Questioning the Role of the Public

Sector in UK Agricultural R&D

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Declaration

I hereby declare that this thesis represents all my own work unless otherwise stated in the body of the thesis.

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Abstract

Agricultural research and development (R&D) has enjoyed public support for much of the twentieth century. For most of this time the agricultural research service (ARS) has experienced growing levels of public expenditure. However, in the latter part of this century radical changes have occurred to both its funding and research focus. Accordingly, there is a need to re-evaluate the role and purpose of publicly-funded agricultural R&D. This encompasses a number of issues which have to be explored.

First, there have been numerous studies assessing the returns to public investment in agricultural R&D and, in general, these have found high rates of return which have pointed to under-funding of research. However, these studies have been questioned recently on a number of conceptual and empirical grounds. Taking account of these criticisms, but still using the traditional production function approach, this study has found that the returns to agricultural R&D remain high, but only for certain areas of the agricultural research service. This has questioned the conventional wisdom that public agricultural R&D is under-funded.

Second, the role that the private sector has to play is in need of further investigation. Little is known about private sector activity in agricultural R&D and its motivations as regards funding it. As part of this research, a survey was conducted and this found that the private sector, in recent years, has reduced rather than increased research expenditures to compensate for the decline in public funding for applied and development work. Moreover, only a small proportion of private R&D expenditure is devoted to collaborative activity with the public sector, so that any recent shift towards promoting funding of agricultural R&D has been at the expense of research cohesion.

Third, the fundamental theoretical basis for public support of agricultural R&D has been the concept of market failure. However, most of the arguments advanced only offer strong support for the public funding of basic research. Therefore, a number of other approaches have been employed to understand the reasons for continued public support of agricultural R&D. Significantly, the relatively recent body of theory connected with transaction cost economics provides some justification for continued public funding of applied research and development work. This, along with arguments advanced by policy analysts, has helped to establish that the ARS still has a role in providing public good research and in ensuring a cohesive framework for the funding of basic, applied research and development to meet effectively the demands of society.

In summary, there is no question that the private sector cannot act as a complete and perfect substitute for publicly-funded agricultural R&D and without a publicly-funded UK agricultural research service would be at a severe disadvantage. Instead, emphasis should be placed on trying to integrate private and public research in this area, as so far the evidence suggests that this has not been very successful.

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List of Abbreviations

ABRC	Advisory Board of the Research Councils
ACARD	Advisory Committee on Applied Research and Development
ADAS	Agricultural Development and Advisory Service
AFRC	Agricultural and Food Research Council
ARC	Agricultural Research Council
ARS	Agricultural Research Service
BBSRC	Biotechnological and Biological Science Research Council
CEC	Commission of the European Communities
DAFS	Department of Agriculture for Scotland
DCS	Department of the Civil Service
DEA	Department of Economic Affairs
DES	Department of Education and Science
FAO	Food and Agriculture Organisation
HEFC	Higher Education Funding Council
MAFF	Ministry of Agriculture, Fisheries and Food
NAAS	National Agricultural Advisory Service
OECD	Organisation for Economic Co-operation and Development
OST	Office of Science and Technology
R&D	Research and Development
RRI	Rowett Research Institute
SOAEFD	Scottish Office Environment, Agriculture and Fisheries Department
UGC	University Grants Commission

Introduction

Throughout this century the organisation and administration of public science has undergone radical changes with regard to its structure and purpose. The Government scrutiny exercise, initiated in 1994, is the most recent addition to a set of measures aimed at imposing questions of relevance and applicability on the allocation of funding towards public sector science institutes. The Agricultural Research Service (ARS), which is taken to include all public bodies involved with the creation and diffusion of agricultural research and development (R&D), has changed both as a result of these shifts in the science system and as a remit of an increased emphasis in agricultural policy on more environmental and rural objectives.

In general, there has been a trend towards creating greater accountability, which has latterly been coupled with changes in the perceived role of publicly-funded research and its size relative to its private sector counterpart. This has been conducted against a background whereby funds for agricultural research have been redirected towards basic science for the benefit of other industries. Accordingly, the role and purpose of public sector agricultural R&D needs to be appraised in light of these changes.

There seems to be no unified definition of agricultural R&D. The OECD (1994a) definition provides the basis for the definition used in this analysis. Thus, agricultural R&D is taken as R&D concerned with the areas of crops and livestock, as well as with related environmental and rural issues. It includes R&D targeted to the development of pre-production inputs, on-farm production and post-farm processing of food and industrial raw materials.

Theoretically, the traditional justification for public support, market failure, has relied on static assumptions about the economy and has tended to support the need for public R&D only at the basic end of the spectrum. After protests from the ARS over cuts in applied near-market research, these assumptions have to be re-evaluated in order to assess whether there are any valid reasons for public intervention in the areas of applied research and development. If there is no justification then it raises a question about the role of such publicly-funded research.

At the same time, the majority of studies which have sought to develop an 'objective' basis for public funding have focused on the apparent returns to research, which have generally suggested that there is under-funding (see for example Thirtle and Bottomley, 1988; Echeverria, 1990). Most have adopted an econometric approach which measures research expenditure against changes in agricultural productivity. However, this methodology lacks credibility, as the dropping of variables or the imposition of restrictions causes a high variance in the estimates of research benefits gained. Moreover, whilst previous studies have seen high rates of return to public sector research as a justification for continued public support, little work has been conducted on whether the public sector has been made less effective as a result of recent changes in the nature and level of funding. Equally, little attention has been given as to whether the private sector has the motivation or ability to substitute for areas previously supported by public funds.

Considering the policy issues outlined above, the analysis which follows aims to understand the reasons for and the role of public funding in relation to agricultural R&D. It aims to accomplish this in a number of ways:

i) by reviewing the development of the agricultural research service in order to fully delineate the major issues which have occurred in its history;

ii) by questioning and re-evaluating the effectiveness of public agricultural research both in terms of its ability to create wealth and to improve the quality of life;

iii) by examining the assumptions behind public funding of agricultural R&D and ascertaining whether there are any reasons which validate the continuation of support in the context of the future development of UK agriculture; and

iv) by ascertaining the activities of the private sector and evaluating the attitude of agri-industry toward the recent changes in public agricultural research.

In order to fully understand the key issues involved in assessing the role of public agricultural R&D, it has to be placed into its historical context. A number of conflicting themes can then be seen to emerge in the evolution of the ARS concerning its management, funding and organisation. Specifically, there are four areas which need to be addressed and which are intrinsic to understanding the forces which impinge on the role of agricultural R&D. These are i) changes to the level of Government involvement in agricultural R&D, ii) the evolution of the institutions which conduct agricultural R&D, iii) the changing relationship between agricultural policy and agricultural R&D, and iv) the increasing influence of the private sector in agricultural R&D. This is the concern of the first chapter of the thesis.

Secondly, the stated objective of changes in the management, funding and organisation of the ARS has been to increase the effectiveness of public funds (Rothschild, 1971; OST, 1993). Consequently, it is worth investigating the mechanisms which supposedly facilitate these changes in order to assess whether there has been an improvement in public investment. These mechanisms can be classified under three headings, namely i) the imposition of 'steerage' to a previously autonomous research system, ii) reductions to and changes in emphasis in respect of the funding of agricultural R&D, and iii) the encouragement of private sector participation in agricultural R&D. Consequently, Chapters 2, 3 and 4 aim to test whether the following hypotheses hold:

H_1: *Public agricultural R&D is under-funded and expenditure should be increased;*

H_2: *Increased Government steerage has improved the efficiency of investment in agricultural R&D; and*

H_3: *Private sector agricultural R&D is more effectively funded than the public sector.*

The aim of Chapters 2,3 and 4 are therefore to establish whether there are any indications of improved effectiveness of public funding in terms of the cost-effectiveness of the research. The concept of effectiveness can be approached in a number of ways. Firstly, by reviewing the literature on the anticipated benefits of management, funding and organisational changes to research systems, indications may be obtained regarding how output is affected. This can be further explored by measuring and comparing changes in agricultural productivity growth in other countries which have experienced similar structural changes to their ARS as that in the UK. Secondly, the changes to the ARS can be evaluated formally using econometric methods. By dividing the history of public funding into periods, it allows for trends and permits an assessment of whether continued funding is justified.

These changes have had implications for the role and activities of both the public and private sectors as regards agricultural research. Consequently, the remaining two chapters seek to assess what changes have occurred to these two sectors and what should be their future roles. Thus, the public sector has experienced shifts in its role and purpose because of changes in research management and, consequently, the fifth chapter seeks to address whether there is currently a role for public sector agricultural R&D and what that role should be. Specifically, the hypotheses which require testing are:

H_4: *Basic agricultural R&D is only justified in terms of public support; and*

H_5: *Agricultural R&D in the public sector should concentrate on enhancing the public good.*

Chapter 6 is concerned with the activities of the private sector and its relationships with public research. The private sector has been called upon to replace areas of applied and development funding which were previously conducted by the public sector (Read *et al.*, 1988). Similarly, firms have been encouraged to foster a closer relationship with public research institutions in order to provide more industrially relevant solutions to commercial problems. Specifically, there are two further hypotheses which require examination:

H_6: *The private sector has replaced public funds in near-market areas; and*

H_7: *Government policies for increased public-private collaboration have been a success.*

In order to investigate these hypotheses an extensive survey was undertaken with firms involved in the area of agricultural research. Specifically, the questionnaire had three general aims, namely i) to quantify the level and trends in private research expenditure, ii) to understand the level of collaborative R&D activity between public and private sectors, and

iii) to assess how the agricultural industry views the changes to the public sector in terms of the quality and relevance of its research output.

By evaluating the reasons for support which have emerged both from economic and policy analysis, a framework has been developed which can assess the validity of continued research in the agricultural sector. Overall, this analysis aims to address the central question of whether public support for agricultural R&D should continue. As the agriculture sector experiences removal of public funding, public agricultural R&D has to find justification for a role which underpins the activities of this industry.

CHAPTER 1

THE PUBLIC SUPPORT OF AGRICULTURAL RESEARCH AND DEVELOPMENT

1.0. The Public Support of Agricultural Research and Development

The majority of studies concerned with agricultural R&D have advocated some degree of continued public support. It is usually argued that the Government has a role, because in a free market economy resources tend not to be allocated in a socially optimal way. Thus, the belief is that by correcting economic distortions the Government can improve the welfare of society. However, as early as the 1960s some economists and, more recently Government, have questioned the assumption that public intervention in the market is required and can offer social benefits (Friedman, 1962; Demsetz, 1969). While these 'Government failure' arguments are just as applicable to agricultural R&D as they are to other sectors, the bulk of commentators on public agricultural R&D funding have argued that it is a special case and requires continued support (see for example Umali, 1992; Alston, Norton and Pardey, 1995). Similarly, the bulk of these arguments emerge from abstract economic theory and have been applied to agricultural R&D with little consideration for the process of research itself, and then only in the form of theoretical support for basic research (Thirtle, 1986).

Accordingly, the central concern of this introductory chapter is to outline the arguments that could be forwarded for the public support of agricultural R&D. More critically, it aims to evaluate which areas of agricultural R&D merit continued public funding and whether there are areas which could viably be funded by the private sector. Consequently, the first section outlines the shifts that have occurred in science policy since the early 1970s. This gives an overview of how the Government has sought to manage its agricultural research system and how it has favoured certain areas over others. This is followed by a critique of the more prominent arguments which have been forwarded for the public support of agricultural science. In this way, the underlying basis for these changes in science policy are examined to test their validity in respect of agricultural science. Finally, the most important arguments are considered in terms of the research process itself, in order to establish the key areas which the public sector should continue to fund.

1.1. Changes in the Balance of Science Policy

Prior to 1970, the agricultural research service (ARS) had enjoyed expanding expenditures. However, the changes that occurred to the research system after this date began to put into question both the area and activity of public sector agricultural R&D. Specifically, these changes raised issues in relation to the balance of research funds between particular areas of the research process. Whilst discussed in more depth in Chapter 2, these issues can be summarised into four, namely i) basic versus applied R&D, ii) productivity versus non-productivity enhancing R&D, iii) agricultural R&D versus agricultural extension, and iv) agricultural R&D versus general R&D.

1.1.1. Basic Versus Applied Research and Development

The first imposed divide between basic and applied R&D emerged with the publication of the Rothschild Report in 1971. However, this divide was brought into sharper relief with the removal of funds for applied 'near-market' R&D in 1988 and their eventual reallocation to basic research. This latter research area has traditionally been held as the domain of the public sector (see for example Nelson, 1959; Umali, 1992). This is because knowledge is difficult to protect, and its dissemination within society is considered to be desirable, as advances for the benefit of society can be developed from extending the frontiers of knowledge. Thus, the changes that have appeared since the mid-1980s have seen the public sector increasingly as a conductor of basic research and this position has gained in importance at the expense of applied research and development.

1.1.2. Productivity versus Non-Productivity Enhancing R&D

The earlier emphasis in agricultural R&D on securing productivity gains has declined in the last decade, as reflected in statements by both MAFF (1996) and the Scottish Office (1994), both of whom now allocate only around half their expenditure towards productivity-enhancing research. This is in sharp contrast to the situation before the mid-1980s, when budgets were directed solely at increasing the productivity of agriculture. Similarly, the goal of enhancing agricultural productivity has been questioned within EU policy, which now directs growing R&D support for farmers away from areas which increase output (CEC, 1998). That R&D has caused productivity growth in UK agriculture seems to be irrefutable. However, coupled with output-enhancing policies, the costs to society in terms of the wastage of natural resources, as well as the side-effects of residues in food products, has led to questions over the social desirability of continuing to encourage these increases.

1.1.3. Agricultural R&D versus Agricultural Extension

A phenomenon which has been observed in the UK and, to some extent, in other developed countries, has been the commercialisation of the extension service. However, the effective transfer of research results ensures that the private sector does not concentrate solely on innovations which can be appropriated to the exclusion of improvements related to animal welfare and the environment. The privatisation of the market-based activities of the

Agricultural Development and Advisory Service and its subsequent replacement with the Farming and Rural Conservation Agency (FRCA) in 1997, established to concentrate on public-good advice, is obviously aimed at correcting this.

1.1.4. Agricultural R&D versus General R&D

Alston and Pardey (1998) have contended that a major issue in the economic justification of publicly-funded agricultural R&D is the level of inter-industry spill-overs which have been of benefit to agriculture, principally from the chemical and biological industries. It could be argued that the recent extension of research interests of the Biotechnological and Biological Science Research Council into non-agricultural areas strengthens public support for non-strategic basic research, i.e. without a principal target group, and is associated with reductions in funding for specific agriculturally directed projects.

1.1.5. Summary

Analysing trends in science policy since the 1970s seems to infer that the UK Government has sought to manage the agricultural research system (ARS) by re-balancing the funding for various parts. Thus, there has developed an explicit divide between basic and applied R&D. Similarly, more recent emphasis has been placed on withdrawing public funding from specific areas, such as extension and near-market research, with a renewed concentration on basic and public-good fields.

Given the prevailing mood of change it seems that the arguments put forward for the public funding of the agricultural research service need to be re-examined. This is especially pertinent, as recent changes have involved a sharp reversal of the post-war view of agricultural R&D as intrinsic to achieving increased productivity. Consequently, what follows is a test of the main arguments advanced for the public support of an ARS, with a view to testing their validity and applicability to UK agricultural R&D at present. It also serves to outline the role publicly-funded agricultural R&D and extension should arguably play within society.

1.2. Arguments for the Support of Agricultural R&D

Arguments, which have developed for the support of public sector agricultural R&D, can be grouped under two headings. There are the general welfare arguments, which seek to justify the presence of the public sector in certain fields of production, and the more specific arguments which emerge from the implementation of agricultural policy. The former tend to offer more abstract justifications for intervention. Thus, whilst applicable to agricultural R&D, they tend to be based on reasons for the general intervention of the public sector within society. In contrast, the latter emerge from the dynamics of agricultural policy and justify public funding of agricultural R&D in terms of the specifics of the UK farming industry. Testing these two conceptual approaches against examples of public agricultural R&D practice helps to give an understanding of their applicability in terms of the UK. The arguments that apply from general welfare analysis will be analysed first and are the concern of the next section.

1.2.1. General Welfare Approach

Economic thought is divided over the degree to which the public sector should be involved within the economy. Those arguing for support generally regard Government involvement as necessary for improving social welfare, whereas those opposed champion the free market on the basis of its allocative efficiency. The most prevalent viewpoint, which supports state intervention, rests on the belief that the market fails to allocate all its resources efficiently because of a divergence between public and private objectives. The Government therefore has a role in filling the gaps left by the private sector (Arrow, 1962). This raises the question of why markets should fail, which is the focus of a more recent body of literature (Arrow, 1969; Williamson, 1985). Specifically, markets are imperfect due to the costs of transacting. Under this conceptual approach the Government has a purpose in investing in R&D in order to reduce prohibitively high transaction costs in certain markets. Linked to this, there are other arguments based on analysis of technological policies and which see the public production of R&D as an essential means to increasing economic growth. All these issues are explored below.

1.2.1.1. Market Failure

Market failure is a deviation from a hypothetical situation where all resources are allocated in a socially optimal way. This requires that markets for all goods, including those delivered in the future and under different circumstances, must exist. The main reason why this does not occur is considered to be due to the existence of 'mixed goods'. These are commodities which carry both public and private attributes. The public aspect of these goods offers a social benefit, as they can be used without reducing another person's consumption of that good. Consequently, their presence in an economy leads to a divergence between private and social goals. Goods with a high public content will be produced sub-optimally in a free market economy, because of the low chances of sufficient private gain. Therefore, due to an inability to protect the knowledge implicit in the creation of a product, various areas of research will not be produced by the commercial sector. Accordingly, whilst some firms do invest in creating knowledge, the central argument of market failure theory is that, where the gain from R&D cannot be captured by private industry, it can only be produced with the support of public funding. More specifically, there are four circumstances in which market failure is relevant to the production of a public good like research and development. These are, namely i) inappropriability, ii) externalities, iii) increasing returns to scale, and iv) uncertainty. The effects are analysed individually to test their validity as regards their justification for Government funding of agricultural R&D.

1.2.1.1.1. Inappropriability

Increasing the level of knowledge is socially desirable, primarily because its application will advance the understanding and solution of problems that society may face. However, where the social return exceeds the private one from research, private investment will be limited. Instead it will only occur in areas where protection is feasible. As a result areas that offer high returns to society, such as environmental protection and the social sciences, but result in products that cannot be easily patented, will not attract private investment.

Accordingly, Demsetz (1969) has argued that appropriability is largely a matter of effective institutional arrangements, e.g. patents, combined with adequate enforcement. Whilst he accepted that public goods exist, he contended that a bargaining solution between producers and consumers will solve the problem of appropriability. Furthermore, Peacock (1979) has argued that technological innovation can eliminate the public nature of some goods by solving the problem of non-excludability. Thus, the introduction of hybrid corn in the United States led to a large expansion of the seed industry. Previously, seed was produced through open pollination which could be reproduced on farm. The private seed industry was concerned with merchandising 'college bred' or publicly-funded varieties, the price of which would not deviate from bulk grain prices. This lack of appropriability, therefore, resulted in limited incentives for private growers to produce better varieties. With the development of hybrid corn, which offered patentability of lines, there was a rise in private research investment from the 1920s onwards.

Consequently, 'appropriability' is not a static concept. In their study of US agriculture, Goodman *et al.* (1987) saw its development in terms of growing industrial appropriation of rural and natural resources. Consequently, if firms continue this trend of capturing returns from agriculture, the role of the public sector should be correspondingly reduced. The recent developments in bio-technology, which offer the patentability of biological processes, has caused large investment by firms in basic research and led to questions concerning the role of the state in this area. This has been outlined by James and Persley (1990), who found that, before a landmark ruling allowing micro-organisms to be patented in 1980, around 80 firms concerned with biotechnology existed in the United States. However, this grew to around 1,000 firms by 1990. Similarly, larger firms such as Monsanto and Dupont began to invest substantial amounts of funds in bio-technological applications in the medical, plant and animal areas.

As industrial appropriation increases the inability of private firms to capture gains from R&D may become a weaker justification for state involvement. At present the areas which show little possibility of industrial appropriation seem to be where public goods are paramount. Accordingly, certain areas of environmental and aesthetic research offer little chance of commercial exploitation, as the benefits from these goods are difficult to quantify and sell. Thus, MAFF (1996) funds work into countryside management and environmental protection which is impossible to protect. However, in the future this may not be the case, as technology develops which may enable some of these benefits to be captured. For instance, the emergence of information technology has led to the development of improved management for agronomy systems. Thus, as profits are captured by companies from the sale of software, there is an incentive for commercial development in the area of agronomic management, an area which is usually considered inappropriable.

Therefore, conditions have to be applied, if the appropriability argument is to remain applicable as far as agriculture is concerned. If the public sector can respond to changes in the industrial environment and shift programmes away from areas which have become industrially appropriable to novel ones, then it is justified. How easily this can be achieved is questionable. Thus, the US grain manufacturers resorted to lobbying Government for the public sector's removal from the development of commercial corn lines. Kloppenberg (quoted in Goodman *et al.*, 1987) stated that, whilst undermining smaller companies entry into the industry, the *''emasculation of public breeding programmes created an important new space for the accumulation of capital''* (ibid., pp. 42). The inference of all this is that the government only has a role in funding research in agriculture, where social returns are high and, more critically, private returns are low.

1.2.1.1.2. Externalities

Mixed goods produce spin-offs, or externalities, from their production or consumption. Pigou (1932) first posited the idea that the indirect nature of a positive or negative externality means that payment cannot be exacted, nor compensation enforced for these third party effects. If R&D were produced solely by private firms, their search for maximising profits generally would lead to an over-production of negative externalities and an under-production of positive externalities (Umali, 1992). There is, therefore, an argument for the public production of R&D which reduces the level of negative externalities or, conversely, produces positive externalities.

In the case of negative externalities, Coase (1960) questioned this assumption as a basis for public intervention. He argued that, where these effects were well defined, the producers of externalities and the individuals affected could negotiate amongst themselves for appropriate compensation for these spill-overs. In a variation on this, Phipps (1989) asserted that the external effects of new technologies could be internalised when and if the benefits from internalisation exceeded the costs. He illustrated this by examining the externalities which occurred with the introduction of an agricultural pesticide. These were i) residues in food, ii) discharge into groundwater, and iii) discharge into surface water. As regards residues in food, he cited the case of Californian grocers who employ a private service to test for pesticide residues. Market prices might be expected to change to reflect differences in the cost of alternative production and the premium consumers are willing to pay for pesticide-free produce. If the damage to ground water affects the farmer's drinking supply, then to some degree the externality will be internalised. However, in the case of surface water there will be little incentive to protect rivers and streams, unless they affect fishing rights owned by a farmer. Therefore some, and not all, areas of externalities merit public intervention.

Related to this issue Rausser and Zilberman (1991) have maintained that, where there are pecuniary benefits, the private sector will invest in areas which produce positive externalities. For example, drip irrigation can increase the value of land and the user of the technology makes a return from the sale of the land. This is a point raised by Harvey (1987), who stated that the price of land will rise as the technological relationship between inputs and outputs improve. He went on to suggest that land-owners should bear a degree of the cost of R&D, pointing to a similar 'land-tax' which is used in France. Accordingly, the argument has to be modified, as the public sector should only be concerned with negative externalities which affect large groups, i.e. the general public and not the farmer.

This is supported by Umali (1992), who contends that, where negative externalities were extremely high or taxes did not seriously damage the producer's profitability, the state has a role in assuming absolute control of that activity.

However, the role of the Government as a producer of 'positive' technology has to be questioned on a number of grounds. Firstly, it relies on a belief that the state can allocate resources effectively in the long-run to maximise social welfare. There is an argument that Government may not be concerned with the 'public interest', but consist of self-serving individuals. As such decision making will be distorted by an official's private agenda or by the power of lobbying groups. The US Government in the 1940s invested in the development of systematic agricultural herbicides. However, a growing interest in biological warfare led to the development of the weed killer '2, 4-dichloro phenoxyacetic acid' which was subsequently used as 'agent orange' in the Vietnam War (Peterson, 1967). Generally, Demsetz (1969) asserts that a failure in Government may lead to a less socially beneficial outcome than even market failure, because of the leviathan nature of public spending programmes.

Regardless of the decision-making process it also requires a belief that Government has the foresight to allocate resources to the correct programmes in order to effectively reduce negative externalities. Public research in the US was directed towards increasing productivity of tomato harvesting in the 1940s and 1950s. A tomato harvester was eventually developed by the University sector into a commercial machine and, when introduced, became a phenomenal success. In 1963 1.5% of the tomatoes grown in California for processing were harvested by machine, but by 1968 this had expanded to become 95%. However, it was found that those gaining from the technology were not compensating those who had become unemployed by the introduction of the new technology (Schmitz and Seckler, 1970). Schuh and Tollini (1979) have argued that it is important to identify which groups benefit and lose and then relate this to the goals of research programmes. However, it is debatable whether agricultural policy has promoted positive externalities. For the bulk of the post-1945 period, Government policy has been associated with developing output-enhancing technology, leading to increased intensification and wide-spread environmental damage. Similarly, the crisis caused by the possibility of human infection from Bovine Spongiform Encelopathy was not foreseen be the UK Government. Accordingly, it has to be questioned whether the same body can provide the correct portfolio of research programmes, which would increase positive externalities in the future.

Another distinction has to be drawn between the public provision of R&D and the regulatory devices which negate some of the effects of these externalities. Regulation has had a significant effect in the area of restricting polluting emissions from private industry. Imposing heavy penalties against environmental effects may be more effective in reducing externalities than producing substitutes for the industry and, arguably, encourages private industry to produce public good research itself (Rosegger, 1980). For instance, regulation against the emissions of CFC's has advanced the industrial development and use of safer substitutes. Similarly, the ban on using offal in animal feed has led companies to invest in other alternatives. However, regulation itself tends to be reactive, emerging as a direct response to the damage imposed on a society. Investing in public R&D in a certain direction can be seen as a means of offering a quicker response or, in the best case scenario, preventing the damage altogether.

An important caveat which also impinges on this argument is that the private sector will create positive externalities when there is a high possibility of return on their investment. The argument for public R&D to produce externalities must therefore be compared against the subsidisation of an industry which is already producing them. For instance, the Philippine Government supported industrial investment into developing a 'geo-thermal' power industry, thus reducing reliance on oil burning plants as a source of energy (Grandstaff and Balagot, 1986). However, this cannot be applied in areas where positive externalities are impossible to identify. Accordingly, the level and direction of subsidy in these circumstances cannot be fairly allocated to industry. This strengthens the argument that, when the boundaries of these effects cannot easily be determined, the state has a role in intervening between the two parties.

The whole concept of externalities is therefore a complex issue. It is exacerbated by its application to R&D which, with the introduction of new products and processes, changes the environment in which society operates and therefore alters the balance of beneficiaries and victims (Rosegger, 1980). In theory, state-funded research is justified in the socially desirable fields of agricultural production, where there are unclear boundaries regarding beneficiaries and losers as evidenced by R&D into public aesthetic values in rural areas, which will benefit local businesses from increased tourism. However, the public provision of R&D has to be considered against the numerous caveats and beliefs outlined above. What is clear is that investment in technology, whether public or private, will create externalities which cannot be foreseen, but in itself offers no unequivocal support for state funding of research.

1.2.1.1.3. Increasing Returns to Scale

The size of the investment in research leads to indivisibilities or 'increasing returns to scale'. Government subsidisation of an industry may be economically justified if it is uncompetitive in the initial stages of its development, but shows clear evidence of profitability in the long run. Economies of scale and time will ensure the sector's competitive position in the long run. An argument against this has been made by Friedman (1962), who opposed Government intervention, because it frequently helped monopoly power to emerge. Bell *et al.* (quoted in Chang, 1996) questioned the application of support due to asymmetries of information between the state and the funded body. They pointed to industries in developing countries which persistently failed to grow out of their 'infancy'. Accordingly, support for an industry over a long period by the community, as a direct objective of making it competitive, is a weak justification for state involvement. The real justification for supporting an industry is that other industries or the community at large gain. It is therefore reasonable for the community to pay a price in terms of protection for that industry to mature (Wells, 1969). That this can work is evidenced by the Philippine seed industry.

The major restriction on private investment in the seed industry of the Philippines was the problem of downy mildew on higher yielding corn hybrids. Research in the public sectors of several Asian countries led to the development of resistant open-pollinated corn hybrids and a way of treating the seed. These two discoveries allowed the possibility of cultivating higher yielding corn. Similarly, the Government initiated a corn production programme - 'Masaganang Maison'- which required farmers to use only approved hybrids or varieties. This, along with several schemes to keep the domestic corn price higher than the World price, created a profitable market for hybrid corn production. As a consequence the industry is now self-supporting and dominated by four players, namely i) a wholly owned subsidiary, ii) a Philippine-based multinational, iii) a joint venture with a foreign firm, and iv) a foreign owned multinational, indicating the possibility of economies of scale (Umali, 1992). This example negates the preceding concerns about market and informational distortions. Instead, it suggests that public agricultural R&D, when it is directed towards a small developing industry, can be justified as a device for increasing the social welfare of a country.

1.2.1.1.4. Uncertainty

Investment in the research process involves a high degree of uncertainty concerning the economic viability of its outcome. As profit-making enterprises are generally risk-averse they will discriminate against projects where the uncertainty is large. Research with an unknown level of public, as opposed to private, gain will experience under-investment within an economy. This is because it generally does not offer enough profit to cover the risks involved. However, the costs of gathering accurate information for a project may outweigh the benefits of market correction. This phenomenon has been observed in centrally-planned economies, where only the minimal amount of information can be processed before the writing of a project (Dobb, 1970; Brus, 1972). Consequently, the level of risk may not be averted, but may have grown. This has to be considered against a growing demand for accountability for funds administered by the Government. Similarly, Thirtle (1986) has argued that the choice of Government projects will be deliberately biased away from the private sector and pointed to the case of forestry which has attracted much public funding.

However, Government involvement can be justified by its effect on social welfare in the short run. Whilst every investment has the potential for failure, if the intentions are to increase social welfare, then it should not deter public funding. Genetic engineering evolved from the public sector as a means of transferring foreign genes into other bodies and thus producing novel genetic combinations. As this needed a high initial investment, the private sector did not see fit to undertake such risks. Similarly the degree of technical knowledge needed for this process led to public researchers acquiring a high level of expertise. The possibilities for genetic development were realised by the public sector and the majority of exploratory work was conducted in the universities. However, the specific applied and development aspects of work were adopted by the sponsoring firm and exploited in the market place (James and Persley, 1990). Genetic engineering and other fields of biotechnology have led to the introduction of biologically based alternatives, which have less short-term harmful effects on the environment than previous chemical pesticides and fertilisers. However, its effect in the long-run, judging the adverse reaction to genetically modified foods in Europe, may prove socially unacceptable. The uncertainty element is therefore large in new fields and it takes the public sector to open up the possibilities for the private sector and spread the risks of researching into new areas. Accordingly, where there is high uncertainty in socially beneficial research, the state has a role in providing investment and absorbing the risks.

1.2.1.2. Transaction Costs

Whilst market failure theory has become the cornerstone of theoretical work on public intervention, a more recent strand of economic thought has developed and this can be applied to the problem of public funding. The essence of this theory stems from the inability of individuals to co-operate with each other. This leads to the establishment of contracts to transfer, capture and protect ownership rights to property. The cost of establishing and enforcing these contracts, defined here as 'transaction costs', can be prohibitively high. Chang (1996) has stated that in the real world both state intervention and market transactions are costly. Therefore, the argument is whether the state can achieve the same allocative efficiency at lower cost than the free market. Accordingly, this approach offers insights into why firms will not invest in certain areas of agricultural R&D, and whether there is any justification for Government involvement. Douma and Schreuder (1998) have outlined a number of factors which can create transaction costs. In terms of the argument relating to agricultural R&D these can be divided into two areas, namely i) opportunism and ii) asset specificity.

1.2.1.2.1. Opportunism

Williamson (1985) has stated that, in general, contracts are formed because some individuals try to exploit a situation to their own advantage. A profit-maximising firm in a highly competitive market typifies this behaviour. This leads to a non-optimal allocation of research spending, as companies will deliberately not disseminate knowledge gained from the creation of products and processes. Accordingly, a justification emerges for the public sector as a distributor of this knowledge.

During the 1960s the Chilean Government developed a national plan for the fruit sector. This included gathering a wide variety of information, such as analysis of foreign markets, and establishing production goals, as well as the introduction of new varieties and storage techniques. In order to facilitate this a ten-year co-operative scheme was initiated between the University of Chile and the University of California. This involved technical co-operation and student exchange. These programmes strengthened the domestic research base and were crucial factors in the acceleration of the growth in fruit exports after 1974. The Government also passed legislation that allowed public sector staff to engage in consulting. The onus was therefore imposed on the private sector to utilise this information and gave an adequate incentive to develop technologies with this expertise. As a consequence Chilean temperate fruit exports grew by around 20% per annum between 1974 and 1991 (Umali, 1992).

A key mechanism in this growth was the transfer of information and expertise from the USA to Chile. This was initiated by public institutions, in this case the universities. Opportunistic behaviour encountered in private firms would not have allowed the knowledge acquired to be freely distributed to other companies. However, the public dissemination of the research results led to the growth of firms, increasing social welfare. Accordingly, as private firms are opportunistic in nature, a public R&D base may be essential to provide for transfer of knowledge to the widest possible audience.

1.2.1.2.2. Asset Specificity

Asset specificity is concerned with 'transaction-specific' assets. An asset is transaction specific if it cannot be re-deployed without a significant reduction in the value of that asset (Douma and Schreuder, 1998). In terms of technology, often an advance in one area cannot be fully exploited until there is an advance in another area. Therefore, given the nature of farming, with its reliance on long-term capital investment, farmers will not be able to adopt new technology, which does not conform to conventional processes or machinery used on the holding, without further large investment. Consequently, this may be a disincentive for a private firm to invest in some areas which may be socially beneficial. For example, the US Congress funded an integrated research programme in 1946 for cotton growers. This was because, with the development of an efficient mechanical picker, the cotton plant had to be adapted to the machine. Accordingly, research was conducted into modifying the cotton plant to grow higher and open over a shorter time. Thus, the breeding of this seed was given over to the public domain in order to avoid exploitation by an individual firm. In around twenty years mechanised cotton cultivation was successfully adopted and became widespread (Fite, 1980). Whilst farmers would willingly pay the costs of developing the seed if benefits exceeded costs, this would lead to under-investment in areas where benefits are not so tangible, e.g. in pest management schemes or in aspects of environmental improvement.

More critically, however, companies may obstruct socially beneficial research by restricting the opportunities for farmers to adopt other forms of related technology. Stuckey and White (1993) have highlighted a situation where one or both parties invest in equipment that can only be used by these parties and which has a low value in alternative uses. Thus, firms may tie in other aspects of their product through technology. This has been observed recently with large seed breeding firms producing genetically modified strains which are only fully responsive to pesticides manufactured by the same firm. In addition, companies, such as Monsanto, have initiated a trend whereby farmers sign agreements to use a firm's specified pesticide before they can obtain and grow the seed itself. This could be negated by the spreading of basic research results through the public domain. However, as genetic modification has emerged in the public sector, as typified by cotton breeding in the US, a more integrated programme of applied and development work would be better justified to prevent this abuse.

An argument against this is the emergence of co-operative buying rings which, through group buying and shared use, buy or rent equipment that a single farmer cannot afford. Thus, if the costs of 'tied-in' technology are too high, this could be spread over a number of farmers who each benefit from the technology. However, the majority of buying rings that exist in the UK only concentrate on the purchase of farming machinery (Thirkell, 1993). This would again suggest that farmers will only invest in areas where benefits are highly tangible. Therefore, it seems that some justification exists for publicly-funded integrated programmes in areas of benefit to society, in order to avoid the problems of asset specificity.

1.2.1.3. General Policy Arguments

There are several other reasons which underpin the justifications of public production which are more practically based. These tend to emphasise the role the public sector plays in providing technology which will accomplish the social good by its introduction. Thus, the first argument refers to the popular idea that R&D helps to promote growth, whereas the second argument refers to the 'equity' of funding areas of the economy which merit support.

1.2.1.3.1. Technology Promotes Economic Growth

The most persuasive argument which has emerged is that state funded R&D is essential to a nation's economic growth. However, economic growth is a paradoxical concept. Rosegger (1980, pp. 314) refers to this as *''an increase in the economy's capacity to produce more goods and services''*. Under this definition it relates to the concept of total factor productivity (TFP), namely the ratio of change in output to inputs. However, TFP is a controversial issue as it does not include any improvement in the quality of people's lives. The OECD (1992, pp. 168) sees economic growth as *''the sustained expansion of the* *productive potential of an economy which, in the long run, converges with the growth of aggregate output*''. In relation to agriculture, economic growth can meet growing needs, without the necessity of using more resources.

Against this background, it is possible to understand the argument which emerges from the wide range of empirical work on the returns to agricultural R&D. By measuring public agricultural research expenditure against increases in supply or total factor productivity, very high rates of return on investment have been recorded (see for example Echeverria, 1990). However, within this framework, it is near-market productivity-enhancing research, rather than basic or non-market orientated research, which justifies public support. This is the view of the Australian government which consciously switched funding towards applied R&D (Hussey, 1996).

The link between basic research and economic growth is more tenuous. This is important as the majority of public agricultural research in the UK today is directed at the basic end of the spectrum. Martin *et al.* (1996) argued that there were six identifiable contributions of publicly-funded basic research to economic performance. These were namely i) increasing the stock of information, ii) new instrumentation and technologies, iii) skilled graduates, iv) professional networks, v) technological problem solving, and vi) creation of new firms. Specifically, if the public sector invests in research it will, hopefully, increase the 'stock of knowledge'. Traditional theories propound the idea that private firms will gain from this knowledge, primarily through academic papers, and so invest in embodying this knowledge into commercially exploitable goods. Arundel *et al.* (1995), in a survey of various industrial sectors, found that pharmaceutical firms in particular favoured embodying knowledge through publications, informal contacts and conferences. Similarly, tacit, or person embodied-knowledge, is growing in importance within the high-tech industries, such as biotechnology. Thus, Zucker and Danby (1995) argued that, as the techniques for replication in high-tech industries involved tacit knowledge, then any scientist wishing to make use of this new knowledge must acquire hands-on experience. Accordingly, the major argument for supporting basic research is that publicly available knowledge may eventually be embodied into the private research process and thus improve its competitive position. Whilst the level of private basic research is low, new techniques can be taken on by a company, which will increase the options of the firm to exploit and grow.

However, more generally, there has been growing controversy over the whole concept of encouraging economic growth. This questions the desirability of Government pursuing such a goal. There is the argument that, on the basis of resource availability, economic growth will not be sustainable in the future. This argument can be traced back to the 18th century and Malthus's predications of the growth in population and agriculture's inability to meet growing food demands (Rosegger, 1980). It has been raised into prominence by debates over the limits to growth (Meadows *et al.*, 1974; McCutcheon, 1979). In conjunction with this, the argument for R&D as a means of achieving economic growth has led to another problem concerning the distribution of incomes. Some groups have benefited more than others from economic growth. For example, technology may distort the market system and subject consumers to unfair pricing schemes. Thus, whilst technology may allow a nation to enjoy increased growth, the beneficiaries may not ultimately be the public paying for that research.

In contrast, an argument has developed whereby public research could be used as a means of creating competition and so reducing monopoly power. Ruttan (1982) suggested that public research could be seen as a means of maintaining or enhancing a competitive structure. Accordingly, he maintained that *''there is for example, considerable evidence that the flow of new technology from public sector R&D has contributed to competitive behaviour in the seed and fertiliser industries''* (ibid., pp. 183). This, he suggested, helps to justify the distribution of research findings within the public domain. However, it conflicts with a policy which supports increased public-private collaborative activity through the use of public funds, as directing resources towards any one firm may distort market power.

The majority of literature on economic growth views research and development within an overall policy for industry. Stout (1981) argues that rates of growth in an economy are related to the speed of response by industry to market changes in the distribution of labour and capital. Accordingly, the role of Government and technology is to speed up the process of re-allocation and re-design of these markets. This could be achieved within the framework of an overall industrial policy which includes the public funding of R&D.

However, UK industrial policy since the 1960s has concentrated much of its financial support on declining industries and has, if anything, significantly slowed down the response to market changes. The nature of agricultural production, with heavy capital costs means it can only respond slowly to these effects. Similarly, post-1945 agriculture is one of the areas where Stout contends that the economic growth of nations has been reduced, because of too much price support for a low growth sector. Indeed, there has hardly been a time since the Industrial Revolution when farming has not been in decline and it seems a weak case for public support of R&D as a means of accelerating economic growth. However, Thirtle (1986) has noted that growth could be realised by using technology to open up newer markets for exploitation and supported this by using the example of biotechnology, which turns sugar cane alcohol into a substitute for use in the petro-chemical industries. Whilst it could be a matter of debate whether this is agricultural R&D in the strictest sense, or should be classified as industrial R&D, it does offer an alternative argument for public support. If agricultural R&D were to concentrate on industrial crops, it could be justified as a supplier of cheaper materials to other industries and so seem to facilitate economic growth.

1.2.1.3.2. Agricultural R&D Only Deserves an Equitable Allocation of Public Funds

The basis of allocation for public funds is finite and Government has to choose between projects which warrant support. Therefore, a fundamental issue must be whether taxpayer's money should be allocated to the agricultural industry, or whether other industries which show more potential should merit this support. Predominantly, any economic justification is weakened because agriculture has become a declining sector of the economy. Furthermore, the fact that this decrease began in the mid-19th century indicates that the growing levels of expenditure for R&D spending during the 1950s and 1960s may actually have been a mis-allocation of public resources. Indeed, if it were in line with its contribution to GDP, the amount of funds directed towards agricultural problems should have been declining long before the cuts of the 1980s.

Nevertheless, numerous studies have not only supported its continued funding, but the majority, especially in the case of the econometric work in this area, have suggested that it deserves an increase in public R&D expenditure. For this to be achieved there has to be confidence that funds are allocated appropriately within the research system. This confidence rests on the belief that the private sector produces the wrong portfolio of projects (Nelson, 1982). However, this is not enough. There has to be a corresponding belief that public facilitators of research have the means to correctly evaluate and eradicate the failure that occurs within markets. In practice this is a difficult task. Thornley and Doyle (1984) suggested that funding decisions should be considered in terms of the past performance of research institutes. However, Harvey (1987) likened project spending to the process of backing horses and contended that R&D is more like a yearling, which offered limited information on form. Consequently, the issue of growing public expenditure has to be considered against its ability to achieve set objectives, which increase social welfare.

1.2.1.4. Summary

A diverse range of arguments emerge when considering the public funding of agricultural R&D. The most salient point from the above analysis is that the presence of the public sector is desirable because of its ability to correct an imbalance in social welfare. However, this tends to rely on a pragmatic belief in Government and, it seems from the above evidence, an argument can easily be put forward for the converse. Similarly, support of agricultural R&D production is complicated by the range of alternatives available. Thus, an argument against public production is the regulation and subsidy of private industry. Consequently, it seems that the arguments from welfare analysis are too general in nature to provide any convincing justification for the public support of agricultural R&D. Accordingly, the next section examines the arguments which have emerged directly from the implementation of agricultural policy in the UK.

1.2.2. Agricultural Policy Approach

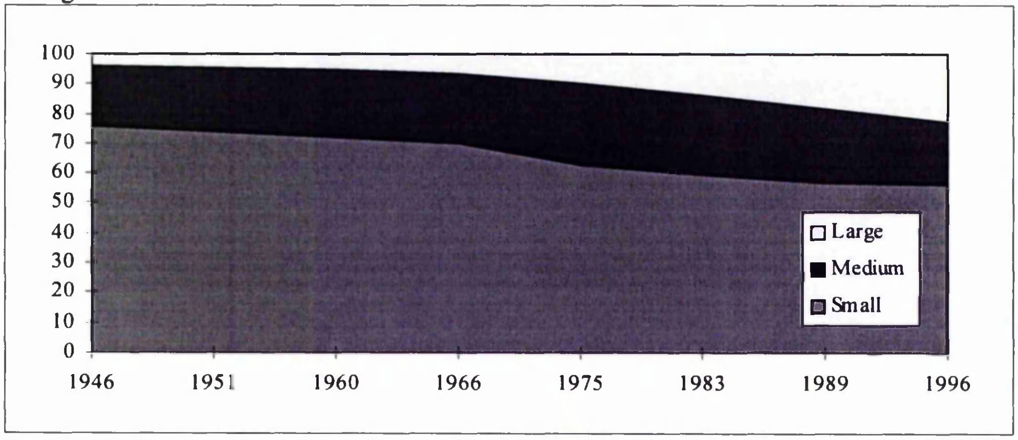
Arguments which have evolved from agricultural policy perceive the provision of R&D in terms of its underlying ability to achieve certain goals. Thus, the justifications advanced emerge directly from the development of UK farming and related policy. It can therefore offer a dynamic perspective on the question of state support and is the concern of the next section.

1.2.2.1. UK Farming is Too Fragmented to Support Agricultural R&D

A dominant argument which emerges for the support of agricultural R&D relies on the belief that individual farmers do not have the ability nor the motivation to fund such investigations, because farming is a small-scale activity. Thus, a low income level and a lack of protection for new technological ideas are seen as the primary obstacles to the farming sector funding its own R&D. Whilst this may certainly have been true in the first part of this century, because of rural impoverishment, it has to be questioned in terms of the developments which have occurred in the agricultural industry during the post-Second World War period. Principally this is because agriculture has received from 1945 onwards a growing level of Government support, which has aimed at improving the income and structure of the farming industry.

Since the Second World War, an increased concentration has been observed in the UK farming industry. This growth in the average size of farms is not a new phenomenon, as farms have been growing consistently larger from the 18th century onwards (Grigg, 1989). However, this trend has been accelerated by support policies after 1945, which have aimed to improve the structure and efficiency of farming and which have led to the substantial observed growth in farm size from this period onwards. Thus, although the majority of farms before the Second World War were only small in size and the sector was highly fragmented, during the 1960s and early 1970s there was significant amalgamation. Figure 1.1 charts the changing distribution of farm by size over this period.

Figure 1.1. Size Distribution of Farm Units in England and Wales between 1946 and 1996, percentage



Source: MAFF (Various Years)

Figure 1.1 reveals the distribution of large, medium and small farms over the period 1946 to 1996 in England and Wales. It indicates that large farms, i.e. farms over the size of 300 ha, have increased from 3.1% of all farms in 1946 to 22.7% in 1996. The proportion of medium-sized farms, between 100 and 299 ha, whilst growing in the 1970s, is now seeing some reduction in overall share within the UK farming industry. The most significant decrease has been in small farms, i.e. farms of between 5 and 99 ha, which have declined by 20% over the same period. Consequently, there has been some concentration within the industry, which may have implications for the argument that farming is too fragmented to support some agricultural R&D investment.

However, while growth has been achieved, this has not translated into an increase in sectoral income. The level of real farming income between 1946 and 1996 has fallen by around 13% (Harvey, 1987; CSO, 1998). However, to a degree, this masks a rise in average incomes as, despite a total decrease in farm income, the number of farm holdings has also been reduced by around 55%, or 291 thousand farms in absolute terms. The greater percentage decrease in agricultural holdings represents a substantial increase in average income per farm.

Specifically, Table 1.1 shows that annual average incomes per farm has risen by around £5 thousand, in real terms, over the fifty-year period. Consequently, it seems that the overall financial position of the farming sector has improved from 1946 to 1996. However, in comparison to the average salaries of workers in most other industries and services, farm incomes are around 20 to 30% less (Marks, 1989). Therefore, whether the farming sector is any more able as a result of these changes to fund R&D work is questionable.

Table 1.1. Farm Income per Holding in 1946 and 1996, in 1985 prices

	1946	*1996*	*Percentage Change*
Number of Holdings, thousands	525	234	*-55%*
Farm Incomes Per Holding, £	5,257	10,226	*94%*

Source: After Harvey (1987) and CSO (1998)

A means to circumvent the fragmented nature of the industry has been the establishment over the century of various collective agricultural groups. This has been successfully implemented in several countries, particularly in Denmark, France and New Zealand. In the last of these countries, a system of co-operatives, the majority of which are voluntary, exist representing all sectors. The voluntary system works as long as the gains captured by the members exceed the costs of collective action. However, co-operatives were formed on commodity lines and their purpose is not specifically related to the funding of agricultural research. There are, therefore, other incentives for voluntary membership. Consequently, it would seem that the marketing systems of a nation's agriculture may be more conducive to gaining levy funds. Within the UK a number of levy boards have been established after the Agriculture Act (1993), with an emphasis on marketing major commodities. These are funded by a levy on producers or processors of that commodity. However, the amount of income allocated to R&D expenditure varies greatly from body to body. In the UK only around £17 million pounds of levy funds were channelled to agricultural R&D in 1996. Consequently, its viability as a practical funding mechanism is weakened.

Accordingly, it seems that, whilst agriculture in the UK has changed quite radically in various aspects, the economic position of farmers has not substantially improved. Indeed the growth in average farm size and the adoption of 'factory' methods of production do not seem to have raised the economic importance of farming within society and, certainly do not obviously allow farming the ability to support its own R&D system.

1.2.2.2. Agricultural R&D Supports Self-Sufficiency

Several arguments for the public funding of agricultural R&D emerge from agricultural policy itself. The predominant contention for public support in the first half of this century was the need for self-sufficiency in food production. This was first voiced after World War One and became a major motivation behind the passing of the 1947 Agriculture Act (Tracy, 1989). Self-sufficiency has always been a prominent area of debate for an island economy, such as the UK. Agricultural R&D could be seen as enabling the country to become sufficient in its own food supplies by i) allowing higher input productivity, as well as reducing the need for inputs from abroad, ii) preventing potential shortages, e.g. through outbreaks of disease, and iii) by modifying non-indigenous agricultural products to grow under local conditions, as with the introduction of sugar beet in the 1920s. Ritson (1977) separates the origins of the self-sufficiency argument into a debate about security and one about the terms of trade.

The security of food supplies argument, whilst questionable at its inception, has weakened considerably throughout the course of agriculture's post-Second World War development. From a purely practical point of view, any future global war potentially threatens the annihilation of the human race and so concerns about the length of sufficiency in food supplies may be spurious. However, both MAFF (1996) and the European Commission (1994) do highlight the threat of a 'Chernobyl type accident' as an argument for the public support of agricultural R&D. Specifically, MAFF (1996) allocated around £834 thousand in 1996/7 towards research on the monitoring of food for radiological contamination. However, this is only a small proportion of the total research budget (0.6%) and in all probability is indicative of the level of justification that this argument merits.

Likewise the power of the terms of trade argument for self-sufficiency has been reduced with the opening of global markets, advances in transport technology and, more recently, entry into the EC internal market. Ritson (1977) pointed out that preserving self-sufficiency in excess of that which would emerge from free trade presumes that the farm sector would be slow to respond to a crisis, requiring the government to take pre-emptive action. However, as underlined by Ritson, increasing the long-term production of food is likely to be a costly method of securing food supplies. Consequently, the argument as a basis for support of agricultural R&D, as means to underpinning this goal, could be considered as part of a costly solution and so questionable.

1.2.2.3 The Taxpayer Benefits from Agricultural R&D

Another more specific argument arises from the long-term trends of agricultural prices and the effect of technology on various groups. Cochrane's 'treadmill effect' (1957) involves a phenomenon specific to the interaction between agriculture and technology. Innovative farmers adopt a particular technology before their fellow farmers, increasing supply at reduced cost and thus gaining higher profits. However, the consequent increase in supply reduces market prices. Consequently, if non-adopters fail to take up the technology, then their profits will be reduced. The implication of this would be that the late-innovating farmers have to acquire the technology to retain previous profit levels. Accordingly, it seems the main beneficiary of agricultural research is the consumer, who experiences lower prices. The inference of Cochrane's work is that it is not practical nor effective to extract payments from such a wide and diverse group as the 'consumer' and, therefore, the funding of underlying agricultural R&D should be financed by taxpayers.

However, a more equitable means of funding this research would seem to be to impose a levy on a specific commodity. This appears to be a fairer system as only the consumer of that commodity would pay for the levy through higher prices. In the UK, the Meat Research Institute was founded by the Agricultural Research Council (ARC) in the early 1960s. Financing for research was provided half through Government funding and half through levies imposed on animals sold at slaughter and handled through the Meat and Livestock Commission. However, after 1971, the contribution from industry began to decline as profits fell, because of increased European competition, and as such levy funding was eventually abandoned in 1980 (Henderson, 1981). This illustrates some problems with levies, namely their enforcement and the reliance on stable economic conditions. More successful schemes have emerged from France and New Zealand. In France, at present, a 'quasi-tax' on agricultural products is collected, which, along with a flat-rate farm tax, funds the majority of agricultural R&D. However, it is generally maintained that the specific institutional and marketing structures involved in French farming have allowed this system to develop and its adoption in other economies is severely limited (Routerier, 1998). In addition, analysis concerned with the spread of benefits of agricultural R&D (Freebairn *et al.*, 1982; Dryburgh and Doyle, 1995) have found that, dependant on the market structure of the industry, the benefits may not be fairly distributed. This latter study found that the main beneficiaries of UK dairy research was the processing sector, with the farmer and consumer actually suffering losses in welfare.

Furthermore, there is an inherent fallacy underlying Cochrane's analysis, namely it only applies in a country without price-supports. As such it is applicable to the 'laissez-faire' period of UK agriculture in the early part of this century, but less obviously valid after the Second World War, during which internal prices have been inflated above world levels, making the argument spurious to UK agriculture today. On the contrary, Harvey (1991) has argued that technology which increases supply under a regime of price support, such as the CAP, is detrimental to both the consumer and the farmer. Specifically, he notes that increases in supply without a subsequent increase in demand will create surpluses, which either have to be stored or dumped cheaply outside the EU, so depressing world prices. He offers three policy options in this case. Firstly, support prices can be reduced, in which case domestic consumers will gain from R&D. However, the damage this would cause to farm incomes has prevented the EU from implementing such a policy. Secondly, restricting supplies using quotas will transfer the benefits of technical change to the owners of quotas, i.e. farmers. Thirdly, and more radically, he proposes stopping publicly-funded agricultural R&D with the aim of reducing surpluses.

What emerges, therefore, is an argument against output-enhancing R&D. That the taxpayer should be the sole means of support for this R&D is questionable. This is because a situation of inflated prices and subsidised production, under the Common Agricultural Policy, has proved costly to the taxpayer. Conversely, because of this, areas of agricultural R&D which reduce output, such as animal welfare and environmental improvement, can be justified as meriting Government support.

1.2.2.4. Summary

Reasoning based on policy needs seems to offer several apparently valid reasons for public support of agricultural R&D. However, the justifications are not unqualified. In particular, agricultural policies since the Second World War, with their reliance on encouraging output, have led to numerous distortions and negative effects on both the industry and the public at large. But while this may have removed some or much of the justification for public funding of output-enhancing research, there still appears to be some justification for public support of non-output enhancing agricultural R&D, such as animal welfare and environmental protection.

Overall, the inference of this analysis is that the question of research funding cannot be considered in such simplistic terms as whether or not to support the agricultural research system, but instead must be assessed in terms of the correct allocation of resources to the different areas of R&D. In other words, some public funding for agricultural R&D is both justified and necessary. The key issue is where these public funds should most appropriately be channelled. Thus, various activities exist where the public sector should be paramount, or in which the private sector has neither the right nor the ability to fund. In order to establish this requires a deeper understanding of the research process within agricultural R&D. This is the concern of the next section.

