war period (1921-1947). Various other crops such as oats, maize, sunflower and later pyrethrum were included under the breeding services. However, in the earlier part of this period these were really minor activities compared to the resources devoted to wheat and one could really apportion almost all the research expenditures to wheat during that period so that one could actually be underestimating the wheat research expenditures for that period using the conversion factor of 0.75. However, the later part of the pre-war period did see an increase in research activities for maize particularly from 1935 onwards when separate facilities for maize started to be established at Kitale. So there could be an overestimate for wheat research expenditures using a conversion factor of 0.75 for the later part of the pre-war period. Nevertheless the pre-war conversion factor has to be higher than the post-war conversion factor of 0.67 which we have calculated above because, as noted, there was a heavier emphasis on wheat than on other crops during the pre-war period. So the conversion factor of 0.75 was taken as a reasonable conversion factor for the pre-war period because it is greater than the immediate post-war period figure of 0.67 and at the same time appears to be a median for the pre-war period, tending to give an underestimate for the earlier part of the pre-war period and an overestimate for the later part of the pre-war period.

For 1963 onwards there were changes in financial accountability so that research figures for maize started to be accounted for under separate votes other than those of the NPBS Njoro. So for the period 1963 to 1973, the figures in column 10 are for wheat and oats which were the main crops being researched under the NPBS financial allocations for that period. However wheat was the main crop being researched on and the conversion factor jumps again to 0.75 for the period 1963 to 1973. However, various other research programmes were introduced at the NPBS from 1967 to 1974, which necessitates us to re-adjust the conversion factors. These new research programmes were on Oil Seed Breeding (1967), Barley Breeding (1972), Oil Seed Agronomy (1974) and Triticale Research (1974). Discussion with the Director of the NPBS confirmed that this re-adjustment was necessary downwards to a level similar to the 1948-1962 level of 0.67. The Director's estimate was 5/8 = 0.63 which is not very much different from 0.67. The factor of 0.63 was then chosen as the conversion factor for the period 1974-1982.

Finally, we note that these conversion factors and the regression estimates for personal emoluments for 1963 to 1976 could be a source of error. However, the likelihood is that any error especially arising from the conversion factors would be an overestimate other than an underestimation of the research expenditures. This would result in an underestimation of the returns to the research expenditures. This means we would be working with the lower limits of the returns. We contend that this is more realistic than working with the upper limits in the estimation of returns to projects.

Column 10 was then multiplied with the conversion factors in column 11 to obtain the wheat research expenditures (current) in column 12.

Table 4.16: Determination of Research Expenditures on Wheat (£)

1	2	3	4	5	6	7	8	9	10	11[b]	12
Year	Colony 1921 - 63 and Kenya Govt. 1963 - 82			Kenya Wheat Board	FAO/ DANIDA	CIDA	IDRC	Rocke-feller	Total NPBS	Conver-sion Factor	Total Wheat Res.
	Recurrent[a]										
	P. E.	Other	Dev.								
1921	2233								2233	0.75	1675
1922	2050								2050	"	1538
1923	3393								3393	"	2545
1924	2129								2129	"	1597
1925	2957								2957	"	2218
1926	4172								4172	"	3129
1927	2665								2665	"	1999
1928	2018	1330							3348	"	2511
1929	2066	1230							3296	"	2472
1930	2318	1280							3598	"	2699
1931	2383	950							3333	"	2500
1932	2467	780							3247	"	2435
1933	2863	230							3093	"	2320
1934	2909	230							3139	"	2354
1935	2859	194							3053	"	2290
1936	2943	186							3129	"	2347

1 Year	2 P.E.	3 Other	4 Dev.	5 Wheat Board	6 FAO/ DANIDA	7 CIDA	8 IDRC	9 R/Feller	10 Total	11 C.F.	12 Total Wheat
1937	2167	192							2359	0.75	1769
1938	2246	195							2441	"	1831
1939	2643	245							2888	"	2166
1940	2407	323							2730	"	2048
1941	2279	376							2655	"	1991
1942	2626	297							2923	"	2192
1943	2806	135							2941	"	2206
1944	3276	111							3387	"	2540
1945	2685	740	1400						4825	"	3619
1946	2363	1010	200						3573	"	2680
1947	2799	480							3279	"	2459
1948	2662	615							3277	0.67	2196
1949	3421	935	450						4806	"	3220
1950	3595	854							4449	"	2981
1951	4645	1020	450						6115	"	4100
1952	4532	1185	2416						8133	"	5449
1953	5275	706	2573						8554	"	5731
1954	7225	991	22702						30918	"	20715
1955	9950	2479	11334						23763	"	15921