1.3. The Process of Agricultural R&D

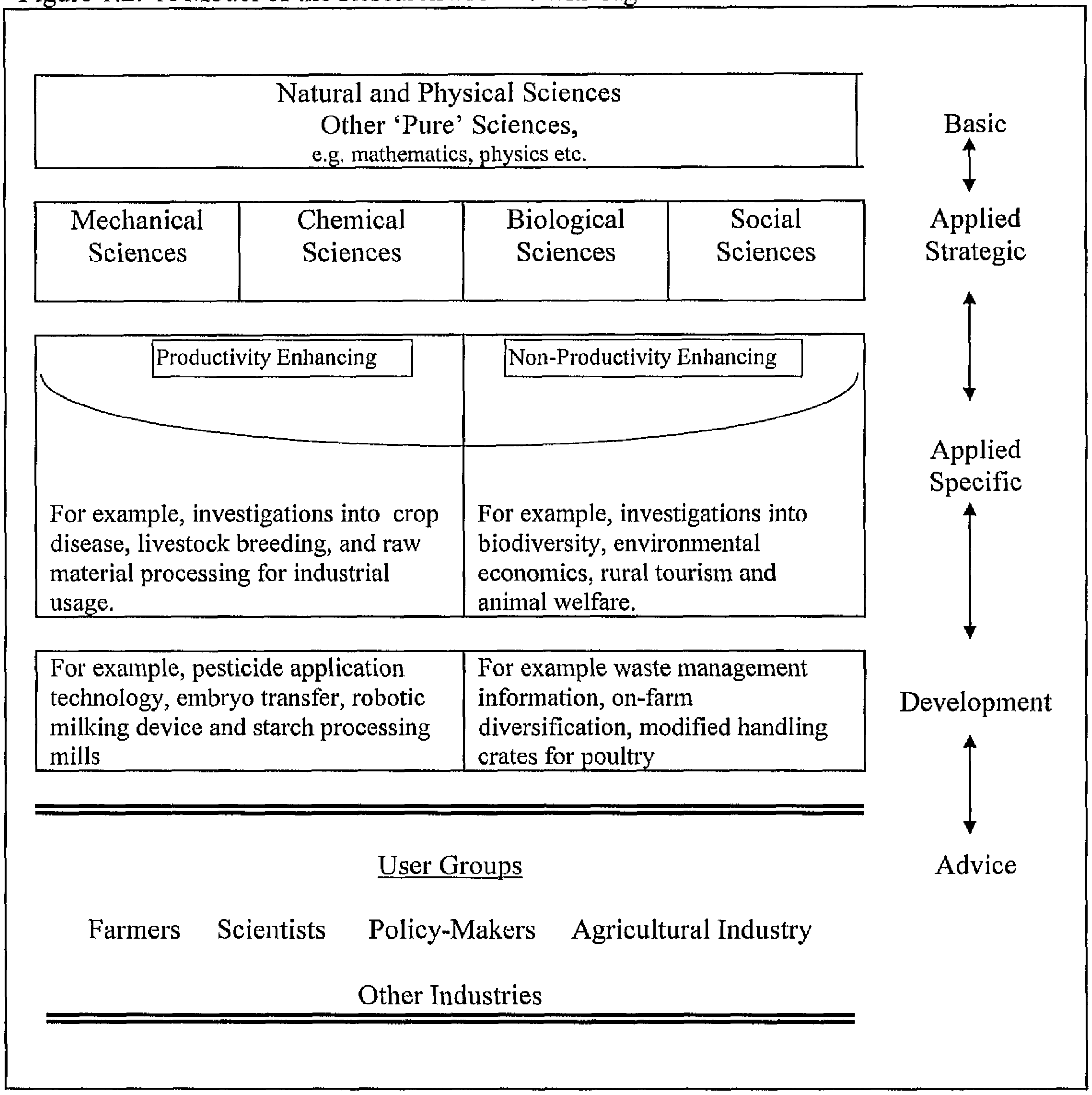
The traditional view of the research process is usually considered in terms of a continuum. Thus, basic research is followed by applied and, finally, development work which leads to the introduction of a technology and in turn this affects economic productivity. A description of these stages could be as outlined in Table 1.2.

Table 1.2. Research and Development Process by Type and Purpose

Research Type	*Definition*
Basic	The acquisition of new knowledge with no particular application in mind
Applied-Strategic	Research into a subject area which has not yet advanced to a stage at which an application that can be clearly specified
Applied-Specific	Research specifically directed to producing an exploitable outcome
Development	Using new or existing knowledge to create new products or processes

Whilst it offers an overview of the research process, Table 1.2 ignores the transfer of technology which is essential to successful adoption. Alston et al. (1995) state that not all research is for the benefit of farmers, but other user-groups, such as policy-makers and scientists who gain from the increases in knowledge. Consequently, they point to the continuum which begins with very basic research in scientific disciplines, e.g. mathematics and genetics, and runs through to very applied and adaptive research with farm-level and policy-level applications (Huffman and Evenson, 1993). Consequently, when considering agricultural R&D, the process of research becomes more complex. This can be illustrated in Figure 1.2.

Figure 1.2. A Model of the Research Process with Agricultural Science



Accordingly, 'pure' knowledge is predominantly created through basic and applied strategic R&D. At the basic end, research can be divided into both the natural and other 'pure' sciences. Both these areas consist of work which is not directly related to agriculture, but could be considered as an essential background from which scientists can develop solutions to agricultural problems. This becomes more relevant when considering applied strategic work, which consists of scientific work which has an agricultural bias. Nevertheless, this work is at such a fundamental level that it could easily be applied to other areas. For instance work in the fields of cell reproduction and nutrition could be used as a basis for work in both human and livestock fields.

The real distinction emerges when considering applied specific research which is solely directed at agricultural problems. Critically, the direction and outcome of this work is far more foreseeable in comparison to the previous types. Hence, this type of research can have general goals and can be directed towards a specific sector, e.g. crops and livestock. In addition, as its outcome can be generally determined, it can be divided into both productivity and non-productivity enhancing areas. Accordingly, non-productivity research in public good areas, such as animal welfare and rural diversification, calls for specific studies in relation to certain categories of animal or types of area. Furthermore, from this work actual solutions can be achieved through development work. This would include the introduction or adaptation of technology or processes to achieve specific goals or, in terms of the social sciences, the use of on-farm consultancies to improve productivity or exploit specific diversification opportunities. An important aspect of this development process is the role of advice between the end-user and the producer of technology, which can help the adaptation of the final product towards the specific needs of an individual or group.

However, a caveat to the above delineation of research is the interaction which exists between types. A number of writers have emphasised that the research process is characterised by a complex series of indefinable linkages (Thornley and Doyle, 1984; Rosenberg, 1990; Pavitt, 1991). Consequently, it has to be emphasised that basic, applied and development work are not distinct categories of the research process, but intrinsically connected. This seems to complicate the traditional view that the public sector should be responsible for the majority of basic research, whereas more applied and development work is the concern of the commercial sector. Therefore, in terms of the balance between basic and non-basic science, whilst knowledge is created through basic research, it can also be gained from applied and development activities, which may be of benefit to future investigations in basic fields. More critically, an emphasis on applied science will actually create more technology for the advance of agricultural policy goals. Thus, active participation by the public sector in these fields must surely be welfare increasing and the balance between these types of R&D should be reconsidered. This is further emphasised by Rosenberg (1990), who contended that private firms conduct basic research to understand new developments in science and to integrate them into their work. There can therefore be no clear division between public basic research and commercially orientated applied R&D and, to a degree, some overlap should occur.

Furthermore, research and development can be separated by activity to identify its level of appropriability and, hence, the role the public sector should play within agricultural R&D

funding. Typically a separation is made between biological, mechanical, and chemical technologies, as well as managerial, e.g. agronomic, research (Ruttan, 1982, Pinstrup-Anderson, 1982; Thirtle and Echeverria, 1994). The last of these studies found that differences occur depending on both the type and area of research conducted. Their ideas may be summarised by the schematic diagram presented in Figure 1.3.

Figure 1.3. Research Process by Type and Area of Technology

Area/Type	*Basic*	*Applied Strategic*	*Applied Specific*	*Development Work*
Managerial	Public			
Biological				
Chemical				
Mechanical				Private

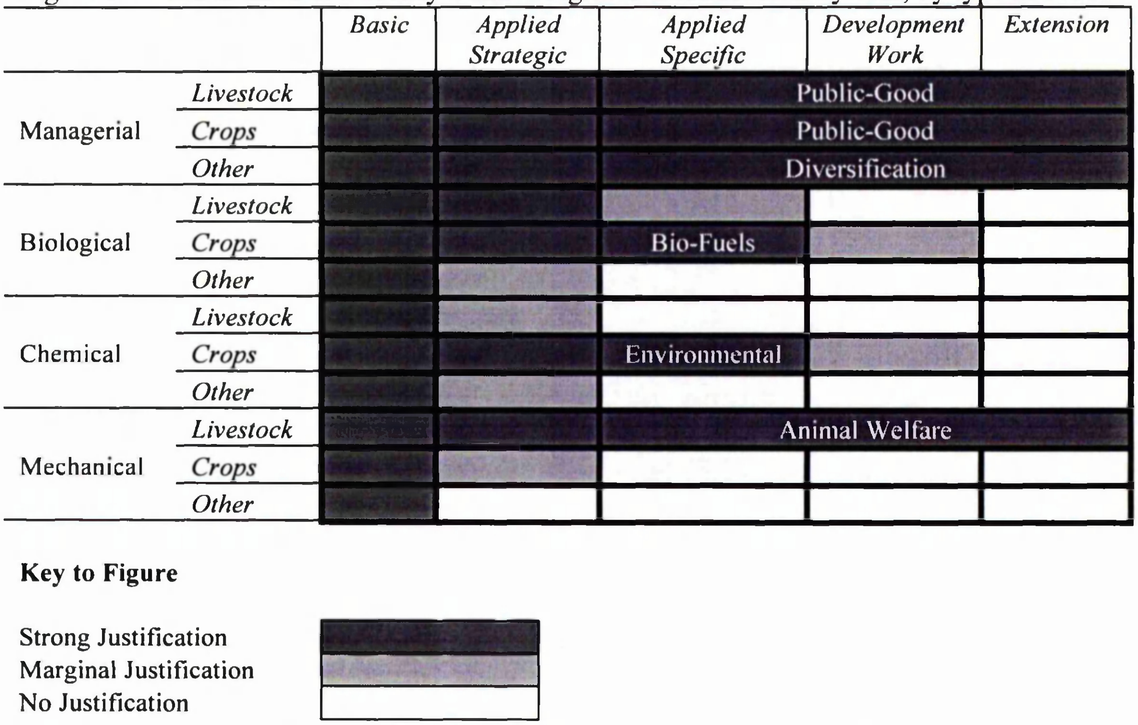
Source: Thirtle and Echeverria (1994)

According to Thirtle and Echeverria (1994), basic research concerned with managerial improvements carries the greatest justification for public support. This is because it is essentially involved in the creation of pure knowledge, which is difficult to protect, as opposed to development, or 'adaptive', work in mechanical fields, which is patentable and, therefore should be the concern of the private sector. Their study went further to suggest that UK agricultural R&D policy has largely ignored this rationale, quoting the case of MAFF allocating around 11% of its R&D budget towards 'tractors and self-propelled vehicles' in 1984.

However, this seems to ignore the interactions outlined above in terms of the different types of research. Consequently, it seems that the above scheme offers a somewhat simplistic view of public agricultural R&D funding. Rather areas of technology can be divided further into discrete blocks in terms of livestock, crop and other agricultural areas. Thus, Figure 1.4 presents this more specific view of a publicly-funded agricultural research system in diagrammatic form.

The justification for public R&D is assumed to be an improvement in the productivity of agriculture, unless it is stated otherwise. Thus, whilst Figure 1.4 seems to follow Thirtle and Echeverria (1994) to some degree, in terms of support for basic research, there are specific areas which require support further up the spectrum and which are concerned with the public good. Accordingly, whilst the majority of work at the applied and development end is considered to be the concern of the private sector, it seems that some areas of R&D still carry a strong justification into both development and advisory fields.

Figure 1.4 Justification of Publicly-Funded Agricultural Research System, by type and area



Specifically looking at the areas themselves, it seems that managerial work has the strongest justification. Again, this is because the creation of pure knowledge is difficult to protect. However, the above schema is somewhat misleading as managerial research into agriculture is, by definition, applied in nature. Consequently, the fundamental work, in areas such as mathematics, geography and psychology, will be conducted and, predominantly funded, from other sources and will 'filter' into fields such as agricultural economics and rural tourism management. Similarly, moving up the research spectrum into development and extension work it seems, from the arguments outlined above, that public support is only justified in offering solutions in respect of non-productivity goals. Thus, public-good research and advice in both livestock and crop areas are justified, along with support for diversification activities. This should merit increased justification, considering recent agricultural policy changes which aim to reduce farm income support for solely output-increasing activities.

In terms of biological areas, a strong argument for public support emerges for work into converting crops into bio-fuels. One of the more salient arguments outlined previously justified public agricultural R&D as a means of supporting infant industries. Therefore, agriculture as a provider of raw materials for other industries would not only be covered by this argument, but support may help to reverse the downward trend in economic growth within the UK agricultural industry. Consequently, work aimed at applied-specific goals is justified, but the case weakens at the development stage, as the private sector should be attracted to take up and develop this technology further.

The areas which are usually considered to be less appropriate for public funding by most writers in this area, namely chemical and mechanical, on closer examination are given a measure of justification in Figure 1.4. However, again this is only in public-good fields. Accordingly, chemical research, whilst central to agricultural productivity for the majority of this century, is decreasing in importance as it has become replaced by biologically based compounds. Thus, the only work in specific applied fields that deserves support is that concerned with providing environmentally-friendly alternatives for crop usage. This too, like bio-fuels, should become appropriable at the development stage and encourage commercial adoption. As such, public support for work at the development end of environmental chemical areas is only marginally justified.

Mechanical R&D for productivity-enhancement at the basic and applied strategic end, in crops and livestock seems justified as a basis for development into other areas, but given the opportunities for appropriation, should only be publicly supported to a degree. However, it seems that work in the field of animal welfare, which includes behavioural studies at the basic end and its consequent application in respect of storage, transportation and feeding equipment, offers a strong degree of justification for government support. Similarly, the dissemination of this information is also critical, which, along with legislation against animal abuse, should encourage effective adoption of improved animal welfare methods.

1.3.1. Summary

Analysing the specifics of the agricultural research system offers a more complex picture of which areas should and should not continue to be publicly funded. This study has found valid arguments for the government support of certain areas of R&D up to the development and extension stage where it is predominantly pursued for the enhancement of the public good. Consequently, it seems that there is no blanket formula for deciding which areas of agricultural R&D to fund and justifications for public involvement have to be considered on a case-by-case basis, as science policy dictates. The stark division between basic and applied R&D, which has occurred since the early 1970s, and the privatisation of the advisory service therefore emerge as rather simplistic policy solutions to the problem of justifying the continued funding of agricultural R&D.

1.4. Conclusion

Various arguments encompass the support of agricultural R&D by the public sector. These have generally emerged in response to specific policy problems or from abstract theory. This gives an overall impression that justifications for public support remain static. However, there has been a very real change both in the goals of agricultural policy and the agricultural research system itself, so that a more dynamic approach to assessing justifications for public funding is needed. Specifically, concentrating on the research process itself has been shown to give a more complex understanding of the justification for public support, as opposed to the standard arguments usually applied to agricultural R&D. These findings have implications for the funding of public agricultural R&D and, as such, are dealt with under various headings outlined below.

1.4.1. The Role of Basic Research in the Public Sector

That the public sector should fund basic research seems irrefutable. Indeed what emerges from analysis of the research process is that basic research within agriculture is virtually non-existent, as this is predominantly an applied science. The conduct of public research as a means to expanding the frontiers of science therefore cannot fail to be justified. Considering this as an indirect means to agricultural growth, the public sector is paramount, simply because the private sector will not fund this.

Real agricultural R&D begins with applied strategic research and this can be the domain of the public or private sectors. That industry will become involved in this area revolves around the concept of appropriability. Thus, the chances of a foreseeable gain dictate whether the private sector will become involved in a certain field. Demsetz's (1969) contention that appropriability is merely a question of applying legal mechanisms bears consideration in this context. Whilst, the passing of appropriate patent mechanisms may make areas profitable, it does not necessarily mean that the private sector will invest into these areas. This is especially so in areas which require large investment.

Consequently, the public support of applied strategic R&D can be seen as a means to reducing the disincentives for the private sector to invest in areas, especially where the social returns are high. However, pure knowledge is useless to the majority of companies operating in the commercial sector, as they have neither the time nor resources to decipher their importance in order to develop agricultural technology from them. Hence, there has to be a degree of work concerned with embodying knowledge into some specific technology. Thus, some investment in applied-specific work has to be conducted to promote this and to encourage adoption of such technologies. Thus, the removal of whole areas of the agricultural research service from the public domain is debatable and it seems that a more cohesive strategy for the removal of research funds should accommodate the continued public funding of basic, applied and development work, along with the appropriate dissemination.

1.4.2. Public Intervention and Output-Enhancing R&D

A growing concern with the public good argument for the state funding of R&D has raised issues over the direction of agricultural research. Until the 1980s the prime concern of the agricultural research system had been to achieve output growth. However, since that time there has been an observable switch towards supporting R&D connected with the environment, animal welfare and rural society. This relatively recent emphasis is quite remarkable, considering that the basis for public sector support, i.e. market failure, must surely be centred on these public good goals. That the bulk of post-1945 agricultural policy has offered lavish supports for output increases and, that agricultural R&D has been the means by which this has been achieved, must surely raise questions retrospectively over the public support offered for the ARS in the last 50 years.

A caveat to the above discussion is that, whilst Government support of science is now defined in terms of its ability to both increase the quality of life and create wealth, the division between these objectives is hard to define. For instance, producing a genetic marker will create wealth for the country, improve the quality of the animal's life by reducing stress and improve the consumers' life by enhancing the quality of meat they consume. Consequently, most public research institutes would claim that their research encompasses both dimensions. Therefore, it would seem that the achievement of both goals should be justified in the future.

1.4.3. The Role of Extension within the Public Sector

Until recently, the extension service was an intrinsic part of the post-1945 agricultural research system. The decision by Government to release output-increasing advice into the commercial sector raised a question over the balance and direction of public support. As outlined in Figure 1.2, it seems that advice is an essential part of the continuum by which R&D is adopted successfully. Thus, the feedback of information could arguably be included as part of the development process itself. However, the promotion of public-good advice is in line with the above reasoning, which questions the justification for public sector involvement on theoretical grounds in relation to output-enhancing areas. Accordingly, the removal of non-public good functions from the public advisory service seems to carry strong justification.

In summary, this chapter has presented an extensive overview of the arguments that have been used to support the public funding of agricultural R&D. However, when considered in the context of agricultural research, development and advice some of these arguments become spurious. Thus, this chapter has provided a conceptual framework for evaluating the justification for public sector agricultural R&D, outlining areas that merit continued support and those which do not. It automatically raises the question of whether the Government has adopted these principles when allocating funding to the public agricultural research service. Consequently, the next chapter provides an overview of the major developments, which have occurred in the UK ARS, as a way of answering this question.

CHAPTER 2

THE INSTITUTIONAL DEVELOPMENT OF PUBLIC AGRICULTURAL RESEARCH AND DEVELOPMENT

2.0. The Institutional Development of the UK Agricultural Research Service

Throughout this century the organisation and administration of science has undergone radical changes in terms of both its structure and purpose. The Agricultural Research Service (ARS) has altered as a result of both the shift in the priorities of the science system and a shift in agricultural policy towards environmental and social goals. However, the history of the agricultural research service reveals a number of issues which, in varying magnitude, have coerced the ARS into its present structure. These forces have emerged from a variety of technological, social, political and economic circumstances and one of the unanswered questions is whether these changes have materially improved or worsened the efficiency and performance of agricultural research. To answer this question the history of the ARS needs to be interpreted and analysed as a series of issues. Previous histories on the development of the Agricultural Research Service have recognised a number of chronological phases (Ellis, 1991; Thirtle, Palladino and Piesse, 1997). However, they have not directly related the phases to changes in Government research philosophy and involvement in science. This is arguably crucial to understanding the question of whether continued public funding for agricultural research is justified.

Four issues need to be addressed. First, how far has agricultural research policy operated within the framework of agricultural policy? Second, how has the influence of Government in agricultural research varied over time in terms of both its direction and level of funding? Thirdly, how have the UK agricultural research establishments adapted to the changes in Government involvement and to the Government's perception of publicly-funded science? Finally, how has the involvement of the private sector in agricultural R&D changed over time and what consequences has this had for the science base in the UK? In this chapter, an attempt is made to review these four issues in the context of the historical development of the ARS.

2.1. Research and Agricultural Policy

Publicly-funded agricultural research and development (R&D) began during the final phase of 'laissez-faire' in British agriculture, evolving as a minor component of rural development policy. It therefore seems that at its inception there was no strong relationship between R&D and agricultural policy. That the Government saw both facets as separate entities during this period is indicated after the repeal of the first interventionist Agricultural Act 1920, which led to the release of money for the funding of agricultural research (Ernle, 1961).

However, the subsequent history of agricultural R&D in the UK is arguably characterised by tensions between science priorities and Government philosophy. Nevertheless, Government statements throughout the century have been conducted in the belief that there is an underlying symbiosis between policy making and research. For this reason the historical development of agricultural policy in the UK can be seen as an evolving package of measures aimed at achieving various objectives. The interactions between agricultural policy and research policy are outlined in more detail below.

2.1.1. Agricultural Policy and Productivity-Enhancing Research

Throughout the 1930s a sporadic collection of measures constituted an agricultural policy, the main thrust of which was the protection of home markets against foreign competition (Tracy, 1989). A systematic policy for agriculture was only established after the Second World War. The Agriculture Act (1947) emerged from the very real threat of world food shortages and a concern over the growing war-time balance of payments deficit. Achieving stability of food supplies through efficiency of production was the main mechanism used to offset these effects. In many respects these policy objectives were consistent with those of publicly-funded agricultural research which, since its inception, had aimed at raising output either through improving the quality of inputs or increasing disease resistance (Riley, 1981; King, 1981).

This expansionist policy continued until production had caught up with demand in staple products when, after 1953, the Government began to pursue a policy of selective growth which guaranteed prices on a set of commodities. A number of wider policy measures also supported this stance and continued to develop into the 1960s. The most prolific of these policies was the National Plan (DEA, 1965) which had the general aim of increasing the UK's competitiveness on international markets. However, the most significant effect on UK agriculture since 1947 was entry into the Common Agricultural Policy (CAP) of the European Union. The system of price intervention gave generous subsidies on most commodities, as well as protection from non-European trade. Agricultural output flourished under this system and in many ways deviated from the UK's plan for selective output, as protection was offered for all commodities. However, the success of the CAP raised questions over the viability of over-producing stocks of food. Reforms had therefore to be instituted within the CAP to curb outputs. The MacSharry plan in 1992 aimed at reducing expenditures on price support, encouraging rural and social development and protecting the environment. Whilst not changing the objectives of the CAP, broad social objectives were emphasised through a system of direct payments, instead of the previous system of commodity price supports. This time controls were intended to restrain production and allow for more environmentally friendly practices.

Closer analysis of Government spending shows increasing productivity as intrinsic within R&D priorities. Around half of the MAFF research budget for 1996/7 was directed towards improving the economic performance of agriculture (MAFF, 1996). Similarly, the Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD) contributes 60% of its resources towards underpinning advances in the competitiveness and efficiency of the agricultural and food industries (Scottish Office, 1994). Recent Government policy seeks to "*underpin the industry's competitiveness and market responsiveness where there is wealth creating potential and where there are opportunities for increased UK sourcing and scope for expansion into new markets*" (MAFF, 1996, pp. 96). This is evidenced by around £50 million expended towards both crop and livestock science in 1996/7 by MAFF with the intention of improving economic performance.

2.1.2. Agriculture and the Wider Public Good

The growing public unease towards intensive farming, coupled with Government concerns over the administration of the CAP, led to a refocusing of agricultural policy during the mid-1980s. Within the UK the Agricultural Act (1986) introduced a number of Government sponsored schemes, most notably the establishment of Environmentally Sensitive Areas (ESA) and the Farm Woodland Scheme (FWS). These programmes supported the idea that, if farmers were to undertake more environmentally friendly practices on the farm, the costs should be subsidised by the Government. Similarly the European Union, through the CAP, directed increasing funds away from output-enhancing programmes, as reflected most notably in the controversial 'set-aside' scheme under which farmers were given payments for taking agricultural land out of production.

Around the same time as these changes to agricultural policy occurred there were shifts in research priorities. The Research Councils organised their responsibilities to include environmental issues. The ARC, whilst concentrating on creating a competitive agriculture, stated an intention to give greater regard to the environmental consequences of agricultural and horticultural practice (AFRC, 1986). MAFF statements also began to show a shift towards emphasising environmental protection. Predominantly, agricultural programmes revealed an increasing concern with the over-use and safety of agro-chemicals (Cabinet Office, 1989). Crop research towards protecting and enhancing the environment attracted around £30 million of R&D spending in 1996/7 (MAFF, 1996; Scottish Office, 1994).

In addition, in the 1990s there have been increasing public outcries over the treatment and transportation of farm animals. This has led to legislation both at national and European levels directed towards the humane treatment of animals. This is reflected by a rise in R&D spending on animal welfare, most of which is concerned with the development and enforcement of statutory and other controls on the treatment of animals. This involves both behavioural research and its application to engineering in producing better environments and handling methods for livestock. Again, in 1996/7 MAFF and SOAEFD animal welfare work accounted for 20% of the 'public-good' component of the R&D programme (*ibid.*).

2.1.3. Agriculture and Rural Development Policy

Agricultural research first began after growing social concerns over rural standards of living led to the 1909 Rural Development Act. However, in the 1930s the emphasis shifted towards market protection rather than rural development. Rural living standards improved drastically after the Second World War and support for farming communities generally emerged from guaranteed prices and, later, incomes policies. As a consequence rural aspects of agricultural policy during this period received less attention and did not achieve any momentum again until the mid-1980s. Shifts away from output-enhancing goals led to support policies directed at non-farm activities. Whilst there were shifts from emphasising productivity in the 1970s with the Mansholt Plan, which directed small amounts of money towards various rural objectives, little was conducted in this area by the EU until the 1988 reforms of structural funds (European Social Fund, the Regional Development Fund and the Guidance Section of the price guarantee scheme). More specific measures were aimed at speeding up the adjustment of agricultural structures, with a particular view to reform the CAP (Tracy, 1989). Consequently, funds have been directed towards improvements on the farm and on social assistance to farmers.

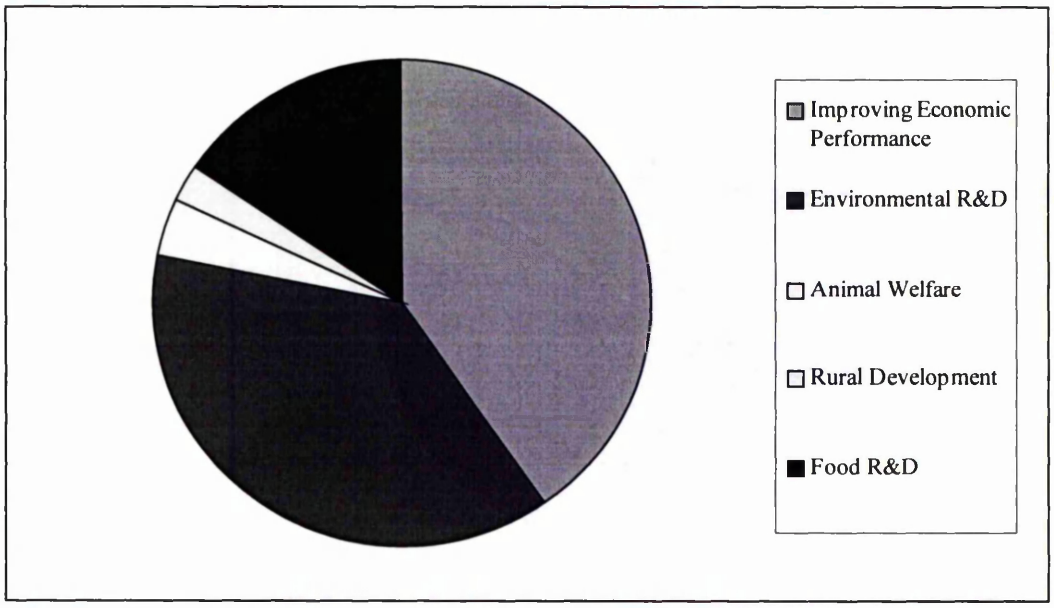
Rural development R&D forms an integral part of a policy for enhancing the countryside. The most prominent area of research funding is concerned with underpinning the Countryside Stewardship Schemes and the establishment of Environmentally Sensitive Areas. This is concerned with research on the interaction between agriculture and the environment, and includes policy research over the operation of these schemes. Generally, the remaining areas of rural development work are related to methods of protecting natural resources and animal environments.

2.1.4. Summary

Whilst the relationship between R&D and Government seemed ad-hoc before the Second World War, the development of a policy for advancing productivity after 1947 was supported by the agricultural research service (ARS). For the bulk of its post-war history the ARS has concentrated on expanding output and increasing efficiency. These two facets were therefore combined to some degree and, during this period, supplied a cohesive policy for increasing productivity in UK agriculture.

Similarly, changes to agricultural research in the early 1980s towards environmental concerns pre-empted agricultural policy in this area. Shifts in public attitudes have led to policy changes which seek alternatives to increasing productivity. Research work concentrating on the public good was, until recently, only minimal. However, at present MAFF and SOAEFD contribute around half of their research budgets towards these aims, with a commitment to increase funding in the future (MAFF, 1996). The divide between research is shown in Figure 2.1.

Figure 2.1. Research Expenditures of MAFF and SOAEFD by area, 1996



Overall, whilst improving economic performance amounted to £54.3 million in 1996, other 'public good' areas garnered around £59.4 million. However, this does not include £21 million allocated towards food research which is principally statutory work on food safety alongside some money towards improving the economic performance of the industry.

Nevertheless, whilst the overall thrust of research has been in line with Government policy, it seems that autonomy in research management has lead to a bias in direction away from

Governmental aims. Accordingly, whilst the ARS sought productivity gains, it did not follow the shifts in Government emphasis, namely towards commodities which offered higher returns. This is exemplified in the case of food research which was established and conducted under no direct policy and as such the work into food quality and storage can be seen as an anomaly in the policy context. Consequently, a major issue in the development of the agricultural research service is its relationship with Government. More specifically, the amount of involvement the Government has desired in the management of public agricultural research. This is the concern of the next section.

2.2. Level of Government Involvement in Agricultural Research and Development

The research institutions formed at the beginning of the century were only part funded by the state. Various public bodies were involved in the administration of grants from their own budgets, predominantly the Departments of Agriculture and the Development Commission, in order to establish and fund research into commodities determined by producer and grower organisations. At its inception, therefore, lines of decision making overlapped between these public and private bodies. Nevertheless, Government influence on research programmes at this stage was minimal and, on the whole, scientists were given the freedom to pursue their own investigations. Only in times of crisis did the Government become involved with research. For instance, a severe outbreak of foot and mouth disease during 1922-23 threatened the UK cattle population and led to the setting up of an animal disease station at Compton (Henderson, 1981).

Since the Second World War, research funding has predominately been channelled through three main bodies, namely i) the agricultural research council (ARC), ii) government bodies, such as MAFF and the Scottish Office, and iii) the universities. However, growing pressures, predominantly rising costs of research and development, led to changes in the organisation and management of the research system. As such various phases can be identified in the development of Government involvement with the agricultural research service (ARS). A distinct period emerges up to 1972 during which the ARS experienced fluctuating levels of autonomy in research management. A number of economic and political factors emerged in the 1960s which led to the introduction of national goals within the overall framework of science planning. This culminated in a phase between 1972 and the early 1990s of strict accountability for the publicly-funded applied and development work of the research bodies. The final phase from 1993 onwards resulted from a re-organisation of the research system, which severely reduced the amount of steerage available to policy makers.

2.2.1. The Extent of Autonomy

The Agricultural Research Council (ARC) was established in 1931 chiefly to provide advice and co-ordinate research amongst the Departments of Agriculture and the Development Commission. However, the decisions on the work to be conducted remained with the funding bodies. That the ARC was to be managed on an autonomous basis had been determined by a Committee established in 1918 concerned with Government administration. The structure of the only research body in existence at the time, the Department of Scientific and Industrial Research (DSIR), was reviewed in light of a decision to establish a medical research council. The DSIR enjoyed a large degree of autonomy and was advised by a Privy Council consisting of scientists, who directed and allocated resources for research programmes. In supporting this structure for future research bodies, the Committee advocated a belief in the 'independence of science':

> *''It is important, also, to observe that, although the Minister in charge of an administrative Department is answerable to Parliament for the work of the Committee [the then Medical Research Committee].....we have of set purpose, and for two clear reasons, classified the Committee as a service of general character and not as a body engaged upon research for the immediate purpose of a single administrative Department''*

(Quoted in Henderson, 1981, pp. 22)

This approach was commonly referred to as the 'Haldane Principle' after the head of the committee, Viscount Haldane. Consequently, the Agricultural Research Council was to be managed on the same lines as the DSIR, with advisory bodies consisting of representatives of scientific repute deciding on research priorities. There were therefore only tenuous links between the Agricultural Research Council and Government bodies at its inception.

The implications of the Haldane principle were only fully realised after the Second World War, when research funds were growing substantially and the ARC was granted the right to establish its own institutions. Concerns were voiced, usually from the ARC, regarding an overlap of interest between its own institutes and those sponsored by the Ministry of Agriculture. The Agricultural Research Act (1956) was passed after much debate over these concerns. Under this legislation the institutes previously controlled by the Ministry of Agriculture were transferred to the ARC's financial and administrative responsibility. Hence the direct influence of Government was removed and shifted to an advisory capacity within the Privy Council for Agricultural Research.

Throughout this time the Higher Education Institutions (HEI) remained relatively free from Government intervention. University research was usually basic in nature and a complement to an institution's educational activities. It was therefore considered to be administratively impossible to control and direct research programmes. Similarly, the National Agricultural Advisory Service (NAAS), established in 1947 for the transfer of research results into practice, operated between the farmer and the research institute. Consequently, it relied on the advice from staff working with farmers to provide direction in research programmes. Accordingly, this system seemed self-governing and it could be ascertained that Government influence was only slight during this period.

2.2.2. Emphasising the National Need

After the Second World War the sophistication of research increased and led to a greater investment in advanced and expensive equipment. Throughout the post-war years as research funds grew, Government science policy showed a growing concern over obtaining value for money on its investment. This influence first emerged on the advisory committees of research bodies. Whilst previously populated by public scientists, Agricultural Departments became increasingly represented on these committees.

However, whilst the autonomy of the Research Councils was not affected, fears were expressed over the lack of co-ordination in research effort and there were calls for *"a rational system of apportioning resources between the research agencies under the Haldane System"* (Trend, 1963, para. 52). This search for producing a system which would increase the national benefit culminated in the Science and Technology Act (1965). The Act sought to modify the organisation of the Research Councils without affecting the independence of scientists and shifted funding decisions away from the Treasury towards the Department of Education. This body was chosen because its functions were not particularly relevant to the fields of the Research Councils and therefore helped to achieve the aim of preserving the Haldane principle to some extent (Henderson, 1981). Consequently, its name was changed to become the Department of Education and Science (DES).

Pressures for national relevance led the Research Councils to begin assessing their own research programmes and set criteria that would allow for the possible success and scientific importance of their work. The ARC stressed the usefulness of the research it was undertaking and, in turn, founded a working party to consider its future programmes in agricultural research and established three criteria for assessing its research projects. These were i) the future importance to agriculture of the chosen objective, ii) the prospects for success, and iii) the scientific importance of the work (Henderson, 1981, pp. 92). However, a later programme which aimed to achieve some systematic planning within programmes stated that little was known about the full extent of research projects conducted within each institute before the 1970s (Ulbricht, 1977). That the ARC could confidently assess all its research against these criteria has therefore to be questioned. Similarly the ARC had not felt the need to establish such a working party before this period, which perhaps indicates that questions of national relevance were being asked for the first time within the ARC.

2.2.3. The Rise in Accountability

Several different factors emerged within the UK Government during the 1960s that culminated with the imposition of an accountability mechanism on the science system. Kogan and Henkel (1983) have traced the rise of administrative prudence in Government. This is evidenced by the establishment of public expenditure surveys in the early 1960s which grew in complexity over the decade and began to consider how much the UK could afford to spend on an area or whether it could be more profitably invested elsewhere.

The early 1970s saw the culmination of these trends with the pursuance by the Heath Government towards gaining certainty in decision making. Ministers were called upon to review the functions of their departments in order to clearly define the levels of responsibility and accountability. Within this remit the Government adopted a report prepared by Lord Rothschild concerned with the management of Government R&D, subsequently referred to as the Rothschild Report.

In an attempt to maximise the efficiency in allocation of public R&D funding, the Haldane principle would be replaced with a 'Customer/Contractor' mechanism. Specifically, this relied on there being an explicit divide between basic research, defined by Rothschild as *''the discovery of rational correlations and principles''* (Rothschild, 1971, para. 7), and applied research which had a practical application as its objective (ibid., para. 6). The direction of applied research, Rothschild contended, should not be decided by scientists, but by the body paying for that research. This body was referred to as the 'Customer'. The Customer would decide on the research needed and then choose a 'Contractor'. The consequence of the Government's adoption of the Rothschild Report was a shift in funding from the DES to MAFF. Initially, Rothschild had foreseen MAFF to be in control of 77.5% of the funds for agricultural research (ibid., pp. 21). However, Table 2.1 shows this target was never achieved and that the MAFF share was never really better than 50% even at the height of its implementation.

Table 2.1. Division of MAFF/DES Research Expenditure in Current Prices, £ million and percent

	1976	*1980*	*1982*	*1990/1*
MAFF	19.1	30.4	44.3	45.1
DES	15.1	29.5	41.9	88.4
MAFF Share of Budget	*56%*	*51%*	*51%*	*34%*

Source: ARC (Various Years)

The principal effect of these changes was the development of a highly complex administrative structure within the agricultural research system. This structure, that was intended to create better value for money, led to feelings within the scientific community that it was removing resources, which could have been better employed in research (Kogan and Henkel, 1983). Furthermore, Ruttan (1982) criticised the fact that, although the administration of research programmes was improved, it did little to refine the management of research. Fears were also expressed over the loss of flexibility experienced by the Research Councils in allocating some of their resources to commissioned work (DCS, 1979).

2.2.4. Shifts in the Accountability Mechanism

The Thatcher administration effected fundamental changes to the research system from 1979 onwards. More pressure was imposed on the Civil Service to create better operating efficiencies within the public sector. This emerged with the creation of the Office of Science and Technology (OST) in 1992. This new body undertook the administration of the science grant from the DES. The Realising Our Potential policy document (OST, 1993) ushered in another change to the re-organisation for the science system. Whilst stating a commitment to strengthening the 'Customer/Contractor' principle for departmental applied and development work (ibid., para. 1.18), it also claimed to support autonomy for the running of Research Councils. The report cited the Haldane principle which it defined as *"the day to day decisions on scientific merits of different strategies, programmes and projects"* (ibid., para. 3.23), but highlighted the need for some mechanism to co-ordinate activities and working practices. This was to be achieved by the establishment of a Director General of the Research Councils (DGRC), who would advise the OST on the distribution of funds between Research Councils. Similarly advice was provided to the OST from newly formed 'Technology Foresight Groups' (TFG) to help decide priorities on the future needs of each industry.

These changes had followed a period of reduced funding for applied and development work with the aim of increasing industrial involvement. Consequently, the Customer/Contractor mechanism became undermined as steerage relied on setting goals for publicly-funded applied and development work. Accordingly, accountability shifted emphasis towards the research institutes themselves through a series of Government scrutiny reviews of public research establishments. These began in 1994 aiming to establish whether duplication of research did occur in areas of public research. These could then be identified as areas which should be privatised (RRI, 1994). Where privatisation was not feasible then the scrutiny would identify areas for rationalisation of facilities and capabilities. It would also consider whether changes in current ownership and financing arrangements would lead to more effective operation and better value for money. Government scrutiny reviews would be undertaken every 4 years for research institutes. Consequently, it seems that the Government has removed itself directly from dictating publicly-funded research programmes within the research institutes. The onus of national relevance of results has therefore been placed back into the hands of the scientists, with the role of Government as an invisible hand threatening privatisation.

2.2.5. Summary

The relationship between the Government and the Agricultural Research Service has changed radically over this century. The Haldane Principle instituted the philosophy within UK research that the scientists were the best qualified to decide on the direction and allocation of funds for research programmes. Whilst this seemed appropriate before the research system grew, increasing levels of expenditure and pressing demands for nationally relevant outcomes within Government gave rise to an accountability mechanism known as the 'Customer/Contractor' principle. The Agricultural Research Council saw half of its funds re-allocated to MAFF for applied project work. However, after subsequent cuts in these areas during the 1980s steerage returned towards concentrating on the relevance and quality of the institutions themselves and autonomy has returned to a lesser extent within the agricultural research service.

The level of Government involvement has had an influence on the size and activities of the Agricultural Research Service. To understand this further, the bodies which operate within the ARS require further examination. This is to establish the extent to which these changes have affected the producers of agricultural R&D. This is discussed in the next section.

2.3. The Evolution of Agricultural Research and Advisory Bodies

The UK agricultural research service (ARS) is comprised of a complex number of bodies. By far the largest conductor of research is the Agricultural Research Council (ARC)[1], which governs institutions in England and Wales, as well as recommending funding arrangements to the Scottish Office for their equivalents, the Scottish Agricultural Research Institutions (SARI, now SABRI[2]). The Department of Agriculture in Northern Ireland (DANI) also conducts research in its own institutes and at the Queen's University, Belfast. The agriculture departments within universities and the agricultural colleges within the UK also undertake research usually of a fundamental nature. The transfer of results was achieved through the Agricultural Development and Advisory Service (ADAS) in England and Wales until 1996, at which time it became a private agency. A much reduced advisory function is now provided by the Farming and Rural Conservation Agency (FRCA). The Scottish Agricultural College (SAC) offers both publicly-funded advice to farmers in Scotland and undertakes research into agricultural problems.

At various stages of its development the ARS has changed in size. For the majority of its history there has been a sustained growth in expenditure, for which the Agricultural Research Council (ARC) has been the main beneficiary. However, radical changes emerged in the 1980s which affected both parts of the research-advice continuum and severely reduced its presence within the agricultural industry. As such, the following analyses can be divided into three stages, namely, i) the establishment of research bodies, ii) the expansion of these bodies, and iii) the decline of agricultural research.

[1] Changes have been imposed on the name throughout this history. It became the Agricultural and Food Research Council (AFRC) in 1982 and the Biotechnology and Biological Science Research Council (BBSRC) in 1994. However for clarity the first names allocated to establishments will be maintained.
[2] Scottish Agricultural and Biological Research Institutes.

2.3.1. The Establishment of Research Bodies

State-funded agricultural research emerged indirectly with the dispensing of sporadic grants to Higher Education Institutions (HEI) in the 1890s. Direct funding of agricultural research did not begin until after 1909. Reflecting the growth of Liberalism in early-twentieth century British politics, the Development and Road Improvement Funds Act was passed in 1909. It intended to improve the living standards of the countryside predominately by a programme of afforestation and road building (Russel, 1966). Consequently, expanding the resources for the proper scientific development of agriculture and fisheries was only a small facet of this policy. Funding was administered by the Department of Agriculture and Fisheries (DAF) in England and Wales on the advice of the Development Commission, which had been established with the concern of promoting the social and economic development of rural England. In Scotland, grants for research were allocated from its own Department of Agriculture. The Commission upheld the belief that specialisation was a necessity for the advance of knowledge and allocated funds to institutions focused on certain areas of research throughout the field of agriculture. Consequently, this Act began the systematic establishment of state-funded agricultural research institutions throughout the UK.

Public funding involved the awarding of a lump-sum grant 'whenever Government saw fit' from a development fund towards the establishment of a research station (Ernle, 1961). The producers' organisations and the County Councils were expected to highlight the need for research in their own specific field and would usually have to offer around half of the running costs. This would be matched by money from the Departments of Agriculture. Whilst the Development Commission would administer grants, the Agriculture Departments would be responsible for the work of these institutes. In total around 32 agricultural and horticultural research establishments emerged to form the public agricultural research service between 1909 and 1931. Of these, 16 were concerned with all aspects of plant and crop science, 12 with animal disease, nutrition and breeding and the remaining four with agricultural engineering, economics and work into food storage quality (Henderson, 1981).

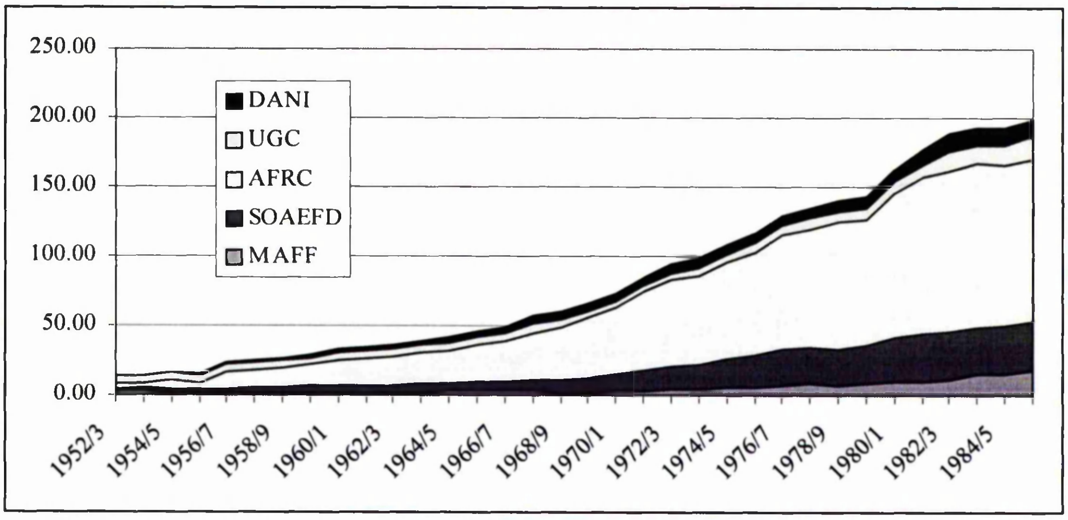
The development of such a large organisation, with its mixture of funding sources and management in the hands of individual scientific institutes, led to risks of an overlap of effort. There was, therefore, a need for the systematic organisation of each research discipline within agriculture. Accordingly, the Agricultural Research Council (ARC) was established in 1931 to provide criticism and advice to the Agricultural Departments and the

Development Commission. To oversee the management and funding of the ARC the Privy Council for the Organisation of Agricultural Research was also established at this time.

2.3.2. The Expansion of Agricultural R&D

The Second World War and its effect on food supplies changed the way in which Government perceived agriculture. Research began to be seen as a means to underpinning productivity increases and, along with the agricultural industry itself, experienced a sustained period of increased public investment. The expansionary period began in the early 1950s and ended in the early 1980s, with the ushering in of the Thatcher Administration and subsequent pressures on public sector financing. Figure 2.2 shows the growth in real terms of the major bodies conducting research during this period. Total funds grew by an average of 7% per annum from 1952/3 to 1983/4. The major recipient of these funds was the ARC. Whilst average growth rates in the Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD) and Ministry of Agriculture, Fisheries and Food (MAFF) research expenditure were 9% per annum, during this period the ARC experienced an average increase in funding of 15% per annum. The research expenditures of the Department of Agriculture for Northern Ireland (DANI) and the University Grants Committee (UGC) remained relatively constant.

Figure 2.2. Total Public Expenditures on UK Agricultural R&D from 1952/3 to 1984/5, in real terms, £ million in 1970 prices[3]



Source: (Various)

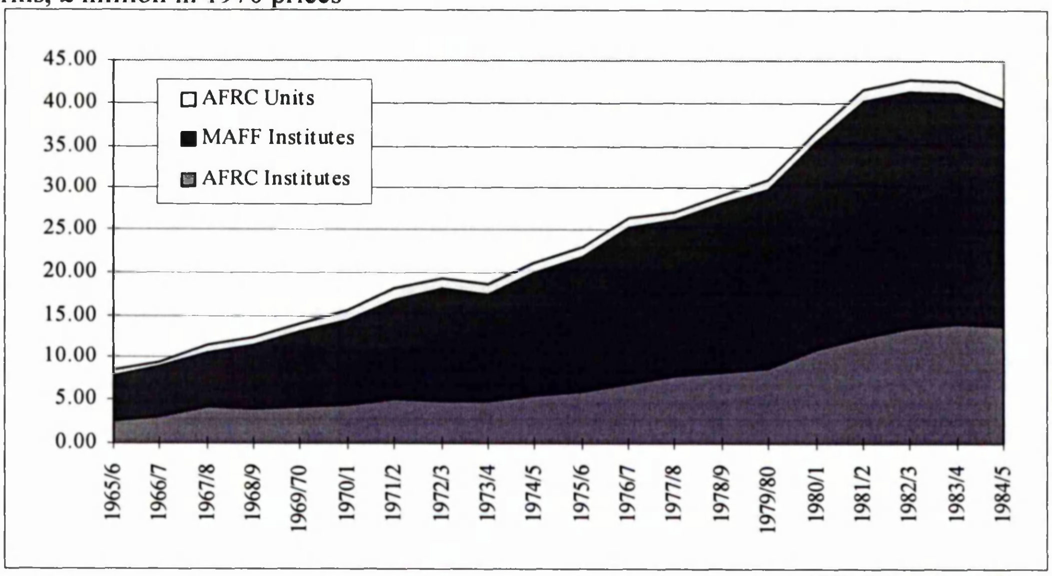
[3] Public expenditures were deflated by the RPI index.

After the 1956 Agricultural Research Act the ARC was charged with the management of the whole organisation for agricultural, horticultural and food research in England and Wales. Accordingly, it secured financial responsibility from MAFF for 14 research institutes. Similarly after the Second World War the ARC began to establish 8 of its own institutes in areas which it believed merited further investigations.

The ARC's approach to organisation seems to outline an ambition to assume responsibility for the whole area of agricultural research and as a consequence it developed into a 'many tentacled structure'. The establishment of Research Units, usually situated within Universities and concentrated on unspecified basic research, seems to have been the ARC's contribution to the advancement of knowledge. Consequently, in light of the relatively low capital costs of establishing Units, it is questionable whether there was a justification for establishing further research institutes. In 1981 it was estimated that around 60 to 80% of an institute's expenditure was on staff costs (Henderson, 1981, pp. 111). The Research Units therefore offered relative flexibility and reduced capital costs. Figure 2.3 shows the distribution of funds between the MAFF institutes, the ARC institutes and the Research Units.

Whilst during this period 22 Units were established, their proportion of the budget was minimal, due largely to low capital costs. However, at the end of the 1970s with the increase in commissioned programmes from MAFF, there was a decline in importance of the Units and many were absorbed into the research institutions themselves.

Figure 2.3. Allocation of AFRC Research Expenditures from 1965/6 to 1984/5, in real terms, £ million in 1970 prices



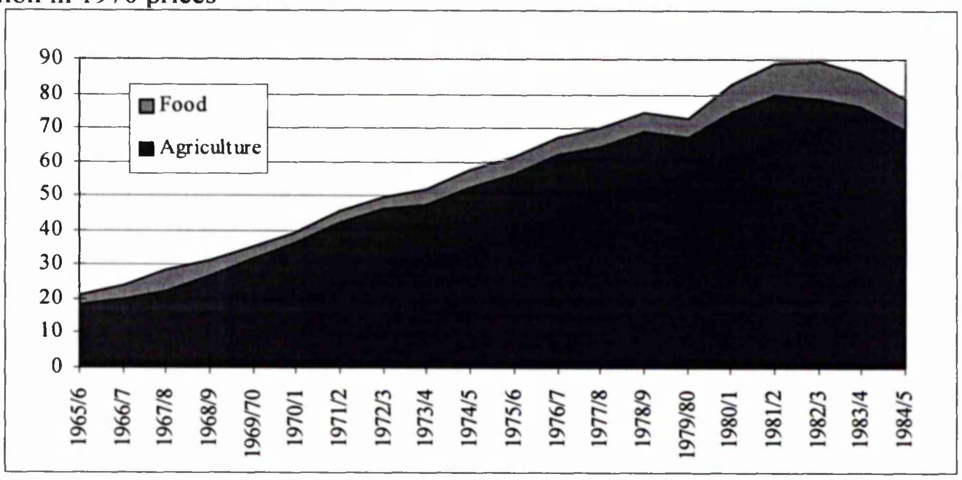
Source: AFRC (Various Years)

2.3.3. The Growth in Food Research

Although the Ministry of Agriculture's in-house activities began in 1940 with the Pest Infestation Laboratory, the safety of food produced and imported was believed to be the remit of the Department of Scientific and Industrial Research (DSIR), which was responsible for the food laboratories during this period. The emphasis of these institutes was on food safety and the analysis of toxic residues in food. It would therefore be true to say that very little research was conducted on food improvement. Research in this area was usually as a spin-off from agricultural problems, such as the quality of meat, which would be part of a wider programme concerned with beef, sheep and pig meat production.

Work directly concerned with the quality of food emerged from the ARC in the early 1960s with the establishment of two institutes, the Meat Research Institute (MRI) and Food Research Institute (FRI). The former was concerned with the effects of storage on the quality of meat carcasses and was part funded by levies from the Meat and Livestock Commission. However, the majority of publicly-funded work was channelled into the FRI and its predecessors, the Low Temperature Research Station and the Ditton Laboratory. Tasks prioritised for this institute related to food in general other than red meat and concentrated more on storage than the quality of food produced. Figure 2.4 shows the allocation of expenditure on food research in proportion to agriculture.

Figure 2.4. AFRC Expenditure on Food in relation to Agricultural R&D, in real terms, £ million in 1970 prices



Source: AFRC (Various Years)

Figure 2.4 highlights the ARC's antipathy towards food research throughout most of its earlier period. Instead the majority of agricultural research institutes concentrated on products up to the farm gate and were constrained by capital costs to continue on this path.

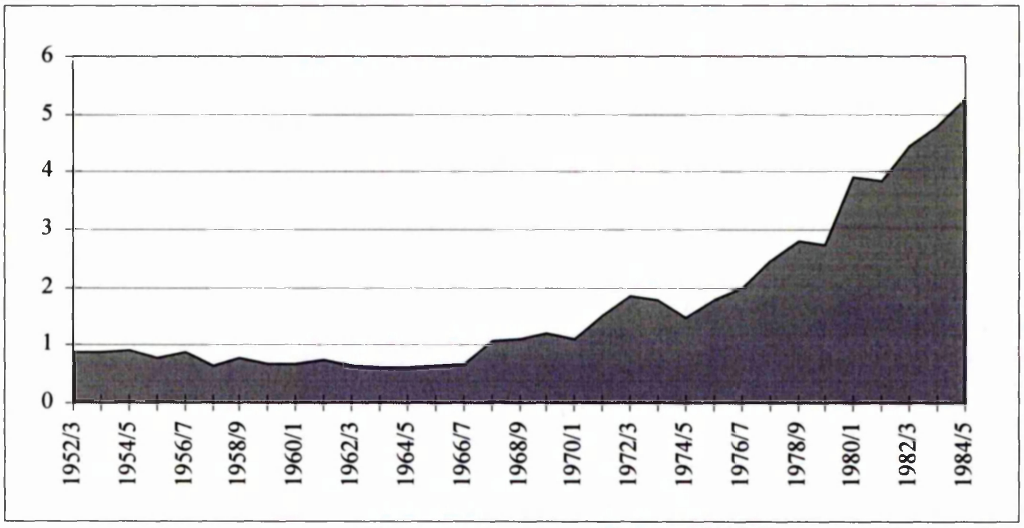
Equally, food science was for much of this earlier period not considered a scientific subject in the same sense as work on genetics or soil chemistry and, therefore, suffered from a lack of top scientists in the field. It was also felt that the private sector should play a bigger role in funding both the MRI and FRI (Henderson, 1981). However, little interest was voiced from industry and the burden of support remained with the public sector. In the early 1980s, after criticism from a Select Committee lamenting the lack of food research, the title and remit of the ARC was changed to incorporate food (Agriculture Committee, 1983). Whilst no new institutes were formed the level of its expenditure grew in proportion to its other disciplines and in 1993/4 food research had a share of total expenditure of around 20% (AFRC, 1994).

2.3.4. The Changing Nature of Advisory Bodies

Public advice to farmers first emerged from the HEI sector at the turn of the century. However, it did not occur on a systematic scale until the Second World War with the advent of the County Agricultural Organisers. The setting up of a national advisory service reflected the growing awareness during the Second World War of the significance of technical advances in improving agricultural productivity. The National Agricultural Advisory Service (NAAS) was established in 1947. Within its advisory capacity the NAAS conducted development work in order to provide technical advice to farmers and to relate research findings to specific regional problems. In undertaking R&D, the NAAS was concerned with the various processes between the scientific and technical aspects of production. This work was conducted on experimental husbandry farms and science stations and concentrated in the main areas of interest to the improvement of farming. These farms were dedicated to applied work on insect pests, soil fertility and animal nutrition (Watson, 1946).

The work of the NAAS continued unchanged throughout the 1960s. Figure 2.5 shows that NAAS expenditure throughout this period hovered around £1-2 million in real terms until the early 1970s. The re-organisation of the NAAS into the Agricultural Development and Advisory Service (ADAS) in 1971 saw larger amounts of money being directed into it. Specifically, the formation of ADAS reflected growing demands from the farming industry for a body involved in overall farm management.

Figure 2.5. Advisory Expenditures for England and Wales, in real terms, £ million in 1970 prices



Source: HM Treasury (Various Years)

ADAS was an amalgamation of the NAAS extension service along with three other Government bodies involved with agricultural problems, namely i) the Agricultural Land Service, advising on land use and structural changes, ii) the Field Drainage and Water Supply Service, involved in land improvement work, and iii) the Veterinary Investigation Service, providing diagnostic services to local veterinarians. This re-organisation was a determined effort to reduce Government involvement in agriculture and increase self-reliance by industry (Emry-Jones, 1970).

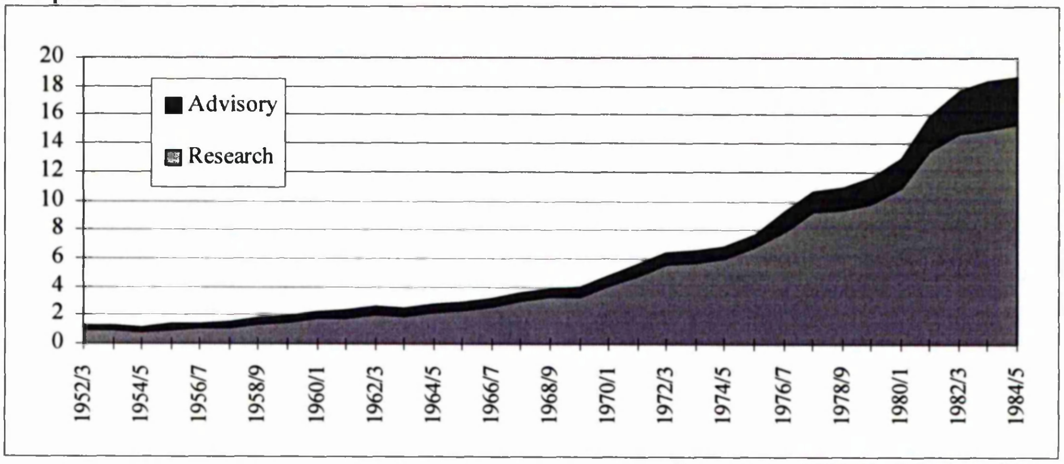
Figure 2.5 shows the increasing annual expenditures directed towards ADAS in support of its duties. From 1970/1 until 1984/5 real annual expenditures increased by an average of 9.9% per annum, compared to an average annual increase of only 2.7% in the preceding period of 1952/3 to 1969/70. Therefore, in light of the earlier statement that Government should reduce involvement and increase self-reliance on the industry, this staggering rise in ADAS expenditure is surprising. If anything the amalgamation of research services and this continued growth in public funds shows an increased involvement by the public sector with the farming industry.

2.3.5. Agricultural R&D in Scotland and Northern Ireland

Constitutional arrangements within the UK led to differences in the organisation of Agricultural Research facilities both in Scotland and Northern Ireland. Whereas England and Wales have undergone the severest changes in management and administration, the rest of the UK has remained relatively unaffected. The organisation that emerged for research in

Scotland now consists of 5 Scottish Agricultural Research Institutes (SARI). The ARC has retained a purely advisory role to the Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD), which is in charge of administering grants between institutes. SOAEFD also distribute grants to the Scottish Agricultural College (SAC), which undertakes the advisory and development work for the farming industry in Scotland. The Universities conducting agricultural research, predominantly Aberdeen, Edinburgh and Glasgow, are the only institutions not funded by SOAEFD, but instead by the University Grants Commission (UGC). Figure 2.6 shows the advisory and research expenditures of SOAEFD.

Figure 2.6. Agricultural and Advisory Expenditures for Scotland, in real terms, £ million in 1970 prices



Source: SOAEFD (Various Years)

Funding has grown relatively steadily throughout the period from 1952/3 to 1984/5. The average increase has been 9% per annum. Disaggregating amongst the various bodies, the SARI's have enjoyed a steady growth until the mid-1980s, when current expenditure reached a peak of around £22 million. In contrast, capital expenditure, in line with the re-building programmes recommended by the ARC, continued to increase at a steady rate for much longer. Advisory expenditures, along with development spending, at SAC also increased steadily upwards during this period.

Within Northern Ireland, the Department of Agriculture for Northern Ireland (DANI) is responsible for all research, education and extension. In-house research and education is conducted at the Queen's University, Belfast and at 8 research divisions around the country. The research is directed by 6 sector Committees which review the needs of the agricultural and food industry[4]. The comparatively small size of the region allows for better co-ordination and closer links between the Committee members (consisting of scientists and representatives of the industry) and the farmers themselves than could be achieved in England and Wales. Data on DANI expenditure is hard to quantify. However, Thirtle, Piesse and Smith (1997) have estimated agricultural R&D expenditure in Northern Ireland to be around £9 million per year, but little can be drawn from these assumptions about funding.

2.3.6. The Decline of Agricultural R&D

The increasing demands from the Thatcher Administration to achieve efficiencies within the Civil Service and the belief in reducing the burden of state funding initiated major changes to the agricultural research system. In 1984/5 cuts appeared in the Government funding of science. The agricultural research budget suffered reductions of £10 million in 1986/7 and of £20 million in 1987/8, predominantly in applied and development work. The changes in research expenditure can be seen in Figure 2.7.

Figure 2.7. Total Public Expenditures on UK Agricultural R&D from 1984/5 to 1994/5, in real terms, £ million in 1970 prices.

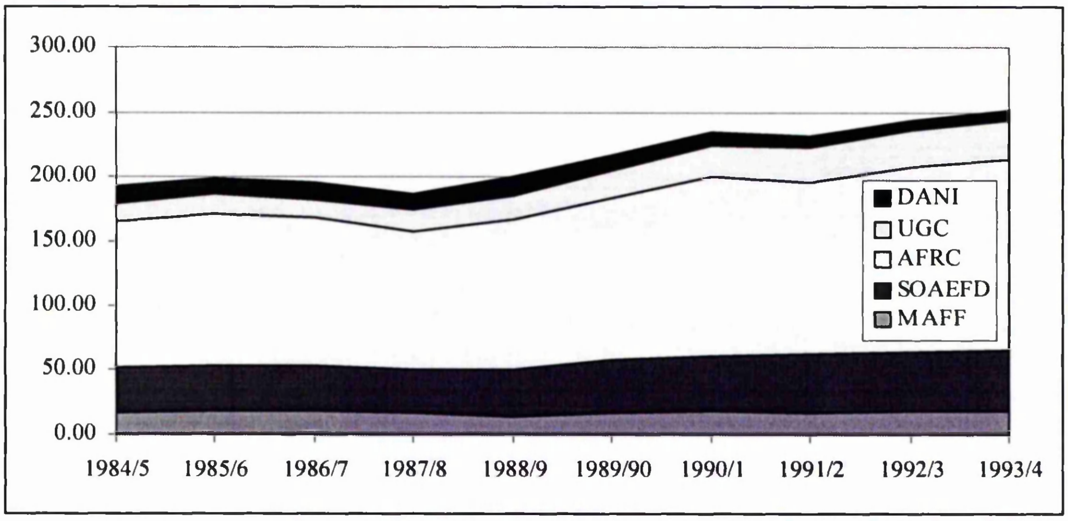


Figure 2.7. shows a slight dip in research expenditures, predominantly experienced by the AFRC. However, funds after 1989/90 returned to previous levels, with an emphasis on basic science (Thirtle, Piesse and Smith, 1997). Along with these funding pressures the AFRC had initiated a restructuring of its research stations which began in the early 1980s. As a consequence research was consolidated into 8 institutions, each concerned with a

[4] The Sector Committees are concerned with; ruminants, non-ruminants, horticulture, environment, fisheries, and

distinct area of agriculture and food research. This naturally led to the loss of areas of expertise with consequent reductions in staff numbers.

The desire within Government to improve accountability and efficiency was further enhanced with the establishment of 'next steps' agencies in 1988. This would mean that certain aspects of the Civil Service could be hived off as agencies, which would provide specific services to the Government or other customers. Thus, from this period onwards the creation of agencies or non-departmental public bodies would be as a means for the Government to release functions which, until that time, enjoyed direct public support. Those functions which would remain in the public sector would have to prove they were both necessary and best carried out under Government control. Consequently a series of reviews were initiated, referred to as 'Prior Options', which would investigate public establishments in terms of their suitability for remaining in the public sector.

Only two years later ADAS was re-organised into two separate agencies. One agency would cover statutory work, whilst the second would be concerned with research and advisory activities. This re-organisation was stated to be a means to facilitate privatisation of certain functions within ADAS (NAO, 1990). Accordingly, after an extensive review it was eventually decided that its consultancy and research activities were to be privatised. MAFF stated the desire to have a 'clean break' in respect of all non-statutory work to the private sector, with an assurance that services provided to the Government could still be delivered effectively. The work which would not be transferred to the private sector, predominantly in environmental and animal welfare areas, was placed with a new agency, the Farming and Rural Conservation Agency (FRCA), which was established on 1st April 1997.

'Realising our Potential' (OST, 1993) substantially altered the purpose and mission of the ARC. Along with its own institutes it had now to encompass the biological work of the Science and Engineering Research Council (SERC) and was charged with developing links with biologically based industries. As such the Council was renamed the Biotechnology and Biological Science Research Council (BBSRC) and adopted four centers from SERC concerned with the molecular and biochemical sciences. Similarly the mission of the BBSRC was widened to encompass the aim of understanding and exploiting biological systems for its potential users which were now listed as; '*the agricultural, bio-processing, chemical, food, health care, pharmaceutical and other bio-technological related industries*' (BBSRC, 1995).

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forestry.

Consequently, the search for a wider market to justify public expenditure saw a shift away from solely agricultural related themes. The research institutes themselves concentrated more on expanding their basic research facilities in order to exploit opportunities in other areas. For instance, the Roslin Institute's most successful product of recent years has been an anti-trypsin drug which is used in the treatment of spina-bifida. Similarly, most of the institutes have developed commercial arms which are concerned with exploiting their own research. The Babraham Institute (BI) conducts basic biological research which can be applied to non-agricultural related fields. Indeed, in 1997/8, the BI claimed to have only one project, concerned with animal welfare, which had any direct link with agriculture (BI, 1997). There are, therefore, some indications that agricultural science has become less well represented within research institutes, now seeking new markets for exploitation.

2.3.7. Summary

The ARC has evolved into the main instigator of agricultural R&D in the public sector. Whilst starting life as only an advisory body to the Agricultural Departments, it has undergone the most radical changes to its role and purpose throughout this century. Post-war increases in funds led to its expansion into most fields relevant to agriculture by either the establishment of institutes or funding fundamental work in research units. However, cuts in expenditure led to a re-organisation into 8 institutes and the widening of its remit towards biological and biotechnological research indicates the decline of overall resources towards agricultural research.

Advisory services emerged within the educational sector and developed into a national service in the early post-war expansionist period. Nevertheless, funds were not heavily directed into this area until it was formed into ADAS. During the 1970s and 1980s increasing expenditure was directed towards ADAS despite, after 1987, charging for non-statutory research and advice. Reflecting the decline in public agricultural research, ADAS was privatised in 1997 and now only conducts statutory functions in its new form, the Farming and Rural Conservation Agency (FRCA).

Consequently, the most recent influence on the bodies involved within the ARS has been the demand placed by post-1979 Government administrations on reducing levels of public support for areas of the Civil Service. By far the most radical changes have occurred since this period and, consequently, the final section of this history is devoted to analysing the effect of these policies.

2.4. The Influence of the Private Sector

The public and private sectors remained relatively independent entities until the late 1970s. However, from 1979 onwards, there has been a commitment to reducing the burden of public funding by releasing public assets into the private sector. A number of Government consultancy documents emerged in the early 1980s which gave an indication that industry ought to take a more participatory role in the conduct of public research. This, the government advocated, would allow for a more efficient use of resources and also increase the exploitability of public sector research (ABRC/UGC, 1982; ABRC/ACARD, 1983).

These policy aims grew in importance after radical cuts in funding were imposed on the agricultural research system during the mid-1980s and reflected the increasing influence of the private sector on both the operation and funding of agricultural research. These key policy developments can be classified as i) the removal of public support for near-market research, ii) privatisation of public bodies, and iii) the promotion of commercial involvement in the public sector.

2.4.1. Declining Public Support for Near-Market Research

The policy of withdrawing support for so called near-market research began in the latter part of the 1980s. Cuts in public expenditure were desired by the Government, which began to encourage industry to take a bigger role in the funding and priority setting of agriculture and food R&D. As part of this process an internal civil service document was produced, referred to as the '*Barnes Review*', which explicitly desired the transfer to industry or termination of near-market research, which was defined as work which was of direct relevance to industry, in the public sector (Read, 1989).

An intrinsic part of this policy should have been the consultation mechanisms involved. However, in identifying programmes to be cut there were no formal consultations outside Government during the course of the Barnes Review (Read, 1989). Similarly, another criticism was the short time span in which this was conducted (Read *et al.,* 1988). This suggests that certain research areas were earmarked within the Ministry for cuts in expenditure. Thus, the consultations might be interpreted as a 'warning' for the research programmes that it no longer desired to fund.

Table 2.2 shows the full extent of applied and development work conducted in the immediate period before the implementation of the near-market policy. From this evidence MAFF-funded research seem to be the most susceptible to cuts in expenditure. If the categories of specific applied and development work were deemed near-market, then around 60% of the MAFF grant would be vulnerable. The ARC, with no research in either of categories areas seemed less likely to suffer reductions. Consequently, over the period between 1982/3 and 1989/90 MAFF research budgets fell by an average of 5.3 % per annum, whereas the ARC for the same period saw a nominal annual increase of 0.1%. However, the severest cuts in the ARC budget came in 1985/6 when grants fell from the previous year's funding by 7.7% in real terms (Cabinet Office, 1991). This implied that near-market cuts impinged on certain areas of applied strategic work as well.

Table 2.2. Government Departmental Spending by Activity in 1985/6, percent

	Basic	*Applied Strategic*	*Applied Specific*	*Development*
MAFF	3.8	32.2	36.4	27.6
ARC	58.3	41.7	nil	nil

Source: Cabinet Office (1986)

Parallel to these changes in public support for R&D, levy boards were established or re-organised following the Agriculture Act (1993), with the overall aim by Government of encouraging levy funds to substitute for reductions in public R&D expenditure (Thirtle, Piesse and Smith, 1997). As such, the boards were to concentrate on near-market research, conducting strategic work of benefit to the sectors involved, the majority of which would be aimed at underpinning the effectiveness and competitiveness of the industry. However, it is evident that the levy boards with a total research spend of around £14 million in 1993/4 (ibid.), had not the ability or will to make up the cuts of around £30 million made in public R&D support in the mid-1980s (Read, 1989).

2.4.2. Privatisation of Public Bodies

Throughout the Thatcher Government there was a concerted push for departments to identify areas which could be transferred to industry. The National Seed Development Organisation (NSDO) was a Government owned body designed to multiply and sell seed varieties. The highly competitive industry within which the NSDO operated made it a candidate for transfer into the private sector. However, it relied predominantly on the varieties produced by the Plant Breeding Institute (PBI). These two bodies were sold as a package to Unilever in 1987, leaving the biotechnology aspect with the newly formed Institute of Plant Science Research (IPSR) in Norwich.

Changes in the extension system began with the *'Report of a Study of ADAS'* (Bell, 1984). In deciding the future shape of the agricultural advisory service the author recommended a market-led approach to the provision of advice. In 1987 this eventually led to charges for consultation and for some of its research. However, public good research and extension, which the report defined as promoting environmental and animal welfare practices for farmers, were to remain publicly funded and provided without charge. Financial targets were set by MAFF and consequently ADAS research establishments were also expected to carry out non-statutory work on a commission basis.

Table 2.3 shows the effect of these changes on applied crop improvement research. Thus, whilst commodity groups increased spending by £4.7 million from 1985/6 to 1991/2, there was still a shortfall in total funds for R&D in this area of £10.2 million in real terms. Pray (1996) also claimed that similar cuts were experienced in the applied animal sciences, while commodity groups for this sector only provided £2 million pounds for research in 1991/2.

Table 2.3. ADAS funding of Field Crop Improvement R&D, in real terms, £ million in 1996 prices

	MAFF	*Commodity Groups*	*Total*
1985/6	27.0	2.3	29.3
1991/2	12.0	7.0	19.0
Level of Change, £ million	*(-15.0)*	*(+4.7)*	*(-10.3)*

Source: Pray (1996)

2.4.3. Commercial Involvement in Public Research Institutes

Indirect contracts from industry have been undertaken with the public sector throughout the history of the agricultural research service. However, these remained minimal until Government policies emerged favouring increased private sector involvement. Webster (1988) traced the idea of a 'market for science', namely a view that science could be developed and exploited in order to contribute to economic growth, to the Rothschild Report of the early 1970s. However, this was only applied internally within the public sector. In the 1980s radical changes emerged when the Thatcher administration fostered the philosophy of an 'enterprise culture'. The public sector was to suffer reductions in expenditure in a bid by Government to create a more competitive atmosphere comparable to industry. Coupled with these reductions were the establishment of various schemes that supported increased co-operation between both public and commercial sectors.

Due to the needs for secrecy, data on the level of linkage have never been declared. The ARC, whilst providing information on its commitment to collaborative programmes, has not disclosed levels of funding from industrial partners. However, the level of spending on collaborative programmes was around £12.3 million in 1993/4. This compares with an overall budget of £156.2 million in the same year (AFRC, 1994). Whilst the ARC did derive another £12 million of income from contract research (ibid., 1994), it only reflects a small proportion of research income emerging from external funding.

2.4.4. Summary

The concerted effort for private involvement by the Government since 1979 has seen a radical change in the direction and purpose of the Agricultural Research Service. Recent Government policy has operated under the belief that the way to create a more efficient public sector producing research relevant to industry's needs is to involve the private sector more. One consequence has been to reduce the public funding to agricultural research institutes. This has led to a major restructuring of both institutes and programmes. However, in terms of increasing private sector funding for R&D conducted in the public sector, the results have been quite small, with most agricultural research institutes still heavily dependent on public funding.

2.5. Conclusion

Whilst the agricultural research service has changed radically over the century, for the bulk of its existence it has remained relatively unfettered by Government influence. Under the philosophy of an autonomous management structure the ARS has grown considerably, emerging from a facet of rural development policy to becoming the basis for all non-medical bio-technological and biological investigations within the UK. This review has sought to describe these changes and why they have occurred. However, with its development a number of issues have appeared which raise questions about the role and effectiveness of the agricultural research service throughout its existence.

The whole debate over policy and research interaction raises questions as to the ability of Government to dictate R&D programmes. The agricultural research system has experienced differing levels of autonomy and accountability from time to time. However, the rises in accountability in the 1970s were the result of internal pressures within the Civil Service, predominantly the push towards certainty in decision making and the rising costs of research. This indicates some degree of dissatisfaction with Government control as opposed to the management of an autonomous research council. The return to a modified system of autonomy under the policies outlined in *'Realising Our Potential'* seems to have been an acknowledgement by Government that its involvement can only be limited and that scientists are the best groups to decide on issues of national relevance.

In conjunction, the large growth of the ARC could also be accredited with the emergence of accountability systems. Under the system of autonomy the ARC enjoyed its longest period of sustained growth and expansion. However, the ARC could also be accused of spreading its resources too thinly to cover all fields, which in agricultural research involves a wide set of disciplines. It may therefore be guilty of believing that funds would rise continuously to cover all scientific areas it deemed would fit the mantle of 'agricultural R&D'. Thus, it could be contended that growth of the agricultural research service may have emerged due to this pursuit of expansionism and that the consequent reductions and re-focusing towards the chemical and bio-technological industries were aimed at improving returns on these resources.

A related issue is the push for industrial involvement during the latter part of the ARS's history. The switch was part of a general policy for removal of public assets. However, what does emerge is the distinct absence of the private sector. Whilst providing for some of the funds removed, indications are that both the levy boards and the commercial sector have not matched the cuts in public research expenditure. The near-market cuts of the late 1980s of around £30 million have only been replaced by around £14 million from the levy boards (Pray, 1996). Similarly, Thirtle, Piesse and Smith (1997) found an overall reduction of commercial research by five percent since the initiation of the research cuts. Therefore, with the cuts in public expenditure, overall research spending in UK agricultural research has been reduced in recent years.

Another issue emerges over the role of the NAAS and the ARC. At the inception of the advisory service its work was considered independent of the ARC's, which was seen as being concerned with more fundamental research. It was considered that the NAAS with stronger links to the farming industry would be better equipped to direct this research. However, it was made clear at its inception that the work of the advisory service was only secondary to that of the ARC (Henderson, 1981). That this decree emerged from a body consisting of ARC members questions whether this was a rational decision or merely a case of empire-building within the public sector. During the 1950s the ARC successfully pushed for control of the MAFF-sponsored research institutes, which suggests overtones of the latter.

Agricultural R&D has, until recently, been predominantly concerned with increasing physical productivity. The general consensus has been that this has been successfully achieved, with average growth in agricultural productivity at around 1.9% per annum (Thirtle and Bottomley, 1992). This has been coupled with an agricultural policy, the main thrust of which has been to increase output since the Second World War. Policy mechanisms have tended to take the form of subsides to encourage productivity. This too has been a success, creating an oversupply of most commodities and self-sufficiency for the majority of foodstuffs within the Common Agricultural Policy (Tracy, 1989). Thirtle and Bottomley (1992) have shown a significant increase in annual average percentage growth of the agriculture sector between 1972 and 1985, with a trebling in growth rates compared to those prior to UK entry into the Common Agricultural Policy. That this has had a great effect on productivity questions the strength of the relationship between research and agricultural policy. Research work conducted before 1972 could only garner a rate of around 1% per annum. The tremendous growth reported after 1972 therefore has to be related to the increased commodity supports which were offered by the CAP. This must cast doubt on just how much of the observed productivity growth of the agricultural sector can be attributed to research induced technological changes. Instead it may indicate that farming had the capacity to increase outputs to some extent, through managerial improvements, regardless of technological innovation.

However, the majority of economists are agreed that research spending is a major causal factor in productivity increases (Norton and Davis, 1981; Echeverria, 1990). If this is the case, then questions arise over the laxity of an agricultural policy which supports output gains, for while subsidies can direct output, research strongly dictates the extent of increases in output. Hence the push for output growth in the 1960s and 1970s led to subsequent problems of over-capacity in farming and of environmental damage, which are now key issues in formulating EU agricultural policies. There has, therefore, been some misdirection in supporting both agricultural R&D and agricultural subsidies. Similarly, now that environmental aims are gaining increasing attention in the formulation of agricultural policy it is very much less clear that agricultural R&D has adapted to the new economic context facing industry. As such, the idea that through the greater involvement of industry agricultural R&D would more closely reflect the needs of industry is open to debate.

What emerges from the analysis is a dislocation between Government and science. External forces have proved to be insufficient in affecting research aims and similarly the autonomous development of the ARC has proved more powerful in creating change. The changes to the research system can be generalised under three headings, namely i) an increasing emphasis on accountability, ii) changes in the level and allocation of funding, and iii) changes in the way results are disseminated. The Government's pursuit of value for money and relevance in research has initiated these changes. It therefore follows that the next question to be asked is how effective have these changes been in terms of the agricultural research service. This issue is addressed in the next chapter.

CHAPTER 3

IN SEARCH OF A MORE EFFECTIVE MODEL FOR THE PUBLIC FUNDING OF AGRICULTURAL RESEARCH AND DEVELOPMENT

3.0. In Search of a More Effective Model for the Public Funding of Agricultural R&D

The historical changes outlined in the previous chapter need to be understood in terms of their underlying effectiveness. Therefore, in this chapter an attempt has been made to assess the literature which has developed on the management, funding and transmission of an agricultural research system (ARS) and, more generally, the science system itself.

Government distinctions of research effectiveness seem vague before the 1980s. Classifications of public R&D before this time tended to revolve around the type of research conducted rather than its effectiveness, for example work was either allocated into crops or livestock Indeed, before 1956 there is little evidence that the Government differentiated between the type of R&D that it was funding. Money was administered in the form of a block grant and the research bodies allocated their resources between disciplines and foci as they deemed most effective. Similarly, during this time, no attempt was made to monitor the effectiveness of resource use. After the passing of the Agricultural Research Act (1956) a clear distinction was made for the first time between Agricultural Research Council (ARC) funding, which was for the conduct of basic and applied work, and the National Agricultural Advisory Service (NAAS) funding, which was for development and extension work (Thirtle, Piesse and Smith, 1997). In 1972, a further partition of funding took place, when the Rothschild Report was taken up by Government and funds were crudely divided between basic and applied research. The former were viewed by Rothschild as *'research with no specific goal'*, whilst the latter were stated to be for *'research with a practical application in mind'*. Nevertheless, only in the mid-1980s did Government begin to classify the primary purpose of the research it was funding. This is presented in Table 3.1.

Table 3.1. Classification of Research by Primary Purpose

Primary Purpose	*Definition*
Advancement of Science	All basic and applied R&D which advances human knowledge
Support for Policy	Research to meet Government's own needs for knowledge
Support for Procurement Decisions	Research where the Government is main supplier of goods or services
Improvement of Technology	Applied R&D to fund the advance of technology of the UK economy
Support for Statutory Duties	Applied R&D which assists Departments to carry out statutory responsibilities
Other Science and Technology Expenditure	Applied R&D which cannot be classified under the other headings, e.g. support for developing countries

Source: Cabinet Office (1985)

This compartmentalisation of R&D helped to give more direction to the allocation of funds and could be seen as a concerted attempt at improving the effectiveness of research resource use. In the 1990s the onus for selecting research topics fell on the research institutes, who were required to undertake projects which attained the broad objectives of *'wealth creation'* and *'improving the quality of life'* (OST, 1993).

What emerges, therefore, is an increasingly sophisticated measure of how resources should be allocated internally to achieve external goals. In something as long-term as R&D, where both internal and external environments can change radically, assessing the effectiveness of resource allocation is at best highly complex and at worst impossible. However, the historical analysis of the previous chapter indicates how the UK Government has striven to improve the relevance and exploitability of the science that it is funding. Overall what has emerged is an increasingly sophisticated market system for research and advice. The three main shifts have been i) changes in the management of the agricultural research service, ii) changes in the allocation and level of funding, and iii) changes in the way that the results of research are disseminated. Nevertheless, these changes to the agricultural research system have not solely been a UK phenomena. During the 1980s most developed countries experienced shifts away from public support for R&D towards an emphasis on a more market orientated system. Accordingly, analysing other national agricultural industries offers some indication of whether changes in research management have had any significant effect. However, before this is done, the bulk of literature which has emerged concerned with how to effectively manage an agricultural research system needs to be reviewed. Thus, once an indication of an effective model is developed it can be tested against actual changes in agricultural productivity in a number of countries in order to establish its validity. This is the concern of the next section.

3.1. In Search of an Effective Model for Public Agricultural R&D

Given the changes in the agricultural research system (ARS), it now has to be established whether there is any evidence that effectiveness of R&D has been improved. This requires an investigation of the factors which are of importance in increasing the efficiency and relevance of the science system. Therefore, this section aims to review the literature which has emerged on the changes in the management, funding and transmission of agricultural R&D. Whilst interactions exist, these three areas will be analysed separately in order to clarify the issues involved.

3.1.1. The Management of Agricultural R&D

The majority of philosophies on the scientific process predominantly consist of two opposing modes of management, namely the 'internalist' and the 'externalist' models. Consequently, the principal arguments of this section centre around the question of whether science is more effective when priorities are set within the research institute compared to Government peer review.

The 'internalist' model of science relies on the belief that the scientific community is self-regulating and has its own value system, which administers rewards and punishments. Kuhn (1970) likens creative discovery to the process of selection in plant and animal species. Scientists filter basic ideas through their own value systems and assess them against what is already known in order to propose projects which they believe to be of scientific merit. Priority setting, therefore, needs no intervention from Government and the idealised internalist model relies on both bodies being autonomous entities. Occasionally these would be brought into a relationship, but are essentially capable of existing independently without any significant effect on each other. Within this internalist environment, agricultural scientists can pursue their own investigations, which, through their contribution to increasing knowledge, may ultimately be of benefit to the agricultural industry. Advocates of this system have pointed to the fact that it allows for serendipity, i.e. the chance discovery of a phenomenon that can be investigated further. A system whereby those closest to the research are responsible for its funding allows for an appropriate allocation of money towards a project's development into an exploitable outcome.

When the autonomous system operated in the UK agricultural research service, it attracted several criticisms. Firstly, whilst it provided the best environment for scientists to produce creative research, it was perceived as unresponsive to the needs of the farmer and the agricultural industries, as scientists tended to devote too much time to basic research (Ulbricht, 1977). There was also the problem of excessive duplication of research. Whilst it has been argued that duplication is another method of solving problems (Thornley and Doyle, 1984), there is a point where excessive duplication affects the productivity of resources allocated to agriculture.

These criticisms led to the promotion of the 'externalist' model. This rejected the idea that science could only be understood by its own internal dynamic and asserted that bodies outside science were just as, if not more, qualified to evaluate and direct research programmes. In adopting a system of accountability the Government aimed to address the problems of duplication and unresponsiveness by making it more transparent. However, implementation of an externalist system usually calls for an explicit divide between basic and applied research under the belief that applied research should be steered towards Government aims. Rosenberg (1990) has questioned this view, quoting numerous examples of applied research that have led to addressing basic problems, e.g. the birth of radio astronomy evolved from investigating how to remove static from telephone calls. Hence a criticism of the externalist approach, with its emphasis on accountability, is that it ignores the basic-applied dichotomy. Kogan and Henkel (1983) and Spedding (1984) have stated the impracticability of imposing such a system on the natural and biological sciences, as agricultural research depends on the complex interaction between natural and biological functions.

The externalist approach also relies on the belief that sponsors removed from science can formulate problems and then contract them out to scientists to solve them. It assumes that science is at a stage where one or a number of disciplines can be applied to a specific problem. This is usually conducted through some system of peer review. However, many research fields of importance are at a pre-paradigm stage, where there are no agreements on the most relevant disciplines and no clear academic networks for the solution of these problems. It is therefore questionable whether a problem can be stated and then solved by external bodies. Specifying objectives also raises the real danger that there are the means and knowledge for solving the problems (Thornley and Doyle, 1984). Moreover, Philip (1978) has questioned the viability of Government peer review, when the main problem with directing research strategies is the long gestation period involved. Research programmes usually last longer than a Government itself and as such national needs are generally set within a short-term framework. This tends to hinder the advice given by the peer review boards themselves. Spedding (1984) has also questioned whether the UK has a long-term agricultural policy which, he suggested, was an essential input for the effective planning of agricultural R&D. Despite these criticisms, in a study of alternative mechanisms, Anderson and Moxham (1992) concluded that decisions on funding basic science have not, and probably never will have, any acceptable alternative to peer review. As discovery cannot be contrived, strategic planning calls for a greater coherence and focus on the lines of scientific inquiry supported (Anderson, 1994). This, therefore, calls for a greater depth of disciplines represented on peer review panels and more two-way communication with scientists conducting the research. Thornley and Doyle (1984) have pointed out that a more effective use of public money is likely to be achieved by improving the efficiency by which the results of R&D in agriculture are evaluated, rather than by sifting the initial proposals for R&D. The costs of a peer review system can be substantial both in terms of money and time for users and providers of research. However, the benefits incurred in terms of the effectiveness of R&D, i.e. increased applicability and relevance to agriculture, make peer review a necessity in obtaining improved research outputs.

An effective research system, therefore, needs to respect the fact that steerage is only limited and over-emphasis on specific research goals could be detrimental to the production of R&D. The research system therefore needs to be flexible enough to allow for serendipity, but also transparent enough to allow some steerage.

3.1.2. The Funding of Agricultural R&D

The issue of expenditure on agricultural R&D tends to revolve around the type of funding practiced. Frequently, this reflects the type of management philosophy undertaken in the science system. Thus, project funding is usually characterised where steerage is a large part of the system. Similarly, research institutes which enjoy autonomy in decision making are usually funded institutionally. The British system of autonomy was supported by institutional funding for many years until contracts for research were developed in the early 1970s. As such project funding has grown in influence to facilitate accountability in research funding. Bredahl *et al.* (1980) have stated that the goal of a research management system is the production of a socially desired mix of research output at the minimum social cost. They concluded that institutional funding has a lower cost, whereas contract funding enables the socially desirable mix to be more directly obtained.

The main criticism of institutional funding of research is that it is limited in its capacity to reallocate scientific effort and financial resources from traditional areas of concern or staff capacity to other areas (Bredahl *et al.*, 1980). With project funding, fears were expressed over the loss of flexibility experienced by the Research Councils in allocating some of its resources to commissioned work. This was especially true of the ARC, which had by the late 1970s 50% of its funding from contract work and 80% of its staff engaged partly or wholly on commissions (DCS, 1979). It was, therefore, considered unwise to increase the proportion of commissions for fear of its effect on the autonomous research conducted within the institutes. Thornley and Doyle (1984) have also pointed out that, where a large proportion of funds are tied to specific projects, this did not allow much room to redirect research rapidly in response to new and unexpected breakthroughs. The costs of an accountable system of research management are not inconsiderable, as it affects the productivity of the research scientist and the research administrator. The research scientist loses time in completing research proposals and, similarly, the research administrator spends time processing applications. A senior researcher, who has only time for formulating grant proposals and managing a laboratory, does not represent the best use of a creative scientist's time (Bonnen, 1987).

However, the funding argument cannot be put into 'either-or' terms, i.e. if one is good then the other has to be bad for science. This obscures the real funding problem and the best method is a mix of both funding types for different forms of research (Bonnen, 1987; Bredahl *et. al.,* 1980). In their analysis of effectiveness in molecular biology institutes, Herbetz and Muller-Hill (1996) concluded that the quality of the research was no different in institutionally supported establishments than in those which were project funded. It seems, therefore, it is how these funds are employed and managed within institutions that affects the behaviour of the researcher. Effective research should allow for both creativity and exploitability. Institutional funding favours creativity and frees money for more research projects, thus increasing the chances of producing more successful innovations. Project funding is costly and affects research productivity, but it arguably stimulates creativity through the entrepreneurial skills involved in obtaining contracts. It may also reduce the costs of exploitability, as the system has become more receptive to the perceived outcomes of that research.

Accordingly, it is hard to draw any conclusions as to which type of funding allows for more effective research. At present the most manageable system seems to be a mix between project funded research for applied activities along with institutional funds for basic research. However, this does not answer the point raised earlier on the need for integration between basic, strategic and applied work in the natural sciences. The two forms of funding systems have to be more flexible in their awareness of this interaction in order to assess any possible avenues for future funding.

Along with questions of the type of funding for a research institute, there are arguments concerned with the relative mix of sources for funding. A wholly publicly-funded research system relies on the relative continuity of funds to allow long-term decision making in certain areas, as well as the free release of accessible information for the future development of research. The history of science is littered with discoveries made on the basis of publicly-available knowledge. Private funding, with its need for secrecy and copyright, will affect how these outcomes are realised. There is, therefore, a problem with the probity of publicly-funded research being infiltrated and exploited for private gain. Read *et al.* (1988) quote a case of the Plant Breeding Institute (PBI), which, when it was in the public sector, refused germ-plasm to a sponsor because it considered it improper that the sponsor should have sole access. Accordingly, the productivity of research is disrupted through restricting the flow of information. Private funding is more precarious, because it is profit-led. In public-private ventures performance measures are imposed on the public system for achieving short-term goals, with the threat of removal of funds if these outcomes are not met. This uncertainty cannot fail to have a negative effect on the productivity of the researcher involved.

There is also the danger of a research institute tailoring its priorities towards explicitly commercial outcomes in order to provide a more attractive investment for firms (Read *et al.*, 1988). This was reinforced by Lindner (1993) in a review of Australian agricultural research policy, which was considered as emphasising public funding for these 'usable technology' fields and was criticised for 'crowding out' private research, i.e. offering technology at no or subsidised cost. A contrasting view was voiced by Pineiro (1986), who argued that the public sector would become more efficient, accountable and offer increased value for money if it responded to particular requests from commercial companies. Whilst there are very real dangers in promoting such a policy, it does tend to reinforce a view that the public sector removed from the market-place is inefficient (Carney, 1998). Consequently, it seems that some interaction with the private sector must be beneficial for both sectors. Accordingly, an effective system of research funding may benefit from close liaison between scientists from both sectors. Privately-funded research is becoming a necessity with decreasing budgets and so, in order to maintain effectiveness, an independent monitoring system is needed to insure against any negative effects occurring. Furthermore, limits to the level and areas of involvement should be imposed on the private sector.

3.1.3. The Transmission of Agricultural R&D

The argument for free advice stems from the origins of agricultural extension, as the spread of knowledge, being a public good. If the dissemination of public research can be efficiently achieved, then the research will be at its most effective. Publicly available information involves the freedom to publish in scientific and technical journals. This ensures that firms are made aware of current research techniques and, therefore, creates a basis for encouraging competition. Similarly, a free advisory service for farmers, solving on-farm problems through research and personal visits, helps to provide a stable and competitive economic environment for the agricultural and food industries.

against the nature of public intervention which aims to improve the welfare of society. However, general opinion about charging for agricultural advice, and its subsequent privatisation, is agreed on the fact that it allows for better targeting. A farmer cannot only choose between advisory bodies, but also will tend to be more responsive to advice that he/she has to pay for. Read *et al.* (1988) have voiced concerns that the charging of advice leads to an increased bias toward larger farms, which ultimately opposes competition from the small-scale farmer. However, Dancey (1993) has pointed out that advice should be seen as an on-farm investment which would offer higher profits. The smaller farmer should therefore allocate his/her budget accordingly to allow for the payment of advice.

However, a problem occurs within a public organisation that has to begin charging for advice. The advisory service has to be set performance targets. One consequence of this is illustrated by the Australian extension service's drive for charging. It began to re-allocate resources towards activities with the potential for generating revenue, rather than to those that were not undertaken in the private sector (Lindner, 1993). Therefore, there was some social cost as advice offered was only concentrated on economic benefits and ignored such things as environmental extension, which offered little immediate reward to the farmer. This has been recognised by the UK Government, which still offers free public-good information in certain areas of farming, after the privatisation of its advisory service. However, Röling (1986) has criticised this as superficial when imposed on an extension service. The tendency is for areas of public good funding not to be based on results but on mistaken beliefs about what it should and can do.

From market research of farmers, the NAO (1991) concluded that the transitions to an organisation driven by market forces has led ADAS to be rated more highly than when it provided advice free of charge. Dancey (1993) reiterated this by pointing out an OECD study of other countries' experiences of market transition. On the whole there was an opinion that advisory resources that were run on a commercial basis were more efficient and effective, offering an enhanced degree of specialisation.

3.1.4. Summary

The goal of re-organising the research system is to realise highly creative science with the maximum potential relevance for industry and society. Clearly, a creative environment for research can be achieved through autonomy which allows scientists the resources to pursue their own investigations. However, this may not result in R&D which is relevant to the needs of the agricultural industry. It may also be welfare diminishing, as public money without any Government control could be tied to areas which are no longer profitable or socially beneficial.

Stability of funding offers an environment for long-term decision making. Decreasing funds will ultimately have implications for the effectiveness of the research conducted and how it should be developed in the future. Research teams also contribute to effectiveness and the multi-disciplinary expertise of staff at institutes needs to be maintained. The main consequence of losing some disciplines may slow down or reduce the spread of benefits of a technological innovation. Therefore, research grants may be altered to be capital intensive, so as to maintain staff and facilities, at the cost of current funds for the actual conduct of research. The mode of transference of information seems to favour the privatisation of dissemination methods, as farmers seem to value the advice more if they have to pay for it.

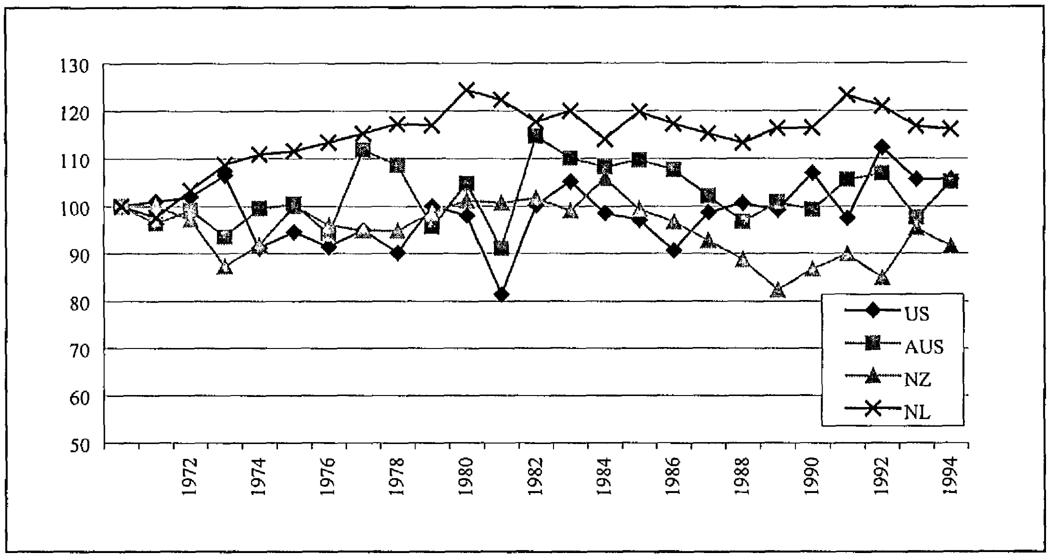
Considering the UK agricultural research service, it seems that some of these factors have been embraced throughout its history. However, there is a psychological effect in that if Government funding feels that useful research is being done then this may have an enhancing effect on performance. Consequently, whilst the above analysis gives an indication of improved effectiveness, it now needs to be assessed whether this is proven by actual practice. For this to be achieved, actual research management changes have to be considered. This is the concern of the next section.

3.2. Productivity Trends and Agricultural R&D: Evidence from Other Countries

Amongst the developed countries, who all have encountered changes in the management and funding of their agricultural research and advisory services which correlate to some degree with UK experience, are the United States, the Netherlands, New Zealand and Australia. Accordingly, it is interesting to consider the trends in agricultural productivity and research funding encountered in these countries.

Using data series provided by the Food and Agriculture Organisation (FAO), some indication can be drawn of each of the above country's productivity trends. Changes in agricultural productivity since 1971 are mapped in Figure 3.1, which show Laspeyres derived productivity indices for four countries, where 'NZ' denotes New Zealand, 'US' the United States, 'NL' the Netherlands, and 'AUS' Australia.

Figure 3.1. Indices of Agricultural Productivity for Four OECD Countries, 1971-1995, 1971=100



Source: FAO (Various Years)

Overall, the trends in productivity show variable patterns. Throughout the period the Netherlands has enjoyed the highest level of growth. Productivity was rising at a steady rate until the early 1980s, when a decline became evident. From the mid-1980s onwards productivity has stabilised, all be it at lower levels. In contrast, in Australia and the US productivity growth has been uneven and seems to hover around 1971 levels throughout the period. The most dramatic decrease has been in the case of New Zealand agriculture which fell 20 points at its most extreme during the late 1980s.

These patterns are clearer when delineated into periods. Table 3.2 shows the average annual growth rates for the four countries over the periods 1971-1981, 1981-1995 and 1971-1995.

Table 3.2. Average Annual Growth Rates in Agricultural Productivity for the Four Countries, 1971-1995, percent

	Annual Growth Rates		
	1971-1981	*1981-1995*	*1971-1995*
Australia	0.52	0.63	0.57
Netherlands	2.36	-0.06	0.70
New Zealand	0.11	-0.49	-0.34
United States	-0.26	0.40	0.19

Source: FAO (Various Years)

3.2.1. Reductions in the Levels of Funding

Table 3.3 shows the annual average growth rates for agricultural research expenditures for the four countries studied in comparison with the OECD average.

Table 3.3. Average Annual Growth Rates in Public Research Expenditures for the Four OECD Countries Compared Against an OECD Average, 1971-1993, percent

	Annual Growth Rates		
	1971-1981	1981-1993	1971-1993
Australia	2.1	0.3	1.2
Netherlands	4.2	0.9	1.6
New Zealand	2.2	-2.2	0.2
United States	2.4	2.3	2.1
Other OECD (22)	2.7	1.8	2.2

Source: Alston, Pardey and Smith (1998)

Overall, during the period 1971 to 1993 all four countries have experienced growth rates in expenditure below the OECD average. This change is more extreme when delineated by time period. Thus, whilst the four have growth rates around the OECD average before the 1980s, this was drastically reduced in three of the countries studied after this date. The most extreme cuts in expenditure during this period were experienced by New Zealand, with a reduction of 2.2% per annum in real expenditure. Whilst expenditure increased in the later period in Australia and the Netherlands, it was below 1% per year and was dramatically depressed when compared with the rises in the 1970s. Only the United States enjoyed relative stability of funding throughout this period, but this too was below the OECD average.

Of course, changes in research funding do not impact immediately, as the full of effect of research is only felt over a period of time. However, there are trends which may reflect differences in research expenditures. Considering the productivity growth rates in Table 3.3, some similarities are revealed when dissaggregated into the two periods. Very obviously, the New Zealand growth rates have decreased from a positive rate of 0.1% per annum during 1971-1981 to –0.5% per annum in the latter period. Similarly, the Netherlands' productivity trend has reversed even more dramatically from the early period of strong positive growth to negative rates for the 1980s and 1990s. This correlates to some degree with falls in research expenditure in these two countries. In contrast, although Australia suffered cuts in expenditure, it still maintained a nominal positive growth in research spending and enjoyed an increase in productivity growth for the latter period. Finally, in the case of the United States, which was the only country to maintain research funds at over 2% per annum throughout the whole period, productivity growth, according to

Table 3.3, increased from negative rates in the 1970s to a positive figure of 0.4% per annum in the 1990s.

Despite the fact that there are difficulties in deriving a causative link between changes in research expenditure and productivity, for instance an overriding effect of productivity will be changes in agricultural policy of a particular country, there does appear to be some circumstantial evidence of a relationship. Reductions in expenditure appear to be associated with downward shifts in productivity, while maintaining a stable level of funding is associated with some level of growth. However, changes in agricultural productivity may be the result of a more complex set of shifts in the management, funding and transmission of research. Consequently, the countries in question have to be analysed with specific reference to their agricultural research systems in order to understand this relationship with productivity change.

3.2.2. United States of America

Huffman and Evenson (1993) have constructed a more sophisticated total factor productivity index (TFP) than those presented in Table 3.2 over the period 1889 to 1990. Consequently, with a longer series of data and more accurate methods, they have calculated a much higher average growth since the Second World War of around 2.9 percent per annum. Accordingly, they provide a consistent series by which shifts in the research system can be measured.

These changes can be classified into three phases, namely i) 1887-1945, a period of rising public expenditures administered institutionally, ii) 1946-1974, a period of stable expenditures during which project funding became dominant, and iii) 1975-1990, a period of continued growth in the share of research supported by project grants as opposed to institutional funds. Within this last period private sector expenditure varied between 47% and 53% of total agricultural research funds (Alston, Pardey and Smith, 1998). However, it seems that in the United States the private sector has always played a relatively larger part in total agricultural research expenditure.

Table 3.4. Total Factor Productivity for US Agriculture, percentage growth per annum, 1887-1990

	1887-1945	*1946-1974*	*1975-1990*
Annual Average Percentage Growth	1.1	1.6	2.4

Source: Huffman and Evenson (1993)

Overall, US productivity has grown throughout the whole period of the research system's existence. This growth rate began to increase more rapidly after the Second World War with stable research expenditures and increased project funding. However, a greater increase is observed in later periods when, with the private sector relatively stable, public research was funded through project grants.

3.2.3. New Zealand

In New Zealand the public sector has always had a higher level of research investment than industry. In 1981 expenditure by commercial firms was estimated at around 7% of total research funds, but this has increased to around 25% of total research funds in 1993 (Alston, Pardey and Smith, 1998). Research in New Zealand, since the early 1970s, has been project funded and after 1984 the Government began a five-year 'forward look' statement of science. Whilst funds have always been relatively low for R&D, after 1984 New Zealand severely reduced public expenditure (Radford, 1996). This was to enable a policy of increasing reliance on levy boards for funding R&D and employed a 'piggy-back' approach to technology adoption from other national research systems.

Table 3.5. Total Factor Productivity for New Zealand Agriculture, percentage growth per annum, 1953-1995

	1953-1983	*1984-1995*	*1953-95*
Annual Average Percentage Growth	1.7	-0.9	1.0

Source: FAO (Various Years)

As shown in Table 3.5, New Zealand productivity growth rates before 1984 were comparable with those in both the UK and the US at around 1.7%. However, a significant change occurred after this period when average annual rates became negative. Whilst this could be the result of the drastic removal of public sector funding, it has to be considered in conjunction with a reduction of price support mechanisms which occurred at the same time. There were, therefore, changes during this period to output prices in relation to input prices, which would impinge on any measure of productivity change. Accordingly, the idea that reduced funding for research causes decreases in productivity has to be approached with caution when considering New Zealand agriculture.

3.2.4. Australia

For Australia the productivity index for the period 1953 to 1995 is presented in Table 3.6. The earlier period reflects a situation where public expenditure dominated and grew annually. This period also showed an annual average rate of productivity growth comparable to other developed countries.

Table 3.6. Total Factor Productivity for Australian Agriculture, percentage growth per annum, 1953-1995

	1953-1980	*1981-1995*	*1953-95*
Annual Average Percentage Growth	1.6	0.6	1.2

Source: FAO (Various Years)

Funds began to decline in real terms during the later period and increased priority was given to applied over basic research. Similarly, Australia, like New Zealand, has a small private agricultural research base, which grew during the 1980s and accounted for 30% of total funding in 1993 (Alston, Pardey and Smith, 1998). In addition to this, levy boards have always played a part in funding research in Australia. From 1953-1994 contributions from commodity groups have been in the area of 20% of total research funds (Mullen *et al.,* 1994). Consequently, the period after 1981 is one of declining Government control and increasing industrial influence (Hussey, 1996). However, while this period has been associated with positive productivity growth rates, there has been a decrease of around 1% per annum in rates of growth since 1980.

3.2.5. Netherlands

The Dutch agricultural research system experienced high rates of expenditure in the 1960s and the establishment of a large number of research institutes. In 1972 the National Council for Agricultural Research (NRLO) was established which instituted a five-year forward look of agriculture. In 1980 the funding for research was decreased and the number of research institutes declined from 22 to 12. In 1986 the most radical decision of the Government was to privatise public agricultural research. The institutions involved had, therefore, to develop stronger market orientation (Roseboom and Ruttan, 1997). The trend in the rates of productivity growth are presented in Table 3.7.

Table 3.7. Total Factor Productivity for Netherlands Agriculture, percentage growth per annum, 1953-1995

	1953-1971	*1972-1986*	*1987-1995*	*1953-95*
Annual Average Percentage Growth	2.6	1.3	-0.4	1.5

Source: FAO (Various Years)

What emerges is that the implementation of the NRLO planning structure and the forward look was associated with a decline in average growth rates. Coupled with the severe reductions in funding from 1980 onward, there was a decrease in the rate of productivity growth for agriculture of around 1.2%. After the decentralisation and privatisation of R&D the rate actually became negative. Consequently, from the point of view of the Dutch agricultural research system all the changes, i.e. declining funds, privatisation and peer review, appear to have had negative effects on the productivity of the industry itself.

3.2.6. Summary

Comparisons of trends in research expenditure and productivity do show some level of association. Generally, in countries where research spending has been reduced a corresponding fall in productivity has been noted. Similarly in the US, which has stabilised funds to some degree, there has been continued expansion of growth. However, this statement has to be approached with caution. Whilst it would seem that the movement towards greater reliance on private funding for agricultural R&D has had a negative effect on agriculture, R&D spending is only one of a number of factors impinging on productivity growth. For instance, only the UK has suffered drastic changes to its advisory system and the modes of transference throughout this period. For the bulk of other countries, the mechanisms for R&D transmissions have been relatively unaffected. More critically, the changes occurred during a period of recession in agriculture, so downward rates of productivity growth could just as well be caused by reductions in demand and investment. As most productivity rates have shown a decline during the 1980s, these could reflect the effect of economic recession. It, therefore, seems that deriving unequivocal relationships between research and productivity is difficult.

3.3. Conclusion

The theoretical literature concerning agricultural research management seems to favour some degree of input from the commercial sector, both in terms of research and extension services. Nevertheless, actual evidence from other countries' experience seems to reveal the negative consequences of adopting increased reliance on private sector funding. Consequently, it seems there are various problems with deriving such a simplistic link between expenditure on R&D and agricultural productivity, and this relationship needs to be explored more deeply. A prime area of investigation should be whether R&D expenditure has such a strong effect on productivity. This is an intrinsic question, as the majority of studies which have supported increased public funding of agricultural R&D have been based on measuring a high return to R&D. Accordingly, various questions emerge which can be framed as hypotheses and tested in the following chapters.

Firstly, in relation to the alleged high returns to public R&D, one question is the extent to which R&D affects agricultural productivity and this may be stated as the first hypothesis:

H_1: *Rates of return to public funds are high and expenditure should be increased.*

Secondly, considering recent Government policy, with its emphasis on basic research at the expense of applied research and development work, an evaluation is required of whether the returns to publicly-funded R&D have been reduced by the removal of near-market funds. Thus a further hypothesis would be that:

H_2 : *Public funding of applied research and development work is intrinsic to improving productivity.*

Thirdly, in relation to the changes in the management and funding of agricultural R&D in the UK, one question which hangs over the history of the agricultural research system is whether increased accountability has improved the efficiency of publicly-funded R&D. This may be expressed as a third testable hypothesis, namely:

H_3 : *Public agricultural R&D has benefited from increased Government influence over its management and funding.*

A fourth area, which has, until recently, been discounted by work on public R&D returns, has been the influence of the private sector. It seems essential to fully account for the effect of private sector involvement when evaluating the correct level of return to public sector R&D. Consequently, a fourth issue to be tested may be expressed as the following hypothesis:

H_4: *The commercial sector has a stronger influence on productivity than the public sector.*

However, since the mid-1980s agricultural R&D has acquired another role in relation to public-good R&D, such as the environment. This type of non-productive R&D may be beneficial, but is mostly non-quantifiable and indirect. As it is growing in importance within Government research agendas, there is a need to discover whether any relationship can be found within R&D spending and improving the quality of life. This leads to a fifth hypothesis:

H_5: *The trend towards lower agricultural productivity growth is a reflection of an increasing proportion of research funding being directed to improving the 'quality of life' rather than 'wealth creation'.*

The next two chapters seek to test these hypotheses. Thus, Chapter 4 examines the whole concept of R&D and productivity in order to gain a clearer understanding of whether previous arguments on research funding hold. In particular an attempt is made to estimate statistically the contribution of R&D expenditure in the UK to agricultural productivity growth rates. In doing this the impact of the changes to the balance of research funding in respect of type and source of funding is explored. In Chapter 5, the idea of the 'effectiveness' of research investment is explored further in terms of economic, social and scientific goals.

CHAPTER 4

MEASURING THE IMPACT OF PUBLIC AND PRIVATE RESEARCH INVESTMENT ON AGRICULTURAL PRODUCTIVITY GROWTH

4.0. Measuring the Impact of Public and Private Research Investment on Agricultural Productivity Growth

The problem of directly relating agricultural R&D activity to productivity growth rates has been highlighted in the previous chapter. However, the bulk of studies dedicated to assessing effectiveness of agricultural resource use have relied on a belief that expenditures on R&D positively affect productivity growth. Consequently, whilst these studies are popular, they suffer a degree of criticism over their use and application (see for example Harvey, 1988; Pardey and Craig, 1989; Huffman and Evenson, 1993). Thus, as studies have developed, a variety of techniques have been used to improve the measurement of returns to agricultural R&D.

Accordingly, the aim of this chapter is to question the underlying basis for assessing R&D spending against productivity growth and, similarly to analyse the various methods used, in order to establish whether they are appropriate to tackling this problem. Specifically, it seeks to test two of the hypotheses outlined in the previous chapter. Predominantly, it aims to establish whether, in view of near-market cuts, public applied R&D has been intrinsic to improving agricultural productivity. Similarly, with regard to the recent desire by Government to increase the involvement of the private sector within agricultural R&D, it also aims to test the hypothesis of whether the commercial sector has a stronger influence on productivity than the public sector.

4.1. The Concept of Total Factor Productivity

Under the assumption of constant returns to scale, a doubling of inputs should double the level of output. However, what is usually observed is that the growth in output exceeds the growth in inputs. This phenomenon is usually attributed to increases in total factor productivity (TFP) which, most economists argue, is caused by disembodied technical progress (OECD, 1992). Technical knowledge is integrated into inputs, which helps to improve the efficiency of resource use, as typified by a more disease-resistant seed variety or a more fuel efficient tractor. Consequently, the majority of studies into agricultural TFP growth have sought to measure the magnitude of its relationship with public R&D (see Norton and Davies, 1981; Echeverria, 1990).

However, there are a number of other issues which could equally be related to changes in TFP. Firstly, these studies ignore the fact that the assumption of constant returns to scale is inappropriate. Over time as firms grow, they begin to acquire knowledge and expertise and so increase productivity. This phenomenon has been observed in UK agriculture, as structural changes, which occurred in the 1950s and 1960s, led to increases in the average size of farms (Grigg, 1989). Similarly, there are other factors which may cause TFP growth. These are i) apparent errors in the measurement of output and inputs, ii) improvements in the quality of capital, land and labour, and iii) imperfect competition.

The majority of studies on TFP within the UK, whilst highlighting some of these problems, have not fully addressed them. Similarly, these studies have usually attributed the majority of TFP growth solely to research expenditure without testing whether there is any causal link between them. Therefore, there is a need to consider how TFP indices are constructed and to establish whether there is any valid relationship between R&D and productivity growth, before measuring the impact of R&D expenditure on productivity.