1	2	3	4	5	6	7	8	9	10	11	12
Year	P.E.	Other	Dev.	Wheat Board	FAO/ DANIDA	CIDA	IDRC	R/FELLER	Total	C.F.	Total Wheat
1956	1519	3649	17284						22452	0.67	15043
1957	17807	8364	21163						47334	"	31714
1958	18410	8844	17002						44256	"	29652
1959	22851	10248	42268						75367	"	50496
1960	29985	9809	35980						75774	"	50769
1961	20180	15581	28604					4770	59596	"	39929
1962	23357	10463	9188					908	42096	"	28204
1963	10151	7134	3592	13400				3297	17580	0.75	13185
1964	11508	7258	–	–				981	17785	"	13339
1965	13046	7355	1500	1209				688	21213	"	15910
1966	14791	7070	3000	3240		38237		580	62518	"	46889
1967	16769	9484	6000	4315		38350		520	70083	"	52562
1968	19011	11550	–	–		38629		536	68654	"	51491
1969	21553	18431	3000	–		38629		279	81334	"	61001
1970	24434	13550	5017	–	13111	40982		433	96661	"	72496
1971	27701	13415	7515	25165	11461	41350			101442	"	76082
1972	31405	20601	5026	31508	10850	41652			109534	"	82151
1973	35604	19300	5468	25085		40192			100564	"	75423
1974	40365	32224	1050	33817		41846	9450		115485	0.63	72756
1975	45761	30865	6450	23019			10455		83076	"	52338

1	2	3	4	5	6	7	8	9	10	11	12
Year	P.E.	Other	Dev.	Wheat Board	FAO/ DANIDA	CIDA	IDRC	R/Feller	Total NPBS	C.F.	Total Wheat
1976	51880	34470	1050	33817			4040		87400	0.63	55062
1977	59435	35591	2280	5879			5400		97306	"	61303
1978	71371	31875	7325			113459	3420		224030	"	141139
1979	73705	37359	8975			113604			233643	"	147195
1980	81892	33448	28944			115476			259760	"	163649
1981	114805	25147				157462			297414	"	157371
1982	134818	25041	10017			187585			357461	"	225200

Notes:

a: The expenditures for years 1921 to 1927 were not available according to 'Personal Emoluments' (P.E.) and 'other' expenditures.

b: Column 10= Columns 2 + 3 + 4 + 6 + 7 + 8 minus 9. Column 5 is already included in column 4 and so is omitted to avoid double counting. Column 9 is also included in column 4 but is subtracted because the Rockefeller funds were funding an activity which was an international one separate from the NPBS national activities.

c: Column 12 = Column 10 x Column 11

e: P.E. = Personal Emoluments = salaries + allowances

f: Other = Other Recurrent expenditures

g: Dev. = Development Expenditures

h: DANIDA = DANISH International Development Agency

i: CIDA = Canadian International Development Agency

j: IDRC = International Development Research Centre of Canada

Source: See Appendix 4.1 notes and section 4.1 of the main text on Data sources.

APPENDIX 4.2

DETERMINATION OF THE CAPITAL FORMATION DEFLATOR (CFD)

The figures available for a Capital Formation Deflator (CFD) were for the years 1952 to 1979 (Ryan, 1983). So the first task was to find any index stretching from 1921 to 1982. Then this index could be regressed on the 1952-79 CFD and the regression equation used to estimate the CFD values for 1921 to 1951 and 1980 to 1982. A Cost of Living Index (CLI) for 1921 to 1982 was constructed for this purpose. The following data was used to construct the CLI:

- A Consumers Price Index (CPI) constructed by Cowen (1978) for 1926 to 1936, Karatina Area, Nyeri.
- A Cost of Living Index (CLI) constructed by Cowen for 1934 to 1962, Karatina Area, Nyeri.
- A Retail Price Index (RPI) for the year 1958 to 1968 from the East African Economic & Statistical Reviews, Lower Income Group.
- A Consumers Price Index (CPI) for the years 1966 to 1975, from the Kenya Statistical Abstracts, Lower Income Group.
- A CPI for the years 1971 to 1982 from the Kenya Statistical Abstracts, Lower Income Group.

These indices were chosen for two reasons: First they had to be overlapping so that they could be converted into one another. Secondly, the indices had to be for the lower income groups. This is because the only index obtainable stretching into the early years was Cowen's and this was for a rural area, Karatina, Nyeri. The Lower Income Group Indices were chosen as they were assumed to be the ones likely to approximate more closely to rural consumers and cost of living indices such as Cowen's.

Referring to Table 4.17, column 2 contains Cowen's Consumer Price Index from 1926 to 1936. This index contains a gap after every even year and goes down only up to 1926. These gaps had to be filled and estimates for 1921 to 1925 worked out. For this purpose, a linear regression equation was computed using the data in column 2 and using a biannual periodicity. The regression equation was:

$$CPI = 142 - 13\,X, \quad 1930/32 = 0$$

$$r^2 = 0.868$$

where the value of X changes by a unit representing two years.