A measure of UK total agricultural productivity was first constructed before the Second World War by Beilby (1938). However, in the post-war period total factor productivity indices have been constructed by numerous authors over various time periods in respect of the UK. MAFF (1961 and 1969) constructed an aggregate productivity index which cumulatively covered the periods 1949 to 1967. Productivity was measured by *''the ratio of output to all inputs other than entrepreneurial labour and interest on tenant's capital''* (MAFF, 1961, pg., ii). By using a method which compared changes in pairs of years, the effects of economies of scale and price distortions were eliminated. The average rate of growth was found to be 1.7 per cent per annum over the period 1949/50 to 1966/67.

More recently, Whittaker (1983), Godden (1985) and Doyle and Ridout (1985) have gone some way to constructing a more accurate measurement of agricultural productivity changes by including factors such as land, labour, rents and quality adjustments. In the last of these studies, outputs and inputs were deflated by an index of 'agricultural output prices' and 'an agriculture means of production index' respectively. Using a Laspeyres index this yielded an average annual rate of growth of 1.8% for the period 1951 to 1981.

Rayner *et al.* (1986) used the more complex Tornqvist index, which compares factor shares in output/input ratios between two successive years. In applying this method an average rate of growth of around 1% per annum was found for the period 1956/7 to 1976/7. Thirtle and Bottomley (1992) adopted a similar procedure and sought to clarify some of the measurement errors involved in the interpretation of UK agricultural accounts. These found an annual average rate of growth of 1.9% was found for the period 1967 and 1990.

Consequently, it seems the majority of studies have adopted different conventions in respect of measurement and calculation. There are, therefore, a number of issues which need to be addressed in deriving an index of total factor productivity. These can be classified into three decisions, namely i) data measurement errors, ii) correct adjustments for changes in the quality of inputs, and iii) the choice of indexing procedure.

4.1.1. Data Measurement Errors

The collection of aggregate data presents many hazards. This is exacerbated when trying to derive a consistent series over a long period. Government statistics change throughout time both by definition and by measurement, as statistical and recording methods advance. This problem cannot be eradicated, but a number of sources are available which record agricultural statistics. For the whole period after the Second World War the agriculture departments have published information in the 'Agriculture in the UK' series. Similarly, the 'Annual Abstract of Statistics' (CSO) contains published aggregate agricultural accounts throughout the period and explains definitional changes as they occur.

However, because a certain level of information was not published, predominantly before the mid-1960s, various series do not reflect their true levels. For instance, in recording labour productivity the accounts do not include 'farmers, partners and directors' until 1978. However, more critically, the accounts do not publish intermediate feeds and seeds until 1964/5. Therefore, final output cannot be derived properly. Using Gross Output for consistency would inflate output statistics relative to their true level. Another problem arises with the time periods for the agricultural accounts. Until 1978 these were recorded in crop years (June/May). However, they are presented in calendar years in subsequent periods. Whilst these errors cannot be eradicated, some allowance can be made for changes in the composition of inputs over time. These and other problems were accordingly considered and the approach employed outlined below.

4.1.2. Quality Adjustments

A possible source of productivity growth could be an improvement in the quality of inputs used. For instance, the constituents of fertiliser in 1946 would be less effective than fertiliser applied today. Thus, improvements in machinery, land, labour and capital could have some effect on productivity growth. These would emerge through more efficient capital investment, a better skilled workforce, or private and public investment in research.

Quality adjustment and its effect on productivity growth has been the concern of a large number of studies in agriculture. Rayner and Lingard (1971) adjusted for quality improvements in the prices and quantities of fertiliser used in British agriculture. More recently, Fernandez-Cornejo and Jans (1995) used hedonic pricing methods to adjust for quality of pesticide usage on four major US crops. These studies both indicated a rapid increase in the quality of agro-chemicals used within farming since the Second World War. However, when adjusting for land quality, Thirtle and Bottomley (1992) found only a nominal increase in productivity growth for the period 1967 to 1990. As regards the question of the quality of capital investment, this has been contentiously applied to TFP indices. Godden (1985) derived a TFP index for agriculture which gave a growth rate of 1.5%, but which was reduced to 1.3% after adjusting for the quality of capital investment. Similarly, Fousekis (1997) accounted for the role of public infrastructure in Greek farming through land improvement and public storage facilities. This study found that the non-inclusion of these external effects would lead to biased estimates of productivity growth.

However, the problem with adjusting for quality is that no coherent estimates, which reflect true quality change, exist on an aggregate level. Thus, the use of quality adjustments may lead to further distortions of actual TFP growth. Consequently, as the estimation of accurate series of quality series are beyond the scope of this study, the decision was taken not to modify the input series for quality changes, especially as finding proxies to measure quality proved difficult.

4.1.3. Choice of Indexing Procedure

When measuring the changes in Total Factor Productivity over time, most studies adopt some form of indexing procedure. However, there is much debate over the most appropriate procedure to use. Christensen (1975) classified two main types of indexing procedure used in production analysis, namely i) the Laspeyres index and ii) the Tornqvist index. In addition, with the advent of newer methods for productivity analysis, recent studies have also adopted the Malmquist indexing procedure (Fare *et al.*, 1997; Hadley *et al.*, 2000).

Previously, most economists have favoured the Laspeyres index, these are either quantity or price indices, which measure changes against a single base year. A Laspeyres quantity index can be presented as (Christensen, 1975):

$$x_1 / x_0 = \sum p_{i0} x_{i1} / \sum p_{i0} x_{i0} \quad (1)$$

where (x_1/x_0) is the relative change in output (input) between the periods t_1 and t_2, and the sum of output (input) prices (p) times output (input) quantities (x) in a particular year (i) is measured over the cumulative value of output (input) in a base year (0). This procedure has interpretive qualities, as its reliance on a base year allows for measuring changes in the value of total inputs resulting from pure quantity changes (Christensen, 1975). However, there are problems in its derivation. On a purely practical level the extent of change is related to the choice of base year. Consequently, it could be open to criticisms of bias arising from the choice of base year. The Tornqvist index overcomes this problem to some degree as it relies on a system of both factor shares and on smoothing a previous year's prices and quantities, rather than relying on a base period. The Tornqvist index is thus written as;

$$\log(x_1 / x_0) = \sum \overline{w}_i (x_{i1} / x_{i0}) \quad (2)$$

where (x_1/x_0) is the relative change in output (input) between two time periods, and $\overline{w}_i$ is the weight allocated to each factor of production *(i)*. The Tornqvist index relies on factor shares and on smoothing a previous year's prices and quantities, rather than relying on a single base period as with the Laspeyres index. Christensen (1975) has pointed out that the Tornqvist index reflects a situation whereby, as the price of an input increases, the producer decreases its use to keep its marginal productivity proportional to the new price. Hence, the prices from both periods are included in the Tornqvist index to represent their marginal productivities. Similarly, the Tornqvist index relies on the previous year's prices and quantities, whereas the Laspeyres index, with its reliance on a base year, can overstate the effects of changes over time. This is critical when attempting to derive an index from 1948 to 1996. On a conceptual level, Alston, Norton and Pardey (1995) found that the Tornqvist index represented price weights most specific to that economic activity. Thus, they favoured the Tornqvist over the Laspeyres when there was *''reason to think that producers are reacting to local prices but cannot do so instantaneously''* (ibid., pp. 128).

The Malmquist index is the most complex of the three procedures, but tends to avoid some of the restrictions of the Tornqvist and Laspeyres measures outlined above. Thus, when coupled with the newer techniques of Data Envelopment Analysis (DEA) and Stochastic Production Frontiers (SPF), it provides a more dynamic picture of productivity change. Malmquist TFP measures can be decomposed to show changes due to technical efficiency change, i.e. the change in a particular farm becoming more efficient and moving closer to the production frontier, or technical change, i.e. an actual shift in the production frontier itself. It does so by calculating the ratio of the distances of each data point relative to a common technology. Equation (3) defines an output orientated TFP change index (which considers a given input vector (x) and the maximal proportional expansion of an output vector (y)[1]) from period (s) to period (t) (Coelli *et al.*, 1998):

$$m_o(y_s, x_s, y_t, x_t) = d_o^t(y_t, x_t) / d_o^s(y_s, x_s)\left[\frac{d_o^s(y_t, x_t)}{d_0^t(y_t, x_t)} \times \frac{d_o^s(y_s, x_s)}{d_o^t(y_s, x_s)}\right]^{1/2} \qquad (3)$$

where

M_o is the output-orientated Malmquist TFP index,

$d_o^s(y_t, x_t)$ is the distance from period t observation to the period s common technology,

$d_o^t(y_t, x_t) / d_o^s(y_s, x_s)$ is technical efficiency change, and

$\left[\frac{d_o^s(y_t, x_t)}{d_o^t(y_t, x_t)} \times \frac{d_o^s(y_s, x_t)}{d_o^t(y_s, x_s)}\right]^{1/2}$ is technical change

The most attractive property of the Malmquist index for this study is that, unlike the Tornqvist procedure, only quantity data are required to derive the index (ibid., pp. 221). Consequently, this would obviate the problem of UK entry into the Common Agricultural Policy in 1973 and high price supports, which would increase growth rates considerably using the Tornqvist procedure. However, the main drawback of the Malmquist is that it requires extensive data. Thus, the majority of studies using Malmquist indexing procedures have only examined specific commodities over a short period of time, where data are available (see for example Battese and Coelli, 1992; Piesse and Thirtle, 1997; Hadley *et al.*, 2000).

For longer time periods studies into TFP have favoured either the Laspeyres or the Tornqvist approach, with the bulk of recent work dedicated to the latter procedure. However, the

[1] An input orientated procedure would consider the minimal proportional contraction of the input vector, given an output vector.

majority of earlier studies have used the Laspeyres index to measure TFP growth. Consequently both indices should be used in order to measure the level of variance between the two.

4.1.4. UK Agricultural Total Factor Productivity

In order to construct a total factor productivity index a number of sources were used. Predominantly, data were assembled from the aggregate agricultural accounts published yearly in the Annual Abstracts of Statistics of the Central Statistical Office (CSO). This was to ensure consistency in measurement. However, because of limits to the amount of data recorded, the 'Agriculture in the UK' series published by MAFF, which in earlier editions included Agricultural Census information, was used for gathering information about employment statistics.

Final output was derived by removing intermediate seed and feed from gross output. However, before 1964 the amount of intermediates are not stated within the agricultural accounts. This is because during the 1960s an increasing amount of farm specialisation occurred and hence the amount of produce traded between farms became significant. Consequently, as approximately 3% of gross output was accounted for by intermediates in 1964, this figure was trended back to 0 in 1948. After 1978 Government began to publish most data in calendar, as opposed to crop, years. In order to maintain consistency, after allocating stocks in the appropriate year, the crop year convention was continued forward, using adjustments for both the output and input series, as advised in MAFF (1990, pp. 19).

Inputs consisted of all intermediate inputs, namely fertiliser, imported livestock, seed and feeding stuffs, along with the costs of hired labour, rents, depreciation on buildings and machinery as well as running costs. Within agriculture the flow of capital stock is produced both on and off the farm. On-farm capital assets, as recorded in the agricultural accounts, are predominantly farm machinery and buildings. In addition, a 3% charge on capital stock to represent the flow of off-farm capital services was included in the input series. This is consistent with USDA recommendations and favoured by Thirtle and Bottomley (1992). However, a possible error occurs in respect of buildings depreciation and farm maintenance, which was not included in the accounts before the mid-1960s, and therefore have had to be imputed through rent and interest values.

The Laspeyres index was derived following Doyle and Ridout (1985), whereby the ratio of outputs to inputs in any particular year was compared to the ratio of a base year. Final output was deflated by the 'Agricultural All Output Index' and the inputs by an aggregate of fertiliser, agricultural feed and machinery prices. Consequently, all prices were based on the mid-year 1970, obviating some of the bias caused by measuring changes over such a large period. Using this index gave an annual average growth rate of 1.9% from 1948 to 1996.

The Tornqvist index operates under a system of factor shares. As a result, the inputs and outputs series had to be disaggregated. Outputs were derived under the four headings given by the aggregate accounts, namely i) farm crops, ii) horticultural crops, iii) livestock, and iv) livestock products, which consisted of wool, milk and eggs. For the input series eight headings were used, namely all four major intermediate inputs of feeding stuffs, fertiliser, seeds and imported livestock, as well as rent, labour (hired workers), miscellaneous expenditure, which includes pesticides after 1986, and an interest on capital stock series. A series for inputs and outputs were constructed using the formula recommended by Rayner *et al.* (1986) and the TFP index derived from:

$$\ln(A_{t+1} / A_t) = \sum \overline{W}_{ij} \ln(Y_{jt+1} / Y_{jt}) - \sum \overline{C}_{ir} \ln(G_{rt+1} / G_{rt}) \quad (4)$$

where

A_t is the level of TFP in year t,

Y_{jt} is the output of commodity j in year t,

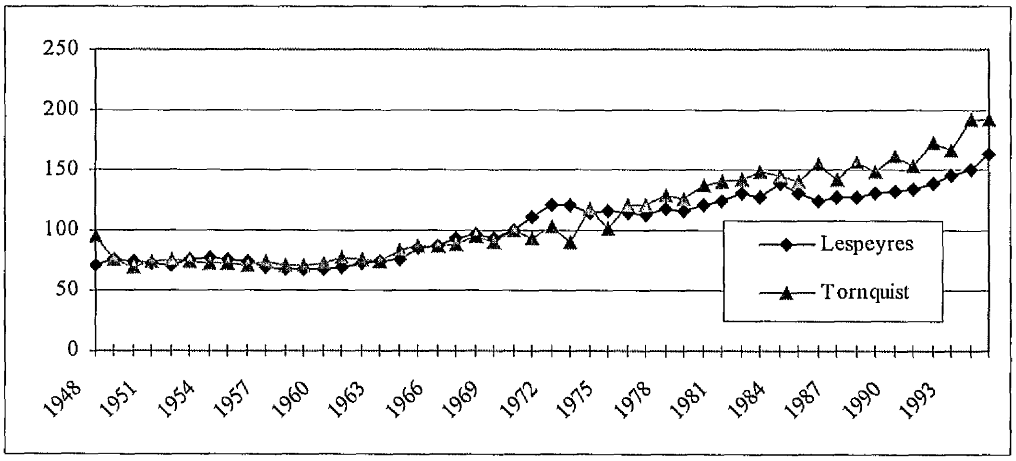
$\overline{W}_{ij} = (W_{jt} + W_{jt+1})/2$ is a moving average of two successive years, where W_{jt} is the value share of the jth product in total output,

G_{rt} is the input of commodity r in year t, and

$\overline{C}_{ir} = (C_{rt} + C_{rt+1})/2$ is a moving average of two successive years, where C_{rt} is the value share of the rth product in total input.

Essentially, this method takes each series of outputs (inputs) and weights their share against the sum of total output (input). This share, a moving average over the year in question and the year ahead, is then multiplied by the log of the ratio of a particular output (input) for the year in question and the year ahead. The total factor productivity index can then be derived by taking the sum of the logged output series minus the sum of the logged input series (Thirtle and Bottomley, 1992). The results were then exponentiated and chained, using 1970 as the base year for chaining. Consequently, both the Tornqvist and the Laspeyres indices can be compared and are shown graphically in Figure 4.1.

Figure 4.1. Comparison Between Laspeyres and Tornqvist Indices for UK Total Factor Productivity, 1948 to 1996



The first impression gained from Figure 4.1 is that the Laspeyres index seems to provide a more smoother interpretation of the productivity series than the Tornqvist. This is especially prevalent in the second half of the series where the Tornqvist seems to exhibit more dramatic productivity growth. In particular, the Tornqvist picks up the drought years of 1975 and 1976. Finally, in the 1980s the Tornqvist rises substantially, if erratically, above the Laspeyres index. This comparison is clearer when Table 4.1 is considered. Annual average growth between the two indices for the entire period seems to be similar at around 1.9%. This compares with the majority of other UK studies, which tend to be just below 2%. However, comparing separate periods, in this case before and after entry into the Common Agricultural Policy, shows a large degree of variance.

Table 4.1. Annual Average Growth Rates Between Laspeyres and Tornqvist Indices, percent

Period	*Laspeyres*	*Tornqvist*
1948-1972	2.37	0.60
1973-1996	1.09	3.25
1948-1996	1.73	1.90

Whilst the Laspeyres has a high growth rate which then declines after 1972, the Tornqvist shows a very slight growth for the period 1948 to 1972 of 0.6%, which then rises substantially to 3.3% per annum after entry into the CAP. In addition, the Tornqvist shows a higher overall rate of growth at 1.9%, whereas the Laspeyres is lower at 1.7%. Consequently, it seems that for the entire period their behaviour is wholly distinct. This is an important point as it raises the issue of which index depicts reality. Thirtle and Bottomley (1992), using the Tornqvist procedure, found a similarly high rate of growth after entry up until 1985. However, before entry, 1967-1972 they found a growth rate of 1.76%. To some degree this correlates with these findings, but it may be indicative of the indexing procedure adopted.

4.1.5. Summary

The development of a total factor productivity index is intrinsic to evaluating returns to agricultural R&D. Thus, by using the two most favoured methods for deriving total factor productivity and removing some of the reasons why there may be a residual, there still appears to be a growth in TFP. There are, therefore, other factors, discounting measurement errors, which have not been accounted for and which are responsible for this growth. The majority of work has centred on the assumption that R&D causes productivity growth, but very few have tested this hypothesis. Consequently, the next section explores the nature and validity of this relationship.

4.2. Concepts in the Econometric Evaluation of Agricultural R&D

Evaluations of past research effectiveness have produced a vast body of literature which have employed various methods to answer the question of whether agricultural R&D is an economically justified public investment. The attempts can be classified into three categories, namely i) the economic surplus approach, ii) the production function approach, and iii) the profit function approach.

The economic surplus approach involves the estimation of the underlying consumer and producer surpluses generated by shifts in the agricultural supply function. These changes tend to result from research-induced unit cost reductions or productivity enhancements. Hence the gains from research represent the net change in total economic surplus, resulting from a gain in consumer surplus and the change in producer surplus. However, the shapes and shifts in supply and demand functions rely on different sets of assumptions. Estimates of the returns to research using the economic surplus approach are highly dependent on these alternative assumptions (Linder and Jarret, 1978; Wise, 1984).

The second method is based on the estimation of a production function for agricultural output, in which research expenditures are included as one of several inputs. Within this approach two main methods have been adopted. The 'integrated' method is concerned with changes in the input-output combinations which results in large, unexplained residuals attributable to research innovation. The basis of this method was pioneered by Griliches (1964), who included expenditure on research and extension in a production function using average per farm data, in order to find the marginal product of research expenditure. From this the social rate of return could be inferred. The problem with this approach is that research is not a direct input to the production process. Rather the results of research expenditure indirectly influence crop and livestock production through its incorporation in new technology.

Alternatively, the 'two-stage decomposition' procedure seeks to explain the changes in the rate of total factor productivity (Knutson and Tweeton, 1979; Thirtle and Bottomley, 1988). Changes in TFP are regressed against variables such as R&D, as well as weather and farmer management skills. As research effects are not immediate, lags are set for the future when an innovation's impact will peak and then decline as it is superseded by other innovations or is overcome by natural forces. The result will show the percentage change in TFP given a one percent change in expenditure on R&D. The sum of the coefficients of R&D expenditures can, therefore, be used to calculate the efficacy of R&D expenditure over time. Harvey (1988) has criticised this method on a number of grounds. Firstly, the method is highly sensitive to the length of lag included. Similarly, most studies in the UK have not included the adoption process, which is critical to increasing productivity in agriculture, as without farmer uptake of new technology there will be no productivity growth.

A third method, which has gained popularity recently, is the 'dual profit function' approach (Bouchet *et al.*, 1989; Khatri and Thirtle, 1996). Profit functions allow inputs to be fixed or variable and can incorporate exogenous conditioning factors such as R&D expenditures (Lau, 1976). Consequently, the model has a degree of theoretical consistency and offers ease of modelling. However, a major restriction is the estimation of the time series data, as it seems unlikely that prices are an exogenous variable. Thus, the estimation of objective functions using prices as independent variables will be biased. Secondly, the estimated functions rarely display the properties required by theory. Accordingly, the use of the method cannot be justified by appeals to theoretical consistency, since most models are not theoretically consistent (Doyle *et al.*, 1994).

Overall the measurement of research effects on productivity encapsulate various practical and conceptual difficulties and no method has successfully overcome these. The choice of a method will therefore involve weighing up the advantages and disadvantages of the different methods. Whilst the profit function approach is conceptually attractive, it was felt that as the vast majority of studies in this area have adopted some form of the production function approach, this should be chosen in order to test the validity of these studies. In addition, advances have been made in respect of the various concerns voiced about previous production function studies in the UK and so these could be integrated into an improved method. Within this broad approach the two-stage decomposition process, which enables advice and private R&D to be disaggregated from public research and allows for an assessment of their effect on productivity, was selected. This was important in a situation where the private sector is being called upon to conduct more research, and the public advisory service is moving towards a market situation. Hence the pay-off to investment in both these areas would help to give indications of the appropriateness of various strands of research policy, aimed at improving the efficacy of R&D.

4.2.1. Previous Studies of Research and Agricultural Productivity

The majority of past studies have estimated a high rate of return on investments in agricultural research (Echeverria, 1990). Ruttan (1982) pointed out that investments in agricultural R&D are between three and five times higher than those on most alternative investments. These levels of return have been used to argue for increasing levels of funding for research, since the returns far exceed the investment costs. Fox (1985) refers to this as the 'under-investment' hypothesis and goes on to state its importance in that, if *''advocates of this view can persuade legislators of the veracity of their contention, then a re-arrangement and/or increase in public expenditures could result''* (ibid., pp. 806). He goes on to say that if this hypothesis were wrong, then this re-allocation of resources would be welfare diminishing. Table 4.2 outlines the studies that have been conducted within the UK and their estimates of the rates of return on agricultural R&D.

Table 4.2. Previous UK Studies into Returns to Agricultural R&D

Author	*Period*	*Rate of Return*
Doyle and Ridout (1985)	1966-1980	10-30% (Decreasing over time)
Wise (1986)	1986	8-15%
Harvey (1988)	1988	-38% to 12%
Russell and Thirtle (1988)	1976-1985	327:1 (Rape Seed)
Thirtle and Bottomley (1988)	1950-1981	70%
Khatri and Thirtle (1996)	1953-1990	18%
Thirtle and Townsend (1997)	1973-1989	44%

Source: After Echeverria (1990)

With a few exceptions the estimated returns to research have been relatively high and therefore calls for more investment to realise the social optimum have been common. However, there is little agreement on the correct method of measuring returns to agricultural research (Huffman and Evenson, 1993). The studies themselves show vast differences in actual returns. As such, Harvey (1988) has questioned the validity of such an exercise because of the non-uniformity of research results. Doyle and Ridout (1985) showed that returns were decreasing over time, which could correlate with the reduction of research funds during that period. They concluded, however, that reduced rates of return could either be due to diminishing returns as investment increases, an inappropriate allocation of resources or a decrease in the efficiency by which scientific knowledge was employed in technology. Since the mid-1980s various efforts have been made to find the true level of returns to agriculture. It seems there are four major factors that have not been addressed in studies before this period. These are:

1) *The effect of international spill-overs* (Huffman and Evenson, 1993). Knowledge is not boundary specific. Consequently, discoveries funded from other countries may be embodied into UK research. With the increasing globalisation of chemical and pharmaceutical firms, the expenditures of foreign Governments and private firms have to be taken into account when assessing returns to a national system. In a study by Schimmelpfennig and Thirtle (1998), which incorporated the effect of international patents, the coefficient measuring the impact of UK public R&D on productivity was reduced from 0.26 to 0.06.

2) *The excess burden of taxation.* Fox (1985) first highlighted the fact that the collection and redistribution of taxes for public spending incurs a cost in itself and rates of return should be adjusted accordingly. Using a previous study on agricultural research, incorporating the excess burden reduced returns from 37% to 26%. Whilst Dalrymple (1990) found this concept to be theoretically sound, the ability to derive an appropriate measure of excess burden was questioned and he asserted that Fox's calculations may have

over-stated the reduction.

3) *Private R&D investments.* Echeverria (1990) in a review of returns to research highlighted the fact that the majority of studies ignored the effect of the private sector on increasing productivity. This is mainly due to difficulties in obtaining data and measuring the true level of information flows between the public and private sectors.

4) *Conceptual and theoretical difficulties.* There has been a growing body of literature which questions the effect of R&D on productivity growth. The OECD (1992) could find no empirical relationship between research and economic growth. More specifically, Hallam (1990) found rates of return were highly dependent on both the length and shape of the lag. He compared the rates of return between the standard inverted 'U' shaped Almon lag with endpoint restrictions used in most previous studies, with variations in restrictions and shape. Whilst the unrestricted and polynomial lags yielded a coefficient of 0.35, the standard restricted model had one of 0.52.

These critiques have gone some way to undermine the 'under-investment hypothesis' and support Harvey's (1988) contention that the application of econometric methods to agricultural research are highly spurious and, in a policy-making context, quite dangerous. What emerges therefore is that studies on the true rate of return of agricultural research, whilst popular, are somewhat debatable in terms of policy-making. Notwithstanding this, an attempt to measure the impact of past research on agricultural productivity will be made, with a view to assessing whether research policy changes have affected the productivity enhancing effects of R&D.

4.2.2. Measuring Agricultural Productivity Change

The bulk of studies on research and productivity have derived some form of relationship similar to that depicted in equation (5) (Thirtle and Bottomley, 1988):

$$P_t = \sum_{i=0}^{n} \alpha_1 R_{t-i} + \beta_1 S_t + \beta_2 E_t + \beta_3 W_t + \mu \qquad (5)$$

where

P is the rate of change in total factor productivity between year t and year t+1,

R is the sum of public expenditures on research, lagged by n years,

S is the public expenditure on advisory activities,

E is an index of the managerial ability of farmers,

W is a weather index that explains a proportion of the variations in P, and

μ is the error term.

Consequently, a series for each of these variables has been derived and assessed for their effect on productivity. The research data were obtained from various sources. Firstly, the University Grants Commission (UGC) records the allocation of block grants which are devoted to research on agriculture and veterinary subjects within Higher Education Institutions. This is provided for England, Wales and Scotland. However, data from Northern Ireland were not available. Similarly, the Government spends money on in-house research. Data are available from the supply estimates published by the HM Treasury and available in yearly statements from HMSO command papers. Scottish data on the development work of the Scottish Agricultural College are declared in the 'Agriculture in Scotland' series of SOAEFD, which also provides information for the research institutes in Scotland. However, Northern Irish data are not available and estimates of research expenditures were taken from Thirtle, Piesse and Smith (1997). The major conductor of agricultural R&D in England and Wales is the Biotechnology and Biological Science Research Council, which from 1965 onwards has published annual statements of expenditure. Before this period, figures had to be obtained from the Government supply estimates of HM Treasury.

These supply estimates were also the source of advisory data for England and Wales, which include both current and capital expenditures. However, the reliability of this data has to be questioned as the activities of ADAS in respect of research and advice are not well delineated. For Scotland, the advisory work of the SAC is published in the 'Agriculture in Scotland' series.

For the education series, an index was derived of the number of diplomas and degrees obtained in agriculture as a percentage of the agricultural population. This series has many faults, as it assumes that all agriculture students enter farming after qualifying, though in reality they tend to enter other related industries (Burrell *et al.*, 1990). However, it remains as the standard proxy for growing entrepreneurial ability within the farming community.

Fluctuations in humidity and precipitation will have a direct effect on the yield of farm crops, as well as the quality of grassland for grazing livestock and the level of feeding stuffs requirements. MAFF (1961) were the first to adjust net income to 'normal' weather conditions. However, in theory, fluctuations in terms of drought and heavy precipitation, in a relatively stable climate such as the UK, should cancel out over time. In practice an index, which gives a coefficient for the effect of weather over the period of study (Doyle and Ridout, 1985; Thirtle and Bottomley, 1988; Huffman and Evenson, 1993), is usually included. The derivation of a weather index is varied. Doyle and Ridout (1985) took a ratio of forecasted crop outputs against actual crop outputs. A similar method was used for international comparisons by Schimmelpfennig and Thirtle (1998). However, there are limitations to data availability and, because of this, most studies have used a 'de Martonne aridity' index (Oury, 1965; Thirtle and Bottomley, 1988; Hallam, 1990), which is a ratio of precipitation and temperature. Whilst not ideal, as it gives no indication of the full effect of various conditions on each commodity, it does account for some of the weather changes responsible for productivity changes.

4.2.2.1. Choice of Deflator

The problem with the production function method is that the series has to be deflated for price fluctuations. In addition, an index of the price of scientific resources does not exist. Davis (1981) suggests using an index of professors' salaries, but, whilst academic wages are published by the UGC, they do not provide a consistent series for the period 1948 to 1996. Consequently, whilst not ideal, the choice of an agricultural input deflator was chosen. This was mainly because it ensures consistency of treatment with the private sector research series (see below). The other possible deflator was the retail price index, but this was considered to only reflect consumer preferences. The agricultural deflator was preferred as it follows, to some degree, the price preferences of farmers for agricultural inputs, which embody technological advances.

4.2.2.2. The Stationarity Problem

Before using time series data within an estimation procedure the series must be first tested for statistical validity. Stationarity is a fundamental assumption of time series. If data are stationary then their statistical properties remain constant over time. However, what has usually been observed is that over time the series tends to drift away from the mean, usually referred to as random walk. If this occurs then the data are said to be non-stationary and, if used in a regression, will lead to spurious results.

When testing for stationarity a unit-root test is performed. When the series are non-stationary this infers that the root of a series is unity (ρ = 0.9-1.1) and follows a random walk with drift (β = 0). Dickey and Fuller derived the distribution for the estimator, when ρ =1, and generated critical values of F-test statistics for the random walk hypothesis (Pyndick and Rubinfeld, 1998). The process of finding an unit root involves first running an unrestricted regression and then a restricted regression. The standard F ratio is then calculated to test whether the restrictions (β = 0, ρ =1) hold and the resulting F-statistic is measured against the F-test tables generated by Dickey and Fuller. However, Mackinnon derived estimates from a wider set of observations and these are the ones used to test for unit roots here.

The most popular methods for measuring unit-roots are the Augmented Dickey-Fuller (ADF) or Phillips-Perron methods. The ADF and Phillips-Perron tests involve integrating lags to the variable on the right hand side of the equation to correct for serial correlation. However, the Phillips-Perron test is favoured as it recommends the length of lag required, using the Newey-West procedure (Lilian *et al.*, 1995). When a series is stationary it is denoted I(0), however if the data are non-stationary then it has to be differenced, denoted I(x), where x is the level of differencing required. The results derived from this procedure for the current data are presented in Table 4.3.

Table 4.3. Test for Unit Roots Using the Phillips-Perron Method

Series, 1948 – 1996	
Tornqvist TFP Index	I(1)
Laspeyres TFP Index	I(1)
Public R&D Expenditure	I(1)
Advisory Expenditure	I(1)
Education Index	I(1)
Weather Index	I(0)

The results show that all the series, apart from weather, were found to be non-stationary. Thus the application of ordinary least squares would be inappropriate. Running the Phillips-Perron test a second time, at the first difference level, rejects the hypothesis of a unit root for all variables. Consequently these series have to be first differenced, before they can be used within a regression.

4.2.2.3. Causality and Productivity

Establishing whether a relationship between research and TFP exists is usually facilitated by a Granger causality test. Essentially, the Granger test works on the idea that if X causes Y, then changes in X should precede changes in Y. In order to establish unidirectional Granger causality two conditions need to be met. Firstly, X should help to predict Y, and secondly, Y should not help to predict X. If Y were to also predict X then bi-directional Granger causality would exist.

Using research data and a TFP index for the period 1967 to 1987, Hallam (1990) could find no causality between research expenditure and TFP. However, the functional form was restricted because of a shortage of degrees of freedom and so a shortened lag had to be used. Pardey and Craig (1989) found that causality could run in the opposite direction. However, recent studies, using a Tornqvist index over a longer period, have found that research expenditure causes, in the Granger sense, TFP (Khatri and Thirtle, 1996; Thirtle and Townsend, 1997). Consequently, using the research data, a Granger test was undertaken. The Laspeyres and Tornqvist indices were regressed against public research and advisory expenditure. All series were logged and deflated at 1970 prices.

The Granger test allowed lags to be imposed to measure effectively the effect of research expenditures on the TFP index. While this is usually considered a weakness of using the Granger test, as it has a high sensitivity to the length of lag used (Gujarti, 1995), a method exists to determine the length of the appropriate lag. Regressing research expenditure against productivity with a lag will have an effect on the Schwartz criterion. Essentially the Schwartz criterion is a method of measuring goodness of fit which corrects for the loss of degrees of freedom that results when additional lags are added to the model. It is the most accurate method of determining lag length as it penalises the addition of right-hand side variables (Pyndyck and Rubinfeld, 1998). The lag structure can be determined by increasing the number of lags until the Schwartz criterion reaches a minimum value. Consequently, the Laspeyres (TFP(L)) series was found to have a lag length of 10 years, whereas the Tornqvist (TFP(T)) had a length of 11 years, when measured against the public research series. The results for the Granger causality test are presented in Table 4.4.

Table 4.4. Granger Causality Test Between Public R&D and Productivity

Null Hypothesis:	*F-Statistic*	*Reject Null Hypothesis*
Research does not Granger Cause TFP(L)	2.54	Yes
TFP(L) does not Granger Cause Research	0.57	No
Research does not Granger Cause TFP(T)	0.83	No
TFP(T) does not Granger Cause Research	1.83	No
Critical F Values at < 0.05 Laspeyres 2.45, Tornqvist 2.54		

If the F-statistic provided by the Granger causality test is higher than its critical value, then the null hypothesis, i.e. that R&D does not cause TFP change, has to be rejected. Thus, it would provide evidence that R&D causes TFP change. For the above pairs of series, both the null hypotheses concerning the Tornqvist TFP series cannot be rejected. Consequently, this indicates that whilst research does not cause TFP, TFP also does not cause research expenditure. However, the same procedure when applied to the Laspeyres TFP index rejected the null hypothesis that research does not cause TFP growth, but did not reject the null hypothesis that that TFP does not cause R&D growth. Consequently, as Granger Causality tests only supported the hypothesis that research causes TFP when the Laspeyres index is used, further analysis was confined to the Laspeyres index.

4.2.3. Agricultural R&D in the Private Sector

Until recently, a major cause of productivity growth, that has been overlooked by studies into public R&D, is the influence of the private sector on research spending. Within the UK Doyle and Ridout (1985) doubled public research expenditures to account for private research, so in this study the effects of public and private expenditures could not be disaggregated. Thirtle and Bottomley (1988), through lack of any published data, had to ignore private R&D and suggested applying Evenson's (1967) estimate of dividing the public rate of return by 1.22 to take into account private R&D spending. However, a major advance occurred with Khatri and Thirtle (1996), who included US chemical and pharmaceutical patents to derive an index which took account of spill-overs from private research. This was developed further by Schimmelpfennig and Thirtle (1998), who included European data on patents. However, a list of patents has a major disadvantage, as a patent series is no indication of the level of research expenditure required to obtain the patent. Similarly, the patent of a private company may have emerged from publicly-funded basic research. It therefore seems inadequate to use such a series for a comparison of the effectiveness of research investment by the public and private sectors. Consequently, for the period 1948-1996 a series of private research expenditure on agricultural R&D has had to be constructed for this analysis.

Measuring the level of private sector expenditures on research is a difficult task because, unlike the USA, firms are not obliged to publish expenditures on research and development within their statements of accounts. Lord and Rogers (1969) tried to obviate this by conducting, what seems to be, the first survey on the commercial agricultural industry's research activity. Information was gathered from larger firms and then re-weighted to cover the UK industry. Table 4.5 shows that expenditures rose, in cash terms, from £5.5 million in

1955/6 to £10 million in 1995/6. Beck (1987) could only offer a rough figure of 'around £100 to £200 million' for 1984/5. This seems consistent with a study by Thirtle, Piesse and Smith (1997). This latter study presented an earlier projection of £301 million for agriculture research spend in 1988/9, which was later found to have declined to £286 million before inflation in the period 1993/4.

Table 4.5. Previous Estimates on Private Sector Agricultural Research, £ million at nominal prices

	1955/6#	*1965/6*#	*1983/4**	*1987/8***	*1993/4***
£M	5.5	10.0	100-200	301.0	286.0

Ashton and Lord (1969); * Beck (1987); **Thirtle, Piesse and Smith (1997)

Consequently, for this analysis there is a need to update these figures. This suggested that one method for assessing private expenditures would be to use surveys. This has the advantage of offering actual data from companies involved in research and by-passes the problem of conjecture in evaluating spending levels. Against this, one problem to be faced is that no published figures are available for the number of firms involved in the agricultural industries. To counteract this, the reported proportion of turnover spent on research in the firms sampled was applied to the published data on sectoral gross output to give an estimate of the overall level of private industrial agricultural research activity. The construction of the questionnaire, the sampling technique and the results obtained are explained in the subsequent sections.

4.2.3.1. Methodology

The survey population consisted of companies in the UK involved in the manufacture of inputs into the farming industry, who undertook research or development. The whole agricultural industry was divided into five sectors, and these are defined in Table 4.6.

Table 4.6. Agricultural Sectors Employed Within the Survey

Sector	Definition
Agrochemicals	crop chemicals, including fertilisers
Veterinary and Medicine	animal pharmaceuticals and welfare
Plant and Crop	seeds, horticulture, agronomy and farming systems
Animal Science	breeding, nutrition, lactation and growth
Agri-Engineering	farm vehicles, buildings and computer systems

The survey was aimed at the Research and Technical Directors or their equivalent in business organisations. Names were gathered from lists of members of agricultural associations and trade directories.

4.2.3.2. Sampling Plan

The questionnaire was administered separately for two sizes of firm, non-large and large firms. Non-large firms were surveyed by means of a postal questionnaire, whereas large firms were approached by personal interview. It was assumed that, as the large firms have more influence on the UK agricultural industry, they had to be questioned further on their R&D activity. However, due to the high costs of a personal visit to a firm, it was felt that only companies with annual turnovers in excess of £100 million from UK activities would be interviewed. Consequently, non-large firms were regarded as companies having a turnover of less than £100 million. The non-large firms were classified by the five sectors defined in Table 4.7 and chosen through random probability sampling, stratified by sector within the survey. Thus, these five sectors were treated as sub-sections from which a population was selected through normal probability sampling. This was in order to help ensure each sector was fairly represented within the sample.

Firms were first contacted in September 1996 by telephone to inquire whether they conducted R&D and, if so, the questionnaire was mailed to them. Of the 717 firms contacted, 430 conducted research and development of some kind and this formed the initial survey size. The incentive of inclusion of a prize draw was included to encourage early response, but follow-up reminders were sent to firms who had not replied by the closing date, which was extended to the 30 November 1996.

As most of the large firms had interests in more than one sector, 50 were targeted separately for personal interview. These were selected from company directories. Similarly, large firms, which were predominantly involved in the food industry but who were known to have interests in an area of agricultural input, were also included in the survey of 50 'large' companies. The companies were approached by a telephone inquiry, followed by a letter confirming the time and date for the interview. The questionnaire still formed the basis of the interviews, but it was intended to secure more detailed information in respect of questions on expenditures, priorities and linkage activities. Out of the 50 companies approached, 15 agreed to disclose information, but only 13 could accommodate an interview. The remaining 2 were sent expanded questionnaires specific to their companies. The whole process of collection of both non-large and large firm data took from September

1996 to February 1997. Table 4.7 shows the distribution by sectors in terms of the sample and the response rates.

Table 4.7. Sample Stratification by Sector, numbers of firms and percent

Main Sector Activity	*Original Sample Size, Firms*	*Number Conducting R&D, Firms*	*Spread by Sectors (%)*	*Number of Response, Firms*	*Spread by Sectors (%)*
Agrochemicals	150	110	*23.4*	26	*22.0*
Veterinary and Medicine	155	91	*19.4*	27	*22.9*
Plant and Crop	160	121	*25.7*	29	*24.6*
Animal Science	161	93	*19.8*	20	*17.0.*
Agri-Engineering	141	55	*11.7*	16	*13.6*
Total	767	470	*100*	118	*100.0*

Table 4.8 shows the total numbers of firms in the original sample, both large and non-large. Of the 767 firms sampled, 470 (61% of the original sample) were found to conduct some form of R&D after a telephone enquiry. These firms were either mailed or visited and this yielded a total response of 118 firms, a response rate of 15% from the original sample, or 25% after the telephone inquiry. These response rates were higher than expected, but may have been the result of targeting specific persons within each company. The results of this survey are outlined below.

4.2.3.3. Private Research Expenditure

As firms were reluctant to provide detailed information on R&D expenditure, they were asked to give an indication of their R&D spend as a percentage of turnover in terms of one of 6 bands or ranges. These ranges were defined as 0%, 1-3%, 4-6%, 7-9%, 10-14% and over 14%. If a company had a research spend above 14%, then they were asked to specify a percentage. However, a problem arose with having to use these categories in that, if the centre of each range were taken as indicative of the firm's R&D spend, this might lead to biased over- or understated estimates. Accordingly, the upper, mid, and lower limits of each range were used to give an indication of possible R&D expenditures. The more detailed survey of the larger firms allowed for clearer indications of exact research spend and obviated this problem.

Accordingly, once the research expenditures were collected, their intensities could be calculated as a means of comparison across sectors. Dividing the total level of turnover for the sample in each sector by the total level of research in that sector gave the research intensity. For the 118 firms responding, the estimated R&D expenditures and intensities, as measured by turnover, in 1996 are given by sector in Table 4.8.

Table 4.8. Estimated Level of R&D Expenditure and Intensity by Agricultural Sector for Survey Respondents in 1996, £ million and percent

	Lower Limit	*Mid-Point*	*Upper Limit*	*Standard Deviation*
Agrochemicals, £ million	88.9	93.2	100.8	6.0
R&D Intensity (%)	*6.9*	*7.0*	*7.2*	*0.1*
Veterinary and Medicine, £ million	16.2	20.3	27.2	5.6
R&D Intensity (%)	*9.5*	*9.6*	*9.9*	*0.1*
Plant and Crops, £ million	33.9	40.0	49.6	7.9
R&D Intensity (%)	*6.8*	*7.0*	*7.4*	*0.1*
Animal Science, £ million	15.5	20.1	27.6	6.1
R&D Intensity (%)	*2.0*	*2.3*	*3.1*	*0.2*
Agri-Engineering, £ million	14.4	15.8	18.2	1.9
R&D Intensity (%)	*2.1*	*2.2*	*2.4*	*0.1*
Total Expenditure, £ million	168.9	189.4	223.4	27.5
R&D Intensity (%)	*5.0*	*5.1*	*5.5*	*0.1*

Whilst there was a provision in the survey that the company should only declare their amount of expenditure on UK based activities, it has to be conceded that the above figures may be overestimated due to the amount of embodied knowledge within multi-national companies. Thus, larger companies which have research interests in other countries may embody this knowledge through internal knowledge transference in scientific staff.

Overall the standard deviation between high, mid and low research estimates hovers around £2 to 8 million. Thus, agri-engineering seems to have the smallest deviation of 1.9 million, whereas the estimates for plant and crops has the largest deviation of £7.9 million. Nevertheless, the research intensities only deviate by around 0.1%, which seems nominal. The total research intensity of the agricultural input industries can be estimated at around 5 to 6% of turnover. The OECD ranks intensities as indicative of an industry's technological standing. According to their definitions, the agricultural sector would rank as below the UK average for a high-tech industry at 8.49% (OECD, 1994b). However, the agricultural industry involves a diversity of scientific disciplines and deriving a total research intensity for the industry seems spurious.

The lowest figures are for agri-engineering and animal science, which each have an intensity of around 2%. Thirtle, Piesse and Smith (1997) concluded that bad economic conditions would mean that the research spend would be lower than 5% for tractor manufacturers and this is near the estimate by Ruttan (1982) of 3% for the farm machinery industry. Similarly, the animal science sector has only a low research intensity. Within commercial feed and breeding activities, appropriability is generally low, and so there is less of an incentive to invest in R&D.

However, the figures of £169, £189 and £223 million are clearly under-estimates, not only because the 470 firms contacted probably do not represent the totality of those involved in agricultural R&D, but also because only 15% of those contacted actually provided usable information. These responses were therefore re-weighted against the Census of Production (CSO, 1998) to reflect each sector's contribution to the turnover of the agricultural industry (See Appendix 3). A more realistic picture of private sector research spend may therefore be reflected in Table 4.9.

Table 4.9. Potential Level of R&D Expenditure by the Agricultural Sector in 1996, £ million

Sector	*Estimated Total R&D Expenditure for all firms*			*Totals from Thirtle, Piesse and Smith*
	Lower Limit	*Mid-Point*	*Upper Limit*	*(Adjusted for 1995/6[2])*
Agrochemicals	122.3	136.8	150.0	161.7
Veterinary and Medicine	25.9	27.8	29.8	45.1
Plants & Crops	111.0	138.1	165.0	21.6
Animal Science	69.5	92.2	114.7	15.1
Agri-Engineering	36.7	42.0	47.4	64.7
Total	365.3	436.9	506.9	308.2

The results of the survey would indicate that total private sector expenditure in the UK on both in-house and externally sponsored research on agriculture in 1996 was at least £365 million and could be as high as £507 million. In comparison, reported UK public sector agricultural R&D funding for 1995/6 was around £335 million. From these results it would appear that the ratio of private to public sector spending within UK agricultural R&D is around 1.3:1 to 1.5:1.

The only other figures available on UK private expenditures are estimates by Thirtle, Piesse and Smith (1997), which are also presented in Table 4.10 for comparison. What emerges is

[2] Adjusted for inflation for 1995/6 using the Retail Price Index.

that the sample figures are around 19 to 64% higher than these previous figures. At the upper limits this a substantial discrepancy. However, a major reason for this could be differences in the definition of the groups involved. For instance, the plant and crop figure of £111 to £165 million is around 5 to 7 times higher than the £22 million given by Thirtle, Piesse and Smith However, this latter figure only reflects the 'Seed Industry', whereas plant and crops, as defined here, covers seeds, horticulture, agronomy and farming systems and therefore should be higher.

The largest discrepancy emerges in the animal science sector. Animal science includes Thirtle, Piesse and Smith's (1997) categories of 'breeding and feeding stuffs', along with research into physiology and dairy production. This figure is increased by around 8 times at its upper limits when including these factors. A recent estimate by the Foresight Panel (OST, 1995b, pp. 14) has stated biomedical research into agriculture is around £0.2 billion. Whilst this figure also includes food and forestry it may indicate that the estimate for animal science actually under-represents the levels of spend by industry. The agrochemical sector is lower but may more truly reflect expenditure, as Thirtle, Piesse and Smith's (1997) figure overstated investment in R&D in the UK. Thus, they contended that this may include multinational research and the actual figure may be less (ibid., pp. 51). Agri-engineering is much smaller than Thirtle, Piesse and Smith, who used a turnover of £1.5 billion for tractor manufacturers and assumed research expenditure at 4%. However, from Table 4.9 it is evident that the research intensity of agri-engineering is nearer half of this. Similarly turnover, according to the Census of Production (CSO, 1998), declined to around £1.3 billion for tractors and agricultural equipment in 1996. Nevertheless, this is an under-estimate as no figures were available for agricultural buildings and computer applications, which are included in this category.

4.2.3.4. Deriving a Series for the Private Sector

The private sector produces inputs for improving on-farm productivity. However, it must be accepted that during certain periods of its history, the public sector also contributed to these inputs. Therefore, whilst not ideal, the levels of inputs from the aggregate agricultural accounts in the Annual Abstract of Statistics (CSO) is central to providing a consistent series of the value of inputs used on UK farms. Analysing these tables offers a number of inputs into the farming system, namely i) feeding stuffs, ii) fertilisers, and iii) seeds. Machinery is also present in the form of depreciation, which can be seen as the flow of capital stock. However, this does not represent the size or shape of the engineering and buildings sector and so was not considered any further in the analysis.

A large increase occurred in inputs after entry into the CAP. The dropping of trade barriers and increases in subsidies encouraged both home production and imports of feeds and fertilisers. Whilst this could be a hazard in deriving the series, it does partially allow international spill-overs to be incorporated into the private industry index. Given this assumption, the level of agricultural research over the period 1948 to 1996 was derived by using the data in Table 4.8 to indicate research intensity for a specific year, which is, in effect, the percentage of turnover dedicated to research. These percentages are presented in Table 4.10.

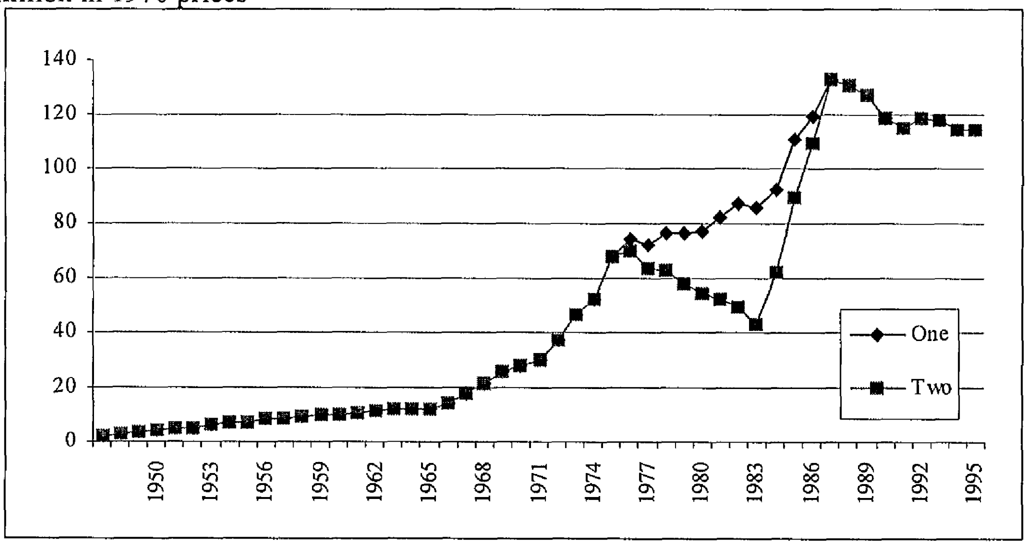
Table 4.10. Expenditure on Private Sector R&D in the UK Agricultural Sector, £ million at current prices and percent

	1955/6	1965/6	1984/5	1995/6
Value of Inputs, £M	468.5	719.0	4350.7	4542.8
Private Research Spend, £M	5.5	10.0	100-200	365-507
R&D Spend, percent	*1.2*	*1.4*	*2.3-4.6*	*8.0-11.2*

Overall, it would appear that private research intensity has grown since 1948. Whilst only nominal at 1.2% in the early 1950s, it has increased to around 10% over the 50-year period. This trend seems to correlate with the idea of 'big science' and the increasing cost and complexity involved in technological advances. Thus, private agricultural firms have moved into areas of biological and biotechnological fields since the early 1980s and this is reflected by increasing research intensities.

Whilst these estimates only represent single years, they could be used as the basis for deriving a series over the whole period of investigation. Specifically, using a simple moving average to smooth rises and decreases in these percentages, a continuous series of private sector research intensity was determined. However, whilst the early and latter parts of the series can be clearly ascertained, due to the lack of alternatives there is an area of contention over the activity within the late-1970s and early 1980s. This is mainly due to Beck's (1987) estimation of research spend as between '£100 and £200 million'. Consequently, two scenarios were assumed to accommodate these differences. Scenario one is based on Doyle and Ridout (1985), presuming that the indications are that private expenditures in the 1970s were roughly equal to public outlays. This correlates with evidence from the chemical industries, which saw an increase in concentration during the late 1960s and 1970s, with the rise of giants such as BP Nutrition and Shell (Dawson and Lingard, 1987). Halving their figure for total UK research expenditure and incorporating Beck's upper limit of £200 million gives scenario one. In contrast, scenario two assumes Beck's lower estimate of £100 million in 1984. Accordingly, by using the derived percentages against the value of total agricultural inputs over the period 1948 to 1996 and then deflating by the agricultural input deflator gives Figure 4.2. This shows the derivation of the two possible scenarios relating to the activity that may have occurred in the UK private sector.

Figure 4.2. Estimates of Private Agricultural Research Expenditure between 1948 and 1996, £ million in 1970 prices



Scenario one seems to provide a smoother series than scenario two. However, this is no indication that it is more valid. Indeed scenario two, where expenditure was assumed to be £100 million in 1984, may reflect the recessionary period of the early 1980s, when investment was reduced. Similarly, the rapid expansion of research expenditure after this period could reflect the substantial investments made into biotechnology by companies such as Unilever and ICI. In order to check causality, a Granger test was conducted on both scenarios. Following the process outlined earlier it was found that at 5% significance levels Granger causality was bi-directional against TFP in both scenarios. However, when tested for stationarity, scenario one was found to be co-integrated at the 5% level with the TFP index. On the other hand, scenario two failed to prove stationary or co-integrated with the TFP series and was accordingly excluded from further analysis.

4.2.4. The Nature of Knowledge Creation and Productivity Growth

Goods and services that enter the economy and have an effect on productivity are the result of many stages of research and development. In terms of R&D some of these processes may be linked to investment specifically in developing that invention, but others may have emerged from different disciplines. For instance, a new tractor may only be a slightly modified model of a previous version. This could be counted as work at the development end of the spectrum, but the new process needed to modify that tractor may have emerged from high investment in the basic side of research, e.g. in robotics or precision agriculture using satellite mapping. Hence tracing the course of a technical innovation may be possible for individual studies, but is impossible at an aggregate level. Accordingly, research is usually viewed as being embodied in a 'stock of knowledge' and any investment in research considered to add to the stock of knowledge. This relationship is represented by equation (6).

$$K_t = (1-\delta)\sum_{i=1}^{n} K_{t-i} + \beta R_t \qquad (6)$$

Research expenditure *(R)* in period t creates 'bits' *(β)* of knowledge (Doyle and Ridout, 1985). These bits add to the stock of knowledge from the previous period (K_{t-i}). The total stock of knowledge *(K)* accumulates over a time period of *(n)* years. The nature of research is to advance the frontiers of knowledge, hence old ideas are replaced by new ideas. This is indicated by the rate of obsolescence (δ).

However, the relationship between knowledge production and agricultural productivity is far more complex. Martin *et al.* (1996) highlight six benefits to economic growth from basic research, which include the training of staff and technological problem solving. Moreover, these benefits follow ill-defined channels to create productivity growth, in comparison to applied and development work which is more directly focused. It was, therefore, felt that research should be divided into 'basic' and 'non-basic'.

The basic series consisted of research expenditures from UGC grants for England, Wales and Scotland, as well as a proportion of AFRC expenditure. However, the AFRC annual report publishes figures for its science budget, along with project funding from MAFF and other bodies only after 1973. If the science budget is considered as money for basic research, and project funding is presumed to be for applied and development work as Rothschild intended, then this could indicate the levels of expenditure for the two types of R&D. However, before this period little is known about the division between different types of research. Consequently, an approximation based on the average percentage split between the basic and non-basic types of research after 1973 was used. This showed a split of 53:47 between basic and non-basic fields respectively.

Furthermore, as basic research may be expected to have a different effect on productivity than applied or development work, basic research expenditures have to be handled differently. Basic research can be seen as the stock of knowledge from which firms and public researchers develop specific products and processes. In this case the traditional model, outlined in equation (6), seems very relevant to deriving the state of basic research in any particular period.

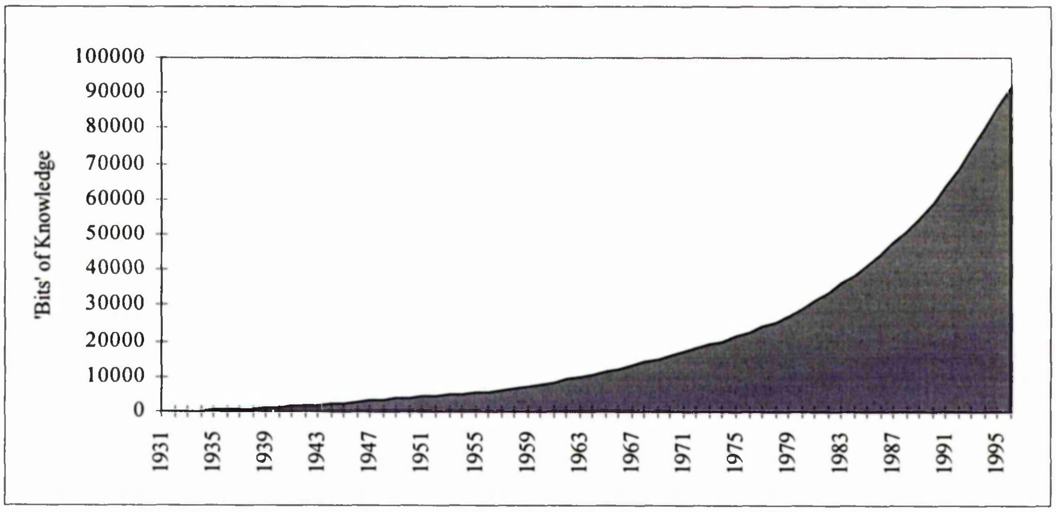
Whilst the series begins in 1948, it was necessary to construct a stock of knowledge before this period. As information on research expenditures is sporadic before this period it was assumed that expenditure grew exponentially from £0.39 million in 1931 (Henderson, 1981, pp. 21) up to £3.79 million in 1948. Whilst there was agricultural research before 1931, it was felt the establishment of the Agricultural Research Council at this time imposed some formative process by which knowledge was pooled and directed towards problems in agriculture. Therefore, the whole of its budget in this period was considered to be for basic research. The monetary value of research has then to be converted into 'bits' of knowledge. In equation (6) this is the β parameter. Taking the number of papers published and setting them against the scientific funding provided gives an indication of the cost of creating basic knowledge. Thus, using 1993 data on the publications and science budget expenditure of the Institute of Grassland and Environmental Research (IGER), the Rowett Research Institute (RRI) and the Institute of Arable Crops Research (IACR), some indication of the value of creating one 'bit' of knowledge is obtained. These calculations are presented in Table 4.11.