Using the above equation, the values for the years 1920, 1922 and 1924 were estimated and are shown in column 3. Then using both actual and estimated values from columns 2 and 3 respectively, the values

Table 4.17: CPI Values 1921 To 1936 (1936 = 100)

Year (1)	Cowen's CPI Values (2)	Regression Estimates (3)	Odd Year Estimates (4)	The Complete Series (5)
1920		220		220
1921			214	214
1922		207		207
1923			200	200
1924		194		194
1925			193	193
1926	192			192
1927			180	180
1928	169			169
1929			154	154
1930	138			138
1931			136	136
1932	133			133
1933			128	128
1934	123			123
1935			112	112
1936	100			100

Source: Column 2: Cowen, M.P. 1978. Capital and Household Production : The Case of Wattle in Kenya's Central Province, 1903 - 1964. Ph.D Thesis, University of Cambridge, Table 5.

Other Columns: Own computations from column 2: See notes in Appendix 4.2.

for the odd years were calculated by simply taking the average of the preceeding and the succeeding years. The values obtained for the odd years are shown in column 4. Column 5 simply consolidates all the values from columns 2, 3 and 4 into one column to show the complete CPI series.

The next step was to calculate conversion factors using the overlapping portions of the indices as shown in Table 14.18. Referring to this table, the brackets} or {indicate the areas of overlap for each pair of indices; the arrow indicates the direction of conversion; and the figure associated with the arrow is the conversion factor (C.F.) as computed from the overlapping area of the respective indices.

The final product of this conversion exercise is the CLI in column 3 stretching from 1921 to 1982. This CLI was then linearly regressed on the Capital Formation Deflator (CFD) available for 1952 to 1979. The regression equation obtained was:

CFD = -0.1404 + 0.00468 CLI, 1952-79 incl.

CFD = 1.0000 in 1976

CLI = 100 in 1962

R^2 = 0.990

The CFD values for 1921 to 1951 and 1980 to 1982 were then estimated using the above equation. The CFD values are given in column 7.

Table 14.18: Computation of Cost of Living Index (CLI), 1921 to 1982 and Capital Formation Deflator (CFD) 1921 to 1982

Year	CPI 1936=100	CLI 1962=100	RPI Oct.1958=100	CPI Aug.1971=100	CPI Jan/June 1975=100	CFD 1976= 1.0000
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1921	214	133				.4820
1922	207	128				.4586
1923	200	124				.4399
1924	194	120				.4212
1925	193	120				.4212
1926	192	119				.4165
1927	180	112				.3838
1928	169	105				.3510
1929	154	95				.3042
1930	138	86				.2621
1931	136	84				.2527
1932	133	82				.2434
1933	128	79				.2293
1934	123	72				.1966
1935	112	70				.1872
1936	100	67				.1732

C.F. = 0.62

	CPI	CLI
(1)	(2)	(3)
1937		68
1938		67
1939		71
1940		70
1941		73
1942		77
1943		78
1944		79
1945		80
1946		80
1947		82
1948		84
1949		87
1950		88
1951		97
1952		94
1953		96
1954		97
1955		97

RPI (4)	CPI (5)	CPI (6)	CFD (7)
			.1778
			.1732
			.1919
			.1872
			.2012
			.2200
			.2246
			.2293
			.2340
			.2340
			.2434
			.2527
			.2668
			.2714
			.3136
			.2499
			.3583
			.2697
			.2864

(1)	CPI (2)	CLI (3)	RPI (4)	CPI (5)	CPI (6)	CFD (7)
1956		98				.2905
1957		98	C.F.=0.95			.2999
1958		98	100			.2999
1959		98	101			.3020
1960		98	103			.3041
1961		99	105			.3114
1962		100	108			.3280
1963		100	108			.3374
1964		100	108			.3374
1965		109	115	C.F.=1.31		.3520
1966		112	118	90.1		.3675
1967		114	120	91.7		.4047
1968		115	121	92.4		.4105
1969		115	121	92.4		.4191
1970		117	123	93.9	C.F.=1.49	.4439
1971		125	132	100.9	68.5	.4613
1972		129	136	103.9	70.6	.5050
1973		148	156	119.5	82.2	.5804
1974		173	182	138.7	91.4	.7276
1975		208	219	166.9	108.2	.8506

	CPI	CLI	RPI	CPI	CPI	CFD
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1976		218	230	175.8	118.0	1.0000
1977		265	279	212.8	142.8	1.0848
1978		301	317	241.8	162.3	1.2084
1979		329	346	263.9	177.1	1.3605
1980		371	391	298.4	200.3	1.5959
1981		443	466	356.1	239.0	1.9328
1982		504	530	405.0	271.8	2.2813

Source: Column 2: Table 4.17.
Column 3: Cowen, 1978. op. cit. Table A.6
Column 4: East African Economic and Statistical Reviews
Column 5: Kenya Statistical Abstracts
Column 6: Kenya Statistical Abstracts
Column 7: 1952 to 1979: Ryan, T.C.I. 1983. Unpublished Data. University of Nairobi.

Other years: Own computations: See notes in Appendix 4.2.

APPENDIX 4.3

WHEAT VARIETIES RELEASED IN KENYA 1920-1982

Registration No.	Name	Year
1	Equator	1920
2	Kenya Governor	1925
3	Kenya Droop	1929
4	Kenya Standard	1930
5	Kenya N. B. 230	1933
6	Kenya N. B. 256.G	1934
7	Sabanero	1934
8	Reward	?
9	Kenya 58.F	1937
10	Kenya 112.A	1936
11	Kenya 117.A	1939
12	Kenya 122	1939
13	Kenya 131	1939
14	DC x Ceres 721	1946
15	Kenya 291	1946
16	Regent	1946
17	Kenya 294.M	1947
18	Kenya 294.B	1948
19	M.K. 1066	?
20	Kenya 318.AJ	1949
21	Kenya 261.R	1949
22	Kenya 117A MK 11	1949
23	Rhodesian Sabanero	1949
24	Kenya Settler	1950
25	Kenya Ploughman	1950
26	Kenya 291, JMK 11	1950
27	Kenya 360.H	1951
28	Kenya 337	1951
29	Kenya Farmer	1951
30	Kenya 338 AA	1951

Registration No.	Name	Year
31	Kenya 184 P	1951
32	Kenya 350	1951
33	Kenya 341	1951
34	Kenya 321	1952
35	R. 64	1953
36	Carleton	1953
37	Kenya 351	1954
38	Kenya 354	1955
39	Kenya 356.A	1955
40	Kenya 261.A	1955
41	Kenya 356.B	1956
42	Kenya 358.AA	1956
43	Kenya 362.B.1.E.4	1956
44	Kenya 358.AC	1957
45	Kenya 358.P	1957
46	Kenya 358 R	1957
47	Kenya 363	1957
48	Kenya 362.B.1.A.1B	1957
49	Kenya 362.B.1.D.3.D	1957
50	1055/1	1957
51	1066/6	1957
52	Mida-cadet	1957
53	Capella	1957
54	Hopeful	1957
55	Impala	1957
56	Kenya 339	1958
57	Kenya B.1.A	1958
58	Kenya 367.AP	1958
59	Kenya 367 BR	1958
60	H. 462	1958
61	RL 2150/A	1958
62	Sabanero/1	1958
63	Kenya Curlew	1959
64	Kenya Eagle	1959

Regist-ration No.	Name	Year
65	Kenya Kark	1959
66	Kenya Burzard	1959
67	Kenya Dove	1959
68	Kenya Plover	1959
69	Kenya Quail	1959
70	Africa-Mayo	1960
71	Kentana Yaqui	1960
72	Wisconsin-supremo	1960
73	Mida-McMurachy-Exchanre	1960
74	S. Africa No 43	1961
75	Yaktana 54	1961
76	Kenya 374	
77	A.K.M.S. x Yaqui[2]	1961
78	Veranopolis	1961
79	Rushmore-Surpressa	1961
80	F.K.N 25	1961
81	Gala	1961
82	Kenya Jay	1961
83	Kenya Grange	1962
84	Yaqui 50	1962
85	Tama	1963
86	Menco	1963
87	Salmayo	1963
88	Lemana	1963
89	Catcher	1963
90	Yaqui 53	1963
91	Kenya Page	1963
92	Cabrino	1963
93	Fronthach	1963
94	Gem	1963
95	Pewter	1964
96	Fanfare	1964
97	Bailey	1964
98	Brewster	1964

Registration No	Name	Year
99	Morris	1964
100	Fury	1964
101	Kenya Hunter	1964
102	Prime x 908 x Fn x CJ 54	1965
103	Kenya Blume	1965
104	Goblet	1965
105	Kenya Kudu	1966
106	Kenya Civet	1966
107	Kenya Leopard	1966
108	Romany	1966
109	Token	1967
110	Bonny	1967
111	Bounty	1967
112	Trophy	1968
113	Beacon	1968
114	Kenya Sungura	1969
115	Tai	1969
116	Kasuku	?
117	Twiga	1970
118	Kenya Kanga	1971
119	Kenya Bongo	1971
120	Kenya Swara	1972
121	Kenya Mamba	1972
122	Kenya Kiboko	1973
123	Kenya Nyati	1973
124	Kenya Kuro	1974
125	Kenya Mbweha	1974
126	Kenya Paka	1975
127	Kenya Tembo	1975
128	Kenya Nungu	1975
129	Kenya Nyoka	1975
130	Kenya Bata	1975
131	Kenya Fahari	1977
132	Kenya Kifaru	1977

Regist-ration No.	Name	Year
133	Kenya Ngiri	1979
134	Kenya Nyangumi	1979
135	Kenya Zabadi	1979
136	Kenya Mwewe	1979
137	Kenya Njiwa	1979
138	Kenya Kengewa	1979
139	Paa	1981
140	Kenya Kongoni	1981
141	Kenya Kulungu	1982
142	Kenya Nyumbu	1982
143	Kenya Popo	1982.

Source: National Plant Breeding Station, Njoro, 1983. Unpublished Data, Njoro, Nakuru.

References

1. Akino, M. and Y. Hayami. 1975. "Efficiency and Equity in Public Research: Rice Breeding in Japan's Economic Development". Americal Journal of Agricultural Economics, 57, pp. 1-10.