Table 4.11. Estimation of 'Beta Coefficient', from publication and science budget data in 1993 public research institutes

	IGER	*RRI*	*IACR*
Publications	346	338	652
'Bits' of Knowledge	692	676	1304
Science Budget, £M	9.20	5.95	13.80
'Bits' per £ million	75.2	113.5	94.5

Consequently, assuming arbitrarily that one publication produced two 'bits' of knowledge, an average of 94.5 bits of knowledge were created per million pounds spent on agricultural R&D. This figure was used in the beta coefficient in equation (6). Similarly, (δ) was taken to be 0.05 after Schimmelpfennig and Thirtle (1998). This is related to the fact that the average life of a patent is 17 years and is presumed to be indicative of the life of a single knowledge 'bit'. Consequently, the stock of knowledge created solely from basic research expenditure could be derived and is presented in Figure 4.3.

Figure 4.3. Estimated Stock of Knowledge Created Through Expenditure on Public Basic R&D



There are obvious restrictions to this method. Firstly, basic research in certain areas, for instance microbiology, makes knowledge obsolescent much faster than every 17 years. Similarly, choosing 1993 as a base year was purely due to data availability and is biased against the 1950s and 1960s, when funding was expanding, but data on publications were not available.

Applied and development expenditures had to be handled differently from basic research. Thus, non-basic research is seen as a more direct expenditure, and as in more traditional studies, a lag has to be imposed on its effect on productivity. For non-basic research, the in-house expenditures for England and Wales were used, along with SAC development expenditure and in-house work in Scotland. The Northern Ireland research provided by Thirtle, Piesse and Smith (1997) was incorporated, assuming that it was predominantly applied in nature.

4.2.4.1. Choice of Lag

The effect of research on productivity is not immediate. There is some length of time before money spent on R&D leads to a product, which is adopted by industry, and consequently has an effect on productivity. Therefore, within the economic evaluation of research, much debate has centred around the shape and length of the lag which should be imposed. The bulk of studies have tended to adopt an approach involving the 'best fit' of the data as an indicator of the true lag length. Under this methodology studies have found an average length of lag of 10 to 20 years. Similarly, the majority of recent studies, which have used the sounder econometric method of minimising the 'Schwartz' criterion for establishing lag lengths, have found comparable ranges for assessing the full effect of research on the economy.

Nevertheless, whilst the Schwartz criterion determines the best length of the lag, there is no theoretically justified method for deriving its shape. The majority have followed conceptual thought on technology adoption, which tends to assume an inverted 'U' shape. Thus, there are early adopters to a technology which, over a number of years, becomes the industry standard and then declines in use as it is replaced by newer technology. The majority of studies have adopted an Almon lag (Cline and Lu, 1976; Doyle and Ridout, 1985; Thirtle and Bottomley, 1988). However, various other shapes have been imposed on the research lag. A 'trapezoidal' shaped lag (where the effect is held constant for a number of years during the mid-period) was used by Huffman and Evenson (1993), and in a recent study by Khatri and Thirtle (1996) a 'gamma' shaped lag was employed. This took the inverted 'U' shape with a longer skew in the earlier years and had a sharper decline in its latter stages. Consequently, the shape of the lag tends to have relied on the 'best fit' approach. However, this is open to the accusation of distortion regarding the true effect of the behaviour of the data. Indeed, Hallam (1990) found that changing the restrictions on the shape of a lag of the same length gave highly varied results.

4.2.5. Estimation of Returns to Agricultural R&D

The model used is a variation of equation (5), whereby (*R*), the research function, is disaggregated by type and sector. However, because of the non-stationarity of the series found in section 4.2.2.2. the first difference was taken of all variables, except the weather series, which proved to be stationary:

$$\Delta \ln P_t = A + \sum_{i=0}^{l} \alpha_1 \Delta \ln R_{t-i}^{bas} + \sum_{i=0}^{m} \alpha_2 \Delta \ln R_{t-i}^{app} + \sum_{i=0}^{n} \alpha_3 \Delta \ln R_{t-i}^{pv}$$
$$+ \beta_1 \Delta \ln S_t + \beta_2 \Delta \ln E_t + \beta_3 W_t + \mu_t \qquad (7)$$

where

P is rate of total factor productivity change in year t,

A is a constant,

R^{bas} is the stock of basic knowledge over the period l,

R^{app} is the sum of public applied and development expenditures, lagged up to m years,

R^{pv} is the sum of private expenditures, lagged up to n years,

S is public expenditures on advisory expenditure,

E is an index of the managerial ability of farmers,

W is a weather index that explains a proportion of the variations in P, and

μ is the error term.

Variants on the above equation were attempted. However, the number of variables proved problematic and incurred some degree of multicollinearity. In particular, the results from using the stock of knowledge index proved highly volatile and insignificant using a variety of lag structures. As a result, the stock of knowledge series was not considered further and the basic research expenditure series had to suffice.

In order to establish the true effect of each type of research, the equations consisted of adding and removing the private research expenditure series. Consequently, four equations were derived using the above procedure.

The first equation used total public research expenditures (R^{pb}), namely the sum of basic plus the applied research and development expenditures, as its primary variable. As determining true lag length was difficult, the procedure adopted was to include only this variable. Different lags and shapes were then imposed on this equation. Adopting the best fit procedure and dropping the Schwartz criterion restrictions allowed lags of between 8 to 26 years to be imposed onto the data. This gave a coefficient which varied from 0.16 to 0.17 for total public research expenditures. However, minimising the Schwartz criterion gave a fit of 8 years, using the standard polynomial lag with both ends restricted to zero. Whilst this is the usual procedure imposed as regards the research coefficient (Doyle and Ridout, 1985; Schimmelpfennig and Thirtle, 1998), it was felt that the coefficient should be measured against changes in the order and restrictions of the polynomial lag. Thus, changing the restrictions and order of the lag imposed various constraints on the shape of the lag. However, differences between restrictions and orders of polynomial were minimal with a minimum sum for the public R&D coefficient of 0.159 and a maximum of 0.174. Consequently, it seems that changes in the order and restrictions of polynomial lags have had very little effect on the measured impact of public R&D. Furthermore, this variance seems insignificant compared to the extreme changes found by Hallam (1990) of around 0.20 between restricted and non-restricted lags.

Therefore, retaining the standard specification of the polynomial lag with length of 8 years, it proved difficult to fit the remaining variables. This was especially the case with advice which proved insignificant for most lag lengths. Consequently, the advisory series was added to the public R&D series (R^{pbadv}). This follows the majority of studies in this area which obey the continuum between R&D and advice. This new series was fitted firstly without private expenditure with a lag of 16 years. This is illustrated in equation (8):

$$\Delta \ln P_t = A + \sum_{i=0}^{16} \alpha_1 \Delta \ln R_{t-i}^{pbadv} + \beta_1 \Delta \ln E + \beta_2 W + \mu \qquad (8)$$

Furthermore, the private research series was then integrated into the equation. Again there was some freedom available in the lag length, which resulted in a variance of between 0.07 to 0.16 using the best fit methodology. Minimising the Schwartz criterion suggested a lag of 7 years for private research using a second order polynomial with both ends restricted to zero. This specification is presented in equation (9):

$$\Delta \ln P_t = A + \sum_{i=0}^{16} \alpha_1 \Delta \ln R_{t-i}^{pbadv} + \sum_{i=0}^{7} \alpha_2 \Delta \ln R_{t-i}^{pv} + \beta_1 \Delta \ln E + \beta_2 W + \mu \qquad (9)$$

The same equations were then run with the separate log series for basic and applied R&D expenditure replacing the public R&D expenditure series. However, the basic series proved difficult to fit, giving highly insignificant results, and had to be dropped from the remaining equations. Similar problems occurred with fitting the applied R&D series with the advisory series and, following equations (8) and (9) they were combined into one series (R^{apadv}). Fitting this series found a lag of 11 years used for equation (10):

$$\Delta \ln P_t = A + \sum_{i=0}^{11} \alpha_1 \Delta \ln R_{t-i}^{apadv} + \beta_1 \Delta \ln E + \beta_2 W + \mu \qquad (10)$$

With the introduction of the private series, the best lag length again was seven years. This gave equation (11):

$$\Delta \ln P_t = A + \sum_{i=0}^{11} \alpha_1 \Delta \ln R_{t-i}^{apadv} + \sum_{i=0}^{7} \alpha_2 \Delta \ln R_{t-i}^{pv} + \beta_1 \Delta \ln E + \beta_2 W + \mu \qquad (11)$$

The results of the fits for all four equations are presented in Table 4.12. The four equations (8) to (11) seem consistent with the majority of previous assumptions about R&D and productivity. Thus, a relatively short lag would be expected for applied research and development work within the public sector, along with an even shorter lag for private sector research which is profit-orientated and mostly short-term. Similarly, the projected total public research coefficient, which includes basic as well as applied R&D, has a lag of 16 years which seems to agree with other studies. The majority of work in this area employs lag lengths of 15 years and upwards.

Table 4.12. Estimated Parameters (with t-statistic in brackets) for the Different Equations, with and without private sector expenditure

Variable		*Coefficient*				
		Lag	*Eq.(8)*	*Eq(9)*	*Eq(10)*	*Eq(11)*
Constant	A	-	2.91 (12.32)	3.08 (12.99)	2.76 (10.80)	3.06 (12.32)
Weather	W	-	0.004 (2.44)	0.004 (2.44)	0.003 (2.34)	0.003 (2.69)
Education	E	-	0.25 (3.82)	0.18 (2.49)	0.31 (4.56)	0.18 (2.45)
Total Public R&D and Advice	R^{pbadv}	16	0.07 (4.43)	0.05 (2.90)		
Public Applied R&D and Advice	R^{apadv}	11			0.09 (3.97)	0.06 (2.61)
Private R&D	R^{pv}	7		*0.09* *(2.10)*		0.12 (3.09)
Adj. R^2			0.96	0.97	0.97	0.98
DW Statistic			2.13	2.54	1.76	2.28

Critical t values for 40 degrees of freedom, one-tailed test, are 90% = 1.30, 95% = 1.68
Critical values for Durbin-Watson (equation 9) (k=4, n=32) are D_L=1.18-D_U=1.73 (D-W value tested is 1.46)

All variables are significant, and the overall fit for the equations is good, with the R^2 statistic indicating that around 97% of the productivity series is explained by these variables. Similarly, most of the Durbin-Watson (DW) statistic lies within the recommended range indicating that there is no significant serial correlation. As regards the results themselves, the first point to note is that the effect of a one percent increase in total public R&D and advisory expenditure varies from 0.05 to 0.07. Significantly, the introduction of private research forces the coefficient for public R&D downward.

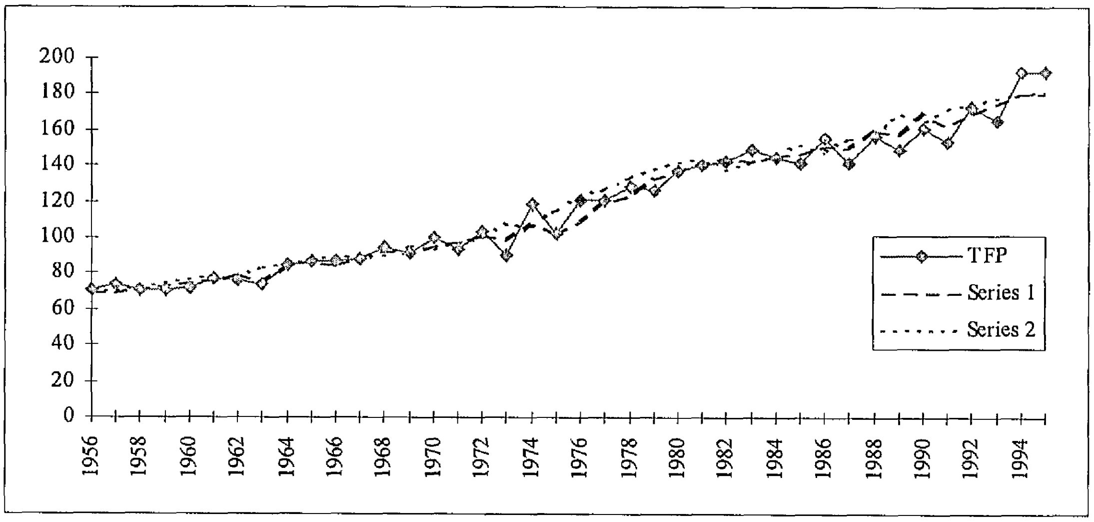
The effect of the private sector can also be seen in the second set of equations concerning applied public R&D and advice. Whereas its coefficient is 0.09 without private expenditure, it is pushed down to 0.06 when this is introduced. However, publicly-funded applied R&D and advice is still higher than the series containing total public R&D expenditure. This seems reasonable as applied R&D is much closer to productivity growth than total public R&D which includes basic research expenditure, which may have a more abstract relationship with productivity.

Another point to note is that private research yields an apparent return from around 0.09 to 0.12, making it higher than publicly-funded R&D and extension. This too seems reasonable as private R&D is motivated by profits and is closer to the market than public R&D expenditures. In addition, it seems that private research yields a higher return where applied research rather than basic research is assumed to be the key factor driving productivity growth. This seems correct, as public support of non-basic areas would reduce the effort for a private firm to develop an innovation into a commercially successful product.

The weather coefficient in all four equations is nominal and seems to correspond with the assumption that periods of dryness are cancelled by wet weather. However, the education coefficient is noteworthy as it varies between 0.18 to 0.25 and even at its lowest is far higher than the equivalent public research coefficients. In a sense, this should be expected, as farmer's entrepreneurial ability directly manipulates agricultural productivity and its effect should be stronger. Following the line of arguments from previous studies, this high rate of return would suggest that funds could profitably, from a social viewpoint, be shifted from research to educational grants in agriculture. However, the education series is an index and it has conceptual problems as a proxy for entrepreneurial behaviour. Similarly, it cannot be quantified in monetary terms.

The goodness of fit between the estimated and actual series are shown graphically in Figure 4.4. Specifically, two series are used. The first (series 1) is total public research and advice with private expenditure, as defined in equation (9). The second consists of total applied R&D and advisory expenditures (series 2), again with private expenditure, as expressed in equation (11).

Figure 4.4. Index of Actual and Fitted Series from Regression Results, 1970=100



Both series mimic the observed trend in productivity quite well, except for a high error in the mid-1970 drought years, where the forecast is smoother than the actual trend in agricultural productivity.

4.2.6. Summary

There are various methods available for evaluating ex-post returns to agricultural R&D. Of these, the production function approach has proved the most popular. However, the bulk of these studies exhibit various conceptual and methodological problems. Chiefly, the establishment of causality, errors in the collection of data and the effect of private sector research expenditures have not been adequately explored in these studies until recently. This study has attempted to unify and correct sources of recording error in the derivation of research and productivity series. It has also introduced a comparable series for private sector research expenditure. Applying this series alongside various measures of research activity in the public sector, it was found that rates of return for public R&D were driven downward. Thus, earlier studies which ignored commercial R&D activity, probably overstated the effect of public investments on agricultural R&D. Overall this conclusion seems to question the reliability of estimated returns to research as a basis for policy decision making. The implications of these findings are explored further in the conclusion.

4.3. Conclusion

Rosenberg (1994) likens the process of R&D to a black box, in which investment in research affects productivity growth in indirect ways. Consequently, evaluating the effect of the public sector on agricultural productivity poses many hazards and problems. However, whilst this cannot be fully corrected, other methods can be used to obviate some of the major errors involved in its measurement.

This research has found public agricultural R&D and extension to have a causal effect on TFP. This may help to answer the first hypothesis that public agricultural R&D has been intrinsic to productivity growth. However, causality was only found when using a Laspeyres index, no causality was found when using the Tornqvist indexing procedure. Accordingly, there has to be some suspicion over the validity of linking R&D with TFP growth in previous studies when the Tornqvist indexing procedure was used. Nevertheless, using the Laspeyres series found a positive coefficient, indicating that some return has been gained from expenditures on public agricultural R&D and extension when measured against productivity growth.

However, there seems to be a divergence between the type of research conducted and its relationship with productivity growth. Thus, basic research affects productivity through indirect channels, which imposes constraints on its accurate measurement. Therefore, the consequent focus on using applied R&D as a measure of research effort, whilst practical, may lead to a distorted assessment of how Government research affects TFP growth. When looking at the public sector it seems that applied R&D and extension has a larger impact on productivity growth than total R&D and extension. Therefore, whilst this may indicate that its removal through 'near-market' research was misdirected, there is a strong suspicion that these constraints have distorted the accurate measurement of returns.

The results from the private sector may give support for another aspect of Government science policy. Specifically, the second hypothesis, introduced at the beginning of this chapter, may have been proved. When including both public and private series, the coefficients are almost doubled for private sector R&D than public sector R&D. Thus, it does seem that private R&D has a higher impact on productivity growth than the public sector. Consequently, the high returns to private research may justify the increased emphasis on private sector involvement within public sector R&D. However, this has ignored the process of transference between the public and private sectors. Thus, the applied R&D conducted in the private sector for a relatively short period of time may only have been possible due to long-term basic research conducted in the public sector.

Consequently, returns to the private sector may be disproportionately high as this does not take into account its reliance on public sector invention.

Nevertheless, assessing the immediate effect of public research expenditure is spurious within the context of the debate over public funding. This is because the Government invests in research in order to receive some social pay-off in the future. Consequently, most studies evaluate this 'social' rate of return to public investment. Accordingly, the next chapter explores the concept of public agricultural R&D in terms of this social return and so aims to evaluate its effectiveness.

CHAPTER 5

ASSESSING THE EFFECTIVENESS OF PUBLIC FUNDING FOR AGRICULTURAL RESEARCH AND DEVELOPMENT

5.0. Assessing the Effectiveness of Public Funding for Agricultural R&D

Until the 1960s little or no economic evaluation was undertaken for the majority of public investments (Tyson, 1989). However, in the early 1960s the first social-cost benefit analysis was undertaken in respect of investment on the Victoria underground line. Since then there has been a movement towards calculating the social costs and benefits incurred in any public investment. Embracing concepts of discounting time preferences, studies value the level of investment against returns on projects in other areas, or against the costs of interest on capital. Typically, this is set at 8% which was considered by a Select Committee on public investment as:

> *''broadly consistent, having regards to different circumstances in relation to tax, investment grants, etc., with the average rate of return in real terms looked for on low risk projects in the private sector in recent years.''*
>
> (HMSO, 1967, para. 10.)

Similarly, the HM Treasury (1991) recommended this as the minimum rate of return on public investments. Accordingly, in terms of national wealth creation, it seems suitable to compare the internal, or 'social', rate of return for agricultural R&D investment against this benchmark return in order to assess the effectiveness of investment. Thus, in terms of the remaining hypotheses, it aims to answer whether rates of return to public agricultural R&D are high and, if so, whether expenditure may justifiably be increased. In addition, the analysis of rates of return can be divided into periods for comparison of research effectiveness. This can be used to address one hypothesis in Chapter 3 which states that public agricultural R&D has benefited from increased Government influence over its management and funding. By choosing periods that are highly relevant to agricultural research management, this hypothesis can be tested.

However, while this seems to be appropriate for evaluating the 'economic' returns on public investment in agricultural R&D, Government policy has recently emphasised that research is intended to contribute to the improvement of the quality of life. Consequently, the second section of this chapter is concerned with the non-economic consequences of technology adoption on UK agriculture. This permits the final hypothesis given in Chapter 3 to be tested, namely that a trend towards lower agricultural productivity growth is a reflection of an increasing proportion of research funding being directed to improving the 'quality of life' rather than 'wealth creation'. In relation to these 'non-economic' benefits, the argument for the public support of science solely as a means to advancing the frontiers of knowledge is considered. As a result, the last section of this chapter evaluates the effectiveness of public funding in terms of knowledge created in agricultural areas.

5.1. Deriving the Internal Rate of Return to Public Agricultural R&D

Calculating the internal rate of return as an investment is a relatively simple task and is computed as the discount rate which will result in a value of zero for the net present value (Alston, Norton and Pardey, 1995). Thus, the aim is to identify the value of r, which satisfies the condition:

$$\sum_{t=o}^{\infty} \frac{B_t - C_t}{(1+r)^t} = 0 \qquad (12)$$

where

B is the benefit in time period t,

C is the cost in time period t, and

r is the internal rate of return on investment (IRR)

Within the literature on agricultural research evaluation, the IRR is usually referred to as the social or marginal rate of return (Davis, 1981; Thirtle and Bottomley, 1988). However, as all studies use a similar accounting function, the point is purely technical. Most work on the IRR for agricultural R&D centers around equation (13) (Griliches, 1964):

$$\left[VMP/(1+r)^n\right] = 0 \qquad (13)$$

The value marginal product (VMP) of research is determined by multiplying the estimated research coefficient by the average product of research. This is usually the sum of research expenditure divided into the sum of benefits from the output series, deflated by an appropriate deflator. Secondly, with n determined as the mid-point of the research lag, the internal rate of return (IRR), denoted by r, is found by iteratively solving equation (13). Within agricultural research evaluation, a number of differing techniques have been employed. Evenson (1967) imposed an inverted V shaped lag onto the returns, but Cline and Lu (1976) derived an inverted 'U' shape for marginal benefits. As the latter mimics the polynomial lag imposed on the research expenditure series, it seemed appropriate to adopt this latter lag structure. Accordingly, the equation used is specified below (Davies, 1981):

$$VMP\left[\sum_{i=0}^{n} Wi / (1+r)^{i}\right] - 1 = 0 \qquad (14)$$

where $\overline{W_i} = \alpha_i / \sum_{i=0}^{n} \alpha_i$ and represents the weights of the polynomial lag.

Thus, the partial research coefficients *(α)* are divided by the sum of partial coefficients to derive an inverted 'U' shaped lag. Generally, the series is divided into blocks of time and the IRR estimated for each period. Considering the phases in public research management outlined in Chapter 2, research and productivity relationships should be evaluated for these stages to assess how changes in management have affected the returns to research. Ideally, the periods should be i) 1948-1972, which was a period of relative autonomy, ii) 1972-1985, which was a period of stable funding with an emphasis on project funding, and iii) 1986-1996, which saw the removal of near-market funds and an increasing emphasis on basic research. However, allowing for the lag effect on research, the data was too short in the last period to assess effectively rates of return. This is especially true in the case of extension which, with a nine-year lag, would mean expenditure beginning in 1986 would not be fully felt until after 1993. Consequently, it was decided to divide the study period into longer units, namely a pre-Rothschild era, 1948-1972 and a post-Rothschild era, 1973-1996. The major problem with this method is that knowledge spill-overs may occur between periods, e.g. expenditure on basic research in 1965 would be accounted for in the first phase, but may only have its full effect in the second stage. Therefore, some distortion of present periods, especially arising from past investments in basic research, may occur under different research management regimes. Whilst not wholly comparable, a similar method was also used for private sector expenditure. In this sense the term 'social return' becomes more misleading as, unlike public investments, the majority of returns are internalised within a firm. Using equation (14) and iterating for r gives the values presented in Table 5.1.

Table 5.1. Internal Rates of Return for UK Agricultural Research, percent

Period	*Publicly-Funded*		*Privately-Funded*
	Total R&D and Extension	*Applied R&D and Extension*	*R&D*
1948-1972	9.9	15.6	46.9
1973-1996	6.2	9.2	29.8
1948-1996	8.1	12.5	38.4

From Table 4.9 there were two sets of coefficients for both total R&D and extension as well as applied R&D and extension, but the lower estimated coefficient has been used in both cases to account for the integration of private sector R&D within the equation. In addition, the lower-bound coefficient for private sector expenditure was used from Table 4.9 to provide the most conservative estimate of rates of return for that sector.

What emerges from Table 5.1 is that there are distinct differences in returns on investment between sectors. Generally, returns to public R&D investments tend to be low, whereas these are high for the private sector. In terms of the applied R&D series returns are around 13%, which agrees with the findings of Doyle and Ridout (1985) and Wise (1986) for a shorter period of study. However, this is lower than recent estimates, using a different method, by Khatri and Thirtle (1996) which put it at around 20%. More critically, returns to total R&D and extension are nominal at 8%, which could be due to including basic research within the series. As discussed previously, basic research has a more abstract relationship with productivity growth and the benefits may not be measured correctly within the standard production function approach adopted here.

Returns to the public sector are dwarfed when compared against private sector R&D expenditure, which yields a return of 38% for the whole period. It should also be emphasised that this is the lower bound coefficient and using the higher bound would realise higher returns. Consequently, from the above findings, it seems that private R&D expenditure is far more successful at yielding a return on investment in terms of productivity growth. The implication of this is that increased involvement by the private sector in the administration of agricultural R&D seems to be justified as it is more effective. Naturally, there are problems with this interpretation as private and public R&D expenditures have different goals and are not strictly comparable. Similarly, the whole process of transferring knowledge between public and private sectors has been ignored. As the private sector conducts little basic, as opposed to development, work the IRR calculation will not include the public investment in creating the knowledge which the innovating firm modifies into exploitable technology. This whole process of the public-private transfer of research knowledge is discussed more fully in Chapter 6.

In respect of the two time periods, the IRR for both series is apparently reduced by around 40% following entry into the Common Agricultural Policy. This seems to correlate with the findings of Wise (1986) and Doyle and Ridout (1985), who both found downward rates of return over time to agricultural R&D investment. Similarly, it contradicts the findings of Khatri and Thirtle (1996), who projected no change in the rates of return to research before and after 1973. Nevertheless, to state that these reductions in rates of return are due to the imposition of the Rothschild framework is debatable, considering that entry into the CAP occurred at the same time.

There are various possible explanations for this trend when considering these time periods. Firstly, Harvey (1988) pointed out that returns to R&D might be expected to exhibit diminishing marginal returns to increasing expenditure principally because of increased sophistication in research, i.e. as research becomes more technically advanced then more money needs to be invested to reap the same level of technical advances. Similarly, there is the possibility that returns were reduced because, in the latter period, research programmes changed emphasis away from strictly productivity-enhancing research. A growing emphasis on improving the public good within agricultural research programmes may have had the effect of reducing its effect on productivity growth. Hence, there may be benefits from public R&D which are not captured by standard TFP measurements. This is explored in a later section of this chapter.

There is no doubt that some, if not all, of the factors outlined above have caused downward trends in rates of return to agricultural R&D after 1972. However, this does not rule out the effect of research management changes on the productivity of research investment. Nevertheless, there is no incontrovertible evidence that changes to the management and funding of research have had little discernible positive effect on the productivity of research investment. In relation to this, a further point made by Fox (1985) is worth noting. Specifically, if his estimate for excess burden were correct, then the estimated returns should be decreased by around a third. This would reduce both estimated rates of return for public R&D series and question the justification for increased support, after taking into account the cost of taxation collection. Furthermore, it could be contended that excess burden of taxation would increase with the implementation of the Rothschild framework. Specifically, the increased costs of establishing peer-review mechanisms for public R&D would reduce returns still further.

5.1.1. Summary

Using the standard methodology for measuring returns to research yields, an internal rate of return of between 8 and 13% for various aspects of public agricultural R&D and extension has been obtained for the UK in the period 1948-1996. Compared to a minimum return of 8% for public investment, continued public support for applied agricultural R&D and advice appears to be justified. However, with the inclusion of basic research the wider justification for public funding is more debatable as estimated returns were certainly below 8% in 1973-1996. Hence, in terms of previous arguments, the inference is that a shift in public funding from basic research to applied R&D and to extension might be justified.

Nevertheless, a degree of caution has to be voiced over the validity of these results. Specifically, in the UK, collection of research and advisory data, especially in the earlier years, is fraught with uncertainties. Similarly, although social-cost benefit analysis is a valid tool of *ex-post* Government decision making, indications are that the Government undertakes *ex-ante* evaluation of specific research projects in terms of the costs and benefits for targeted groups, mostly farmers, consumers and agri-businesses. In addition, previous studies, using different methods of estimating the IRR, have yielded results between minus 38% and plus 700%, which throws doubt over the exercise as a basis for policy making.

Another reason why these results have to be questioned is the validity of using productivity growth as an indicator of the success of the agricultural R&D policy. Since the mid-1980s there have been policy changes as regards the relationship between agriculture and society. Specifically, there has been a concerted effort by both UK and European policy makers to promote socially and environmentally beneficial practices within the farming industry. Consequently, measures have been directed at rural, environmental and other public-good goals, as opposed to gaining increases in productivity. Within the European Union, a similar shift of policy emphasis has occurred (CEC, 1998). Consequently, the effectiveness of agricultural R&D in terms of improving the quality of life must be examined. This is the concern of the following section.

5.2. Agricultural R&D and Improving the Quality of Life

Whilst productivity growth has been the central objective of agricultural R&D policy, the environmental and social costs of improvement have only recently become a concern of policy makers. This is evidenced by the majority of studies into agricultural R&D, which have solely focused on productivity growth. The environmental and social costs of agricultural productivity have not been incorporated into the majority of these studies. However, the environmental damage caused by such increases has led to a very real degradation in the quality of life for both rural and urban areas. In essence, awareness has been growing regarding the levels of nitrate within water supplies, the effects of ammonia on the quality of air and the overall effects on human health of chemical application to agricultural products. There is, therefore, a growing concern that, while productivity growth has been significant in agriculture, the full costs of this have not been accounted for by traditional approaches to measuring agricultural growth. Archibald (1988) points out a number of implications that may be relevant to this study:

> *''Firstly, productivity growth may over or understate the gains from technology without the inclusion of externalities, as some resource costs are not included. Secondly, ...as producers are increasingly required to bear more of the costs of production and to internalise externalities, the total, or social, costs and benefits from technology must be determined. Thirdly, as interest focuses on the long-run profitability of technology, the biological and physical sustainability of technology becomes critical.''*
>
> *Archibald (1988, pg. 366)*

Consequently, a growing number of studies have attempted to isolate and remove the effect of externalities from agricultural productivity indicators, both at aggregate and at commodity levels. Thus, Archibald (1988) examined growing pesticide resistance within the cotton-growing sector of California. Oskam (1991) studied the effect of chemical residues in air, water and soil at an aggregate level for the Netherlands. This last study found that annual average rates of TFP growth decreased by between 2% and 10%, depending on assumptions about the price of external effects. Ball *et al.* (1994) concentrated on the effects of nitrogen pollution and found that agricultural growth rates were reduced by around 12 to 28%.

Thus, as no study has been conducted for UK agriculture, there is a need to remove the externalities, which may have been caused over the period 1948 to 1996, due to productivity growth in the UK agriculture. This would therefore help to give a truer understanding of TFP growth and its consequent research effectiveness.

5.2.1. UK Agricultural Total Factor Productivity Including Externalities

Whilst various methods have been employed for integrating externalities into productivity series (Hailu and Veeham, 2000), the methodology used by Oskam (1991) seemed more appropriate for this study. This was because data used for the derivation of the productivity series in Chapter 4 could be modified for inclusion of externalities. Accordingly, equation (2) can be modified to include externalities, thus;

$$\ln P^* = \sum \overline{W}_{ij} \ln(Y_{jt+1} / Y_{jt}) + \sum \overline{X}_{ig} \ln(E_{gt+1} / E_{gt}) - \sum \overline{C}_{ir} \ln(G_{rt+1} / G_{rt}) \qquad (15)$$

where

P^* is the adjusted productivity ratio for periods t and t+1,

E_{gt} is the (positive or negative) share of the value of the external effect g, relative to total externalities, and

$\overline{X}_{ig} = (X_{gt} + X_{gt+1})/2$ is a moving average of two successive years, where X_{gt} is the value share of the gth external cost or benefit in total external costs or benefits.

Generally, equation (15) employs Tornqvist indices where each series of externality (positive or negative) is weighted against the sum of externalities. This is then added to the output series to accommodate the inclusion of both negative and positive externalities[1]. However, lack of available data restricted the opportunities for analysis. Consequently this study concentrated on two specific negative externalities, i.e. pesticide and nitrogen pollution, and the value of externalities were subtracted from the output series.

Data were obtained from Pitman (1992), who provided estimates of chemical application for certain years within the post-1945 period. To construct a series, figures for inorganically produced nitrogen supplied for home consumption were obtained from the CSO Annual Abstract of Statistics. However, it has to be conceded that these are an over-estimate as they also included fertiliser application for non-agricultural uses, such as forestry and local amenities. In addition, the level of nitrogen produced by livestock through manure had also to be computed. This was done by collecting actual figures for livestock, again from the CSO series for 1948 to 1996, and then multiplying them by estimates of the nitrogen produced by each type of animal taken from estimates given in SAC (1998, pp. 106). From these estimates the total levels of nitrogen were converted to an index and used to complete the series given by Pitman (1992) for the period 1948 to 1996. From these data the quantities of nitrogen absorbed by crops and plants had to be deducted. This is a contentious issue, as nitrogen loss, or leaching, varies according to the levels of application of fertiliser, soil type and weather. In a review of the literature on this subject, Pitman (1992) offered an estimate of around 17% of all nitrogen applied being lost through leaching on arable land and 15% on grassland.

Levels of pesticide application were more difficult to derive as ADAS only began sporadic surveys of their usage from the early 1970s. Consequently, a moving average had to be constructed between surveys to derive a series. However, after experimentation, it was found that more convincing results were produced by assuming gradually declining usage from 1972 to 1948. This seemed reasonable as pesticide application rates in the 1940s and 1950s would have been low. Following Oskam (1991), no account was taken of the level of pesticide taken up by crops and plants.

Once quantities for nitrogen and pesticide applied had been derived, the most contentious stage of the exercise was to establish prices for non-market activities. A number of methods were available for this, notably: i) contingent valuation, which offered direct valuation of environmental damage, principally through survey work (Hanley, 1990; Johanson, 1987); ii) hedonic pricing, whereby goods were priced on the basis of their individual characteristics (Lancaster, 1966); iii) the use of marginal costs of environmental measures in other parts of the economy (Bressers, 1988); and iv) estimates made of the costs per unit for measures to be taken in the future (Oskam, 1991). This last method proved attractive as various environmental measures had recently been planned and costed and these provided valuations for environmental schemes which could be translated into the prices for these non-market goods.

Specifically, ENTEC (1998, pp. 14), in a Government commissioned evaluation of Nitrate Sensitive Areas, listed payments to farmers were given of between £60 per ha per year for

[1] The inclusion of positive externalities such as improved animal welfare would, of course, have the effect of increasing social productivity growth.

arable land, and £590 per ha per year for unfertilised, ungrazed areas, rich in diverse species. For nitrogen use, the median price given by ENTEC (1998) of £340 per ha was used. This is the level of subsidy paid for land in Nitrate Sensitive Areas, on which producers have agreed to limit nitrogen use to 150 kg/ha with optional grazing. Similarly, pesticide use was priced at the cost of running the organic aid scheme of MAFF. Whilst this cost varies by type of farming activity, generally the average cost of this is agreed to be £400 per ha over a five-year period (MAFF, 1998b, para. 8).

To be consistent with previous series, the valuations were converted to 1970 prices, using the agricultural output price indices, giving a figure of £81.5 per ha. A simple calculation was then performed to derive the full cost to society. For example, given the total amount of nitrogen applied in the UK in 1996, the amount lost through ammonia volatilisation and denitrification (at 17%) was therefore 111.7 kg/ha. Thus, the cost per kilogram of nitrogen use was £81.5 divided by this figure, which gives £0.73 per kg/ha. This was then multiplied by the arable area in the UK to give a valuation on harmful nitrogen loss in 1996. A similar method was used to value the environmental cost of pesticide usage. Taking the payment of £400 over a five-year period, this gave a cost per year of £80 per ha (or £19.2 in 1970 prices). Average pesticide applications in 1996 were estimated to be around 6.5 kg/ha. Dividing the cost by the amount of pesticide gave a figure of £3.1 kg/ha. This was then multiplied by the amount of arable land in the UK to give the total environmental cost of pesticide application. Combining both series, the projected costs of environmental damage for both arable and grassland for selected years are presented in Table 5.2. Aggregating these two data sets yielded the total costs of environmental damage arising from increased nitrogen and pesticide usage within UK agriculture.

Table 5.2. Cost of Nitrogen and Pesticide Application within UK Agriculture, £ million in 1970 prices

	Nitrogen Use		*Pesticide Application*	
	Arable Land	*Grassland*	*Arable Land*	*Grassland*
1948	237.36	6.21	86.18	2.37
1972	540.06	61.59	86.39	2.60
1995	458.29	88.83	104.75	1.26

There are obvious problems with the derivation of these costs. Specifically, median prices for nitrogen application were used. Changing these prices will obviously have an effect on the overall assessment of the cost of fertiliser and pesticide application. In addition, due to data availability, the series did not take into account the effect of positive externalities. This would have had the effect of depressing the earlier part of the series, whilst increasing the estimates from the late-1980s onwards when UK and EU policy makers began to emphasise environmental and social concerns.

Nevertheless, considering the costs of nitrogen and pesticide application, equation (15) could be used to derive what Oskam (1991) referred to as a 'social', as opposed to a 'private', TFP index. A comparison of the two series, using the Tornqvist method, are presented in Figure 5.1.

Figure 5.1. Comparison Between Social and Private Total Factor Productivity Indices, 1948-1996, 1970=100

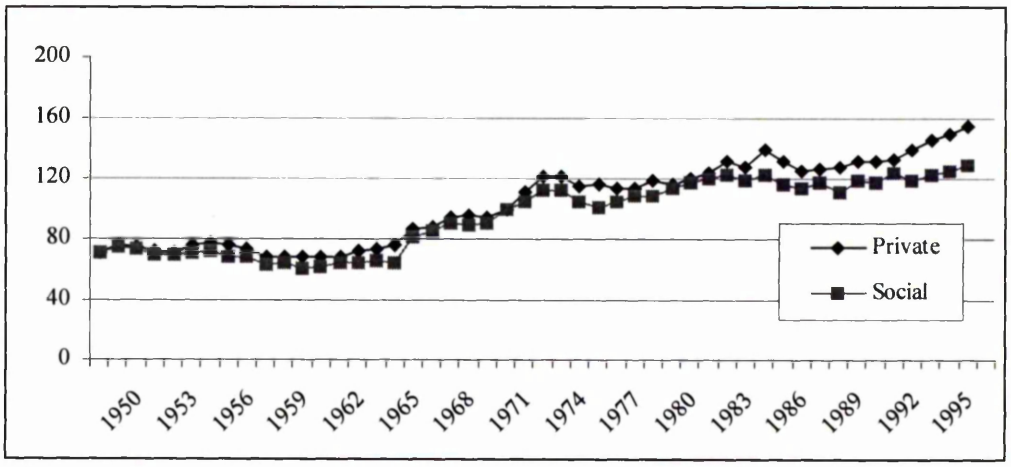


Figure 5.1 shows the series derived for total factor productivity within the UK, 'corrected' (social) and 'uncorrected' (private) for the costs of environmental externalities. What emerges is that the two series offer a contrasting view of agricultural growth after entry into the Common Agricultural Policy (CAP). Before 1972 the social TFP index seems to shadow the private series. Nevertheless, after 1972, whilst the private TFP grows steadily, the increasing use of pesticides and nitrogen fertilisers has a strong negative effect on the 'social' TFP measure. This agrees with findings on the growing environmental insensitivity of agricultural production, exacerbated by generous supports for increasing output, and so may present a more accurate indication of TFP levels, after accounting for environmental damage. The adjusted average annual rates are presented in Table 5.3 for the three periods 1948 to 1972, 1972 to 1996 and 1948 to 1996.

Table 5.3. Average Annual Growth Rates for Social and Private TFP, percent per annum

	Private TFP	*Social TFP*
1948-1972	2.37	2.11
1973-1996	1.09	0.69
1948-1996	1.73	1.41

Overall, the introduction of externalities reduced annual productivity growth by around 20% over the period 1948 to 1996, which is a more extreme decrease than that reported by Oskam (1991) for Dutch agriculture, but corresponds with estimates by Ball *et al.* (1994) for US agriculture. When considering between period differences, the contrast between private and social rates is more evident. The majority of growth for the social rate apparently occurred in the period before entry into the CAP. Whilst intensity was growing during that period, the share of non-market 'outputs' in respect of total outputs may have been minimal. This is in stark contrast to the period post-1972, when increasing use of nitrogen and pesticides appears to have cut radically 'social' growth rates by around 35%.

5.2.2. Agricultural R&D and Social Total Factor Productivity

Having derived the social TFP index, it could then be assessed against the previously constructed time series and used to give a truer return to public investment in agricultural R&D and advice. Consequently, using the same procedure as that outlined in Chapter 4, elasticities were ascertained. For brevity, the two public research series, both total *(R^{pbadv})* and non-basic *(R^{apadv})*, were included, along with the private sector research series *(R^{pv})*. Using equations (9) and (11) as a basis, various fits were found by minimising the Schwartz criterion. Equation (16), using a fourteen-year lag for total public research and advice, and a six-year lag for private sector research expenditure, was selected:

$$\ln \Delta P^{*}_{t} = A + \sum_{i=0}^{14} \alpha_1 \Delta \ln R^{pbadv}_{t-i} + \sum_{i=0}^{6} \alpha_2 \Delta \ln R^{pv}_{t-i} + \beta_1 \Delta \ln E + \beta_2 W + \mu \qquad (16)$$

Similarly, substituting the non-basic series for the total research and advisory expenditure series changed the specifications of the equation, giving lags of eight-years for the non-basic series and six-years for the private series. This is shown in equation (17):

$$\ln \Delta P^*_t = A + \sum_{i=0}^{8} \alpha_1 \Delta \ln R^{apadv}_{t-i} + \sum_{i=0}^{6} \alpha_2 \Delta \ln R^{pv}_{t-i} + \beta_1 \Delta \ln E + \beta_2 W + \mu \qquad (17)$$

Overall, fitting both equations (16) and (17) proved more problematic than for the private TFP series, with lower, but still significant, Durbin-Watson statistics and low t-statistics for the Weather variable. The results are presented in Table 5.4.

Table 5.4. Comparison of Regression Results using the Social and Private Total Factor Productivity Indexes, incorporating a private series

Variable		*Lag* *	*Coefficient* Eq(9)	*Eq.(16)*	*Eq.(11)*	*Eq.(17)*
Constant	*A*	-	3.08 *(12.99)*	3.11 *(15.24)*	3.06 *(12.32)*	3.12 *(14.60)*
Weather	*W*	-	0.004 *(2.44)*	0.001 *(1.42)*	0.003 *(2.69)*	0.001 *(1.26)*
Education	*E*	-	0.18 *(2.49)*	0.22 *(3.47)*	0.18 *(2.45)*	0.20 *(3.27)*
Total Public R&D and Advice	R^{pbadv}	14	0.05 *(2.90)*	0.05 *(3.22)*		
Public Applied R&D and Advice	R^{apadv}	8			0.06 *(2.61)*	0.06 *(2.88)*
Private R&D	R^{pv}	6	0.09 *(2.10)*	0.07 *(1.99)*	0.12 *(3.09)*	0.11 *(3.69)*
Adj. R^2			*0.97*	*0.98*	*0.98*	*0.98*
DW Statistic			*2.54*	*1.65*	*2.28*	*1.44*

t-statistics in brackets. Critical t values for 30 degrees of freedom, one-tailed test, are 90% = 1.31, 95% = 1.70
Lag is for equations (16) and (17).

In Table 5.4 actual results for the 'social' TFP series are compared against the elasticities derived for the private TFP series (from Table 4.13). However, it has to be conceded that the two series are not strictly comparable, as the private series had been derived by the Laspeyres procedure and the 'social' TFP series based on the Tornqvist formula. Nevertheless, what can be seen is that coefficients are generally unaffected for most of the variables, except for private R&D which shows a decrease of around 10% to 20% depending on which public R&D variable is used. It seems reasonable to suggest that the private sector, which is closer to the market than public R&D, would suffer the most decline in rates of return when productivity growth is reduced in the adjusted series. It would also seem reasonable to expect that the applied R&D and advisory series would be affected by a reduction in productivity growth rates, as this is near the market research. However, Table 5.4. shows no difference between coefficients for the 'private' and 'social' series for this variable.

The second stage in this process was to derive the internal rate of return on R&D investment. Following equation (14), the returns are illustrated in Table 5.5.

Table 5.5. Comparison of Internal Rates of Return for Agricultural R&D and Extension, percent

Period	*Publicly-Funded*				*Privately-Funded R&D*	
	R&D and Extension		*Applied R&D and Extension*			
	Private	*Social*	*Private*	*Social*	*Private*	*Social*
1948-1972	9.9	8.3	15.6	13.5	46.9	31.5
1973-1996	6.2	5.6	9.2	7.2	29.8	22.6
1948-1996	8.1	7.0	12.5	10.4	38.4	27.1

Table 5.5 compares the rate of return derived from using the 'social' TFP index against those derived in Table 5.1. Whilst the coefficients for the public R&D series were unaffected there is a still a decline in rates of return due to using the adjusted TFP and output series in the IRR calculations. Thus, rates of return for total public R&D and extension were reduced by 14% with the equivalent figure for applied R&D and extension of 17%, and for privately-funded R&D of 30%. Accordingly it seems reasonable to suggest that the variables with the highest returns are those which most obviously affect productivity change and they can be seen to have been most affected, when considering externalities. Thus, in the case of the private sector series, it emphasises the idea that the commercial sector is primarily responsible for negative externalities and this is the main justification for the public sector as a provider of non-market goods. In this sense, it would be expected that accounting for externalities in the productivity series would most affect private sector returns. This seems to be the case in the above results.

What should be noted is that rates of return also decrease after entry into the Common Agricultural Policy. This seems reasonable as the negative effects of intensification may be more evident with the introduction of support for unrestrained output growth as evidenced in the 1970s and 1980s. Using the above methodology, this should reduce the value of agricultural output net of environmental costs accordingly. This has critical implications for public R&D funding as, after 1972, rates of return for both series fall below the Treasury benchmark of 8%.

5.2.3. Summary

In assessing the quality of life within productivity indices, lack of data availability and the non-quantifiable nature of most life improving factors have led to the omission of the non-productivity effects within most previous analyses of agricultural productivity. However, accounting for some of the environmental costs caused by nitrogen and pesticide use reduced the rate of TFP growth within UK agriculture itself. More critically, it led to a reduction in the rates of return for R&D expenditures, when compared with the 'private' TFP series.

Significantly, it supports the contention that it is the private sector which causes negative externalities, as evidenced by the fact that the largest fall in returns after their removal from the productivity series is projected for private R&D. However, it has also had effects on the public R&D and extension series, which both suffer a decline in rates of return. In the case of both of the latter series, returns fall below levels, normally considered as satisfactory by the Treasury, after entry into the Common Agricultural Policy. Consequently, it seems when assessing the negative effects of agricultural production that justifications for continued public funding of R&D become less easy to support unquestioningly.

5.3. Research and the Advancement of Science

Another means of evaluating the effectiveness of agricultural R&D is via its contribution to the advancement of science. A variety of literature has emerged which analyses the level of publications or citations produced by a research institute or a country in general. This is explored in this next section.

With the withdrawal of near-market research and development funding, the focus of the public sector is increasingly seen to be the advancement of basic knowledge. Citation or publication analyses are the predominant means for measuring advances in this stock of knowledge. Bibliometric studies are concerned with counting the number of citations with which papers within a certain field have been accredited. Whilst it must be accepted that incorrect results are cited in papers aiming to change scientific views and also the academic climate may force more citation of own papers, citation analysis is presently the only way in which a measurement can be made of the effectiveness of investment into knowledge production.

May (1997) made international comparisons of research output in terms of the level of total citations and of a 'relative citation index' (RCI), which took a country's average number of citations per paper multiplied by the ratio of all citations to all papers. These findings for agriculture and related fields are presented in Table 5.6, which shows the country rankings in each of the main agriculturally-related discipline areas by citation and by May's quality index.

Table 5.6. Top Five Position of International Citations in Agriculture and Related Disciplines

Field	*By Total Citations*	*By RCI*
Agriculture	US,JP,**UK**,CA,GE	SE,**UK**,DE,CA,NE
Biology and Biochemistry	US,**UK**,JP,GE,CA	US,SW,SE,**UK**,GE
Molecular Biology	US,**UK**,GE,FR,JP	SW,US,GE,**UK**,IS
Plant and Animal Science	US,**UK**,CA,GE,AU	**UK**,SE,DE,US,AU

Source: May (1997).

On the whole the UK science base emerges as having a healthy position in most scientific fields, proving to be the World leader in areas such as plant and animal science, as well as having a strong presence in most fields related to agriculture. By comparison, of the other four leading OECD countries studied earlier, only the US has a similar presence as measured by the quality index and then only in fields related to agriculture, but not agriculture itself. Consequently, on this evidence it would seem that the changes in research funding and management in the UK have had little overall effect on the output of the science base, and may have improved its standing in several disciplines within the World.

5.4. General Conclusions

This study has taken the form of analysing three main outputs of a publicly-supported agricultural research system. Thus, by examining its ability to enhance the economic, social and scientific needs of the UK population, the effectiveness of public agricultural R&D funding has been explored. The conclusions related to these issues are outlined below.

5.4.1. Agricultural R&D and Productivity Growth

The improvement of agricultural productivity since the Second World War has accounted for an increased stability of production for farmers. Whilst this was necessary in the years immediately preceding the end of the Second World War, it is questionable whether it is desirable given the present circumstances of society in general. Consequently, framed against this background, *ex-post* analysis of how R&D expenditure affects productivity can only go so far towards providing a policy basis for continued, or indeed expanded, investment in the future.

Nevertheless, using the fairly standard methodology, rates of return on public agricultural R&D and extension reach socially acceptable levels. In relation to the first hypothesis, this must be seen as an argument for continued public sector support in this area. As regards previous arguments about the under-funding of agricultural R&D, the current econometric analysis is less supportive, with the nominal returns derived for total agricultural R&D and extension expenditure being, generally, around 6% to 10%. As this study showed, this may be due to the fact that basic research has not impacted in the same way on productivity growth and may require to be handled differently. However, by omitting basic research expenditures from the fitted relationship, the estimated returns to applied R&D may be overstated. This must also be true of the other elements of R&D activity within the TFP equations. Nevertheless, it is difficult from this study to presume that the estimated returns to R&D can be interpreted as indicative of either over- or under-funding. Similarly, arguments advanced for increased public R&D expenditure are flawed by the fact that there seems to be little agreement over the degree by which R&D expenditures should be increased. Work on assessing the level of the 'social optimum' for agricultural R&D have adopted various techniques which have furnished numerous wide-ranging results, questioning the viability of the exercise (see for example Knutson and Tweeton, 1979; White and Havlicek, 1982).

When comparing the public and private sectors, the internal rate of return for private investment in R&D was estimated to be far higher than public investment. This would suggest that private sector research has a stronger influence on productivity than the public sector. This could be interpreted as an indication that the increased reliance by policy makers on private sector R&D is justifiable in terms of its ability to enhance productivity. Within this it could also be argued that this evidence provides tenuous support for the belief that using public funds to subsidise industrial R&D would have been more desirable than supporting a public research base over the last fifty years. Thus, offering incentives and public contracts through open bidding, as opposed to institutionally funding science, may have been more successful. This may have had the added advantage of reducing 'crowding out' by public research institutes, which may have been making available technology at little or no cost, and so deterring commercial R&D investment in some areas. Accordingly, an effective means of research management would involve some form of commercial influence. One policy option may be to stabilise public funds, with the private sector contributing increasing levels of support, so bringing agricultural R&D closer to the 'social optimal'. Whether this has been and can be achieved is explored further in Chapter 6.

5.4.2. Changing Management and the Agricultural Research Service

Changes in the management of agricultural R&D have reduced rates of return to agricultural R&D investment. Whilst there are many problems with this interpretation, it does seems to indicate that public agricultural R&D has not benefited from increased Government influence over its management. Consequently, it seems to support the contention of scientists that autonomy in research and institutional funding of agricultural R&D is the best practice for the management of an agricultural R&D system.

In this sense, indications of the recent changes to science policy are perceived to have been mostly beneficial to UK agricultural research. This is predominantly because there has been some return to autonomous decision making within public research institutes. Whilst project funded for specific work, the bulk of publicly-funded agricultural research is now basic in nature. Scientists within institutions have, therefore, a level of control within the allocation of resources for pursuing scientific problems. In addition, research funding has now stabilised and is growing at a steady rate.

As regards the advisory service, there is some indication that the findings in Chapter 3 are supported. Coupled with R&D expenditure, public advice has only shown a low rate of return. Thus, this may favour increased reliance on the private sector to deliver technology transfer. This is because it is contended that it will be better targeted by commercial providers and better utilised by the recipients, who have to pay for this element of research. Similarly, in favour of privatisation, it has to be maintained that, within the context of changes in agricultural policy, it is difficult to argue for a continuation in support for productivity enhancing research by the public sector. As an increasing share of agricultural support is directed at non-agricultural activities, the refocusing of the public advisory services away from productivity goals must surely carry a greater justification for public expenditure, regardless of returns obtained in the previous period.

5.4.3. The Role of Non-Market Agricultural R&D

The role of the public and private sectors in agricultural R&D have been brought into sharp contrast by recent policy shifts towards non-output enhancing goals. Thus, the final hypothesis to be tested, namely that a trend towards lower agricultural productivity growth is a reflection of an increasing proportion of research funding being directed to improving the 'quality of life' rather than 'wealth creation', becomes prominent when analysing rates of return to agricultural R&D investment.

From the evidence outlined above, it seems the inclusion of certain externalities have had negative effects on measures of productivity, as well as on returns to agricultural R&D. What emerges strongly when analysing these returns is that the private sector has apparently been responsible for the majority of externalities. Hence it emerges that the role of the public sector becomes critical as a provider of public-good technology which aims to reduce externalities. Essential to this is the adoption process. On the evidence of the past 50 years it could be argued that the public sector has failed to transfer this technology to the private sector for exploitation. Thus, it seems that there is a need for both sectors to cooperate more in future on reducing the social and environmental externalities of technical progress.

In terms of overall effectiveness, this study has raised two key questions over the direction and role of publicly-funded agricultural R&D. First, in terms of the changes to science policy, the continuation of public funding across the board for agricultural R&D has to be questioned. This was explored in Chapter 1. Second, it seems that a major factor in increasing the effectiveness of public R&D will be the private sector. Therefore the role which the private sector could play in public research agendas has to be investigated further. This is explored in Chapter 6.

CHAPTER 6

PUBLIC AGRICULTURAL R&D
AND THE PRIVATE SECTOR

6.0. Public Agricultural Research and the Private Sector

Increasingly, the public agricultural research service has relied on the private sector for its funding. This trend accelerated from 1979 onwards, when the Thatcher administration initiated a series of measures aimed at reducing the burden of public expenditure. Within science policy these measures have found expression in two ways, namely i) forcing the public sector to seek external money by reducing funds for commercially relevant near-market research and ii) refocusing the markets for public research by encouraging increased exploitation of the science base through links with commercial companies.

Consequently, it seems the private sector has been forced to take on the burden of displaced public funds. Thus, the findings of the previous chapter, which outlined the roles that public and private sectors should play, become critical to the success of Government science policy. With the removal of public funds from certain areas of the agricultural research service, the private sector needs to step into the research areas which have suffered through these cuts. To understand this firstly requires an understanding of the nature of technology creation. This is outlined below.

6.1. The Nature of Technology Creation

Agricultural R&D can be conducted by a large number of bodies, both public and private. Specifically, Pray and Echeverria (1991) have identified four major groups from which agricultural technology can emerge. These are presented in Table 6.1.