2. Andrews, F.M. (ed.). 1979. Scientific Productivity: The Effectiveness of Research Groups in Six Countries. Paris, UNESCO.

3. Annerstedt, Jan. 1979. A Survey of World Research and Development Efforts: The Distribution of Human and Financial Resources Devoted to Research and Experimental Development in 1973. Paris, OECD.

4. Araji, A.R., R.J. Sim and R.L. Gardner. 1978. "Returns to Agricultural Research and Extension Programs: An Ex-ante Approach". American Journal of Agricultural Economics, 60. pp. 964-8.

5. Arrow, K.J. 1965. "Discounting and Public Investment Criteria." In A.V. Kneese and S.K. Smith (Eds.) Water Research. Baltimore, John Hopkins Press.

6. Arrow, K.J. and M. Kurz. 1970. Public Investment, the Rate Return and Optimal Fiscal Policy. Baltimore, John Hopkins Press.

7. Atkinson, A.C. and A.H. Bobis, 1969. "A Mathematical Basis for Selection of Research Projects." IEE Transactions on Engineering Management. EM-16, pp. 2-8.

8. Ayer, H.W. and G.E. Schuh, 1972. "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil." American Journal of Agricultural Economics, 54, pp. 557-69.

9. Bohndal, M., N.E. Gibbs and W.K. Simmons. 1968. Nutrition Survey and Campaign Against Malnutrition in Kenya 1964-68: Report to the Ministry of Health of Kenya on the WHO/FAO/UNICEF Assisted Projects. Nairobi, Ministry of Health, Republic of Kenya.

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

11. Cartwright, R.W. 1971. Research Management in a Department of Agricultural Economics. PhD Thesis, Purdue University.

12. Cetron, M.J. and J.N. Johnson. 1972. "Technological Forecasting in a Dynamic Environment. In M.J. Cetron, H. Davidson and A.H. Rubenstein (eds.). Quantitative Decision Aiding Techniques for Research and Development Management, N.Y., Gordon and Breach, Science Publishers, Inc.

13. Cline, P.L. 1975. Sources in Productivity Change in the United States Agriculture. Ph D Thesis, Oklahoma State University.

14. Cowen, M.P. 1978. Capital and Household Production: The Case of Wattle in Kenya's Central Province, 1903-1964. Ph D Thesis, University of Cambridge.

15. Davis, J. 1979. Stability of the Research Coefficient for U.S. Agriculture, Ph D Thesis, University of Minnesota.

16. Davis, O.A. and M.I. Kamien. 1977. "Externalities, Information and Alternative Collective Action". In R. Dorfman and N. Dorman (eds.) Economics of the Environment. N.Y., W.W. Norton & Co.

17. de Castro, R.J.P and G.E. Schuh. 1977. "An Empirical Test of an Economic Model for Establishing Research Priorities: A Brazil Case Study". In T.M. Arndt, D.G. Dalrymple and V.W. Ruttan (eds.). Resource Allocation and Productivity in National and International Agricultural Research. Minneapolis, University of Minnesota.

18. Dixon, G.E. 1960. "A Review of Wheat Breeding in Kenya." Euphytica. 9, pp. 209-21.

19. Duncan, R.C. 1971. "Evaluating Returns to Research in Pasture Improvement." Australian Journal of Agricultural Economics. 16, pp. 153-68.

20. Duncan, R. and L. Tisdell. 1971. "Research and Technical Program: The Returns to Producers." Economic Research. 47, pp. 124-29.

21. East African Community. East African Economic and Statistical Review, Annual. Arusha, East African Community.

22. Eckaus, R.S. 1955. "The Factor Proportions Problem in Underdeveloped Areas." AER. XLV, pp. 539-65.

23. Eddleman, B.R. 1977. "Evaluation of Economic Benefits from Agricultural Production Research and Implications for Marketing." Proceedings of National Workshop on Coordination of Marketing Research pp.29-41. As cited in Norton and Davis, 1981. p.44.

24. Evenson, R.E. 1967. "The Contribution of Agricultural Research to Production." Journal of Farm Economics. 49, pp. 1415-25.

25 __________. 1982. "Benefits and Obstacles to Appropriate Agricultural Technology." Center Paper No. 313. Economic Growth Center, Yale University.

26. Evenson, R.E. and Y. Kislev. 1975. Agricultural Research and Productivity. London, Yale University Press.

27. Fishel, W.L. 1981. "Changes in the Need for Research and Extension Evaluation Information." In G.W. Norton, W.L. Fishel, A.A. Paulsen and W.B. Sundquist (eds.). Evaluation of Agricultural Research: Proceedings of a Workshop Sponsored by NC-148. Misc. Publication No. 8-81. Agricultural Experiment Station, University of Minnesota.

28. Fishelson, G. 1971. "Returns to Human and Research Capital and the North-South Agricultural Sector of the United States." American Journal of Agricultural Economics. 53, pp. 129-31.

29. Flores - Moya, P., R.E. Evenson and Y. Hayami, 1978. "Social Returns to Rice Research in the Philippines: Domestic Benefits and Foreign Spillover." Economic Development and Cultural Change. 26, pp. 591-607.

30. Gaude, J. 1975. "Capital-Labour Substitution Possibilities: A Review of Empirical Evidence." In A.S. Bhalla (eds.). Technology and Employment in Industry. Geneva, ILO.

31. Gittinger, J.P. 1972. Economic Analysis of Agricultural Projects. Baltimore, John Hopkins University Press.

32. Griliches, Z. 1958. "Research Costs and Social Returns: Hybrid Corn and Related Innovations." JPE. 66, pp. 419-31.

33. __________. 1964. "Research Expenditures, Education and the Aggregate Agricultural Production Function." AER. 54, pp. 961-74.

34. Gsaenger, H.G. and G. Schmidt. 1977. "Decontrolling the Maize Marketing System in Kenya." Discussion Paper No. 254. Institute for Development Studies, University of Nairobi.

35. Hanson, H., N.E. Borlaug and R.G. Anderson. 1982. Wheat in the Third World. Colorado, Westview Press.

36. Harberger, A.C. 1971. "On Measuring the Social Opportunity Cost of Labour". International Labour Review. 103, pp. 559-79.

37. Harris, J.R. and M.P. Todaro. 1969. "Wages, Industrial Employment and Labour Productivity." East African Economic Review. 1, pp. 29-46.

38. __________. 1970. "Migration, Unemployment and Development: A Two Sector Analysis." AER. 60, pp. 126 - 142.

39. Hayami, Y. and V.W. Ruttan. 1971. Agricultural Development: An International Perspective. London, The John Hopkins Press.

40. Heertje, A. 1977. Economics and Technical Change. London, Weidenfeld and Nicolson.

41. Hertford R. and A. Schmitz. 1977. "Measuring Economic Returns to Agricultural Research." In T.M. Arndt, D.G. Dalrymple and V.W. Ruttan (eds.). Resource Allocation and Productivity in National and International Agricultural Research. Minneapolis, University of Minnesota.

42. Heyer, J. 1976. "The Marketing System." In J. Heyer, J.K. Maitha and W.M.Senga (eds.). Agricultural Development in Kenya: An Economic Assessment. Nairobi, Oxford University Press.

43. Heyer, J. and J.K. Waweru. 1976. "The Development of Small Farm Areas". In J. Heyer, J.K. Maitha and W.M. Senga (eds.). Agricultural Development in Kenya: An Economic Assessment. Nairobi, Oxford University Press.

44. Hicks, J. 1946. Value and Capital, Oxford, Clarendon Press.

45. House, W.J. 1973. "Wages, Employment and Productivity in Kenya: Some Further Evidence." East African Economic Review. 5, pp. 75-8.

46. ILO. 1972. Employment, Incomes and Equality: A Strategy for Increasing Productive Employment in Kenya. Geneva, ILO.

47. International Development Association (IDA). News Releases 1980-82. Washington, IDA.

48. International Service for National Agricultural Research (ISNAR). 1981. Kenya's National Agricultural Research System: A Report to the National Council for Science and Technology and the Government of Kenya. The Hague, ISNAR.

49. Irvin, G. 1978. Modern Cost-Benefit Methods: An Introduction to Financial, Economic and Social Appraisal of Development Projects. London, The MacMillan Press.

50. Jamieson, B.M. 1981. Resource Allocation to Agricultural Research in Kenya from 1963 to 1978. Ph D Thesis, University of Toronto.

51. Kalbermatten J.M., D.S. Julius, D.D. Mara and C.G. Gunnerson. 1980. Appropriate Technology for Water Supply and Sanitation: A Planner's Guide. Washington, The World Bank.

52. Kaplinsky, R.M. 1974. "Choice of Technology in the Kenyan Manufacturing Sector with Particular Reference to the Situation and Orientation of Technical Change: A Project Outline." Working Paper No. 202. Institute for Development Studies, University of Nairobi.

53. _________. 1978. "Inappropriate Products and Techniques in UDC's: The Case of Breakfast Foods in Kenya." Working Paper No. 335. Institute for Development Studies, University of Nairobi.

54. Kenya. 1966. Report of the Maize Commission of Inquiry. C. Singh, Chairman. Nairobi, Government Printer.

55. _________. 1973. Report of the Select Committee on the Maize Industry, W.Wabuye, Chairman. Nairobi, Government Printer.

56. _________. 1974. Development Plan 1974-78 Part I. Nairobi, Government Printer.

57. _________. 1979. Development Plan 1979-83 Part I. Nairobi, Government Printer.

58. _________. 1980. Sessional Paper No. 4 of 1980 on Economic Prospects and Policies. Nairobi, Government Printer.

59. _________. Annual Appropriation Accounts and Audit Reports 1955-82. Nairobi, Government Printer.

60. _________. Central Bureau of Statistics. Statistical Abstracts, Annual. Nairobi, Government Printer.

61. ________. Colony Development and Welfare Fund (CD & W). Annual Reports 1945-51. Nairobi, Government Printer.