Table 6.1. Potential Sources of Agricultural Technology

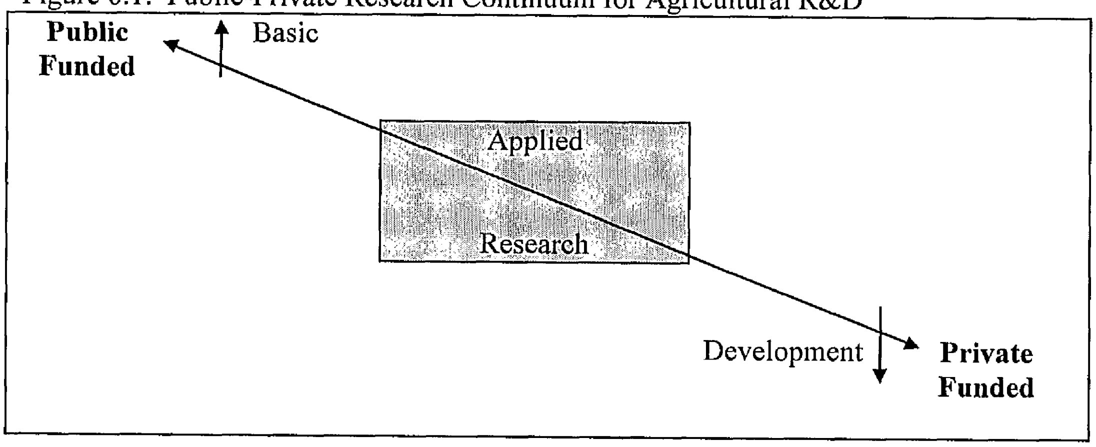
	Institutional Location	
	Domestic	*Foreign*
Public	Ministry Research Institute Research Council University	Ministry Research Institute University International Agricultural Research Institute
Private	Co-operative Foundation Commodity Institute Plantation Processing Company Input Company	National Company Multi-National Company Co-operative

Source: Pray and Echeverria (1991)

Consequently, it seems that R&D can emerge from both profit and non-profit orientated institutions either at home or abroad. However, whilst the processing and input industries are responsible for introducing the majority of technological innovations, they rely on exploratory work which could have emerged from either a public research institute or a commodity board funded by farmers. Consequently, even in areas that are driven predominantly by the commercial sector, such as in mechanical or chemical research, there may be some degree of public sector R&D work involved. This diversity has been further emphasised by Thirtle and Echeverria (1994), who found that, out of a possible 36 theoretical combinations for producing technology, only 3 were conducted solely by either a public or private sector body. This was because, with the privatisation of research institutes, the existence of levy funding, and public investments in private research institutes, the distinction has become blurred between public and private sector agricultural R&D.

The inference of this work is that the private sector should not be seen as a substitute for public funding, but as a complement. This is emphasised by Evenson (quoted in Pray and Echeverria, 1991), who stated that the role of the private sector was to conduct the majority of work on 'usable technology', whereas the public sector largely produced 'pre-technology'. In addition, he identified an area of research, termed 'prototype technology', with which both the public and private sectors would be concerned, and their level of involvement was dictated by the size and technological competitiveness of markets. Therefore, there seems to be a 'public-private research continuum', in which both sectors have clearly defined roles at the extremes, i.e. the public sector in basic research and the private sector in commercial exploitation, with blurring and overlap of roles in-between. This conceptualisation is illustrated in Figure 6.1.

Figure 6.1. Public-Private Research Continuum for Agricultural R&D



The diagonal line in Figure 6.1 indicates the source of R&D funding, whereas the vertical lines reveal the amount of expenditure by sector. Accordingly, as basic research cannot be directed, i.e. towards either productivity-enhancing or public-good research, the majority of its funding emerges from the public sector. However, there is some overlap with the private sector because, in areas such as biological and chemical research, the private sector conducts some exploratory work. Similarly, the reverse is true for development work. The shaded area, consisting of applied strategic and specific work, can be considered as similar to Evenson's 'proto-type technology'. That the activities between the public and private sectors are less delineated within this category leads to a confusion over their respective roles. Government policy towards commercialisation relies on the expansion of the private sector within this shaded area, and the public sector's role is seen as supporting this work.

Accordingly, the central concern of this chapter is to establish the role of the private sector and its relationship with the public agricultural research system. Specifically, it seeks to establish whether their roles have changed since the mid-1980s. Firstly, it attempts to assess the attitudes of the private sector towards public research institutes, and whether public science is a viable base from which innovations can be developed. This is followed by an attempt at quantifying the level of transference of public knowledge through collaborative activity and the public domain. The second part of this chapter has the aim of establishing the role and trends of private R&D activity. This leads directly from the work in the previous chapter on justifications for public sector R&D and seeks to establish whether the model developed there conforms to expectations regarding private agricultural R&D. Similarly, it aims to estimate the overall trends in expenditure after the mid-1980s, in order to establish whether the private sector has responded to Government policy initiatives for increasing the presence of commercial expenditure directed towards UK agricultural R&D.

The majority of this chapter relies on the results of a survey conducted on the UK agricultural sector during 1996. The methodology of this survey was outlined in section 3.2.3.1. Whilst this gave an understanding of research expenditures, it also presented an opportunity to explore the activities of the private sector in-depth. The full questionnaire is given in Appendix 2 and the results are given below.

6.2. Collaborative Activity Between Public and Private Sectors within UK Agricultural R&D

The more specific transfer of research emerges when some form of collaboration occurs between the public and private sectors. Whilst links have occurred throughout the history of the agricultural research system, they have recently formed an intrinsic part of Government science planning. By introducing a number of collaborative schemes to provide a greater incentive for firms to invest in co-funded research, it has sought to increase technology transfer to the commercial sector. Thus, the next section is concerned with the attitudinal aspects of this activity. Specifically, it aims to outline reasons for firms becoming involved with the public sector.

However, before this is done, a definitional point has to be made concerning the suppliers of public agricultural R&D. This is predominantly conducted by Biotechnology and Biological Science Research Council (BBSRC) institutes and units. Similarly, in Scotland, their equivalent are the Scottish Agricultural and Biological Research Institutes (SABRI). In addition, the agricultural colleges and the Departments of Agriculture within Universities conduct agriculturally-related research, often with funding from the BBSRC. The Government also has a collection of establishments that conduct statutory research or in support of its policy goals. However, recent moves to privatise institutes in the public sector has led to a confused situation. Thus, when the survey was conducted in 1996, ADAS was still in the public sector. Similarly, the Horticulture Research Institute still regarded itself as a public sector research establishment (HRI, 1996) and was considered as such in terms of the survey analysis.

6.2.1. Attitudes to Collaboration

Firms were asked to give their opinion on linking with the public sector. The firms which had undertaken some form of collaboration were asked to give an indication of their reasons for involvement with public agricultural research institutions. Similarly, those firms which had chosen not to become involved with the public sector were asked to give their reasons. The reasons for collaborating given by firms are presented in Figure 6.2.

Figure 6.2. Motivations of Commercial Firms for Collaboration with the Public Sector, percent

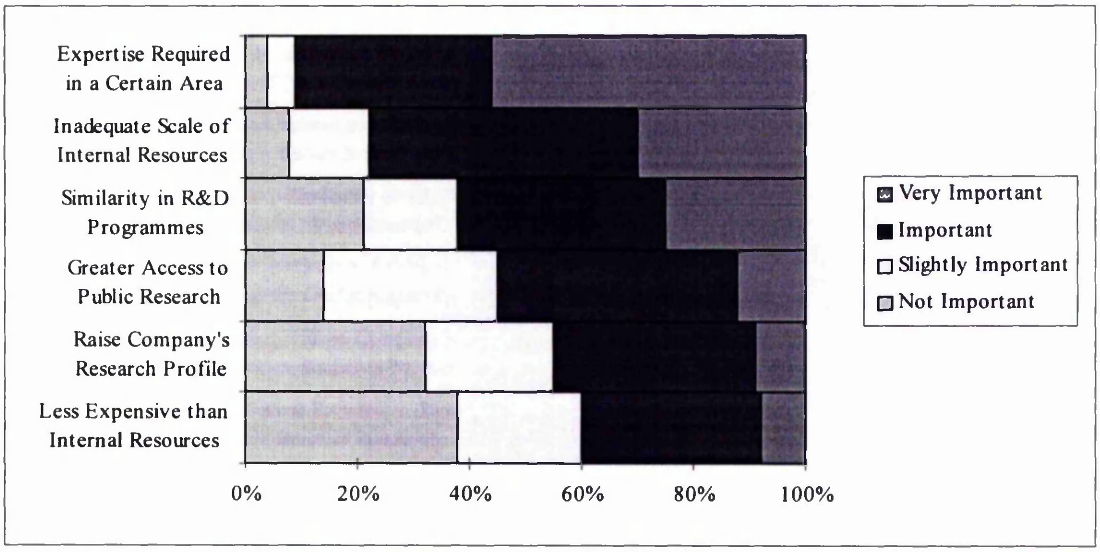


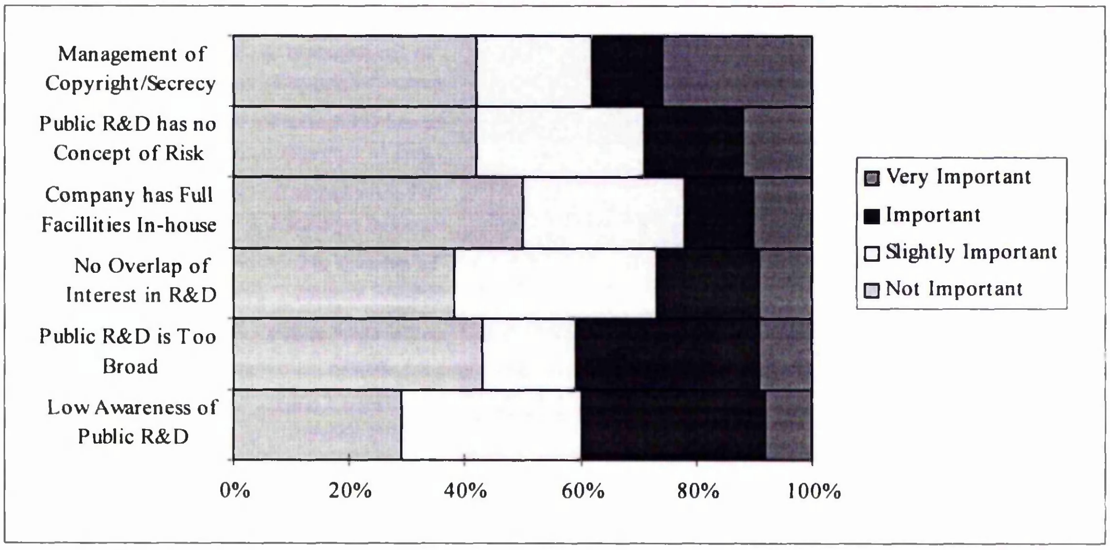
Figure 6.2 is concerned with motivations for collaboration. Considering solely the areas that firms identified as 'Very Important', the most prominent reason that emerged for using the public sector was its expertise in a specific area. In terms of reasons having little bearing on the decision to link, around 25 respondents did not consider public research less expensive than their own in-house activities. Similarly, 19 responses did not consider linking as a means to raising their own research profile.

The predominant reason for involvement with the public sector therefore seems to be the acquisition of expertise in a specialist area. The public institutions offer a very specialised service, giving in-depth expertise in limited subjects, which equates with the aims of the BBSRC's re-organisation, which focused on creating a base for multi-disciplinary research (BBSRC, 1994). Similarly, the Higher Education Institutes have undergone changes in their organisation, re-focusing scientific and technological departments to increase their relevance to the needs of industry (Charles *et. al.*, 1988). It therefore seems that the changes have developed a more focused R&D base for exploitation of private agriculture.

Firms indicated that size of internal resources was not an issue in collaboration and this suggests that the majority of firms do not consider themselves sufficiently restricted by size to make it a conscious decision to become involved with the public sector for other reasons. Instead similarity in research seemed to be rated an important reason for collaboration. This point was analysed by sector and, whilst high similarity was evenly voiced by most sectors, agri-engineering proved an exception with only 27% of all firms claiming any similarity between their work and that offered by the public sector. A reason for this could be the agri-engineering sector conducts a high degree of development work in comparison to other sectors (see section 6.4). As such, this seems to be one indication that research into agri-engineering may have suffered the severest decline, following the cuts in public research under the near-market policy. However, it has long been considered that the engineering sector has been the least able to benefit from public agricultural research (Lesser and Lee, 1993). Moreover, research work on vehicles is highly appropriable and it is questionable whether public research should intervene in this field.

It is interesting to examine why firms elected not to initiate collaborative arrangements with public research institutions. Figure 6.3 presents schematically the reasons given by firms for not becoming involved with public sector research institutions.

Figure 6.3. Obstructions to Collaboration of Commercial Firms for Collaboration with the Public Sector, percent



However, the results are less clear with around 40 to 50% of firms stating that all reasons given in the survey were not important. Nevertheless, what does emerge is that, when considering the category of 'very important' on its own, the predominant impediment to collaboration is the management of copyright and confidentiality within public institutions. The environment and culture of public R&D is such that secrecy may be difficult to maintain. Similarly the length of time needed to negotiate contracts is seen as causing a prohibitively high legal cost on the type and level of collaboration conducted. Any increase in collaboration between public and private R&D sectors also poses a problem for the direction and objectives of public R&D. The multi-disciplinary nature of public R&D, which encourages discussion between researchers, may be hindered by concerns over the management of secrecy. Moreover, a potential conflict between the support of the public science base and the encouragement of funding could emerge. As the Government aims for more influence by industry (MAFF, 1996), there is a danger that the multi-disciplinary element of public research will be affected adversely.

6.2.1.1. Summary

The attraction of public sector collaboration is that it offers a high level of expertise in specialised areas. However, a potential conflict exists as public R&D, which encourages discussion between researchers, may hinder collaboration with the private sector through concerns over the management of confidentiality.

Nevertheless, what the survey of private companies revealed was that the size of public R&D may be less important than the quality of research produced. Thus, the success of collaborative research policies depend on a healthy public research base, producing relevant agricultural R&D. Consequently, the next section examines the attitudes of firms towards public R&D in these terms.

6.2.2. Relevance and Quality of Public Agricultural R&D

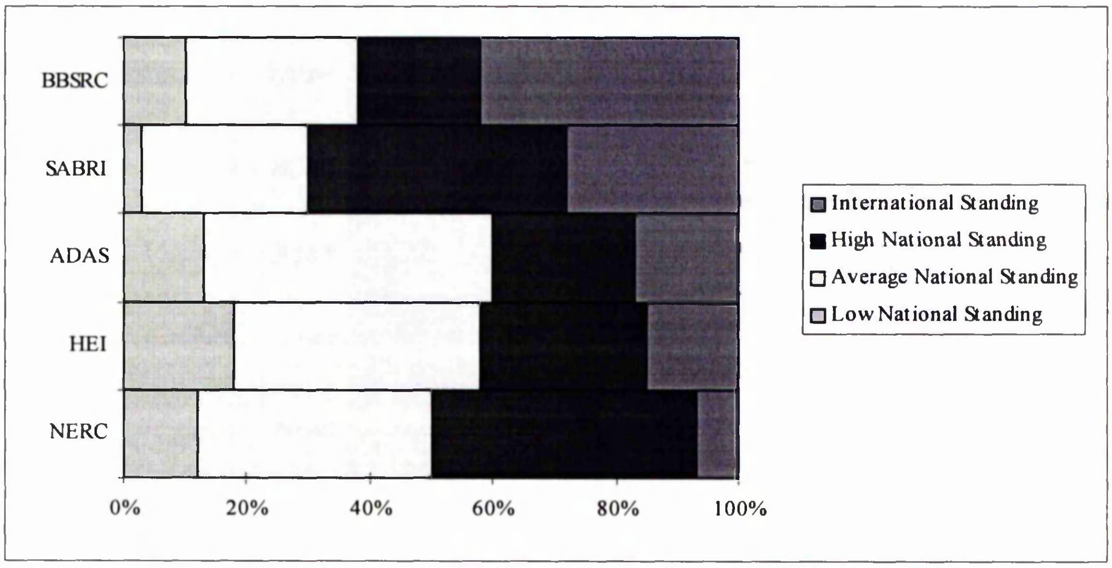
To evaluate how firms viewed the quality of public agricultural R&D they were asked to indicate how they perceived each main supplier of public agricultural R&D in terms of international or national standings[1].

The Biotechnology and Biological Science Research Council (BBSRC) and the Scottish Agricultural and Biological Research Institutes (SABRI) were rated highest with around 30 to 40% claiming their research to be of an international standing. In contrast, the Higher Education Institutes (HEI), the Agricultural Development and Advisory Service (ADAS) and especially the Natural Environment Research Council (NERC) institutes were most likely to be rated of low research standing. This seems reasonable, as the BBSRC and SABRIs are strongly focused on agriculture, whereas the NERC provides research directed

[1] See Appendix 2: Question 21

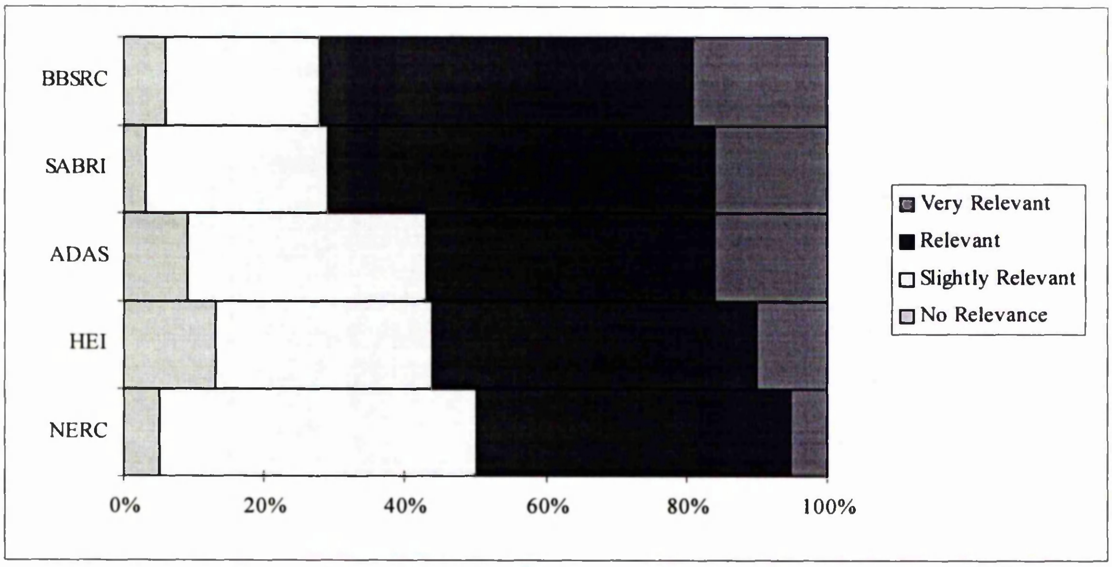
to the improvement of the environment, which would not be of importance to the majority of firms in the agriculture sector. These results are presented in Figure 6.4.

Figure 6.4. Quality of Public Agricultural R&D by Research Body, percent



The firms were also asked for views on the relevance of the research produced in public institutes and the responses are presented in Figure 6.5.

Figure 6.5. Relevance of Public Agricultural R&D by Research Body, percent



Again, the BBSRC and SABRI institutes were perceived to be producing work which was highly relevant to the private sector. However, ADAS, with the majority of its work in applied fields, was also perceived to be producing work which was very relevant to around

20% of companies in the agricultural sector. About 10% of respondents rated the output from Higher Education Institutes of little or no relevance. However, the bulk of research work in the HEI sector is basic research and therefore its potential for commercial exploitation may not be so apparent to agricultural firms. A further indication of the quality and relevance of public agricultural research is the rate of 'take-up' of research results from the public domain. This is discussed below.

6.2.2.1. Public Domain Research

Most publicly-funded research of relevance to firms emerges through the public domain. Thus, the majority of basic or strategic investigations into products and processes are generally disseminated in academic journals or publicly available reports. However, as this is usually considered to be background research, it is difficult to assess its impact on the commercial sector. Accordingly, in order to measure its effect, firms were asked if they had made use of the results of public domain research in the last three years. The data collected gave a rough indication of the level of 'take-up' of public domain research. The results are shown in Table 6.2.

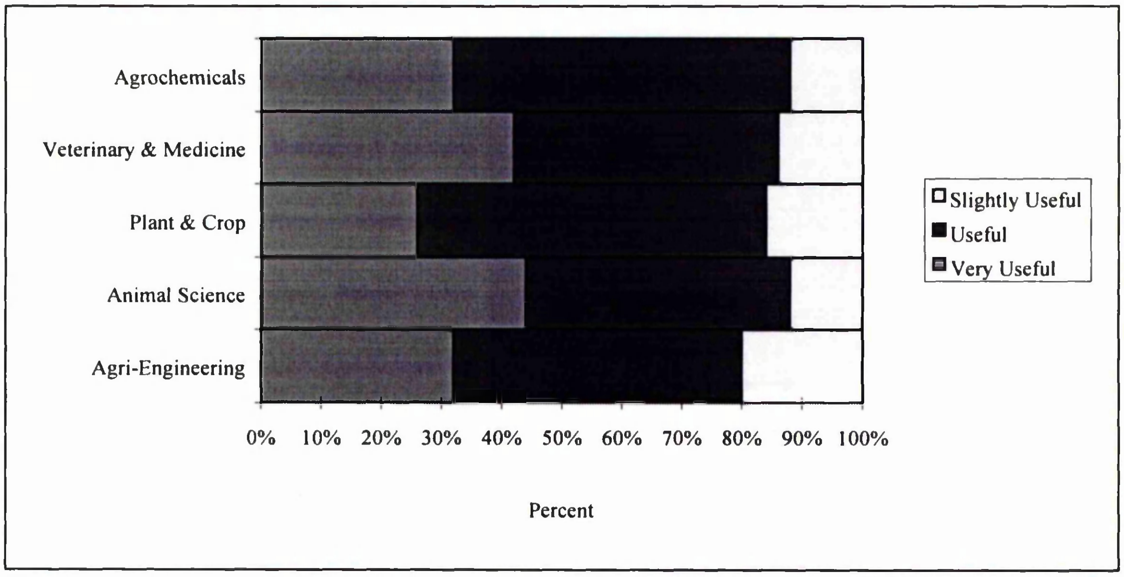
Table 6.2. Level of 'Take-Up' of Public Domain R&D, percent

Sector	*Yes*	*No*
Agrochemicals	67	33
Veterinary and Medicine	61	39
Plant and Crops	67	33
Animal Science	71	29
Agri-Engineering	32	68
Total	62	38

In total around 60% of companies claimed to have embodied public domain research into their products. Disaggregating between sectors shows that, whilst most sectors hover around this 60% mark, agri-engineering has a lower level of take-up. It can be no coincidence that the high level of development research needed within this sector means that public R&D was highly vulnerable to cuts due to the near-market policy. Therefore, whilst the public sector produces basic research on engineering, this does not seem to have been valued successfully by the commercial sector.

Firms were then asked to state how useful they found publicly-funded research in terms of the technical knowledge gained or of new product development. The percentage for each sector for those firms claiming to have found public research useful in some way is shown in Figure 6.6.

Figure 6.6. Usefulness of Public Domain Research to the Private Sector, percentage of firms making use of public R&D



Most firms claimed in the survey to find public domain research 'useful' to some degree. However, only in animal science and veterinary and medicine was public R&D rated as 'very useful' by a significant proportion of private firms. Consequently, it seems that publicly-funded work on pharmaceuticals and the physiology of livestock is showing some level of commercial relevance. Nevertheless, a more revealing category seems to be the number of firms who found agricultural research only 'slightly useful'. Animal science had the lowest level of dissatisfaction with public research, which seems to imply that it is the most successful area of public research. However, whilst the plant and crop sector showed the highest level of firms finding public domain research useful, it also has one of the highest percentages claiming it to be only 'slightly useful'. Similarly, the same tendency is seen with agri-engineering, with around 20% stating that public research was of limited value. This may indicate a misdirection in research within these areas.

6.2.3. Summary

The public research base seems to have some degree of influence on linkage with private research activity. Thus, the low levels of privately-funded basic research recorded may indicate that industry prefers to modify internally research produced by the public sector. High take-up rates of around 60 to 70% were recorded for most firms within the agricultural industry, indicating highly effective and targeted basic research. The exception to this is agri-engineering which, with its heavy reliance on development work, implies a divergence between present-day private and public R&D priorities. In terms of the recent changes to the research system, there is some indication that the relevance and quality of UK agricultural R&D are highly regarded by most commercial firms. This is especially obvious with regard to the BBSRC and SABRIs.

Whilst the assessment of attitudes may be indicative of the views of private sector firms of public sector research, a more quantifiable effect is the level of exploitation of the public research base through formal linkage mechanisms. Thus, the amount and type of contract work, as well as collaboration and sponsorship between the two sectors gives an indication of the direct economic effect of publicly-funded agricultural R&D. Consequently, the next section looks at collaboration in terms of expenditure levels and type.

6.3. Level of Collaboration Activity

Companies were asked to give an indication of their level of involvement with public institutions in respect of their agricultural research activity during the three years from 1993 to 1996. Overall, 65 firms, 55% of the total, claimed to have had some form of association with public agricultural research institutions. The remaining 45% consisted of 45 companies conducting no external research at all and 8 companies that only had interests in foreign public sector research facilities. When questioned further the majority of these latter companies cited organisational reasons for their decision. However, several large firms did mention the lack of expertise available in the UK for certain aspects of their research activities.

Firms, which had developed links with the public sector, were asked to state the percentage of total R&D expenditure given to collaborative work. This involved indicating a rough estimate within ranges[2] and, as such, the results have been presented in terms of a lower and upper limit. The results of this analysis are shown in Table 6.3.

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[2] See Appendix 2: Question 7

Table 6.3. Private Sector Research Expenditure on Activities Conducted with Public Agricultural Research Institutes, £ million and percentage of total R&D expenditure

	R&D Spend, £ million	*Collaborative Research Spend, percent*
Agrochemicals	6.8 - 10.7	8 - 11
Veterinary & Medicine	5.2 - 7.9	32 - 29
Plant & Crops	2.0 - 5.1	6 - 10
Animal Science	3.8 - 7.8	25 - 28
Agri-Engineering	1.1 - 1.2	8 - 7
Total	18.9 - 32.7	11 - 15

What emerges is that around 11 to 15% of total private research spend was directed towards collaboration. In absolute terms this was a total spend of between £19 million and £33 million pounds. Therefore, in proportion to their total R&D spend, the majority of collaborative activity seems to have been conducted by firms in animal science or veterinary and medicine. This is confusing as, whilst the veterinary and medicine sector emerged as one of the most research intensive sectors, animal science ranked low in terms of total R&D research expenditure. The least active were firms in agri-engineering, reinforcing the impression that there is some incompatibility in research priorities between the public and private sectors in this area. However, whilst the above table reveals levels of collaborative activity, it does not show the areas in which the private sector is involved. This is the concern of the next section.

6.3.1. Type of Collaboration

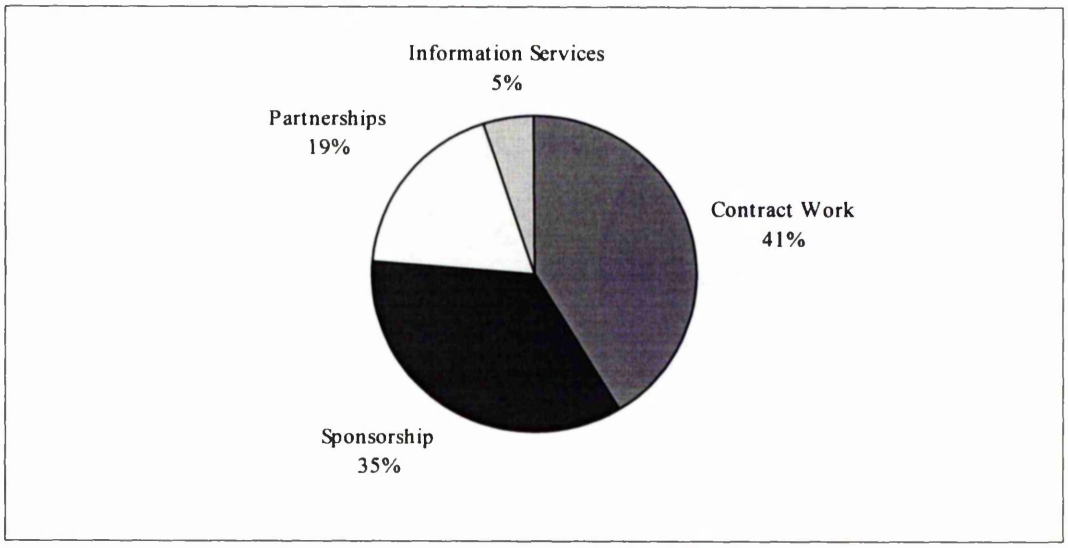
Activity between the public and private sectors can encompass a number of different formal links. Collaboration usually exists as a one-way activity between a firm and a public sector research institute, e.g. a contract with a specified outcome. However, other interactions have emerged, for instance, a BBSRC and HEI establishment working with a consortium from industry. Collaboration can also be conducted with international public or private institutions. Nevertheless, within this analysis any collaboration that involves a predominantly UK based private sector establishment and a UK public sector institution qualifies for inclusion. Accordingly, there are four types of collaborative activity could be identified, namely i) sponsorship, ii) collaboration, iii) contract work, and iv) the use of information services. These are defined in Table 6.4.

Table 6.4. Type of Formal Collaboration Activity

Type of Collaboration	*Definition*
Contract Work	The hiring of Government facilities to undertake a specific activity for a firm, e.g. field trials, micro-biological analysis and consultancy work.
Sponsorship	Funding research in public institutions for new product or process development, or the modification of an existing product. The commercial sector usually invests all or the majority of the expenditure and has control over the direction and the rights to the research.
Partnerships	The sharing of research activity between the commercial and public sectors to generate new technological information. The results of research partnerships that are exploited are usually shared on a proportionate basis to investment.
Information Services	The use of library facilities, referencing of compounds and routine consulting such as disposal of chemicals.

Companies, which had conducted some collaborative work, were asked to give details of their activity with public institutions by type, based on these definitions. The numbers of firms involved in collaborative activity of some kind were aggregated and, as some firms conducted activity in more than one sector, the results were converted into percentages. These data are illustrated in Figure 6.7.

Figure 6.7. Commercial Firm's Activity with Public Agricultural Research Institutions, percent

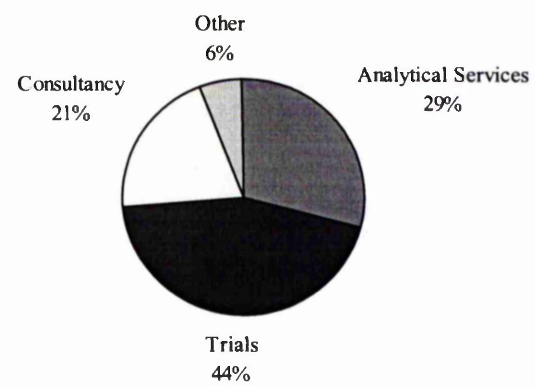


Contract work includes analytical services, such as spectrometry and biochemistry, testing and trials, as well as consultancy. In total 52 firms undertook some form of contract work, which proved to be the most popular use of the public sector. Around 45 firms, 35% of the total, conducted some form of sponsorship. Partnerships, consisting of a number of different Government schemes are intrinsic to commercial exploitation of the research base, as they involve the linkage of funds and expertise between public and private sectors. However, only 19% of the sample conducted some form of true partnership activity. Lastly, limited use seemed to be made of information services, such as library and computer databases. Only 6 firms claimed to use public research institutions for such a service. Each of these forms of collaboration are explored in more depth below.

6.3.1.1. Contract Work

Contract work usually involves routine research methods and makes use of the facilities of a public sector research institute. Therefore, the work has little pretence to expand knowledge frontiers. The percentage breakdown of contract work placed by the private sector in public research institutes in 1996 is outlined in Figure 6.8.

Figure 6.8. Total Firm's Contract Work with the Public Sector, percent

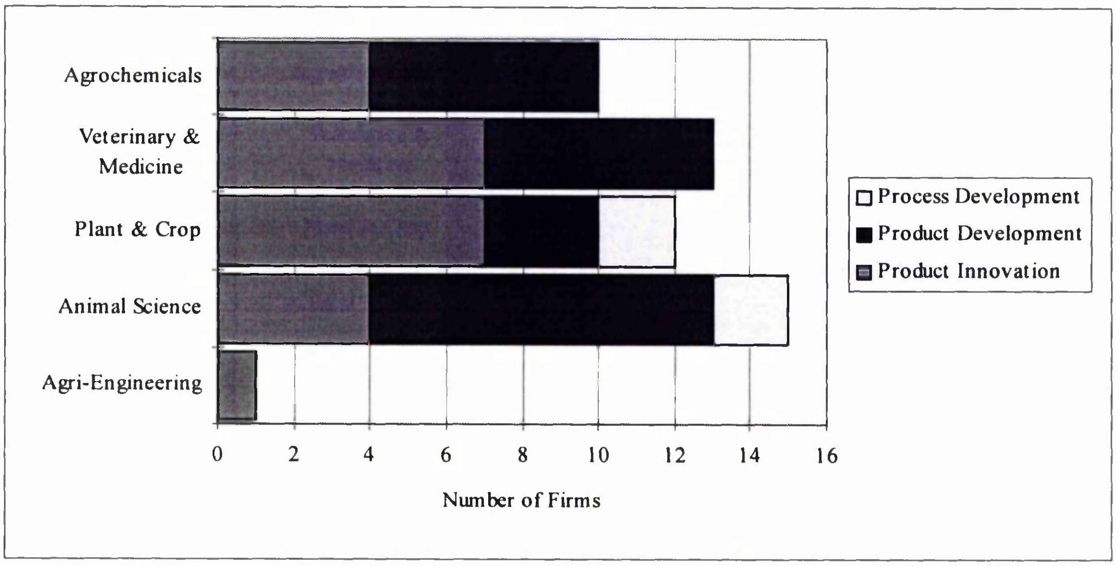


Analysing this in more detail reveals that the majority of firms, around 44%, conducted trials with the help of public sector research institutes. This consisted of both testing, e.g. soil analysis, and conducting trials for new products and fieldwork, such as growing newly developed seed varieties. Around 29% of firms contracted the public sector for analytical services, which included the use of biochemistry and microbiology activities, as well as data processing and mass spectrometry. Consultancy formed around 21% of all firms' contract work, whereas only 6% were reportedly concerned with other activities, predominantly the licensing of public research.

6.3.1.2. Sponsorship

Sponsorship activity by commercial firms was divided into three categories for survey purposes, namely i) process development, ii) product development advice, and iii) product innovation. In terms of the first category, around 48% of firms had been involved with product development in the last three years, which was defined as *'using the public sector for the development of a firm's current product to realise new opportunities'*. Similarly, 44% of firms had used the public sector within the last three years for product innovation. This involved employing the public sector for the initial exploratory research before its commercial development within the firm. However, only a small proportion of firms (8%) had links with public institutes in order to conduct research into process development. This involved modifications to previous mechanical and chemical processes. Figure 6.9 summarises these three categories of sponsorship activity, disaggregated by sector.

Figure 6.9. Number of Firms Involved in Sponsorship with Public Agricultural Research Institutes



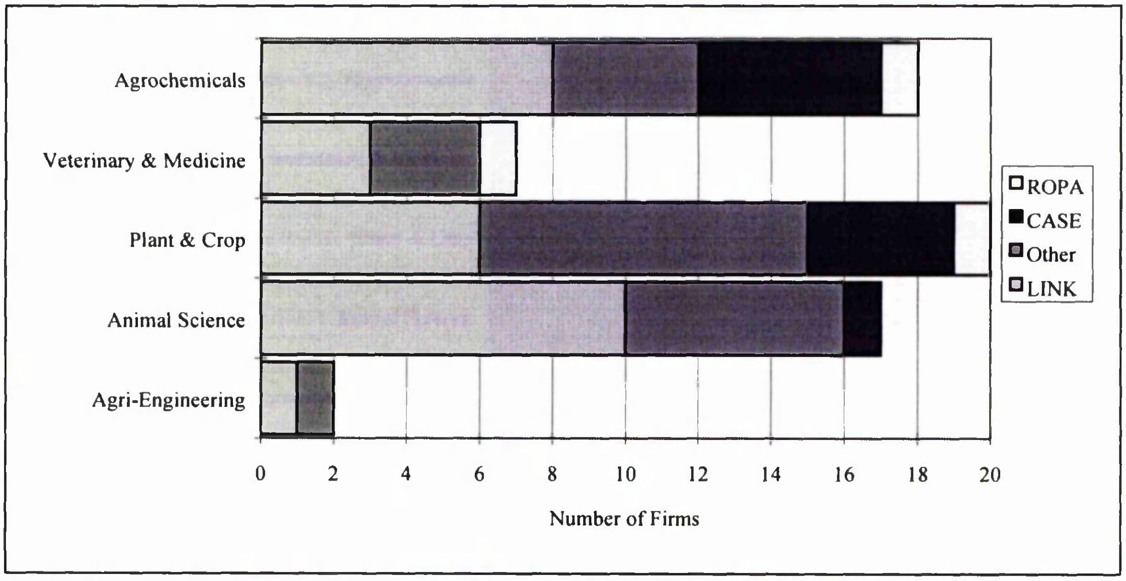
The most prominent sponsors of public institutions, in respect of product development, seem to be those operating in the animal science sector. Thus, considering that private companies involved in animal science have a low level of research expenditure, it is understandable that they would only seek public sector assistance as a means of helping to modify present products, with little consideration for more fundamental changes. Contrary to this, the veterinary and medicine sector shows the highest level of involvement in respect of using public research institutions for product innovation. These differences in the nature of collaborative activities may have a logical explanation. Whilst firms with low research intensities, such as those in animal science, see the public sector as a means to modifying products, firms with high R&D intensities, as those in veterinary and medicine sectors, invest the most in active research with the public sector. This is also evident in the plant and crop sector, which has a high level of involvement with public research institutes in respect of product innovation.

6.3.1.3. Partnerships

Firms were asked if they were involved with any Government schemes aimed at forming partnerships between both sectors. The LINK scheme, a programme which has been in place for a number of years, proved the most popular amongst the firms surveyed, with 43% saying that they participated. The Co-operative Awards to Science and Engineering scheme (CASE) ranked second, with 16% of firms having some involvement. However, the majority of sectors had a number of schemes specific to their area and few conclusions can be drawn. Realising Our Potential Awards (ROPA) are relatively new and only 5% of firms surveyed had any involvement with this scheme. Of those categorised as 'Other' the most prominent included the BBSRC Collaboration with Industry and Teaching Company Schemes.

In total, the sectors involved in the largest numbers of partnership schemes were the plant and crop (20 firms, 31% of the sample) and the agrochemical sectors (18 firms, 28% of the sample). This again may indicate that these sectors, which have high research intensities, are most likely to have the greatest involvement in research partnerships with the public sector. These results, disaggregated by sector, are presented in Figure 6.10.

Figure 6.10. Number of Firms Involved in Partnerships with Public Agricultural Research Institutes



6.3.1.4. Information Services

Only a small proportion of the companies within the survey claimed to have used information services as part of their research. The majority of firms that used these services (63%) sourced them from within the UK. Use of non-UK information was stated to be due to either organisational reasons or the specialist nature of problems requiring specific databases or services. Around 28% of companies reported that they used European information services, e.g. CORDIS or Biotechnology Registration, whereas only 9% referred to non-European services. However, the very recent establishment of web-sites by UK research institutions, which offer comprehensive research services, may have improved the level of public R&D information services used, compared to the level observed in the survey.

6.3.1.5. Summary

In terms of actual commitment to collaboration, an average of 11% of total private research expenditure is devoted to this activity. Furthermore, it emerges that firms with high research intensities were spending significant proportions of their budget on work directed towards creating more fundamental knowledge, whereas the work of those with a low research expenditure seemed more adaptive in nature.

Overall the majority of work is conducted through contracting, whereas activities, which involve more scientific explorations such as sponsorships and especially partnerships, are conducted less by the commercial sector. This may suggest that the public sector is not being used for its expertise, so much as a cheaper source of research facilities. Thus, it questions how the commercial sector views publicly-funded agricultural research institutes. Specifically, Government science policy is based on the assumption that the commercial sector understands public science and its ability to improve industrial competitiveness. However, attitudes towards the public sector do not seem to reflect this. Consequently, there is a need to establish whether trends in collaborative activity support this belief. This is the concern of the next section.

6.3.2. Trends in Collaborative Activity

Data from the public sector on the level of private industrial funding is difficult to obtain. Explicit figures from the HEI's generally or for agricultural departments specifically are not available. Similarly, ADAS, whilst in the public sector, does not reveal levels of industry funding. However, the BBSRC gives a figure for overall external income, which includes money from levy boards and European Government contracts. The BBSRC has had a growing percentage of its income emerging from external sources over the last ten years (see Table 6.5). However, whilst industry funding of public R&D has increased, it is only nominal and to some degree this tallies with the survey findings discussed earlier.

Table 6.5 Level of External Income Raised by BBSRC Institutes, £ million

	1986/7	*1991/2*	*1993/4*	*1995/6*
Industry Contribution (£ M)	5.9	6.5	10.8	12.3
Percentage of Total Income	*5*	*6*	*7*	*8*

Source: AFRC (Various Years)

When surveyed the large companies were asked to say whether they were spending a higher proportion of their total research budget on public sector collaboration than ten years ago. Around half, 46%, were spending more, with 42% seemingly unaffected by the changes and 12% spending less on UK research collaboration. Accordingly, it seems that, whilst around half the firms are increasing their investment, in absolute terms their actual expenditure on collaboration only represents a small increase from ten years ago. Consequently, from the above evidence, the policy mechanisms are being taken up, but the slow rate at which linkage has occurred over the decade strongly indicates that the mechanisms for collaboration have not been a dramatic success and have not fully compensated for the reduction in public sector funds for the public research institute.

6.3.2.1. Summary

Trends in collaborative activity have shown only a nominal growth since the cuts in near-market expenditure occurred. This seems to indicate that the Government policy for collaboration has not been particularly successful. Accordingly, there is a need to establish how private sector expenditure has changed recently. Thus, the remainder of this section seeks to answer the issues presented in the previous chapter. Firstly, in relation to the model outlined in section 5.3, the programmes of private sector research can be analysed to assess whether the assumed role for commercial activity is being undertaken. Secondly, in view of the spending activity of the private sector, an evaluation of the trends in research activity can be made. Overall, this will allow an understanding of whether the private sector is responding to the Government initiatives regarding commercial R&D funding initiatives from the mid-1980s onwards.

6.4. The Role of Private Sector Agricultural R&D in the UK

In section 3.2.3.2. the level of private sector research expenditure was estimated from the survey at between £365 and £507 million for 1996. In addition, firms were asked to estimate the proportion of their R&D expenditure allocated to the four main types of research, defined in section 5.3, namely:

Basic research involving the acquisition of new knowledge with no particular application in mind;

Applied strategic research involving research into a subject area which has not yet advanced to a stage that an application can be clearly specified;

Applied specific research involving research specifically directed to producing an exploitable outcome; and

Development involving the use of existing knowledge to create new products and processes.

These figures were tallied and then re-weighted (see Appendix 3) and are presented in Table 6.6. However, after analysis it was found that there were limits to the survey definitions, as interpretations of 'basic' and 'strategic' research within firms were usually subjective. Therefore the cumulative amount of basic and strategic research was presumed to give a clearer indication of the spread of research spend by type.

Table 6.6. Breakdown of Private Sector Research on Agriculture by Type in 1996, percentage of total R&D spend*

Sector	*Basic and Applied Strategic Work*	*Applied Specific*	*Development*
Agrochemical	5.2	16.2	78.6
Veterinary and Medicine	5.9	84.9	9.8
Plant & Crop	4.0	19.4	76.7
Animal Science	6.9	33.1	59.9
Agri-Engineering	4.4	6.1	85.6
Totals	5.4	42.3	52.3

* Totals may not tally through rounding

Considering basic and applied strategic research on its own indicates that the agrochemical, veterinary and medicine and animal science sectors have the highest level of expenditure on this type of research. However, the average level of private spend on such work in all areas is only 5%, with agri-engineering and plant and crop sectors having lower levels than this. Firms in the veterinary and medicine sector spend far more on applied than development work. At the other extreme, agri-engineering firms spend around 86% of their total R&D money on development work. This corresponds with the general opinion that commercial agri-engineering tends to be solely concerned with modifications of previous innovations (Lesser and Lee, 1993).

A comparable survey of the US private agricultural sector found that around 15% of total R&D expenditures were devoted to 'relevant basic research', which seems to compare with the category of 'basic and applied strategic' work, while around 43.5% was spent on applied work and 41.5% on development work (Crosby, 1987). Accordingly, although US firms spend a very high proportion of their research budget on applied and development work, they still spend twice as much on basic research as UK companies. Whilst comparisons between countries are fraught with difficulties, this may indicate that at present UK companies have a greater reliance on the public sector for underpinning basic research. This is an important area to consider after the recent changes in science policy and requires further investigation. Thus, the next section examines the activity of private sector R&D, disaggregated by type, into aspects of crop, animal and mechanical science.

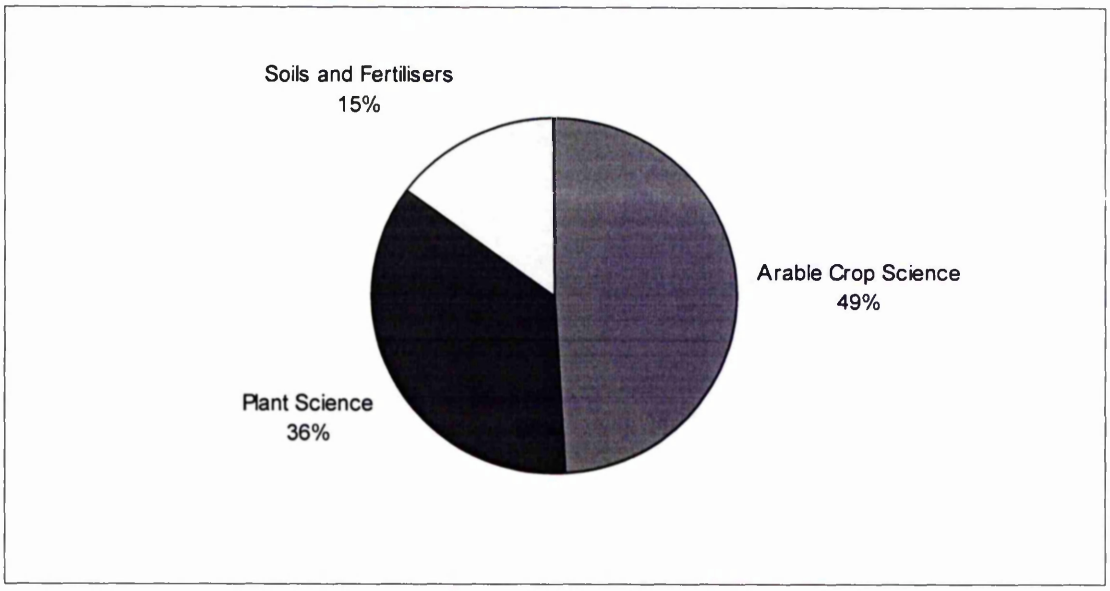
6.4.1. UK Private Sector Research Activity

Firms were asked to detail their main areas of scientific investigation and give some indication of expenditure in these areas. However, as these were only indications, their derivation and re-weighting are contentious (see Appendix 3 for further details). Therefore, there is a degree of conjecture in the results that follow. Nevertheless, it will permit an overview of the research activity in comparison to the conceptual model outlined in section 5.3. Thus, this section aims to test the theoretical model derived in the previous chapter against the findings of the survey.

6.4.1.1. The UK Private Sector in Plant and Crop Science

Figure 6.11 shows the level of private research expenditure directed towards plant and crop science.

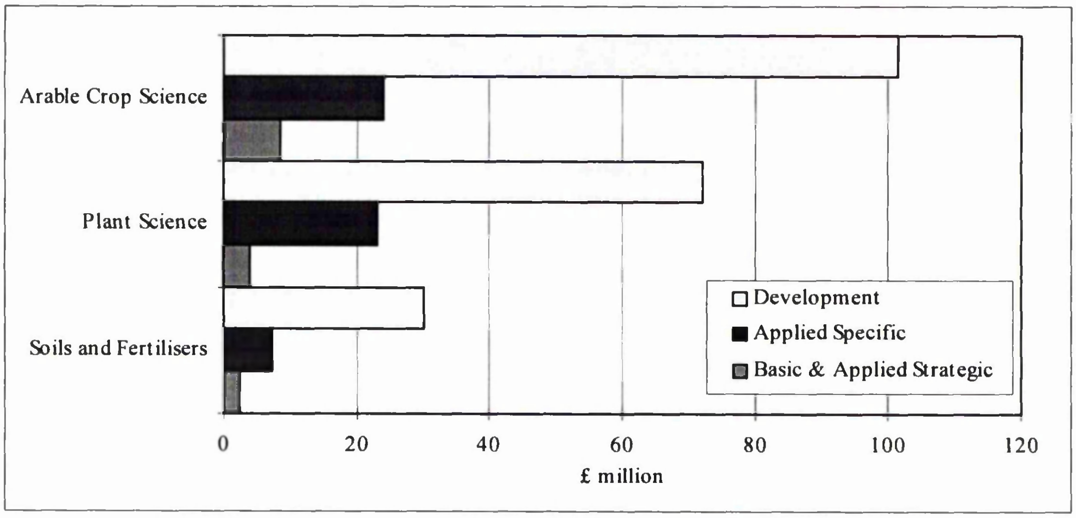
Figure 6.11. Private Sector R&D Expenditures in Plant and Crop Science, percent



Around 49% of this research expenditure was directed towards 'arable crop science' in 1996. Approximately £134 million was spent in this area, whereas around £99 million (36%) was concentrated on 'plant science'. The smallest category, 'soils and fertilisers', experienced a spend of around £40 million, or 15% of the total plant and crop expenditure.

In line with the delineation of public R&D in the previous chapter, private expenditures on R&D can be disaggregated further in order to compare their activities. Thus, in terms of arable crop science, basic and applied strategic agrochemical R&D was approximately 5% of total expenditure (from Table 6.6), representing around £7 million for the year 1995/6. Applied and development work, at £127 million, is around 12 times higher than this. This is further illustrated in Figure 6.12 which outlines expenditure on research by type within the crop and plant sectors.

Figure 6.12. UK Private Sector R&D Within Crop and Plant Science, breakdown by research type, £ million



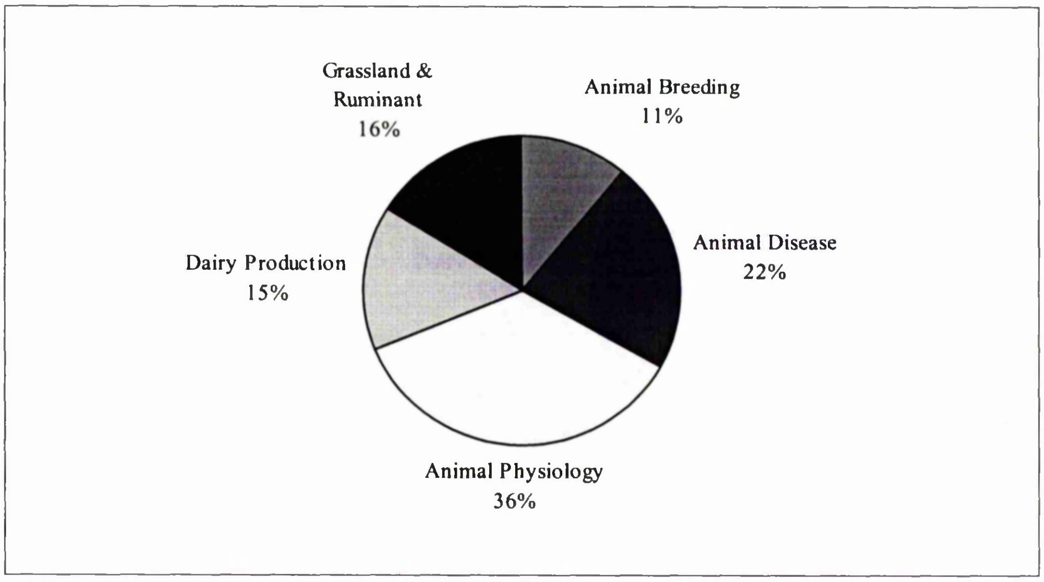
In comparison, in the area of plant science private companies spent around £99 million, which was predominantly directed towards plant breeding and genetics. If the plant and crop sector devoted around 4% to basic and strategic research, then private expenditure would have been only around £4 million. The remaining £95 million of private R&D spending was devoted to applied and development research. Work on soils and fertilisers constituted around £40 million of the private research spend, out of which only £2 million was directed towards basic and strategic work.

Whilst it seems that the majority of work in the fields of plant and crop science is centred on development work, some degree of research is conducted in exploratory fields. Thus, fundamental arable crop science, which involves activity in both biological and chemical investigations, was allocated around £7 million pounds in 1995/6. Accordingly, whilst the argument for publicly-supporting basic and applied strategic research appears strong from the evidence in Figure 5.4, some degree of productivity-enhancing research is still conducted in the commercial sector. This may, therefore, weaken the apparent justification for the presence of the public sector in these fields. Nevertheless, there is contrary evidence that supports the idea that public research has no conceivable role in the conduct of applied and, especially, development work in these areas (Thirtle, 1986; Umali, 1992). The exception to this is in respect of work in bio-fuels and environmental research. In this respect, some indication was found in the survey of private sector activity into 'farm-yard waste', as well as 'environmental work'. However, as can be seen from Figure 6.12, expenditure allocated towards 'soils and fertilisers' was the lowest out of all three fields. This lack of commercial activity seems to strengthen the justification for the presence of the public sector in applied specific work on the environmental aspects for crops and plants.

6.4.1.2. The UK Private Sector in Livestock Science

Figure 6.13 shows the breakdown of private expenditure in the livestock sector in 1995/6.

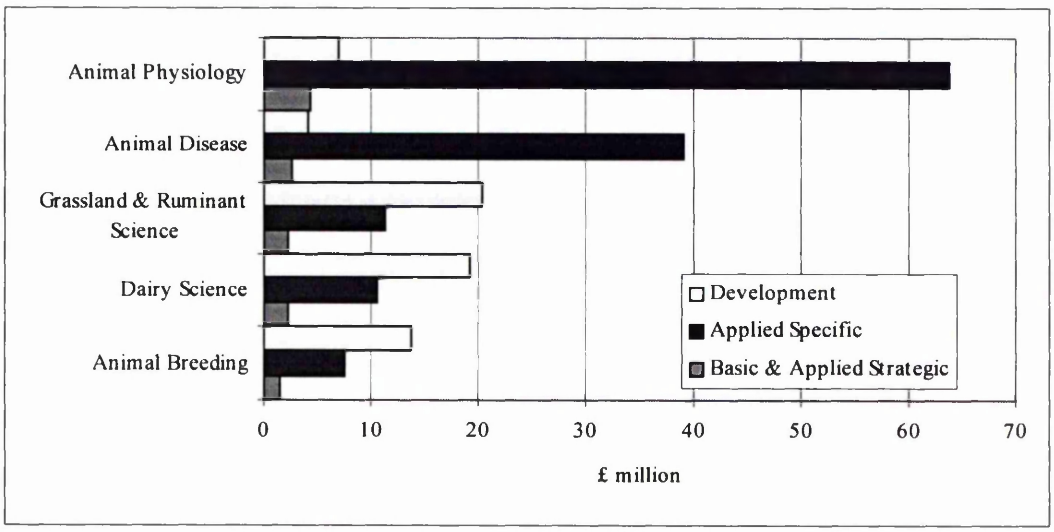
Figure 6.13 . Companies Involved with Livestock Production in 1995/6, breakdown by research sector, percent



The largest areas of expenditure were on 'physiology' at £75 million, 'animal disease' at £46 million and 'grassland and ruminant science' at £34 million. By comparison, 'dairy production' attracted £32 million, while the lowest area of private R&D investment was 'animal breeding', which absorbed around £23 million.

In terms of disaggregating by research type, Figure 6.14 shows the allocation to each field. Thus, basic research into 'animal physiology', using the figure of 5.9% for basic research in veterinary and medicine sciences, accounted for around £4.4 million of private funds in 1996. Similarly, around £2.7 million was spent in the same period for basic and applied strategic work on 'animal disease'. However, this was overshadowed by large investments in applied specific work in both fields of around £103 million, which was much higher than development work and may indicate the requirement for a strong biological and chemical facility in order to compete in this field. Basic and strategic work in 'grassland and ruminant science' and 'dairy science', received around the same level of private R&D funding by type, while the lowest investment was in R&D into 'animal breeding', at less than £1.6 million.

Figure 6.14. UK Private Sectors Within Livestock and Related Science, breakdown by research type, £ million



In terms of the model of public R&D, it seems that the justifications for publicly-funded R&D in livestock is weaker than it is for crop and plant science. Thus, whilst environmental considerations are paramount in the public arena, the appropriability of biologically and chemically based pharmaceuticals reduces the need for public support in these areas. Thus, it seems that the onus for funding livestock R&D remains, to a large degree, with the private sector. Figure 6.14 shows a strong emphasis on applied specific and development work. However, research in fundamental fields remains minimal. In total, basic and applied strategic work in the animal sciences accounted for only £13 million in 1996. Consequently, it seems that the public sector is critical as the provider of fundamental research. In this respect, whilst chemical research carries a weak justification, there is a more obvious case for public support of applied strategic research into investigations to reduce residues in meat and to ensure livestock health.