62. ____________. Department of Agriculture. Annual Reports 1921-37.. Nairobi, Government Printer.

63. __________. Development and Reconstruction Authority (DARA). Annual Reports 1945-51. Nairobi, Government Printer.

64. __________. Estimates of Revenue and Expenditure 1926-54. Nairobi, Government Printer.

65. __________. Ministry of Finance and Planning. 1978. Public Sector Projects Handbook. Vol. III, Preliminary Edition, Nairobi, Ministry of Finance and Planning.

66. __________. Ministry of Agriculture. 1963. Unpublished Reports on the Scott Agricultural Laboratories and the National Plant Breeding Station, Njoro. Nairobi, Ministry of Agriculture.

67. __________. Ministry of Agriculture. End of Year Ledgers 1974-82. Nairobi, Ministry of Agriculture.

68. __________. National Archives. Kenya Government Files, Archives Ref. Nos. 1/511, 1/512, 1/520, 1/521 on the National Plant Breeding Station, Njoro. Nairobi, Kenya National Archives.

69. __________. National Plant Breeding Station, Njoro (NPBS). Records of Expenditure and Authority to Incur Expenditure 1957-1981. Njoro, NPBS.

70. __________. National Plant Breeding Station, Njoro (NPBS). 1980. General Information. Njoro, NPBS.

71. Kenya Wheat Board. Annual Reports 1963-76. Nairobi, Kenya Wheat Board.

72. Khalon, A.S., H.K. Bal, P.N.Saxena and D. Jha. 1977. "Returns to Investment in Research in India." In I.M. Arndt, D.G. Dalrymple and V.W. Ruttan (eds.) Resource Allocation and Productivity in National and International Agricultural Research. Minneapolis, University of Minnesota.

73. Kislev, Y. and H. Hoffman. 1978. "Research Productivity in Wheat in Israel." Journal of Development Studies. 14, pp. 166-81.

74. Kislev, Y. and U. Rabiner. 1979. "Economic Aspects of Selection in the Dairy Herd in Israel." Australian Journal of Agricultural Economics. 23, pp. 128-46.

75. Knutson, M. and L. Tweeten. 1979. "Toward an Optimal Rate of Growth in Agricultural Production Research and Extension." American Journal of Agricultural Economics. 61, pp. 70-6.

76. Lal, D. 1973. "Disutility of Effort, Migration and the Shadow Wage Rate." OEP. 25, pp. 122-26.

77. Lindner, R.K. and F.G. Jarrett. 1978. "Supply Shifts and the Size of Research Benefits." American Journal of Agricultural Economics. 60, pp. 48-56.

78. Little, I.M.D. and J.A. Mirrlees. 1974. Project Appraisal and Planning for Developing Countries. London, Heinemann.

79. Lu, Y., L. Quance and C.L. Liu. 1978. "Projecting Agricultural Productivity and its Economic Impact." American Journal of Agricultural Economics. 60, pp. 976-80.

80. Maitha, J.K. 1973. "Capital-Labour Substitution in Manufacturing in a Developing Economy: The Case of Kenya." East African Economic Review. 5, pp. 43-52.

81. Mansfield, E. 1968a. Industrial Research and Technological Innovation. N.Y., W.W. Norton & Co.

82. ________. 1968b. The Economics of Technological Change. N.Y., W.W. Norton & Co.

83. ________. 1969. "Technological Change and Industrial Research." In E.S. Phelps (ed.). The Goal of Economic Growth. N.Y., W.W. Norton & Co.

84. ________. 1971. Technological Change. N.Y., W.W. Norton & Co.

85. Mishan, E.J. 1975. Cost-Benefit Analysis. London, George Allen & Unwin.

86. Morawetz, D. 1976. "Elasticities of Substitution in Industry: What do We Learn from Econometric Estimates?" World Development. 4, pp. 539-65.

87. Mureithi, L.P. 1974. "A Production Function Analysis of Different Firm Sizes in Kenya." Working Paper No. 183. Institute for Development Studies, University of Nairobi.

88. ________. 1979. "Scope and Salient Features of Rural Development in Kenya." Israel Journal of Development. 5, pp. 14-20.

89. Muturi, S.N. 1981. The System of Resource Allocation to Agricultural Research in Kenya. Unpublished Paper, Kenyan National Council for Science and Technology.

90. Norton, G.W. and J.S. Davis. 1981. "Review of Methods Used to Evaluate Returns to Agricultural Research." In G.W. Norton, W.L. Fishel, A.A. Paulsen and W.B. Sundquist (eds.). Evaluation of Agricultural Research: Proceedings of a Workshop Sponsored by NC-148. Misc. Publication No. 8-1981. Minnesota Agricultural Experiment Station, University of Minnesota.

91. Organisation for Economic Cooperation and Development (OECD). 1968. Manual of Industrial Projects Analysis. Vols I and II. Paris, OECD.

92. ________. 1976. The Measurement of Scientific and Technical Activities: Proposed Standard Practice for Surveys of Research and Experimental Development - 'The Frascati Manual'. Paris, OECD.

93. Pinstrup-Andersen, P. and D. Franklin. 1977. "A Systems Approach to Agricultural Research Resource Allocation to Developing Countries." In T.M. Arndt, D.G. Dalrymple and V.W. Ruttan (eds.). Resource Allocation and Productivity in National and International Agricultural Research. Minneapolis, University of Minnesota.

94. Pinstrup-Andersen, P., N.R. de Londono and E. Hoover. 1976. "The Impact of Increasing Food Supply on Human Nutrition: Implications of Commodity Priorities in Agricultural Research and Policy." American Journal of Agricultural Economics. 58, pp. 131-42.

95. Pinto, F.F. and E.A. Hurd. 1970. "Seventy Years with Wheat in Kenya." East African Agricultural and Forestry Journal. xxxvi, Special Issue.

96. Roemer, M. and J.J. Stern. 1975. The Appraisal of Development Projects: A Practical Guide to Project Analysis with Case Studies and Solutions. N.Y., Praeger Publishers.

97. Rose, F. 1980. "Supply Shifts and Research Benefits: A Comment." American Journal of Agricultural Economics. 62, pp. 834-37.

98. Russel, D.G. 1977. "Resource Allocation in Agricultural Research Using Socio-Economic Evaluation and Mathematical Models." Canadian Journal of Agricultural Economics. 23, pp. 29-52.

99. Ryan, T.C.I. 1983. Unpublished Data on the Capital Formation Deflator, 1952-1979. University of Nairobi.

100. Scherer, F.M. 1965. "Government Research and Development Programs." In R. Dorfman (ed.). Measuring Benefits of Government Investments. Washington, The Brookings Institution.

101. Schmidt, G. 1979. "Maize and Beans in Kenya: The Interaction and Effectiveness of the Informal and Formal Marketing System." Occasional Paper No. 31. Institute for Development Studies, University of Nairobi.

102. Schmitz, A. and D. Seckler. 1970. "Mechanical Agriculture and Social Welfare: The Case of the Tomato Harvester." American Journal of Agricultural Economics. 52, pp. 569-78.

103. Schuh, G.E. and H. Tollini. 1979. "Costs and Benefits of Agricultural Research: The State of the Art." Staff Working Paper No. 360. Washington, The World Bank.

104. Schultz, T.W. 1953. The Economic Organization of Agriculture. N.Y., McGraw-Hill.

105. Scobie, G.M. 1976. "Who Benefits From Agricultural Research?" Revised Marketing Agricultural Economics. 44, pp. 197-202.

106. _________. 1979. "Investment in International Agricultural Research: Some Economic Dimensions." Staff Working Paper No. 361. Washington, The World Bank.

107. Scobie, G.M. and R.T. Posada. 1978. "The Impact of Technical Change on Income Distribution: The Case of Rice in Columbia." American Journal of Agricultural Economics. 60, pp. 85-91.

108. Scott, M.F.G. 1974. "How to Use and Estimate Shadow Exchange Rates". OEP. 26, pp. 168-84.

109. Shumway, C.R. and R.J. McCraken. 1975. "Use of Scoring Models in Evaluating Research Programs." American Journal of Agricultural Economics. 57, pp. 714-18.

110. Souder, W.E. 1972. "A Scoring Methodology for Assessing the Suitability of Management Science Models." Management Science. 6, pp. 81-6.

111. Squire, L. and H.G. van der Tek. 1975. Economic Analysis of Projects. Baltimore, John Hopkins University Press.

112. Tweeten, L.C. and F.K. Hines. 1965. "Contribution of Agricultural Productivity to National Economic Growth." Agricultural Science Review. 3, pp. 40-5.

113. UNCTAD. 1980. Co-ordinated Technological Research and Development in Developing Countries: Regional Cooperation to Strengthen Indigenous Capabilities for Innovation. TD/B C.6/63. Geneva, UNCTAD.

114. UNDP. 1977. Compedium on Development Assistance to Kenya as of 31 December 1976. Nairobi, UNDP

115. UNESCO. 1980. Statistical Yearbook. Paris, UNESCO.

116. UNIDO. 1972. Guidelines for Project Evaluation N.Y., UN.

117. Wharton, C.R. 1969. "The Green Revolution: Cornucopia or Pandora's Box?" Foreign Affairs. 47, pp. 464-76.

118. White, F., J. Havlicek and D. Otto. 1978. "Agricultural Research and Extension Investiment Needs and Growth in Agricultural Production." Paper No. 33. Department of Agricultural Economics, Virginia Polytechnic and State University.

119. White, L.T. 1978. "The Evidence on Appropriate Factor Proportions for Manufacturing in Less Developed Countries: A Survey." Economic Development and Cultural Change. 27, pp. 27-59.

120. Wise, W.S. and E. Fell. 1980. "Supply Shifts and Research Benefits: Comment." American Journal of Agricultural Economics. 62, pp. 838-40.

121. World Bank, The. 1975. Kenya Into the Second Decade. Washington, The World Bank.

122. ___________. News Releases 1980-82. Washington, The World Bank.