6.4.1.3. The UK Private Sector in Agri-Engineering Science

The majority of private research in the agri-engineering sector is concerned with work on vehicles, which constitutes a high degree of the total private R&D expenditure, as shown in Table 6.7.

Table 6.7. Private Research Expenditure in the Agri-Engineering Sector in 1995/6, £ million

Agri-Engineering	*40.6*
Agricultural Vehicles	34.6
Other Agricultural Areas	2.8
Agricultural Computing and Software Design	2.4
Farm Buildings	0.8

If the amount of basic and applied strategic research spent in this field was equivalent to 4% of the total (see Table 6.6), then £1.8 million of private money was directed in 1995/6 towards these areas. However, the theoretical model derived in section 5.3 found that there was a weak justification for the continuation of funding for agri-engineering. Indeed, the only area which appeared to justify public support was animal welfare. The closest indication of private R&D expenditure in this area is the £0.8 million allocated to farm buildings. As this constitutes only 2% of the total private research budget, it seems to strengthen the support for public R&D in this area. A further point has to be made regarding managerial research, which was given strong support in Figure 5.4. There is some indication that work is being conducted on computing and software design, which internalises this management activity to some degree. Consequently, support for managerial research in livestock and crops, especially at the development end of research, may be weakened by this evidence, as there is some opportunity for private appropriation of the research in this area.

6.4.1.4. Summary

The analysis of the UK private sector in agriculture reveals a skewed spread of R&D expenditure both by area and type. For the most part, large expenditures are allocated to applied specific and development work with little attention to funding fundamental research. In this respect, it seems the public sector has become paramount in supplying the fundamental work needed for the future exploitation of these industries. This seems to be especially the case in fields such as 'soils and fertilisers' and 'animal breeding', where public basic research spending seems to be critical. Moreover, this reliance on the public sector may have been affected by recent changes in research management. Consequently, the next section examines how the private sector has responded to changes in the level and output of public agricultural R&D which were instigated from the mid-1980s onwards.

6.4.2. Trends in UK Private Sector Agricultural R&D

In terms of replacing lost public funds the private sector can be divided into two distinct groups, namely i) the private non-profit making bodies and ii) private companies involved in the agricultural input industries. Within the UK, a number of non-profit making bodies exist which conduct agricultural related R&D. Firstly, charitable organisations may fund research to further the understanding of a particular area. The institutions with the highest profile among these are the Wellcome Trust and the Rockefeller Foundation, who together have donated large amounts of funds for the furtherance of knowledge on biological processes and interactions. However, whilst some of the discoveries may have a spin-off benefit to agriculture, these are mainly directed towards human science. More specific interest groups, which fund a small number of R&D projects in more agriculturally-related areas, also exist. Of these, such UK bodies as 'Friends of the Earth', the 'Pesticide Trust' and various heritage bodies conduct a degree of research related to public-good issues.

Secondly, and most prominently, a number of representative organisations exist which have been formed to collect levies from producers and processors. Many agricultural commodity markets have been subject to the control of these representative boards since the Marketing Acts of the 1930s. However, after the 1993 Agriculture Act, a number of new bodies emerged, whilst previously existing organisations have been re-modelled, with the overall aim of encouraging levy funders to make up for reductions in public R&D expenditure. As such the boards tend to concentrate on strategic work of benefit to the sectors involved (Thirtle, Piesse, and Smith, 1997). Their level of expenditure by body and commodity is illustrated in Table 6.8.

Table 6.8. Statutory Bodies Currently Established in the UK and their Spending Activity in 1995/6, £ million

Levy Board	*Commodity Group*	*R&D Spend (£M)*
British Potato Council	Potatoes	1.8
Home Grown Cereals Authority	Cereal and Oilseeds	4.7
Meat and Livestock Commission	Beef meat, Sheep and Lambs, Pork and Bacon	1.9
Processors and Growers Research Association	Peas and Beans	0.2
Milk Development Council	Dairy Produce	3.0
Horticultural Development Council	Horticultural Produce	3.0
Sugar Beet Research and Education Council	Sugar Beet	2.2
Apple & Pear Research Council	Apple & Pear	0.4
National Hops Association	Hops	0.1
Total Levy Board Expenditure		17.3

Sources: (Various)

Thus, Table 6.8 reveals that around £17.3 million were spent during the period 1995/6 on research relevant to the agricultural industries. The Home Grown Cereals Authority apparently spent the largest share of this, around £5 million pounds. However, it was stressed at the time that this was a once only payment, as a commitment to its role in increasing UK competitiveness (HGCA, 1996). In addition, this was recorded in a period of relative stability within agriculture and may be seen as an upper limit to the levy board's commitment to agricultural R&D. Consequently, it seems that the figure of £17.3 million may be providing an over-optimistic picture of levy board funding in the long run within the UK. Nevertheless, even if the figure is accepted, then only around half of the £30 million removed in public near-market funds has been replaced by levy board funds (Read, 1989).

In terms of the expenditures of private companies conducting agricultural R&D, the only figures available for private agricultural research expenditure in the last decade are estimates made by Thirtle *et al.* (quoted in Thirtle, Piesse and Smith, 1997) for private activity during 1987/8. These are presented in Table 6.9 as a means to compare against the findings of this survey. Whereas some problems occur in definition they still give some indication of changes to expenditure in the private sector.

Table 6.9. Comparison of Private Research Expenditures, 1987/8 to 1995/6, £ million

Sector	*Research Spend* *1987/88*[3]	*Total Research Spend in 1995/6* *Range*	*Change (%)*
Agrochemical	151	123 - 150	-19 - -1
Veterinary & Medicine	32	26 - 30	-20 - -7
Plant & Crop	32	111 - 165	243 - 410
Animal Science	24	70 - 115	193 - 384
Agri-Engineering	84	37 - 47	-56 - -44
Totals	323	365 - 507	13 - 57
Totals†	267	185 - 227	-31 - -15

† Removing Plant and Crops and Animal Science sectors

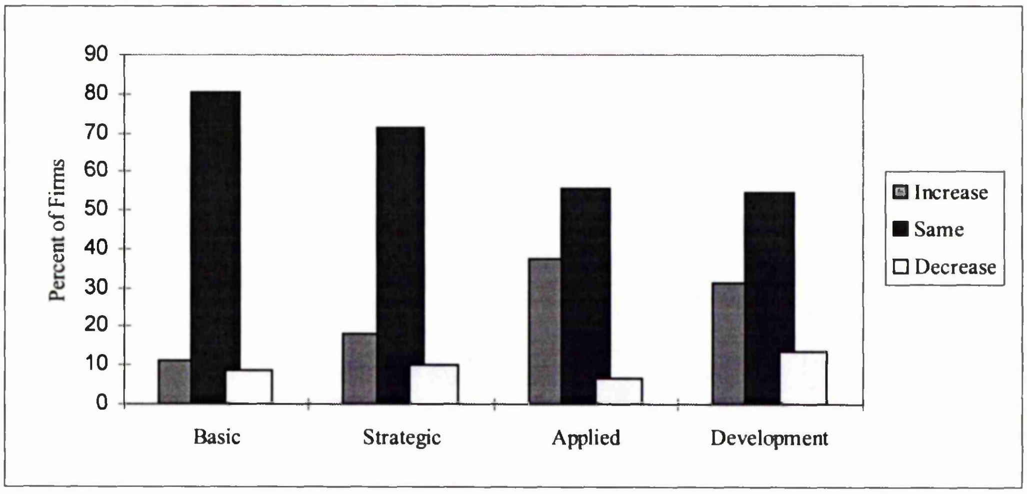
From the above table it seems that private expenditure has risen by between 13% and 57% since 1987/8. However, the trends between sectors are not similar, with those for plant and crops and animal science being very different from the rest. With the removal of these two sectors, the remaining categories have all experienced a decline in R&D expenditure, apart from agrochemicals at the upper limit, which is projected to have remained relatively constant. Analysing private R&D expenditure, apart from plant and animal science, gives an overall decline of between 15% and 31% from 1987/8. In absolute terms, this could mean that research levels have decreased by around £82 million at their most extreme. Even at the upper limit, where expenditure is £227 million, compared to the 1987/8 figure of £267 million, private expenditure appears to have decreased by around £40 million.

However, clearly given the way that the 1987/8 and 1995/6 figures were obtained, care is needed in interpreting this trends. Perhaps more meaningful is a survey of firm's perceptions of their changing level of R&D investment. Thus, the firms were asked to give an indication of whether their R&D intensities by type had either increased, remained the same, or decreased over the last ten years. What emerges is that the allocation of funding by each type of R&D has remained relatively constant compared to ten years ago. This was

[3] Thirtle, Piesse and Smith (1997) figures inflated to 1996 prices using the RPI.

especially so at the basic end of research, in that around the same number of firms claimed to have increased their expenditure as those reducing their spending levels. Figure 6.15 illustrates how expenditures have changed in relation to the four key types of research.

Figure 6.15. Trends in Private Expenditure by Type from 1985/6 to 1995/6, percent



However, a shift can be seen to have occurred towards applied research and development. Around 40% of firms claim to be increasing their levels of expenditure in applied specific work, whereas around 35% have expanded their development activities. If this were the case in reality, then it would indicate expansion into near-market areas. However, this seems a contradiction in terms, when the possible large contraction in private R&D expenditure is considered. It may mean that this increased focus on applied R&D by some firms has been to the further detriment of basic and strategic work. This may account for the low levels of basic and strategic work in the UK, compared to US firms and may indicate an increased reliance on publicly-funded basic research.

6.4.2.1. Summary

The private sector conducts the majority of agricultural R&D within the UK. However, indications are that its commitment to research is falling in real terms as opposed to ten years ago, especially in basic and strategic research. With regard to actual expenditures as a whole, it seems that the reduction in public funds of £30 million has only been compensated by levy funding of £17 million, which has left a gap of £13 million pounds. In addition, with a fall of between £40 million to £82 million in commercial funding, total R&D

expenditures within UK agriculture have fallen by around £53 to £95 million pounds over the period 1987/8 to 1995/6. Consequently, whilst there is some evidence that this has been in basic and strategic areas, it is difficult to believe that the commercial sector has compensated to any degree by expanding into near-market research.

Accordingly, this leads to a number of issues which require further investigation. Firstly, there is a need to understand why the private sector has reduced funding to such an extent. Thirtle, Piesse and Smith (1997) attributed the fall that they observed between 1988/9 and 1993/4 to economic recession. However, the UK economy in the 1990s has been relatively stable and recent rises in economic growth seems to run counter to the continued fall in R&D expenditure in the 1996 period. Nevertheless, an associated reason could be that the attitude towards investment in agricultural R&D has changed. With the continued decline and losses reported in various agricultural commodities, firms may have begun to either centre research on developing countries, which offer more exploitable opportunities, or have withdrawn completely from the agricultural sector itself. If this were the case, then it seems Government attempts to induce the private sector to increase its spend on agricultural R&D appear to have been misdirected.

More crucially, the commercial sector's relationship with publicly-funded agricultural R&D may have changed. Reductions in public funds could have had the reverse effect to that anticipated and led to a corresponding reduction in commercial funding of agricultural R&D in the UK. This has been emphasised by Umali (1992), who contended that an expanding private research facility could only occur with support from a healthy public agricultural R&D base. Taking account of the evidence that UK firms may be more reliant on externally produced basic research than those in the US, this may explain the phenomena of reduced private expenditures. Accordingly, in the UK it may be the case that the public and private sectors are more interdependent in terms of agricultural R&D than in the US, and consequently research investment has suffered as a result of the cuts in funding of the late 1980s.

6.5. Conclusion

The aim of the private sector is usually to maximise profits. In theory, because of this it rarely considers the long-term effects of its strategies in order to recoup higher returns. Therefore, research and development, as a means to underpinning this objective, will generally be short-term in nature. It seems the role of the public sector is quite distinct from this, providing long-term research with the aim of increasing knowledge rather than profits. However, this could be disputed as public investments before the 1980s towards applied research and development, as well as advice, testify to the Government directly aiming to support increases in industrial productivity and competitiveness. Accordingly, the removal of near-market funding and a subsequent emphasis on basic research may reveal an attempt by Government to delineate the roles for public and private sectors as distinct providers of agricultural R&D.

Given this new divide, the above analysis has tended to concentrate on how results are transmitted from public agricultural research institutes to the commercial sector. More specifically, it has attempted to quantify and assess the means by which the private sector integrates research from either the public domain or through direct collaboration. The implications which emerge from the analysis can be divided into two. Firstly, the role of the commercial sector has been explored in terms of its relationships and attitudes toward public agricultural R&D. Secondly, the impact of commercialisation policy on the structure and practice of public agricultural research institutes has been examined. These two areas are considered below.

6.5.1. The Role of the Commercial Sector in Public Agricultural R&D

The removal of near-market funds opened a gap which the Government believed would be filled by the private sector. Critically, however, the level of private agricultural research spending has decreased since these policy changes. An answer to this phenomenon may lie in the corresponding 'health' of both sectors. In a review of the economic benefits of public basic research, Martin *et al.* (1996) contended that advanced industrial countries needed their own, well developed basic research capabilities. It would seem from this analysis that the removal of applied and development work has also had an effect on the activities of private research funding.

Furthermore, reductions have been very evidently mapped in the areas of basic and strategic work. Rosenberg (1990) and Pavitt (1991) see private basic research activity as an 'entry ticket' to the world's stock of knowledge. Thus, the fall in private R&D expenditure may be an indication that interest in agricultural research by the UK commercial sector may be declining. Therefore, in this sense, any policy prescription for correcting this would have to be aimed at encouraging new markets through public research. Similarly, it was found that the public sector conducts the majority of basic research in most UK sectors. This was quite extreme in certain areas and may either indicate a dependence on externally produced basic research or, in line with the findings above, a reliance on applied and development work. Thus, if the former were the case then the vigour of the public sector is critical to the future development of industry. However, if the latter is correct, then reductions in activity of the public sector will have little immediate effect on commercial sector R&D.

After the near-market cuts, it is interaction between sectors which becomes critical. It is the contention of numerous writers (see for example Kogan and Henkel, 1983; Thornley and Doyle, 1984; Pavitt 1991), that both applied and basic work offer opportunities for further growth. In this sense, if the public sector conducts no applied or development work, it is likely that a significant proportion of its basic research findings will not be exploited and developed. Thus, with the private sector apparently concentrating on near-market work, the public sector is essential to undertaking the basic research required for a company's applied activities. To a degree this impinges on the findings of Gibbons *et. al.* (1994), who argued that, as collaborative activity emphasises commercial applicability, the distinction between the aims of the public and private sectors becomes blurred. Therefore, close interaction through collaboration may offer more success for publicly-funded basic research, which would be better targeted to the needs of the private sector.

However, the level of collaborative activity within the UK was found not to be large enough for Government policy in this area to be deemed a success. Furthermore, this may be due to a lack of policy coherence. Thus, Webster (1988) has pointed out that the AFRC was particularly suited to private sector collaboration, because its work has been traditionally applied in nature. With the removal of near-market funds, therefore, one would expect these trends to decrease. Consequently, there is a possibility that the near-market policy may have reduced the opportunities for expansion of collaboration and may account for its slow growth rate.

6.5.2. The Commercialisation of Public Agricultural R&D

Public agricultural research now has a more clearly defined role. It must provide the basis for increasing the UK's competitiveness by opening and creating markets which can be successfully exploited by industry. With the reductions in applied and development work, public research has several channels to increase this exploitability. Specifically, this consists of offering services for and collaborating with an industrial partner. Similarly, its original activity of providing knowledge through public channels has more importance within this context.

However, what emerges from this and the previous chapter is that there are definite sectoral differences in respect of agricultural R&D. Consequently, the role of public R&D within commercialisation policy will be distinctly affected by whether it is aimed at livestock, crop or mechanical areas. When analysed at the sectoral level, the mechanical sciences seem to be the most susceptible to commercial influence. Predominantly, this is because it is difficult to establish any strong justification for the continuation of public support. Thus, as most of the private research in the agri-engineering sector is concentrated on farm vehicles, it seems to discount the relevance of the public sector in this area.

Where the public sector remains paramount is in enhancing the public good which, in the case of agri-engineering, is centred around animal welfare. However, this argument begins to weaken as improved animal welfare emerges as an appropriable product of agri-engineering R&D, such as modified housing and feeding facilities. That the survey found only a limited representation of the private sector in this field may reflect the need to understand background research, i.e. animal behavioural studies. Thus, it may be the case that basic research is not conducted due to its non-appropriability and, reiterating Pavitt's (1991) contention over firms which conduct no basic research, companies have no facility for understanding this knowledge. This gives the public sector a vital role as a provider of this knowledge. Consequently, it seems that collaboration between sectors in this field will allow behavioural studies to be translated into appropriable innovations.

Like mechanical areas, support for public livestock R&D has only concentrated on providing for the basic and applied strategic work needed to develop solutions to animal-related problems. Within this, biological investigations have been favoured over the development of chemically-based research. In terms of livestock R&D, it was found that certain areas of the private sector allocated a substantial proportion of funds towards the applied sciences, which might indicate the interactive nature between different types of research in this field. Consequently, the public sector will have a role in supporting these explorations, through providing public domain research related to biological investigations.

As regards crops, it was noted that there are several strong justifications for the continuation of public sector support. Thus, work which enhances the public good should not have to depend on private sector support. This was especially so for R&D into biological control of pests and diseases which may reduce the need for applying chemicals. As a consequence, chemical research has been found to carry a weak justification for public funds. Similarly, the large amounts of private money allocated to arable crop science would suggest that the removal of public funds in this area would not create a problem. It therefore seems that there is some divergence between public and private sector goals in plant and crop science. The possibilities for collaboration may be severely reduced because of this. However, one area where both sectors have similar aims is in the development of bio-mass, which offers a relatively environmentally-friendly means to producing fuel. Consequently collaborative activity could occur in this area, which may reduce the justification of publicly-funded applied specific work in this area.

Finally, an important area that should be considered within the overall understanding of the commercialisation of research institutes is the role that the public sector scientist plays. Critically, the motivations for a publicly-funded scientist could substantially differ from those of an industrial scientist. At the risk of some simplification, the work of a public researcher aims at increasing the spread of knowledge concerning a certain subject area, whereas a scientist within a company forsakes a degree of freedom and choice in research projects in lieu of other reasons, e.g. higher remuneration and access to better facilities. With the onset of increased commercialisation, scientists, refused the right to publish or discuss their work, may conceivably seek opportunities elsewhere. This could principally occur by movement to the commercial sector, thus reducing the opportunities for creating useful knowledge within the public science base.

Related to this, Webster (1988) and Read *et al.* (1988) have both voiced concerns over the probity of industrial involvement. If it affects a public scientist's time to an extent where it infringes on work funded by the taxpayer or, more critically, if publicly-funded research areas become focused towards industry rather than public needs, then serious questions have to be asked over the validity of encouraging a policy for commercialisation.

The fact remains, however, that reduced funds for agricultural R&D are a reality and the science base needs to be increasingly maintained by external sources. On the above evidence the levels of linkage have grown only slightly. This is regardless of the fact that the commercial sector values the expertise and relevance of UK public research. Similarly, citation rates for agricultural and agricultural related research disciplines are still high (May, 1997). Nevertheless research suffers from long lags between actual expenditure and final output, which have been estimated from 16 years and upwards, and therefore it is only now that the consequence of the cuts in public R&D funding in the mid-1980s will be felt. Accordingly, due to the dichotomy between levels of expertise and trends in commercial funding, collaboration may begin to decline. The Government response to such a situation may be to push more money into the system, but the expertise and image of scientific excellence once lost may be a difficult thing to regain.

Overall, the last two chapters have re-emphasised the results of some of the hypothesis tested in Chapters 3 and 4. Specifically, whilst it was found that changes in research management were generally to the detriment of agricultural research effectiveness, what has emerged from this chapter is that a highly relevant public research base remains. Whilst, it is difficult to ascertain whether this has improved because of the changes in research management, the high regard in which the commercial sector holds public research institutions hardly indicates that the relevance and quality of public research has declined.

Similarly, in line with the findings of Chapter 5, applied research is intrinsic to the success of agricultural policy goals and its gradual removal, along with development and transference, seem to be to the detriment of public agricultural R&D. In particular, the high rates of return recorded for applied R&D and extension in Chapter 4 are given more weight by these findings. Thus, there is strong evidence that, for the public agricultural research service to continue to be successful, all areas along the research continuum must continue to be funded. This appears to be a point which recent policy decisions seemed to have ignored. The implications of this are discussed in the conclusions.

CHAPTER 7

CONCLUSIONS

7.0. Conclusions

Several key areas have emerged from this analysis which impinge on the central question of whether support for agricultural R&D is a justifiable activity for the public sector. Firstly, the claim that, not only is public agricultural R&D justified, but that it merits increased expenditures, has been explored. Secondly, the role of the Government in agricultural R&D has been examined with regard to whether its changes have been successful. Finally, throughout this analysis the role and activity of the private sector has been investigated. Consequently, the conclusions examine these issues as a series of questions, with the aim of defining the role of publicly-funded agricultural R&D. These questions can be identified as: i) is agricultural R&D under-funded?; ii) for what type and area of agricultural R&D is public support justified?; iii) have all the shifts in research policy had a positive effect on the productivity of agricultural R&D?; iv) what is the role of the private sector in agricultural R&D?; and v) how should public sector agricultural R&D be conducted in the future? The chapter closes with an examination of future research issues that still need to be addressed.

7.1. Is Agricultural R&D Under-Funded?

Resources for agricultural R&D in the UK, as in most of the developed world, are becoming increasingly scarce. The contention of most economists is that, as returns to R&D are high, there is clearly under-investment in agricultural R&D and funds should be increased. This study has found a return to applied agricultural R&D and extension above the recommended limits for a public investment. However, this has to be compared with negative returns which were derived for total public agricultural research expenditures. Therefore, this study could find no irrefutable evidence which supports the idea that agricultural research is under-funded.

However, more critically, it may not be the case that high returns necessarily indicate a need to increase public research funding. This is especially so in the case of agriculture which has enjoyed substantial public support over the last 50-year period, as the high returns could easily reflect artificially inflated prices. In this respect the Malmquist indexing procedure, which only relies on quantities, would have been a more useful indicator of TFP growth. However, as mentioned in Chapter 4 lack of data restricted analysis to the Laspeyres and Tornqvist TFP indices. Furthermore, the destructive externalities caused by agricultural industrialisation have raised questions over the direction of agricultural production. It has to be conceded that, as research has been the engine by which misguided policies for excessive farm outputs have been realised, then the role of publicly-funded agricultural R&D, in terms of increasing social welfare, has to be questioned. Similarly, to expect the taxpayer to pay twice, both for production subsidies and for output-enhancing research, has further implications for social welfare.

In addition, it is not necessary to increase R&D investment to realise technological progress. Certainly, there is growing evidence that inter-country spill-overs are an important facet of the technological process (see for example Thirtle and Townsend, 1997). In particular, the New Zealand government has consciously adopted a 'piggy-back' approach, whereby other countries' research knowledge is explicitly incorporated into the agricultural system. Thus, whilst the obvious limitation to this strategy is that it relies on other countries to continue to provide research in the public domain, it seems that a reduction in research funding may not impede economic growth, as R&D results can be imported.

What is clear from the above argument is that there is no satisfactory evidence suggesting that high rates of return indicate under-funding of agricultural R&D. However, what emerges from the remainder of this study is that a clearer argument can be made for public support of selected areas of research. This is discussed further in the next section.

7.2. For What Type and Area of Agricultural R&D is Continued Public Support Justified?

Agriculture, as an industry, seems to be in perpetual decline. Therefore, in economic terms, Government spending within this sector to realise gains in industrial growth seems misdirected. In addition, no identifiable growth has occurred in real incomes throughout the last 50-year period (Harvey, 1987). That this occurred in a period when investment in agricultural R&D was increasing seems to discount the ability of technological innovation to reverse the economic position of farmers. Indeed it is only when the wider social impact of farming is taken into account that justifications for public support seem to be credible. Thus, the diversity of costs and benefits to separate user-groups complicates the debate over whether public funding for agricultural R&D is justified. It therefore seems that, in trying to establish the need for continued public support, both the type and area of agricultural R&D performed have to be considered.

It seems to be irrefutable that the public sector should fund basic research. The support of work into both the natural and social sciences helps primarily to expand the frontiers of knowledge. Thus, support can be justified not only as a means to creating wealth, but also as an aid to creating knowledge. Ruttan (1982) contended that the two were not mutually exclusive, but complementary. Accordingly, it is difficult to argue for a reduction in research funds for basic science, when it would quite clearly have a negative effect on knowledge resources in the natural and social sciences.

In this respect, this must also apply when considering exploratory work which has an agricultural slant, i.e. applied strategic research. This is primarily because it supports the advancement of knowledge within the agricultural sciences which, like basic research, makes it difficult to identify any specific outcome. Consequently, the funding of applied strategic research should be considered as a means to providing an adequate knowledge base to the agricultural sciences. In addition to supporting knowledge development, it also offers opportunities for further development both by the public and private sectors. In terms of actual public support for basic and applied strategic work, these areas have experienced an increase in public expenditure since the early-1990s. Therefore, as the funding of this exploratory work is justified on *a priori* grounds, there seems to be little apparent divergence between theory and practice.

However, when considering specific applied research, a delineation emerges between work which should be publicly-funded and work which should be the concern of the private sector. The majority of public work in these fields is funded either through MAFF for England and Wales, SOAEFD for Scotland, and DANI in Northern Ireland. However, only MAFF (1996) produces figures for research funding for this period in any specific detail. As such, Figure 7.1 outlines the areas of MAFF funding that were justified on the basis of the theoretical framework developed in Chapter 5 and compares them against expenditure in areas which received little support for continued public funding.

Figure 7.1. Comparison of Theoretical Framework for Public Funding of Specific Applied R&D against Work funded by MAFF in 1996, £ million

		Justified	*No or Partial Justification*
Managerial	*Livestock & Crops*	3.7	3.1
	Other	1.2	
Biological & Chemical	*Livestock*	1.8	16.47
	Crops	10.7	10.5
Mechanical	*Livestock*	4.2	

Source: MAFF (1996)

In terms of managerial research, the framework found that most work, which either enhanced the public good or supported diversification, was justified. Around £5 million was spent on research concerned with countryside management, wildlife conservation and farm woodlands in 1996. However, the £3 million pounds spent primarily on 'improved marketing' was adjudged to carry no justification. In terms of biological and chemical research, public good work on crops (which includes statutory work on fertilisers, pesticides and research into organic farming) gains the same level of funding as that for research into crops which aims to improve economic performance. The largest deviation from the theoretical framework emerges in respect of livestock research where public good work into veterinary medicines was over-shadowed by investment of around £16 million into productivity-enhancing fields. The only area which seems to truly follow the theoretical framework was agri-engineering, where around £4 million was spent on animal welfare, with MAFF making no direct payments for specific applied R&D engineering work aimed at improving economic performance during the 1996 period (MAFF, 1996).

Overall, what emerges from the above analysis is that the balance of MAFF research funding is not entirely consistent with the theoretical framework developed for judging the justification of public funding of agricultural R&D. Similarly, whilst figures for Scotland are difficult to dissaggregate into specific fields, this observation could equally apply, if around 60% of their research budget continues to be allocated towards improving productivity (Scottish Office, 1994). Therefore, the inference is that funds are being mis-directed within the research budget. A re-allocation of funding by MAFF might also counter the contention that agricultural R&D is under-funded, as expenditure in those areas which should be supported would be substantially increased, at the expense of areas which arguably should not be conducted by the public sector.

7.3. Have all the Shifts in Research Policy had a Positive Effect on the Productivity of Publicly-Funded Agricultural R&D?

The 1960s saw an emergence of accountability mechanisms within Government which have evolved into increasingly more sophisticated systems of appraisal for the distribution of money between areas of public investment. That shifts in research management have been reflected in downward rates of return may indicate that the changes have had a negative effect on the productivity of research. However, it is equally plausible that the decline in returns are independent of the shift in the management of research funding.

In particular, there are indications that changes in the modes of funding have had little effect on institutional performance (Herbetz and Muller-Hill, 1996; Bourke and Butler, 1999). In addition, the high rates of return estimated for applied R&D and, especially extension, belie any suggestion that shifts in policy have adversely affected research performance. Thus, this study tends to support the contention that research management changes have not appreciably affected research output, either positively or negatively. Instead they have only served to increase apparent accountability. Given that R&D management costs have increased as a result, the unanswered question is whether the benefits justify the transaction costs.

7.4. What is the Role of the Private Sector in Agricultural R&D?

As outlined in Chapter 6, the private sector can be divided into two distinct groups, namely the statutory boards and the commercial sector. In terms of the statutory boards, examples from other countries reveal that levy board funding can provide cohesive support for the strategic work specific to productivity gains. An argument against this is that the success of this funding route relies on the specific institutional circumstances of a country's agriculture. Hence, it could be argued that the UK could not develop a system which offers a viable base for levy board funding for agricultural R&D. This has been evidenced recently with the 1993 Agricultural Act. Whilst the Government increased the number of statutory commodity bodies, there was no corresponding increase in research funding from these organisations. Similarly, relying on levy board funding is very susceptible to changes in economic conditions and, considering the recent downward trends in farming incomes, it is difficult to accept that they offer a viable means to conducting stable research activity within the UK.

On the other hand, commercial investment in agricultural research has grown with the onset of biotechnology in the mid-1980s. Mainly due to the commercial opportunities from this process, firms have shown increased activity in basic biological research. Consequently, whilst productivity-enhancing applied research and development is predominantly the domain of the commercial sector, the growing investment in the basic sciences by private firms must impinge on public sector R&D activity itself. However, it is difficult to ascertain whether this increased private investment will continue. As evidenced by the survey of private research providers, there has been a contraction of UK commercial R&D activity since the mid-1980s. As such, the main impetus for the provision of basic and strategic science in all areas of agriculture still continues to depend on the public sector.

As regards the future role of the private sector, funding of applied research and development work in the field of productivity enhancement must be the sole prerogative of firms in the agricultural and food industries. That companies have not responded to the contraction of near-market research funding may indicate a lack of sufficient incentives to conduct R&D. These may be improved through subsidies for industrial research activity. This is discussed in the next section.

7.5. How Should Public Sector Agricultural R&D be Conducted in the Future?

There are strong indications that an autonomous research system, based on institutional funding, has been the most effective means for managing the UK agricultural research system. To some degree this autonomy has returned, due to the increased concentration on basic research, which has primarily been determined by the agricultural research institutes, during the 1990s. However, project funding has remained the basis of conducting and managing public applied R&D (OST, 1993). That the adoption of this mechanism for research funding has had no discernible positive effect on rates of return must question the value of continuing it, due to its costs of operation. However, criticism of the earlier system found that, with institutional funding, UK agricultural research spent too much time on basic research, with little applied and development activity (Ulbricht, 1977). Therefore, in order to avoid this trend recurring, it seems that some kind of steerage mechanism remains necessary, as it is important for the public sector to produce viable technology which enhances environmental, rural and social goals. In addition, this study has found little evidence to justify the removal of applied research and development from public agricultural research. Rather the balance of funding between basic and non-basic fields should be reconsidered, with more public funds directed toward applied R&D.

What also emerges from this analysis is a case for the public sector investing in productivity-enhancing research in the commercial sector. Thus, commissioning projects for applied R&D through competitive bidding may allow more effective targeting of R&D than can be achieved by institutional funding. Subsidising industry may also obviate the problems of 'crowding out' and duplication in public research, by concentrating on providing strategic research which complements, rather than deters, industrial research activity.

However, there are numerous drawbacks to allowing the private sector to conduct work for the Government. Firstly, there is the very obvious problem of reducing available knowledge in the public domain. This could be avoided by demanding the publication of research findings, which are certainly not technology specific in the basic and strategic sciences. Secondly, there is the danger of firms diverting programmes towards their own technological needs. Thus, some monitoring system has to be introduced which would, hopefully, avoid these problems. Intrinsic to this would also be the development of joint applied research programmes, involving close consultation between industry, farmers and the public sector. Whilst this would increase transaction costs, if the high rates of return to private R&D estimated in this study are to be believed, then public investment would still be more effective than relying on a purely publicly operated Agricultural Research Service, if estimates of return from public R&D in the last 50 years are accepted.

An argument which supports this is that during times of economic depression private agricultural research tends to be reduced. Therefore if industry could be subsidised during these periods to continue investing in areas which offer growth, it might reduce the effects of recessionary conditions. Indirectly this has been achieved within the food sector. Little non-statutory food research is conducted by the public sector and research programmes tend to be directed by industry, with the public sector offering funding to encourage this (MAFF, 1996).

Overall, what emerges is an explicit division between the roles of the public and private sectors in agricultural R&D. The public sector research institutes should have continued institutional funding for basic and strategic activity, whereas applied R&D for the public good should be project-funded by Government. Similarly, the private sector should enjoy increased funding from public sources to support the development of the competitiveness of the UK farming industry.

7.6. Recommendations for Future Research

This analysis has questioned the assumptions on which public funding of agricultural R&D is based and established an argument for the continuation of public applied R&D which enhances the public good. However, there are several issues which have emerged from this analysis and which require further study. These are listed below:

1) It is quite evident from previous studies into UK public agricultural R&D that the role and activities of the private sector have been ignored. However, there are a number of reasons why this should not be the case in future studies, namely: i) the expenditure of the private sector has become increasingly important since the mid-1980s for the conduct of agricultural research in the UK; ii) it is evident that both sectors need to be aware of their research activities in order to become more effective, and thus avoid excessive

duplication and 'crowding-out'; and iii) the increase in interest toward bio-technology has blurred the traditional distinctions between the roles of public and private sector R&D activity. Thus, the private sector has begun to invest substantial amounts of money into basic research, normally seen as the domain of the public sector. Consequently, studies into the activities of the private sector need to be conducted on a regular basis in order to provide policy makers with more information for establishing public research goals.

Furthermore, as the interaction between the public and private sectors has increased since the mid-1980s, more work is needed on quantifying this effect. Whilst this study has identified levels of collaborative work undertaken, along with public domain research, an important aspect of study is the amount of synergy and duplication between public and private sectors in agricultural R&D. This would help to establish the effectiveness of collaborative ventures, along with helping to provide a truer indication of the level of return to public agricultural research investment.

2) It is apparent that the methodology for estimating returns to R&D needs to be modified further. Thus, whilst existing methods have various conceptual problems when applied to agricultural R&D, there seems to be no accepted methodology by which returns to research can be assessed. In this respect, the various issues over causality and stationarity addressed in Chapter 3 need to be consistently employed in order to create a level of statistical acceptability. Similarly, the credibility attached to academic studies is undermined by the wide variation in the marginal internal rate of return to R&D dependent on the method of calculation. Thirtle and Bottomley (1988) found that a variance of around 20% occurred between three standard methods for calculating the internal rate of return to UK agricultural R&D. Davies (1981) noted a similar distortion caused by the use of discounting procedure. This latter issue could also benefit from an improved methodology. In this respect, it is worth noting that growing criticism has emerged over the issue of calculating the internal rate of return. The most prominent writer on this subject, Kula (1992, 1997), has suggested various alternatives for discounting public investments. His principal criticism is that previous methods do not adequately reflect the effect of public investments on the future, and he outlines several methods to overcome this. These suggestions have implications for the analysis of rates of return to agricultural R&D and should be explored further.

3) Finally, an interesting field which has only recently been investigated in the UK context is the effect of international spill-overs on the productivity of research. Recent explorations by Thirtle and Townsend (1997) have found significant spill-over effects between the UK and other national agricultural research systems. The effect of these spill-overs has led Huffman and Just (1999) to call for increased international co-ordination in agricultural R&D. Thus, future quantification of this effect will, with reducing public resources for UK agricultural research, become increasingly important to policy-makers for the successful administration and conduct of agricultural R&D in the future.

List of References

Advisory Board of Research Councils and Advisory Council on Applied Research and Development. (1983). **Improving Research Links Between Higher Education and Industry.** London: HMSO.

Advisory Board of Research Councils and University Grants Commission. (1982). **Report of the Joint Working Party on the Support of University Scientific Research.** Cmnd. 8567. London: HMSO.

Agriculture Committee. (1983). **First Report of the Agriculture Committee: Organisation and Financing of Agricultural Research and Development.** Cmnd. 38-I. London: HMSO.

Agricultural and Food Research Council. (Various Years). **Annual Report**. London: HMSO.

Agricultural Research Council. (Various Years). **Annual Report**. London: HMSO.

Alston, J.M., Norton, G.W. and Pardey, P.G. (1998). **Science Under Scarcity.** Wallingford: CAB International.

Alston, J.M. and Pardey, P.G. (1998). Principles for Public Investment in Agricultural and Natural Resources Research. In: Persley, C.J. ed. (1998). **Investment Strategies for Agriculture and Natural Resources.** Wallingford: CABI Publishers, pp. 221-248.

Alston, J.M., Pardey, P.G. and Smith, V.H. (1998). **Financing Agricultural Research and Development in Rich Countries: What's Happening and Why.** *Australian Journal of Agricultural Economics*, **42**, *1*, pp. 51-82.

Anderson, J. (1994). **Foresight Analysis in Research Funding Agencies.** *Higher Education*, **28**, pp. 39-57.

Anderson, J. and Moxham, J. (1992). **Peer Review: A View from the Inside.** *Science and Technology Policy*, February, pp. 7-15.

Antle, J.M. and McGuickan, T. (1993). Technological Innovation, Agricultural Productivity and Environmental Quality. In: Carlson, G. A., Zilberman, D. and Miranowski, J. A. eds. (1993). **Agricultural and Resource Economics.** Oxford: Oxford University Press, pp. 175-220.

Archibald, S.O. (1988). Incorporating Externalities into Agricultural Productivity Analysis. In: Capalbo, S.M. and Antle, J.M. eds. **Agricultural Productivity: Measurement and Explanation.** Washington: Resources for the Future, pp. 366-393.

Arrow, K.J. (1962). Economic Welfare and the Allocation of Resources for Invention. In: Nelson, R. ed. (1962). **The Rate and Direction of Inventive Activities.** Princeton: Princeton University Press, pp. 609-625.

Arrow, K.J. (1969). The Organisation of Economic Activity: Issues Pertinent to the Choice of Market Versus Non-Market Allocation. In: US Joint Economic Committee. **The Analysis and Evaluation of Public Expenditure: The PPB System.** Vol. 1. Washington: US Government Printing Office, pp. 59-73.

Arundel, A., Van De Paal, G. and Soete, L. (1995). **Innovation Strategies of Europe's Largest Industrial Firms: Results of the PACE Survey for Information Sources.** Limburg University, Maastricht: MERIT.

Ball, V.E., Lovell, C.A.K., Nehring, R. and Somwaru, L. (1994). **Incorporating Undesirable Outputs into Models of Production: An Application to US Agriculture.** *Cahiers d'Economie et Sociologie Rurales.* **31**, pp. 60-74.

Battese, G.E. and Coelli, T.J. (1993). **Frontier Production Functions, Technical Efficiency and Panel Data: With Application to Paddy Farmers in India**. *Journal of Productivity Analysis*, **3**, pp. 153-169.

Babaraham Institute. (1997). **Annual Report.** Cambridge: BI.

Beck, H. (1987). **A Description of Research and Development in the UK Agricultural Sector.** Reading: University of Reading. EPARD Discussion Paper Number 2.

Beilby, O.J. (1938). **Changing Agricultural Production in England and Wales**. *Journal of the Royal Agricultural Society of England*, **100**, *2*, pp. 62-73.

Bell, R. (1984). **Report of a Study on ADAS.** London: MAFF.

Biotechnological and Biological Sciences Research Council. (1994). **Corporate Plan 1994-1999.** Swindon: BBSRC.

Biotechnological and Biological Sciences Research Council. (1995). **Annual Report.** Swindon: BBSRC.

Bonnen, J.T. (1987). A Century of Science in Agriculture: Lessons for Science Policy. In: Ruttan, V.W. and Pray, C.E. eds. (1987). **Policy for Agricultural Research.** Boulder, Colorado: Westview Press, pp. 395-409.

Bouchet, F.C., Orden, D. and Norton, G.W. (1989). **Sources of Growth in French Agriculture**. *American Journal of Agricultural Economics*, **71**, *2*, pp. 280-293.

Bourke, P. and Butler, L. (1999). **The Efficacy of Different Modes of Funding Research: Perspectives from Australian Data on the Biological Sciences.** *Research Policy*, **28**, *5*, pp. 489-499.

Bredahl, M.E., Bryant, W.K. and Ruttan, V.W. (1980). **Behaviour and Productivity Implications of Institutional and Project Funding of Research**. *American Journal of Agricultural Economics*, **62**, *2*, pp. 371-383.

Bressers, H. (1988). Effluent Charges Can Work: The Case of Dutch Water Quality Policy. In Dietz, F. and Heijman, W. eds. (1988). **Environmental Policy in a Market Economy.** Wageningen: Pudoc, pp. 5-39.

Brus, W. (1972). **The Market in a Socialist Economy.** London: Routledge and Kegan Paul.

Burns, J., McInerney, J. and Swinbank, A. (1983). **The Food Industry: Economies and Policies.** London: Heinemann and CAB.

Burrell, A., Hill, B. and Medland, J. (1990). **Agrifacts: A Handbook of UK and EEC Agricultural and Food Statistics.** London : Harvester Wheatsheaf.

Cabinet Office. (Various Years). **Annual Review of Government Research and Development.** London: HMSO.

Carney, D. (1998). **Changing Public and Private Sector Roles in Agricultural Service Provision.** London: Overseas Development Institute.

Central Statistical Office. (Various Years). **Annual Abstract of Statistics.** London: HMSO.

Chang, H-J. (1996). **The Political Economy of Industrial Policy.** Basingstoke: Macmillan Press Limited.

Charles, D, Howells, J. Del Castillo, J., Gomez, P, Samano, A. and Tsipouri, L.J. (1988). **Innovation Sprint: HEI/Research Centre/Industry Links in Europe.** Luxembourg: Commission of European Communities.

Christensen, L.R. (1975). **Concepts and Measurement of Agricultural Productivity.** *American Journal of Agricultural Economics*, **57**, *5*, pp. 910-15.

Cline, P.L. and Lu, Y-C. (1976). **Efficiency Aspects of the Spatial Allocation of Public Sector Agricultural Research and Extension in the U.S.** *Regional Science Perspectives*, **6**, pp. 1-16.

Coase, R.H. (1960). **The Problem of Social Cost.** *Journal of Law and Economics*, **3**, pp. 1-44.

Cochrane W. (1957). **Farm Prices.** Minneapolis: University of Minnesota Press.

Coelli, T., Rao, D.S.P. and Battese, G.E. (1998). **An Introduction to Efficiency and Productivity Analysis.** Boston: Kluwer Academic Publishers.

Commission of the European Communities. (1998). **Proposals for Council Regulations (EC) Concerning the Reform of the Common Agricultural Policy.** COM(1998) 158 Final.

Cooke, G.W. (1981). Plant Breeding. In: Cooke, G.W. ed. (1981). **Agricultural Research 1931-1981.** Old Woking: Agricultural Research Council, pp. 183-202.

Council for Scientific Policy. (1966). **Report of the Council for Scientific Policy.** Cmnd. 3007. London: HMSO.

Council for Scientific Policy. (1967). **Second Report of the Council for Scientific Policy.** Cmnd. 3420. London: HMSO.

Crosby, E.A. (1987). Private Sector Agricultural Research in the United States. In: Ruttan, V.W. and Pray, C.E. eds. (1987). **Policy for Agricultural Research.** Boulder: Westview Press, pp. 395-409.

Dalrymple, D.G. (1990). The Excess Burden of Taxation and Public Agricultural Research. In: Echeverria, R.G. ed. (1990). **Methods for Diagnosing Research System Constraints and Assessing the Impact of Agricultural Research - Vol. 2**. The Hague: ISNAR, pp. 117-137.

Dancey, R.J. (1993). **The Evolution of Agricultural Extension in England and Wales: Some Reflections.** *Journal of Agricultural Economics*, **44**, *3*, pp. 375-393.

Davies, J. (1981). **A Comparison of Procedures for Estimating Returns to Research Using Production Functions.** *Australian Journal of Agricultural Economics,* **25,** *1,* pp. 60-72.

Dawson, P.J. and Lingard, J. (1987). Input Markets. In: Harvey, D. ed. (1987). **The Future of the Agricultural and Food System.** Reading: University of Reading. EPARD Working Paper Number 1, pp. 83-106.

Demsetz, H. (1969). **Information and Efficiency: Another Viewpoint.** *Journal of Law and Economics,* **12,** pp. 1-22.

Department of the Civil Service. (1979). **Review of the Framework Document Cmnd 5046.** Cmnd. 7499. London: HMSO.

Department of Economic Affairs. (1965). **National Plan.** Cmnd. 2765. London: HMSO.

Department of Education and Science. (Various Years). **Statistics of Education. Volume 5: Finance and Awards**. London: HMSO.

Department of Education and Science. (1991). **Higher Education: A New Framework.** Cmnd. 1541. London: HMSO.

Dobb, M. (1970). **Socialist Planning: Some Problems.** London: Lawrence Wishart.

Doti, J.L. and Adibi, E. (1998). **The Practice of Econometrics with E-Views**. 2nd ed. Irvine, California: Quantitative Micro Software.

Douma, S. and Schreuder, H. (1998). **Economic Approaches to Organisations.** 2nd ed. London: Prentice Hall.

Doyle, C.J., Macgregor, M., Davies, S., Chadwick, L. (1994). **A Framework for Evaluating R&D Projects within SAC.** Report Prepared for the Scottish Agricultural College and the Scottish Office Agriculture and Fisheries Department, June 1994.

Doyle, C.J. and Ridout, M.S. (1985). **The Impact of Scientific Research on UK Agricultural Productivity.** *Research Policy*, **14**, *2,* pp. 109-116.

Echeverria, R.G. (1990). Assessing the Impact of Agricultural Research. In: Echeverria, R.G. ed. (1990). **Methods for Diagnosing Research System Constraints and Assessing the Impact of Agricultural Research. Volume 2.** The Hague: ISNAR, pp. 1-31.

Ellis, F.B. (1991). **Farmer-Funding of R&D, with particular reference to Cereals.** *Journal of the Royal Agricultural Society,* **151**, pp. 148-160.

Emry-Jones, W. (1970). **The New A.D.A.S.** *Agriculture,* **77**, pp. 397.

ENTEC. (1998). **Economic Evaluation of the Nitrate Sensitive Areas Scheme.** London: MAFF.

Ernle, Lord. (1961). **English Farming Past and Present.** 6th ed. London: Heinemann.

European Commission. (1994). **European Economy: Reports and Studies.** Brussels, Belgium: ECSC-EC-EAEC. Report Number 4.

Evenson, R.E. (1967). **The Contribution of Agricultural Research to Production.** *Journal of Farm Economics*, **49**, *5*, pp. 1415-25.

Fare, R., Grosskopf, S. and Roos, P. (1997). Malmquist Productivity Indexes: A Survey of Theory and Practice. In: Fare, R., Grosskopf, S. and Rossel, R.R. eds. (1997). **Index Numbers: Essays in Honour of Sten Malmquist.** Boston: Kluwer Academic Publishers, pp. 89-106.

Fernandez-Cronejo, J. and Jans, S. (1995). **Quality Adjusted Price and Quantity Indexes for Pesticides.** *American Journal of Agricultural Economics*, 77, *3*, pp. 645-659.

Fite, G. (1980). **Mechanisation of Cotton Production Since World War Two.** *Agricultural History*, **54**, *1*, pp. 190-207.

Food and Agriculture Organisation. (Various Years). **Annual Trade Yearbook.** Rome: Food and Agricultural Organisation for the United Nations.

Foreman, S. (1989). **Loaves and Fishes.** London: HMSO.

Fox, G. (1985). **Is the United States Really Underinvesting in Agricultural Research?** *American Journal of Agricultural Economics*, **67**, *4*, pp. 806-812.

Friedman, M. (1962). **Capitalism and Freedom.** Chicago: University of Chicago Press.

Gibbons, M. *et al.* (1994). **The New Production of Knowledge.** London: Sage.

Godden, D.P. (1985). **Technological Change and Demand for Output at Farm Level in UK Agriculture 1950-1980.** Unpublished PhD thesis. London School of Economics.

Goodman, D., Bernado, S. and Wilkinson, J. (1987). **From Farming to Biotechnology: A Theory of Agro-Industrial Development.** Oxford: Blackwell.

Grandstaff, S. and Balagot, B. (1986). Tongonan Geothermal Power Plant Project in Leyte, Philippines. In: Dixon, J.A. and Hufschmidt, M.M. eds. (1986). **Economic Valuation Techniques for the Environment.** Baltimore: John Hopkins University Press, pp. 83-101.

Grigg, D. (1989). **English Farming: A Historical Perspective.** Oxford: Blackwell.

Griliches, Z. (1960). **Measuring Inputs in Agriculture: A Critical Survey.** *Journal of Farm Economics*, **42**, *5*, pp. 1411-1427.

Griliches, Z. (1964). **Research Expenditure, Education and the Aggregate Agricultural Production Function.** *American Economic Review*, **54**, *6*, pp. 961-74.

Gujarti, D.N. (1995). **Basic Econometrics.** 3rd ed. New York: Mcgraw-Hill.

Hadley, D. et. al. (2000). **A Stochastic Frontier Approach to Farm level Efficiency, Technical Change, Productivity and Risk in UK Dairying.** *Paper presented at the Annual Agricultural Economic Society Conference, University of Manchester*, 14-17 April.

Hailu, A. and Veeman, T.S. (2000). Alternative Models for Environmentally Sensitive Productivity Analysis, *paper presented at the International Association of Agricultural Economists, Humboldty University, Berlin,* August 13-19.

Hallam, D. (1990). **Agricultural Research Expenditure and Agricultural Productivity.** *Journal of Agricultural Economics*, **41**, *3*, pp. 434-439.

Hanley, N. (1990). **The Economics of Nitrate Pollution.** *European Review of Agricultural Economics*, **17**, *2*, pp. 129-151.

Harvey, D. (1987). An Overview of the Agricultural and Food Sector. In: Harvey, D. ed. (1987). **The Future of the Agricultural and Food System.** Reading: University of Reading. EPARD Discussion Paper Number 1, pp. 39-56.

Harvey, D.R. (1988). **Research Priorities on Agriculture.** *Journal of Agricultural Economics*, **39**, *1*, pp. 81-97.

Harvey, D. (1991). The CAP and Research and Development Policy. In: Ritson, C. and Harvey, D. eds. (1991). **The Common Agricultural Policy and the World Economy**. Wallingford: CAB International, pp. 185-204.

Henderson, W. (1981). British Agricultural Research and the Agricultural Research Council. In: Cooke, G. ed. (1981). **Agricultural Research 1931-1981.** Old Woking: Agricultural Research Council, pp. 3-113.

Herbetz, H. and Muller-Hill, B. (1996). **Quality and Efficiency of Basic Research in Molecular Biology: A Bibliometric Analysis of Thirteen Excellent Research Institutes.** *Research Policy*, **24**, pp. 959-979.

HMSO. (1967). **Nationalised Industries: A Review of the Economic and Financial Objectives.** Cmnd. 3437. London: HMSO.

HM Treasury. (Various Years). **Supply Estimates**. London: HMSO.

HM Treasury. (1991). **Economic Appraisal in Central Government: A Technical Guide for Government Departments**. London: HMSO.

Home Grown Cereals Authority. (1996). **Annual Report.** London: HGCA.

Horticulture Research Institute. (1996). **Annual Report 1995/6.** Warwick: HRI.

Huffman, W.E. and Evenson, R.E. (1993). **Science for Agriculture: A Long Term Perspective.** Ames: Iowa State University Press.

Huffman, W.E. and Just, R.E. (1999). **The Organisation of Agricultural Research in Western Developed Countries.** *Agricultural Economics*, **21**, *1*, pp. 1-18.

Hussey, D. (1996). Public Funding of Agricultural R&D: Policy Trends and Implications for Research Evaluation. In: Brennan, J.P. and Davis, J.S. eds. (1996). **Economic Evaluation of Agricultural Research in Australia and New Zealand.** Canberra: Australian Centre for International Agricultural Research. ACIAR Monograph No. 39, pp. 68-73.

James, C. and Persley, G.J. (1990). Role of the Private Sector. In: Persley, G.B. ed. (1990). **Agricultural Biotechnology: Opportunities for International Development.** Oxford: CAB International, pp. 367-377.

Johansson, P-O. (1987). **The Economic Theory and Measurement of Environmental Benefits.** Cambridge: Cambridge University Press.

Khatri, Y.J. and Thirtle, C.G. (1996). **Supply and Demand Functions for UK Agriculture: Biases of Technical Change and the Returns to Public R&D.** *Journal of Agricultural Economics*, **47**, *3*, pp. 338-354.

King, J.W.B. (1981). Animal Breeding Research in Britain, 1931-1981. In: Cooke, G.W. ed. (1981). **Agricultural Research 1931-1981.** Old Woking: Agricultural Research Council, pp. 277-288.

Knutson, M. and Tweeton, L.G. (1979). **Toward an Optimal Rate of Growth in Agricultural Production Research and Extension.** *American Journal of Agricultural Economics,* **61,** *1,* pp. 70-76.

Kogan, M. and Henkel, M. (1983). **Government and Research: The Rothschild Experiment in a Government Department.** London: Heinemann Educational Books.

Kuhn, T.S. (1970). **The Structure of Scientific Revolutions.** 2nd ed. Chicago: University of Chicago Press.

Kula, E. (1992). **Economics of Natural Resources and the Environment.** London: Chapman and Hall.

Kula, E. (1997). **Time Discounting and Future Generations: The Harmful Effects of an Untrue Economic Theory.** Westport: Quorum.

Lancaster, K. (1966). **A New Approach to Consumer Theory.** *Journal of Political Economy*, **74**, pp. 132-157

Lau, L.J. (1976). **A Characterisation of the Normalised Restricted Profit Function.** *Journal of Economic Theory*, **12,** pp. 131-163.

Lee, N. (1989). Performance Measurement. In: . In: Devine, P.J., Lee, N., Jones, R.M. and Tyson, W.J. eds. (1989). **An Introduction to Industrial Economics.** 4th ed. London: Unwin Hyman, pp. 301-330.

Lesser, W. and Lee, D.R. (1993). Economics of Agricultural Research and Biotechnology. In: Rayner, A.J. and Colman, D. eds. (1993). **Current Issues in Agricultural Economics.** Basingstoke: Macmillan Press, pp. 178-204.

Lilian, D.M. *et al.* (1995). **Econometric Views.** Version 2.0. Quantitative Micro Software.

Lindner, R.K. (1993). **Privatising the Production of Knowledge: Promise and Pitfalls for Agricultural Research and Extension.** *Australian Journal of Agricultural Economics*, **37**, *3*, pp. 205-225.

Linder, R.K and Jarret, F.G. (1978). **Supply Shifts and the Size of Research Benefits.** *American Journal of Agricultural Economics*, **60,** *1*, pp. 48-56.

Lord, R.F. and Rogers, S.J. (1969). The Current Organisation of Research, Education and Extension in British Agriculture. In: Ashton, J. and Lord, R.F. eds. (1969). **Research, Education and Extension in Agriculture.** Edinburgh: Oliver and Boyd, pp. 1-41.

Mackintosh, M. *et al.* (1996). **Economics and Changing Economies.** London: Open University and International Thompson Business Press.

Marks, H.F. (1989). Labour. In: Britton, P.K. ed. (1989). **A Hundred Years of British Food and Farming: A Statistical Survey.** London: Taylor and Francis, pp. 15-17.

Martin, B. *et al.* (1996). **The Relationship Between Publicly Funded Basic Research and Economic Performance: A SPRU Review.** London: HM Treasury.

May, R. (1997). **The Scientific Wealth of Nations**. *Science*, **275**, *7*, pp. 793-796.

McCutcheon, R. (1979). **Limits of a Modern World: A Study of the 'Limits to Growth' Debate.** London: Butterworth.

Meadows, D.H. *et al.* (1974). **The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind.** London: Pan Books.

Ministry of Agriculture, Fisheries and Food. (Various Years). **Agriculture in the UK.** London: MAFF.

Ministry of Agriculture, Fisheries and Food *et al.* (Various Years). **Agricultural Statistics.** London: HMSO.

Ministry of Agriculture, Fisheries and Food. (1961). **Productivity Measurement in Agriculture.** *Economic Trends,* pp. ii-v.

Ministry of Agriculture, Fisheries and Food. (1968). **A Century of Agricultural Statistics 1866-1966.** London: HMSO.

Ministry of Agriculture, Fisheries and Food. (1969). **Productivity Measurement in Agriculture.** *Economic Trends*, pp. xxvi-xxx.

Ministry of Agriculture, Fisheries and Food. (1996). **Research Strategy 1996-2000.** London: MAFF.

Ministry of Agriculture, Fisheries and Food. (1997). **Veterinary Laboratories Agency to Remain an Executive Agency.** Press Release, 29th January. Number 31/97.

Ministry of Agriculture, Fisheries and Food. (1998a). **MAFF Scientific Centre of Excellence Consolidated at York.** Press Release, 21st May. Number 209/98.

Ministry of Agriculture, Fisheries and Food. (1998b). **Review of the Organic Aid Scheme.** MAFF: London.

Mullen, J.D., Lee, K. and Wrigley, S. (1994). Financing Agricultural Research in Australia: 1953-1994. In: Brennan, J.P. and Davis, J.S. eds. (1994). **Economic Evaluation of Agricultural Research in Australia and New Zealand.** Canberra: Australian Centre for International Agricultural Research. ACIAR Monograph No. 39, pp. 45-57.

National Audit Office. (1990). **Advisory Services to Agriculture.** Cmnd. 358. London: HMSO.

National Audit Office. (1991). **Report by the Controller and Auditor General: Advisory Services to Agriculture.** London: HMSO.

Nelson, R.R. (1959). **The Simple Economics of Basic Scientific Research**. *Journal of Political Economy*, June, pp. 297-306.

Nelson, R.R. (1982). **Government and Technical Progress.** New York: Pergamon Press.

Norton, G.W. and Davis, J.S. (1981). **Evaluating Returns to Agricultural Research: A Review.** *American Journal of Agricultural Economics*, **63**, *4*, pp. 688-699.

Office of Science and Technology. (1993). **Realising Our Potential: A Strategy for Science, Engineering and Technology.** Cmnd 2250. London: HMSO.

Office of Science and Technology. (1995a). **Technology Foresight: Progress Through Partnership**. Volume 11. London: HMSO.

Office of Science and Technology. (1995b). **Technology Foresight: Progress Through Partnership.** Volume 4. London: HMSO.

Organisation for Economic Co-operation and Development. (1992). **Technology and the Economy: The Key Relationships**. Paris: OECD.

Organisation for Economic Co-operation and Development. (1994a). **Frascati Manual 1993: Proposed Standard Practice for Surveys of Research and Experimental Development.** Paris: OECD.

Organisation for Economic Co-operation and Development. (1994b). **Manufacturing Performance: A Scoreboard of Indicators.** Paris: OECD.

Oskam, A. (1991). Productivity Measurement, Incorporating Environmental Effects of Agricultural Production. In. Burger *et al.* eds. (1991). **Agricultural Economics and Policy: International Challenges for the Nineties.** Amsterdam: Elsevier, pp. 186-204.

Oury, D. (1965). **Allowing for Weather in Crop Production Model Building.** *Journal of Farm Economics*, **47**, *2*, pp. 270-283.

Pardey, P.G. and Craig, B. (1989). **Causal Relationships Between Public Agricultural Research Expenditures and Output**. *American Journal of Agricultural Economics*, **71**, *1*, pp. 9-19.

Pavitt, K. (1991). **What Makes Basic Research Economically Useful?** *Research Policy,* **20**, pp. 109-119.

Peacock, A. (1979). **The Economic Analysis of Government.** Oxford: Martin Robertson.

Peterson, G.E. (1967). **The Discovery and Development of 2,4-D.** *Agricultural History,* **61**, *3*, pp. 243-253.

Philip, J.R. (1978). **Towards Diversity and Adaptability: An Australian View of Governmentally Supported Science.** *Minerva*, **16**, pp. 397-415.

Phipps, T.T. (1989). **Externalities and the Returns to Agricultural Research: Discussion**. *American Journal of Agricultural Economics*, **71**, *2*, pp. 466-7.

Piesse, J. and Thirtle, C.J. (1997). **Sector Level Efficiency and Productivity in Hungary Primary, Secondary and Tartiary Industries 1985-1991**. *Eastern European Economics*, **35**, pp. 5-39.

Pigou, A.C. (1932). **The Economics of Welfare.** 4th ed. London: Macmillan.

Pineiro, M. (1986). **The Development of the Private Sector in Agricultural Research: Implications for Public Research Institutes.** The Hague: ISNAR. ISNAR Proagro Paper Number 10.

Pinstrup-Anderson, P. (1982). **Agricultural Research and Technology in Economic Development.** London: Longman.

Pitman, J.I. (1992). Changes in Crop Productivity and Water Quality in the United Kingdom. In: Hoggart, K. ed. (1992). **Agricultural Change, Environment and Economy.** London: Mansell Publishing, pp. 89-122.

Pray, C.E. (1996). **The Impact of Privatising Agricultural Research in Great Britain.** *Food Policy,* **21**, *3*, pp. 305-318.

Pray, C.E. and Echeverria, R.G. (1991). Private Sector Agricultural Research in Less-Developed Countries. In: Pardey, P.G., Roseboom, J. and Anderson, J. eds. (1991). **Agricultural Research Policy: International Quantitative Perspectives.** Boulder: Westview Press, pp. 342-364.

Pyndyck, R.S. and Rubinfeld, D. L. (1998). **Econometric Models and Economic Forecasts.** 4th ed. Boston: Irwin Mcgraw-Hill.

Radford, J. (1996). New Zealand Agricultural Research. In: Brennan, J.P. and Davis, J.S. eds. (1996). **Economic Evaluation of Agricultural Research in Australia and New Zealand.** Canberra: Australian Centre for International Agricultural Research. ACIR Monograph 39, pp. 25-27.

Rausser, G.C. and Zilberman, D. (1991). Public Agricultural Research in Agriculture: An Alternative Institutional Framework. In: Kaul, T.K. and Sengupta, J.K. eds. (1991). **Essays in Honour of Karl A. Fox.** Amsterdam: Elsevier Science, pp. 33-53.

Rayner, A.J. and Lindner, J. (1971). **Fertiliser Prices and Quality Change**. *Journal of Agricultural Economics*, **22**, 2, pp. 149-162.

Rayner, A.J., Whittaker, J.M. and Ingersent, K.A. (1986). **Productivity Growth in Agriculture Revisited: A Measurement Framework and Some Empirical Results.** *Journal of Agricultural Economics*, **37**, *2*, pp. 127-150.

Read, N. (1989). **The 'Near Market' Concept Applied to UK Agricultural Research.** *Science and Public Policy,* **16**, pp. 233-238.

Read, N., Quinn, J. and Webster, A. (1988). **Commercialisation as a Policy Mechanism in UK Agricultural Research, Development and Extension.** *Agricultural Systems*, **26**, *1*, pp. 77-87.

Reay, Lord. (1908). **Report on Agricultural Education in England and Wales.** Cmnd. 4206. London: HMSO.

Reinhard, S., Lovell, C.A.K. and Thijssen, G.J. (1996). **Econometric Estimation of Technical and Environmental Efficiency: an Application to Dutch Dairy Farms,** *paper presented at the Georgia Productivity Workshop, Athens GA, USA*, 4-6 November.

Riley, R. (1981). Plant Breeding. In: Cooke, G.W. ed. (1981). **Agricultural Research 1931-1981.** Old Woking: Agricultural Research Council, pp. 115-137.

Ritson, C. (1977). **Agricultural Economics: Principles and Policy.** London: Crosby Lockwood Staples.

Röling, N. (1986). Flexibility versus Targets on Setting Extension Objectives. In: Jones, G.E. ed. (1986). **Investing in Rural Extension: Strategies and Goals**. London: Elsevier Applied Science Publishers, pp. 107-112.

Roseboom, H. and Ruttan, H. (1997). **The Transformation of the Dutch Agricultural Research System: An Unfinished Agenda?**. Paper Presented at EAAE Seminar on Innovation for Innovation, Zandvoort, Holland, 21-23 April, 1997.

Rosegger, G. (1980). **The Economics of Production and Innovation: An Industrial Perspective.** Oxford: Pergamon Press.

Rosenberg, N. (1990). **Why Do Firms Do Basic Research (with their own money).** *Research Policy*, **19**, pp. 165-174.

Rosenberg, N. (1994). **Exploring the Black Box: Technology, Economics and History.** Cambridge: Cambridge University Press.

Rothschild, Lord. (1971). The Organisation and Management of Government R&D. In: (1971). **A Framework Document for Research and Development.** (*Green Paper).* Cmnd. 4814. London: HMSO.

Roturier, C. (1998). France. In: Persley, C.J. ed. (1998). **Investment Strategies for Agriculture and Natural Resources.** Wallingford: CABI Publishers, pp. 23-38.

Rowett Research Institute. (Various Years). **Annual Report.** Aberdeen: RRI.

Russel, E.J. (1966). **A History of Agricultural Science in Great Britain.** London: George Allen and Unwin.

Ruttan, V.W. (1982). **Agricultural Research Policy.** Minneapolis: University of Minnesota Press.

Schimmelpfennig, D. and Thirtle, C.G. (1998). **The Internationalisation of Agricultural Technology: Productivity Convergence, R&D Spillovers and Patents in the European Union and United States.** Paper Presented at the Agricultural Economics Society Conference, Reading, UK, 25-28 March.

Schmitz, A. and Seckler, D. (1970). **Mechanised Agriculture and Social Welfare: The Case of the Tomato Harvester.** *American Journal of Agricultural Economics*, **52**, *4*, pp. 569-577.

Schuh, G.E. and Tollini, H. (1979). **The Costs and Benefits of Agricultural Research: The State of the Arts.** Washington: World Bank. World Bank Staff Working Paper Number 360.

Scottish Agricultural College. (1998). **The Farm Management Handbook.** 19th ed. Edinburgh: SAC.

Scottish Office. (1994). **Forward Look of Government Science, Engineering and Technology.** Edinburgh: Scottish Office.

Scottish Office Agriculture, Environment and Fisheries Department. (Various Years). **Agriculture in Scotland.** Edinburgh: HMSO/Scottish Office.

Select Committee on Science and Technology. (1988). **Agriculture and Food Research: Volume 1.** House of Lords Paper 13-I. London: HMSO.

Spedding, C.R.W. (1984). Agricultural Research Policy. In: Goldsmith, M. ed. (1984). **UK Science Policy**. London: Longman, pp. 2-19.

Stout, D.K. (1981). The Case for Government Support in Agricultural R&D. In Carter, C. ed. (1981). **Industrial Policy and Innovation.** London: NIESR, Heinemann, pp. 116-127.

Stuckey, J. and White, D. (1993). **When and When not to Vertically Integrate**. Mckinsey Quarterly, **1**, pp. 3-27.

Thirkell, J.D. (1993). **Co-operation: A Key to Success.** *Farm Management*, **8**, *6*, pp. 277-285.

Thirtle, C.G. (1986). **A Summary of Arguments For and Against the Public Provision of Agricultural R&D.** Manchester: University of Manchester. Working Papers in Agricultural Economics WP/02.

Thirtle, C. and Bottomley, P. (1988). **Is Publicly Funded Agricultural Research Excessive?** *Journal of Agricultural Economics*, **39**, *1*, pp. 99-111.

Thirtle, C. and Bottomley, P. (1992). **Total Factor Productivity in UK Agriculture 1967-1990.** *Journal of Agricultural Economics*, **43**, *3*, pp. 381-400.

Thirtle, C.G. and Echeverria. R.G. (1994). **Privatisation and the Roles of Public and Private Institutions in Agricultural Research in Sub-Saharan Africa**. *Food Policy*, **19**, *1*, pp. 31-44.

Thirtle, C.G., Palladino, P. and Piesse, J. (1997). **On the Organisation of Agricultural Research in the United Kingdom, 1945-1994: A Quantitative Description and Appraisal of Recent Reforms**. *Research Policy*, **26**, pp. 557-576.

Thirtle, C.G., Piesse, J. and Smith, V.H. (1997). **An Economic Approach to the Structure, Historical Development and Reform of Agricultural R&D in the UK.** Reading: Centre for Agricultural Strategy. CAS Paper 35.

Thirtle, C.G. and Townsend, R. (1997). **Efficiency Differences in European Agriculture: Multi-National Productivity Indices and the Returns to R&D with Spillovers.** Paper Presented at EAAE Seminar on Innovation for Innovation, Zandvoort, Holland, 21-23 April, 1997.

Thirtle C.G. *et al.* (1998). **The Rise and Fall of Public Sector Plant Breeding in the United Kingdom.** *Agricultural Economics,* **19**, *1-2,* pp. 127-143.

Thornley, J.H.M. and Doyle, C.J. (1984). **Management of Publicly Funded Agricultural Research and Development in the UK: Questions of Autonomy and Accountability.** *Agricultural Systems*, **15**, *4*, pp. 195-208.

Tracy, M. (1989). **Agriculture in Western Europe 1880-1988.** 3rd ed. Hemel Hempstead: Harvester Wheatsheaf.

Trend, B. (1963). **Committee of Enquiry into the Organisation of Civil Science.** Cmnd. 2171. London: HMSO.

Tyson, W.J. (1989). Government Relations with the Public Industrial Sector. In: Devine, P.J., Lee, N., Jones, R.M. and Tyson, W.J. eds. (1989). **An Introduction to Industrial Economics.** 4th ed. London: Unwin Hyman, pp. 398-439.

Ulbricht, T.L.V. (1977). Contract Agricultural Research and its Effect on Management. In: Arndt, T.M., Dalrymple, D.G. and Ruttan, V.W. eds. (1977). **Resource Allocation and Productivity in National and International Agricultural Research.** Minneapolis: University of Minnesota Press, pp. 381-393.

Umali, D.L. (1992). **Public and Private Sector Roles in Agricultural Research: Theory and Experience.** Washington: World Bank. World Bank Discussion Paper 176.

Universities Statistical Record. (Various Years). **University Statistics. Volume 3: Finance**. Cheltenham: USR.

Watson, J.A.S. (1946). **How the N.A.A.S. Will Work**. *Agriculture*, **53**, pp. 217.

Webster, A.J. (1988) **Changing Structural Relationships between Public Sector Science and Commercial Enterprise.** Cambridge: Science Policy Support Group.

Wells, S.J. (1969). **International Economics.** London: George Allen and Unwin.

White, F.C. and Havlicek, J.G. Jr. (1982). **Optimal Expenditures for Agricultural Research and Extension: Implications of Underfunding.** *American Journal of Agricultural Economics*, **64**, *2*, pp. 47-55.

Whittaker, J.M. (1983). **An Economic Analysis of Productivity Growth in UK Agriculture.** Unpublished M.Phil. thesis. University of Nottingham.

Williamson, O.E. (1985). **The Economic Institutions of Capitalism.** New York: Free Press.

Wise, W.S. (1984). **The Shift of Cost Curves and Agricultural Research Benefits.** *Journal of Agricultural Economics*, **35**, *1*, pp. 21-30.

Wise W. S. (1986). **Calculation of Rates of Return in Agricultural Research from Production Functions.** *Journal of Agricultural Economics*, **37**, *2*, pp. 151-162.

Zucker, L.G. and Danby, M.R. (1995). **Virtuous Circles of Productivity: Star Bioscientists and the Institutional Transformation of Industry.** Cambridge: NBER. Working Paper 5342.

List of Appendices

Appendix One

Public Expenditures on Agricultural R&D and Extension, 1948 to 1996, in nominal terms

Total Research and Advisory Expenditures for England and Wales (£000's)*								
Year	AFRC Research	In-House Research	Advisory Services (Capital)	Advisory Services (Current)	Special Investig.	UGC Research Grants	Totals Research Expenditure	Totals Advisory Expenditure
1948	*778*	*67*	*224*	*279*	*381*	*1,041*	*2,268*	*503*
1949	*819*	*70*	*236*	*294*	*402*	*1,096*	*2,387*	*530*
1950	*863*	*74*	*249*	*309*	*423*	*1,153*	*2,512*	*558*
1951	*908*	*78*	*262*	*325*	*445*	*1,214*	*2,645*	*587*
1952	*956*	*82*	*276*	*343*	*468*	*1,278*	*2,784*	*618*
1953	1,006	86	290	361	493	1,345	2,930	651
1954	998	98	300	388	673	1,375	3,145	688
1955	1,995	122	240	371	219	1,406	3,741	611
1956	1,212	137	300	398	233	1,436	3,018	698
1957	3,626	170	230	291	263	1,466	5,525	521
1958	3,862	182	241	406	282	1,496	5,822	647
1959	4,196	185	185	387	317	1,527	6,224	572
1960	4,545	190	185	401	331	1,557	6,622	586
1961	5,605	185	200	443	342	1,587	7,719	643
1962	6,044	216	147	431	359	1,617	8,237	578
1963	6,508	214	113	440	361	1,648	8,730	553
1964	7,387	267	130	434	413	1,678	9,745	564
1965	8,165	276	170	443	437	1,678	10,556	613
1966	9,313	288	160	484	510	1,789	11,900	644
1967	9,935	271	521	512	544	1,592	12,342	1,033
1968	11,974	332	543	543	389	2,115	14,810	1,086
1969	13,350	290	596	596	404	1,465	15,509	1,192
1970	15,023	303	452	648	363	1,342	17,031	1,100
1971	16,930	430	308	1,242	440	1,230	19,030	1,550
1972	19,964	470	466	1,477	470	1,277	22,181	1,943
1973	21,918	522	424	1,702	908	1,391	24,739	2,126
1974	23,682	666	563	1,346	854	1,682	26,884	1,909
1975	29,196	1,029	680	1,777	1,358	2,315	33,898	2,457
1976	34,180	974	825	2,047	1,812	2,510	39,476	2,872
1977	41,820	1,330	1,101	2,650	2,276	2,798	48,224	3,750
1978	45,590	1,686	1,376	3,252	2,745	3,194	53,215	4,628
1979	53,084	1,609	1,530	3,228	2,646	3,559	60,898	4,758
1980	59,910	2,474	2,521	4,500	3,502	3,875	69,761	7,021
1981	74,870	2,640	2,196	4,870	4,012	4,701	86,223	7,066
1982	86,250	2,589	2,626	5,690	5,340	5,526	99,705	8,316
1983	92,160	3,368	2,841	6,338	5,846	9,259	110,633	9,179
1984	96,780	3,856	3,234	6,999	9,305	8,791	118,732	10,233
1985	98,820	4,344	3,628	7,661	9,607	9,553	122,324	11,288
1986	104,490	4,669	4,021	8,206	11,126	10,586	130,871	12,227
1987	105,070	5,071	3,657	8,645	11,101	7,716	128,958	12,302
1988	99,100	3,628	4,085	10,042	11,521	9,540	123,789	14,127
1989	107,490	2,185	4,513	11,439	10,598	12,129	132,402	15,952
1990	120,290	2,467	4,814	12,578	12,831	13,507	149,095	17,392
1991	133,510	2,743	4,930	13,820	15,455	15,623	167,331	18,750
1992	130,090	2,648	2,345	15,202	14,320	16,265	163,323	17,547
1993	140,550	2,552	4,151	16,723	14,946	18,153	176,201	20,874
1994	145,340	3,132	4,827	18,395	14,950	20,331	183,753	23,222
1995	*145,340*	*3,132*	*4,827*	*18,395*	*14,950*	*20,331*	*183,753*	*23,222*
1996	*145,340*	*3,132*	*4,827*	*18,395*	*14,950*	*20,331*	*183,753*	*23,222*
Sources:	*AFRC Annual Reports*	*Supply Estimates (Ministry Research)*	*Supply Estimates (Advisory Services)*	*Supply Estimates (Advisory Services)*	*Supply Estimates (Special Investig.)*	*Educat. Statistics (Ag./For/ Vet.)*		

* *Italics Denote Estimates of Expenditures*

Total Research and Advisory Expenditures for Scotland (£000's)*									
Year	Depart. Research	Research Institutes (Capital)	Research Institutes (Current)	SOAEFD Flexible Funding	Advisory SAC	R&D SAC	UGC Research Grants	Totals Research Expenditure	Totals Advisory Expenditure
1948	*22*	*103*	*256*		*179*	*126*	*1*	*509*	*179*
1949	*23*	*108*	*270*		*188*	*133*	*2*	*536*	*188*
1950	*24*	*114*	*284*		*198*	*140*	*2*	*564*	*198*
1951	*25*	*120*	*299*		*208*	*147*	*2*	*593*	*208*
1952	*27*	*126*	*315*		*219*	*155*	*2*	*625*	*219*
1953	28	133	331		231	163	2	658	231
1954	29	80	345		252	172	3	629	252
1955	36	107	421		270	188	4	755	270
1956	45	78	553		276	193	5	874	276
1957	41	72	533		326	227	8	881	326
1958	37	79	716		369	275	11	1,119	369
1959	36	95	789		377	302	16	1,237	377
1960	26	260	849		393	310	23	1,467	393
1961	26	293	894		407	330	32	1,575	407
1962	33	325	1,050		461	389	46	1,843	461
1963	29	154	1,137		507	433	66	1,819	507
1964	18	180	1,270		510	453	94	2,015	510
1965	15	164	1,398		537	495	134	2,207	537
1966	15	109	1,610		570	570	177	2,481	570
1967	16	164	1,757		623	675	217	2,830	623
1968	17	348	1,794		651	735	236	3,129	651
1969	30	308	1,912		660	806	226	3,282	660
1970	37	500	2,165		722	957	355	4,015	722
1971	38	667	2,667		815	1,125	349	4,846	815
1972	41	942	3,213		880	1,320	372	5,888	880
1973	44	1,042	3,733		950	1,550	428	6,797	950
1974	78	970	4,199		1,120	1,890	516	7,653	1,120
1975	84	942	5,516		1,220	2,210	596	9,348	1,220
1976	88	1,132	5,980		1,900	3,500	639	11,340	1,900
1977	111	1,290	8,060		2,100	3,900	729	14,089	2,100
1978	133	1,376	8,857		2,500	4,100	975	15,440	2,500
1979	164	1,545	9,995		3,000	4,200	1,212	17,116	3,000
1980	197	1,648	11,546		3,600	4,900	1,329	19,620	3,600
1981	260	2,009	14,807		4,500	6,200	1,500	24,776	4,500
1982	247	2,826	16,440		5,600	6,500	1,640	27,653	5,600
1983	357	2,833	17,812		6,400	6,200	1,709	28,911	6,400
1984	401	2,820	18,336		6,417	6,300	2,027	29,884	6,417
1985	858	3,300	19,528		6,433	6,400	2,348	32,434	6,433
1986	914	3,450	20,182		6,450	6,500	3,398	34,444	6,450
1987	1,130	3,054	20,476		6,467	6,600	4,486	35,746	6,467
1988	793	2,843	19,706		6,483	6,700	5,138	35,180	6,483
1989	1,191	4,479	21,820		6,500	6,800	6,087	40,377	6,500
1990	1,175	7,685	22,587	592	6,500	6,800	7,306	46,145	6,500
1991	1,468	7,003	23,011	2,289	6,517	6,900	7,708	48,379	6,517
1992	4,916	4,221	24,934	2,736	6,533	7,000	9,563	53,370	6,533
1993	5,470	3,921	25,443	3,349	6,550	7,100	9,420	54,703	6,550
1994	5,782	3,942	25,090	4,260	6,567	7,200	9,500	55,774	6,567
1995	*5,782*	*3,942*	*25,090*	*4,260*	*6,567*	*7,200*	*9,500*	*55,774*	*6,567*
1996	*5,782*	*3,942*	*25,090*	*4,260*	*6,567*	*7,200*	*9,500*	*55,774*	*6,567*
Source:	*Supply Estimates (Depart. R&D)*	*Supply Estimates (Research Institutes)*	*Supply Estimates (Research Institutes)*	*Agriculture in Scotland*	*Agriculture in Scotland*	*Agriculture in Scotland*	*Educat. Statistics (Ag./For/ Vet.)*		

* *Italics Denote Estimates of Expenditures*

Appendix Two

Copy of Questionnaire Used to Survey Agri-Food Companies

For Coding Use
□□□□□

PUBLIC AGRICULTURAL RESEARCH AND THE PRIVATE SECTOR

AIMS OF QUESTIONNAIRE

The aim of the following questionnaire is to collect information on your relationship with public agricultural and food research institutions. Ultimately we would like to assess ways in which these public institutes can conduct research that is complementary to that of the private sector.

As such the questionnaire is divided into the following four parts:-

Part One aims to identify and categorise the level of agricultural research being conducted within the private sector.

Part Two follows by determining the level of collaborative research being conducted with the public sector and assessing your reasons for either collaborating or not collaborating.

Part Three aims to obtain an indication of how much research in the public domain has been exploited by private industry and by your company in particular.

Part Four seeks your opinions on the quality and relevance of research being conducted within public agricultural research establishments.

Completing the questionnaire

The questionnaire consists of twenty three questions which can be answered by merely ticking an appropriate box or boxes. The term 'agricultural research' includes both agricultural and food research.

If you have any queries regarding the questionnaire please contact:-

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PART ONE

1) *Please could you give an indication of the size of your gross annual turnover associated with your UK-based activities*

< £1 Million ☐1	£6 - 10 Million ☐3	£21 - 40 Million ☐5
£1 - 5 Million ☐2	£11 - 20 Million ☐4	+ £40 Million (specify)...........6

2) *Please Indicate the percentage of this turnover attributable to each sector below*

	<10%	10 - 25%	26 - 50%	51 - 75%	76 - 100%
Food and Drink *(processing, production etc.)*	☐1	☐2	☐3	☐4	☐5
Agrochemical *(crop chemicals, incl. fertilisers, organic compounds etc.)*	☐10	☐11	☐12	☐13	☐14
Veterinary and Medicine *(animal pharmaceuticals, welfare etc.)*	☐20	☐21	☐22	☐23	☐24
Plant and Crop *(horticulture, agronomy,. farming systems etc.)*	☐30	☐31	☐32	☐33	☐34
Animal Science *(breeding, nutrition, lactation and growth etc.)*	☐40	☐41	☐42	☐43	☐44
Agri-Engineering *(buildings, computer systems etc.)*	☐50	☐51	☐52	☐53	☐54
Non-Agriculture	☐60	☐61	☐62	☐63	☐64

3) *Please indicate the research areas within which you operate*

Plant Science50		**Soils and Fertilisers55**		**Arable Crop Science60**	
Breeding and Genetics	☐1	Fertilisers	☐5	Weed Control	☐9
Plant Virus	☐2	Farm Waste	☐6	Pest Control	☐10
Plant Cell Structures	☐3	Environmental	☐7	Fungal Control	☐11
Other	☐4	Other	☐8	Other	☐12
Animal Breeding65		**Animal Disease70**		**Animal Physiology75**	
Behaviour	☐13	Infectious	☐17	Metabolism/Digestion	☐21
Fertility	☐14	Genetic	☐18	Feed Behaviour	☐22
Genetics	☐15	Nutritional	☐19	Other	☐23
Other	☐16	Other	☐20		
Agri-Engineering80		**Food Science85**		**Dairy Production90**	
Vehicles	☐24	Production	☐28	Breeding	☐32
Buildings	☐25	Safety	☐29	Feeding Systems	☐33
Computing	☐26	Processing	☐30	Grassland Management	☐34
Other	☐27	Other	☐31	Other	☐35

Grassland/Ruminants[36]		Other(specify)..
Cell biology	❑36	....
Nutrition	❑37	39
Other	❑38	

4a) *Please tick the box which best identifies current R&D expenditure as a percentage of gross turnover*

0%	❑1	4-6%	❑3	10-14%	❑5
1-3%	❑2	7-9 %	❑4	+15% (specify)..........6	

4b) *Please indicate whether this represents a greater, similar or lower percentage than ten years ago*

Greater percentage than 10 years ago	❑1
Around the same percentage as 10 years ago	❑2
Lower percentage than 10 years ago	❑3

5a) *Given the definitions outlined below please indicate the percentage of total research expenditure allocated to each category within your company*

Basic is defined here as 'Acquiring new knowledge with no particular application in mind'.
Applied Strategic is defined here as 'Research in a subject area which has not yet advanced to a stage of application that can be clearly specified'.
Applied Specific is defined here as 'Research with the specific aim of producing an exploitable outcome'.
Development is defined as 'Using existing knowledge in creating new products and processes'.

	0%	1-10%	11-25%	26-50%	51-75%	76-100%
Basic	❑1	❑2	❑3	❑4	❑5	❑6
Applied Strategic	❑1	❑2	❑3	❑4	❑5	❑6
Applied Specific	❑1	❑2	❑3	❑4	❑5	❑6
Development	❑1	❑2	❑3	❑4	❑5	❑6

5b) *Please indicate whether these represent greater, similar or lower percentages than ten years ago in respect of basic, applied and development work*

	Basic	Applied Strategic	Applied Specific	Development
Greater than 10 years ago	❑1	❑10	❑15	❑20
The same as 10 years ago	❑2	❑11	❑16	❑21
Lower than 10 years ago	❑3	❑12	❑17	❑22

PART TWO

6) *Have you been involved with public institutions conducting agricultural research in the past three years either through collaboration and/or sponsorship?*

Sponsorship ❑1 No ❑3 go to question 15
Collaboration ❑2

7) *Please indicate the percentage of your company's research expenditure invested in external research to the public sector either within or outside the UK*

0 %	❑1	11-25%	❑3	51-75%	❑5
1-10 %	❑2	26-50%	❑4	76-100%	❑6

8) *Have you funded research within a UK institution conducting public agricultural research within the last three years?*

Yes ❑1 go to question 9 No ❑2 go to question 10

9) *Please indicate the UK public agricultural research institutions you have conducted research with in the last three years*

Biotechnology and Biological Sciences Research Institute ❑1
(Institute of Arable Crops Research, Institute of Animal Health, John Innes Centre, Babraham Research Institute, Grassland and Environmental Research Institute, Roslin Research Institute, Silsoe Research Institute)

Scottish Agricultural and Biological Research Institute ❑2
(Hannah Dairy Research Institute, Macaulay Land Use Research Institute, Moredun Research Institute, Rowett Research Institute, Scottish Crop Research Institute)

Higher Education Institution ❑3

Agricultural Development and Advisory Service Institute ❑4
(Central Science Laboratory, Central Veterinary Laboratory)

National Environment Research Institute ❑5
(Institute of Hydrology, Institute of Freshwater Ecology, Institute of Terrestrial Ecology, Institute of Virology and Environmental Microbiology)

Other(specify)..
....6

10) *Have you conducted joint agricultural research with public agencies outside the UK in the last three years?*

Yes ❑1 go to question 11 No ❑2 go to question 13

11) *Please indicate which public agencies you have conducted research with in the last three years and if possible under which programme*

European Commission		US Department of Agriculture	
Framework Programme	❑1	Federal Research Agencies	❑5
EUREKA	❑2	State Agricultural Experimental Stations	❑6
Other (specify)..............................3		Other(specify)..7	
Other			
Country(specify)..10			
Programme(specify)...11			

12) *Please rank in importance the reasons why you have conducted agricultural research with public bodies* ***outside the UK***

	Very Important	Important	Slightly Important	Not Important
Scale of UK research too small	❑1	❑2	❑3	❑4
No relevant expertise in the UK	❑1	❑2	❑3	❑4
Organisational reasons	❑1	❑2	❑3	❑4
UK Grant-awards not adequate	❑1	❑2	❑3	❑4
UK Linkage schemes not adequate	❑1	❑2	❑3	❑4
Other (Please specify)..10				

13) *Please state the nature of your involvement with public agricultural research institutions both within and outside the UK*

Contract Work		Collaborative Work	
Analytical Services		*Sponsorship*	
Biochemistry	❑1	New Product Development	❑20
Molecular Biology	❑2	Product Development	❑21
Data Processing	❑3	Process Development	❑22
Spectrometry	❑4	*Collaboration*	
Other	❑5	Government LINK	❑23
Licensing	❑6	Government ROPA	❑24
Testing/Trials	❑7	BBSRC Collaboration with Industry Scheme	❑25
Consultancy	❑8	CASE Studentship	❑26
Launch Marketing	❑9	Teaching Company Scheme	❑27
Fieldwork	❑10	Other	❑28
Other	❑11		
UK Information Services	❑30		
European Information Services	❑31		
Non-European Information Services	❑32		

***14)** Please rank in importance your reasons for involvement with public agricultural research institutions*

	Very Important	Important	Slightly Important	Not Important
Similarity in research areas	❑1	❑2	❑3	❑4
Less expensive than using internal resources	❑1	❑2	❑3	❑4
Greater access to public research	❑1	❑2	❑3	❑4
Inadequate scale of internal resources	❑1	❑2	❑3	❑4
Expertise required in a specific area	❑1	❑2	❑3	❑4
To raise company's research profile	❑1	❑2	❑3	❑4
Other (Please specify).. 10				

Please go to question 16

***15)** Please rank in importance your reasons for no involvement with public agricultural research institutions*

	Very Important	Important	Slightly Important	Not Important
Company has full facilities in-house	❑1	❑2	❑3	❑4
Public programmes are too broad	❑1	❑2	❑3	❑4
Public research has no concept of risk	❑1	❑2	❑3	❑4
Management of copyright/secrecy	❑1	❑2	❑3	❑4
No overlap of interest in research areas	❑1	❑2	❑3	❑4
Low awareness of public programmes	❑1	❑2	❑3	❑4
No approach by public institutions	❑1	❑2	❑3	❑4
No relevant institution geographically close	❑1	❑2	❑3	❑4
Other (Please specify).. 10				

PART THREE

16) *Have you made use of the results of agricultural research coming from the UK public sector in the past three years?*

Yes ❑1 go to question 17 | No ❑2 go to question 19

17) *Have you concluded a patent with a UK public agricultural research institution?*

Yes ❑1 go to question 18 | No ❑2 go to question 19

18a) *Please indicate with which public agricultural research institutions you have concluded patent agreements*

Biotechnology and Biological Sciences Research Institute ❑1
(Institute of Arable Crops Research, Institute of Animal Health, John Innes Centre, Babraham Research Institute, Grassland and Environmental Research Institute, Roslin Research Institute, Silsoe Research Institute)

Scottish Agricultural and Biological Research Institute ❑2
(Hannah Dairy Research Institute, Macaulay Land Use Research Institute, Moredun Research Institute, Rowett Research Institute, Scottish Crop Research Institute)

Higher Education Institution ❑3

Agricultural Development and Advisory Service Institute ❑4
(Central Science Laboratory, Central Veterinary Laboratory)

National Environment Research Institute ❑5
(Institute of Hydrology, Institute of Freshwater Ecology, Institute of Terrestrial Ecology, Institute of Virology and Environmental Microbiology)

Other(Please specify)..
....6

18b) *Please indicate which areas of research the patent agreements cover*

Plant Science	❑1	Soils and Fertilisers	❑2	Arable Crop Science	❑3
Animal Breeding	❑4	Animal Disease	❑5	Animal Nutrition	❑6
Agri-Engineering	❑7	Food Science	❑8	Dairy Production	❑9
Grassland/Ruminants	❑10	Other(specify)...20			

19) *Is there an area of public agricultural research that has proved useful to your company in the last three years?*

Yes ❑1 go to question 20 | No ❑2 go to question 21

20a) *Please indicate which areas of public research have been of use to you*

Plant Science	☐1	Soils and Fertilisers	☐2	Arable Crop Science	☐3
Animal Breeding	☐4	Animal Disease	☐5	Animal Nutrition	☐6
Agri-Engineering	☐7	Food Science	☐8	Dairy Production	☐9
Grassland/Ruminants	☐10	Other(specify)..11			

20b) *Please indicate in terms of new product development and/or increases in technical knowledge how useful you found the research*

Very useful	☐1	Slightly Useful	☐3
Useful	☐2	Not Useful	☐4

PART FOUR

21) *Please Indicate how you perceive the* ***quality*** *of research carried out in the public agricultural research sector of the UK*

	International Standing	High National Standing	Average National Standing	Low National Standing
Higher Education Institution	☐1	☐2	☐3	☐4
Biotechnology and Biological Sciences Research Council	☐1	☐2	☐3	☐4
Scottish Agricultural and Biological Research Institute	☐1	☐2	☐3	☐4
Agricultural Development and Advisory Service	☐1	☐2	☐3	☐4
National Environment Research Council	☐1	☐2	☐3	☐4
Other..........................	☐1	☐2	☐3	☐4

22) *Please indicate how you perceive the* ***relevance*** *of agricultural research in the public sector in the UK compared to that coming from the private sector*

	Very Relevant	Relevant	Slightly Relevant	No Relevance
Higher Education Institution	☐1	☐2	☐3	☐4
Biotechnology and Biological Sciences Research Council	☐1	☐2	☐3	☐4
Scottish Agricultural and Biological Research Institute	☐1	☐2	☐3	☐4
Agricultural Development and Advisory Service	☐1	☐2	☐3	☐4
National Environment Research Council	☐1	☐2	☐3	☐4
Other..........................	☐1	☐2	☐3	☐4

23) *Given the level of public expenditure on agricultural research in 1994-5 outlined below indicate whether you feel that this expenditure was too high, about right, or too low for each of the sectors indicated.*

Government Expenditure on Agricultural Research in 1994-5 was:-

£200 Million	Biotechnology and Biological Sciences Research Council
£80 Million	Educational Sector
£18 Miilion	Agricultural Development and Advisory Service
£35 Million	Scottish Office Agriculture and Fisheries Department

	Too High	About Right	Too Low
Biotechnology and Biological Sciences Research Council	☐1	☐2	☐3
Educational Sector	☐1	☐2	☐3
Agricultural Development and Advisory Service	☐1	☐2	☐3
Scottish Office of Agriculture and Fisheries	☐1	☐2	☐3

Please feel free to include any other comments that you wish to make on any of the issues raised

....
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....
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....
....
....

Thank you for your co-operation. All the information will be treated in the strictest confidence.

Please return by 29/11/96 in the pre-paid envelope provided

Appendix Three

Calculation of Survey Data

A3.0. Calculation of Research Expenditure Within the Private Sector

The survey was divided into large and 'non-large' enterprises. Non-large enterprises were asked to give an indication of their research expenditure within a number of ranges. However, a problem arose with the categories, in that if the centre of each range were taken as indicative of the firm's R&D spend it could either overstate or understate expenditure in certain areas. Therefore for each sector an upper, mid and lower limit were calculated using the survey data.

Appendix Table 3.1. Sample Private Research Expenditure for the UK Agricultural Industry by Size and Intensity, £ million and percent

	Lower Limit	*Mid-Point*	*Upper Limit*
Agrochemicals			
Non-large, £M	3.1	7.4	15.0
R&D Intensity (%)	*2.5*	*3.5*	*4.4*
Large, £M	85.8	85.8	85.8
R&D Intensity (%)	*7.7*	*7.7*	*7.7*
Total, £M	88.9	93.2	100.8
R&D Intensity (%)	*6.9*	*7.0*	*7.2*
Veterinary and Medicine			
Non-large, £M	4.0	8.1	15.0
R&D Intensity (%)	*6.3*	*7.2*	*8.1*
Large, £M	12.2	12.2	12.2
R&D Intensity (%)	*12.2*	*12.2*	*12.2*
Total, £M	16.2	20.3	27.2
R&D Intensity (%)	*9.5*	*9.6*	*9.9*
Plant and Crops			
Non-large, £M	6.4	12.5	22.1
R&D Intensity (%)	*4.0*	*5.3*	*6.6*
Large, £M	27.5	27.5	27.5
R&D Intensity (%)	*8.1*	*8.1*	*8.1*
Total, £M	33.9	40.0	49.6
R&D Intensity (%)	*6.8*	*7.0*	*7.4*
Animal Science			
Non-large, £M	3.7	8.3	15.9
R&D Intensity (%)	*2.3*	*3.2*	*4.1*
Large, £M	11.8	11.8	11.8
R&D Intensity (%)	*1.9*	*1.9*	*1.9*
Total, £M	15.5	20.1	27.6
R&D Intensity (%)	*2.0*	*2.3*	*3.1*
Agri-Engineering			
Non-large, £M	1.9	3.3	5.7
R&D Intensity (%)	*3.2*	*3.9*	*4.6*
Large, £M	12.4	12.4	12.4
R&D Intensity (%)	*2.0*	*2.0*	*2.0*
Total, £M	14.4	15.8	18.2
R&D Intensity (%)	*2.1*	*2.2*	*2.4*
Total Expenditure, £M	168.9	189.4	223.4
R&D Intensity (%)	*5.0*	*5.1*	*5.5*

Appendix Table 3.1 shows the results from the following procedure. For the survey the number of respondents had to be increased to cover the selected sample size. This was achieved by using simple ratios. For example, within the agri-engineering sector 55 firms (3 large firms, 52 non-large firms) were identified within the survey. However, only 1 large firm and 15 non-large firms replied. Thus, for the large firm responding, expenditure was given as around £4.1 million on agricultural R&D. This was multiplied by 3 (3/1) to give £12.4 million. Similarly, the 15 non-large respondents gave expenditure at just under £1 million at the mid-point. This was multiplied by 3.47 (52/15) to give the value of £3.3 million for R&D expenditure within the sample.

A3.1. Re-weighting Procedure

The previous figures only represent a proportion of the total number of firms undertaking research in agriculture. Therefore, in order to gain a clearer indication of actual research spend for the UK agricultural industry the figures had to be re-weighted. As the numbers of firms operating within the UK by sector could not be ascertained, the only alternative was to use Census data from the Annual Abstract of Statistics (CSO, 1998). Appendix Table 3.3 below gives the turnover data by sector.

Appendix Table 3.3. Sector Turnovers for UK Agricultural Industry in 1996, £ million

Sector	*CSO Category*	*Industry Turnover*
Agrochemicals	*Fertilisers/Nitrogen* *Pesticides/Agrochemicals*	2,581[I]
Veterinary and Medicine	*Veterinary and Medicine*	317[II]
Plant and Crops	*Horticulture* *Seeds*	2,424[II]
Animal Science	*Feeds for Farm Animals*	3,116[II]
Agri-engineering	*Agricultural Tractors* *Other Agricultural and Forestry Equipment*	1,381[I]

[I] Annual Abstract Census of Production
[II] Agricultural Inputs (Agricultural Census of Production)

The large firms represented in the sample were assumed to be responsible for total large firm spend. Thus, removing the turnover of the large firms surveyed from the sectoral figures, presented above, gave an indication of the remaining non-large enterprises' turnover. Furthermore, removing known non-large turnovers at the lower, mid and upper limits would reveal the level of turnover of firms not surveyed. This procedure and subsequent data are provided in Appendix Table 3.4.

Appendix Table 3.4. Level of Industry Turnover by Area, £ million

Sector	Industry Turnover	LESS: Large Firm Turnover	LESS: Non-Large Firm Expenditure		
			Lower	Mid-Point	Upper
Agrochemicals	2,581	*1,461*	*1,338*	*1,246*	*1,119*
Veterinary and Medicine	317	*217*	*154*	*104*	*32*
Plant and Crops	2,424	*2,084*	*1,926*	*1,851*	*1,748*
Animal Science	3,116	*2,512*	*2,349*	*2,253*	*2,125*
Agri-Engineering	1,381	*759*	*698*	*672*	*635*

Assuming this unknown portion of firms behaved in the same way as the sampled non-large firms, then it could be assumed that multiplying known non-large firm R&D intensities by the remaining turnover gives an indication of total research spend. Multiplying the figures in the last three columns of Appendix Table 3.4. by their appropriate non-large firm R&D intensity (from Appendix Table 3.1) gives an estimate of R&D spend by sector. These results are presented in Appendix Table 3.5 along with totals for non-large firms, large firms and each sector's total spend.

Appendix Table 3.5. Potential Level of Private Expenditure for UK Agricultural Industry, £ million

		Lower Limit	*Mid-Point*	*Upper Limit*
Agrochemicals	Non-large Estimated	33.43	43.61	49.24
	Non-large Sample	3.12	7.43	14.96
	Total Non-large	36.55	51.04	64.2
	Large	85.80	85.80	85.80
	Total	**122.30**	**136.84**	**150.0**
Veterinary and Medicine	Non-large Estimated	9.70	7.49	2.59
	Non-large Sample	3.97	8.13	15.01
	Total Non-large	13.67	15.62	17.6
	Large	12.2	12.2	12.2
	Total	**25.87**	**27.82**	**29.80**
Plant and Crops	Non-large Estimated	77.04	98.10	115.37
	Non-large Sample	6.37	12.46	22.08
	Total Non-large	83.41	110.56	137.45
	Large	27.54	27.54	27.54
	Total	**110.95**	**138.10**	**164.99**
Animal Science	Non-large Estimated	54.03	72.10	87.13
	Non-large Sample	3.73	8.3	15.85
	Total Non-large	57.76	80.4	102.98
	Large	11.75	11.75	11.75
	Total	**69.51**	**92.15**	**114.73**
Agri-Engineering	Non-large Estimated	22.34	26.21	29.21
	Non-large Sample	1.93	3.34	5.72
	Total Non-large	24.27	29.55	34.93
	Large	12.44	12.44	12.44
	Total	**36.71**	**41.99**	**47.37**

A3.2. Research By Type

As the comparison of research by type was confined to percentage differences, it was not necessary to re-weight or transform data. Instead, only the mid-points were used for the non-large firms, as they remained relatively constant over their respective ranges. It was found that estimates for basic and strategic work individually were purely subjective and so were collated together to provide a more accurate picture of the sector's activity (see Appendix Table 3.6).

Appendix Table 3.6. Private Research Funding by Area, £ million			
Sector	*Basic and Strategic Work*	*Applied Specific*	*Development*
Non-large	0.94	1.89	4.50
Large	4.35	14.86	75.17
Agrochemical	**5.29**	**16.46**	**79.67**
Percentage Spread	***5.22***	***16.23***	***78.55***
Non-large	1.19	2.22	4.42
Large	4.77	83.64	4.86
Veterinary and Medicine	**5.96**	**85.86**	**9.28**
Percentage Spread	***5.90***	***84.93***	***9.18***
Non-large	0.26	4.64	7.19
Large	1.36	3.32	24.28
Plant & Crop	**1.62**	**7.96**	**31.47**
Percentage Spread	***3.95***	***19.39***	***76.66***
Non-large	1.22	2.87	4.01
Large	0.18	3.82	8.09
Animal Science	**1.40**	**6.69**	**12.1**
Percentage Spread	***6.93***	***33.14***	***59.93***
Non-large	0.06	0.35	2.67
Large	0.64	0.62	10.95
Agri-Engineering	**0.7**	**0.97**	**13.62**
Percentage Spread	***4.40***	***6.09***	***85.55***
Non-large	3.67	11.98	22.80
Large	11.30	106.26	123.35
Total	**14.97**	**118.24**	**146.15**
Percentage Spread	***5.36***	***42.33***	***52.32***

A3.3. Research By Priority Area

Firms were asked to give indications of research spend by priority area. For the non-large firms this was based on the average percentage of turnover for the sample firms and the recorded total turnover of the total sector. As such the expenditures rest on considerable inference.

Appendix Table 3.7. Research Areas in Crop and Livestock Science, £ million

	Non-large (mid-Point)					*Large*	*Totals*
	Agro-chemicals	*Vet & Med*	*Plants and Crops*	*Animal Science*	*Agri-Engin.*		
Breeding and Genetics	0.12	0.40	6.89	0.01		9.97	17.39
Plant Virus	0.10	0.20	1.71			1.81	3.82
Plant Cell Work	0.01					8.16	8.17
Others			0.05				0.05
Plant Science							**29.43**
Fertilisers	4.41		0.50	0.05		0.18	5.14
Farm Waste	0.02		0.12	0.01		0.27	0.42
Environmental	0.09		0.12	0.01	0.06	0.18	0.46
Other	0.05						0.05
Soils and Fertilisers							**6.07**
Weed Control	1.28	0.13	0.37			22.21	23.99
Pest Control	1.50	0.83	0.43	0.01		22.21	24.98
Fungal Control	1.34	0.84	0.43	0.01		22.21	24.83
Other	0.05	0.01	0.31			21.12	21.49
Arable Crop Science							**95.29**
Behaviour		0.37		0.90	0.10	0.38	1.75
Fertility		0.46		0.52			0.98
Genetics		0.33		0.57		0.33	1.23
Other					0.01		0.01
Animal Breeding							**3.97**
Infectious	0.05	2.88		0.06		8.46	11.45
Genetic		0.45		0.03		8.04	8.52
Nutritional	0.59	0.16		0.93		8.17	9.85
Other		0.07	0.03				0.10
Animal Disease							**29.89**
Metabolism & Digestion	1.08	0.11	0.05	2.13		36.39	39.76
Feed Behaviour	0.01		0.05	0.52		2.25	2.83
Other		0.01		0.05		1.91	1.97
Animal Physiology							**44.56**
Breeding		0.13	0.05	0.22			0.40
Feeding Systems	0.05	0.02	0.44	0.41	0.13	15.84	16.89
Grassland Management	0.01			0.14	0.01	1.91	2.07
Other				0.04	0.01		0.05
Dairy Production							**19.40**
Cell Biology				0.13		15.84	15.97
Nutrition	0.82	0.10	0.06	1.10	0.01		2.09
Other							0.00
Grassland & Ruminant							**18.06**

Appendix Table 3.7. (Continued). Research Areas in Related Areas, £ million

	Non-large (mid-Point)					*Large*	*Totals*
	Agro-chemicals	*Vet & Med*	*Plants and Crops*	*Animal Science*	*Agri-Engin.*		
Vehicles		0.40			2.47	12.00	14.87
Buildings		0.10			0.05	0.12	0.27
Computing		0.10		0.05	0.19		0.34
Other					0.32		0.32
Agri-Engineering							**15.80**

A3.4. Re-Weighted Priorities

Appendix Table 3.7 only shows actual expenditures from the survey respondents. Therefore, in order to derive a picture of the agricultural industry, the figures had to be re-weighted. Using the mid-points of research expenditure to derive expenditure by priority and multiplying each sector by the appropriate weighting gave a more accurate depiction of research in the agricultural industry. These data are presented in Appendix Table 3.8.

Appendix Table 3.8. Re-weighted Priority Spend by type, Crops and Livestock, £ million

	Non-large (mid-Point)					*Large*	*Totals*
	Agro-chemicals.	*Veterinary & Medicine*	*Plants and Crops*	*Animal Science*	*Agri-Engin.*		
Breeding and Genetics	0.82	0.77	61.14	0.10		9.97	72.80
Plant Virus	0.69	0.38	15.17			1.81	18.05
Plant Cell Work	0.07					8.16	8.23
Others			0.44				0.44
Plant Science							**99.52**
Fertilisers	30.29		4.44	0.48		0.18	35.39
Farm Waste	0.14		1.06	0.05		0.27	1.52
Environmental	0.62		1.06	0.05	0.53	0.18	2.44
Other	0.34						0.34
Soils and Fertilisers							**39.70**
Weed Control	8.79	0.25	3.28			22.21	34.54
Pest Control	10.30	1.59	3.82	0.10		22.21	38.02
Fungal Control	9.21	1.61	3.82	0.05		22.21	36.89
Other	0.34	0.02	2.75			21.12	24.23
Arable Crop Science							**133.68**
Behaviour		0.71		8.72	0.88	0.38	10.69
Fertility		0.88		5.04			5.92
Genetics		0.63		5.52		0.33	6.49
Other					0.04		0.04
Animal Breeding							**23.14**
Infectious	0.31	5.53		0.58		8.46	14.88
Genetic		0.86		0.29		8.04	9.20
Nutritional	4.05	0.31		9.01		8.17	21.54
Other		0.13	0.27				0.40
Animal Disease							**46.02**
Metabolism & Digestion	7.42	0.21	0.44	20.63		36.39	65.10
Feed Behaviour	0.07		0.44	5.04		2.25	7.80
Other		0.02		0.48		1.91	2.41
Animal Physiology							**75.31**
Breeding		0.25	0.44	2.13			2.82
Feeding Systems	0.34	0.04	3.90	3.97	1.15	15.84	25.25
Grassland Management	0.07			1.36	0.04	1.91	3.38
Other				0.39	0.04		0.43
Dairy Production							**31.88**
Cell Biology				1.26		15.84	17.10
Nutrition	5.63	0.19	0.53	10.66	0.04		17.06
Other							
Grassland & Ruminant							**34.16**

Appendix Table 3.8. (Continued). Re-weighted Priority Spend in Related Areas, £ million

	Non-large (mid-Point)					*Large*	*Totals*
	Agro-chemicals	*Vet & Med*	*Plants and Crops*	*Animal Science*	*Agri-Engin.*		
Vehicles		0.77			21.85	12.00	34.62
Buildings		0.19			0.44	0.12	0.75
Computing		0.19		0.48	1.68		2.36
Other					2.83		2.83
Agri-Engineering							**40.11**

A3.5. Level of Expenditure on Collaboration

Levels of expenditure on collaboration were calculated by total lower, mid and upper limits indicated by companies (see questionnaire, Q7). This was expressed as a percentage of the total R&D expenditure calculated for each sector (Appendix Table 3.3). These results are presented in Appendix Table 3.9.

Appendix Table 3.9. Actual Levels of Collaboration, £ million and percent

	Lower Limit			Mid-Point Limit			Upper Limit		
	R&D, £M	Collaborative Research Spend, £M	%	R&D, £M	Collaborative Research Spend, £M	%	R&D, £M	Collaborative Research Spend, £M	%
Agrochemicals	88.9	6.8	*7.6*	93.2	8.0	*8.6*	100.8	10.7	*10.6*
Veterinary & Medicine	16.2	5.2	*32.1*	20.3	6.0	*29.6*	27.2	7.9	*29.0*
Plant & Crops	33.9	2.0	*5.9*	40	2.9	*7.3*	49.6	5.1	*10.3*
Animal Science	15.5	3.8	*24.5*	20.1	5.1	*25.4*	27.6	7.8	*28.3*
Agri-Engineering	14.4	1.1	*7.6*	15.8	1.1	*7.0*	18.2	1.2	*6.6*
Totals	**168.9**	**18.9**	***11.2***	**189.4**	**23.1**	***12.2***	**223.4**	**32.7**	***14.6***

Appendix Four

Data Tables Used Within Regression Analysis

Key to Tables

Name	Description
BASIC	Total Public Expenditures on Basic Agricultural Research, £M in 1970 prices
APPLIED	Total Public Expenditures on Applied Research and Development, £M in 1970 prices
ADVICE	Total Public Expenditures on Agricultural Extension, £M in 1970 prices
PRIVATE	Total Private Expenditures on Agricultural Research and Development, £M in 1970 prices
LESP	Lespeyres Index of Total Factor Productivity, 1970 = 100
EXT	Index of Total Factor Productivity, with Removal of Externalities, 1970=100
EDAL	Index of Educational Levels Within the Agricultural Population, 1970=100
WEATHER	Index of Precipitation and Temperature

Year	Basic £m	Applied £m	Advice £m	Private £m	LESP 1970=100	EXT 1970=100	EDAL 1970=100	Weather Index
1948	3.8	1.7	1.6	2.9	73	72	66	50
1949	3.7	1.7	1.5	2.9	76	71	66	50
1950	3.5	1.6	1.5	3.9	73	65	66	50
1951	3.4	1.6	1.4	4.6	71	70	66	50
1952	3.4	1.5	1.4	5.2	73	71	66	50
1953	3.0	1.4	1.3	5.2	75	72	69	53
1954	2.9	1.3	1.3	6.4	77	72	66	65
1955	3.7	2.0	1.2	7.3	72	71	63	50
1956	3.1	1.6	1.2	7.0	76	70	60	57
1957	5.1	3.3	1.2	8.6	71	70	55	60
1958	5.5	3.7	1.4	8.8	71	71	62	56
1959	5.9	4.1	1.3	9.5	69	68	63	56
1960	6.5	4.5	1.4	9.9	69	68	68	58
1961	7.1	5.1	1.4	9.7	72	71	67	55
1962	7.6	5.6	1.4	10.6	72	71	75	57
1963	7.8	5.8	1.4	11.1	73	72	73	41
1964	8.4	6.4	1.4	12.0	73	70	79	59
1965	8.8	6.8	1.5	12.0	86	83	81	63
1966	9.7	7.5	1.5	12.4	87	84	70	65
1967	9.4	7.6	1.9	14.3	93	85	85	64
1968	11.1	8.7	2.0	18.0	96	92	103	57
1969	11.0	9.4	2.1	21.6	94	93	94	54
1970	11.1	9.6	1.8	25.4	100	100	100	61
1971	11.4	10.3	2.2	27.9	110	105	120	49
1972	11.9	10.8	2.3	29.9	120	114	117	53
1973	11.0	10.1	2.1	36.9	125	117	107	50
1974	11.5	10.7	2.0	46.4	117	110	113	61
1975	15.3	12.9	2.4	52.2	117	114	103	48
1976	13.3	14.5	2.9	67.9	118	113	114	53
1977	15.8	16.6	3.3	70.0	120	114	144	59
1978	16.8	17.7	3.9	63.9	121	119	148	59
1979	19.2	18.8	4.0	62.8	119	117	171	66
1980	20.4	20.5	5.2	58.1	121	118	197	64
1981	24.5	24.3	5.4	54.0	125	122	219	65
1982	26.7	26.5	6.3	52.0	133	129	231	65
1983	28.5	27.4	6.8	49.4	129	126	241	55
1984	29.2	28.4	7.2	43.0	139	129	232	60
1985	29.6	28.8	7.4	62.1	130	126	214	63
1986	35.2	32.1	8.3	89.4	124	120	214	69
1987	36.6	32.8	8.4	109.0	126	122	219	57
1988	35.9	30.1	9.1	132.7	127	122	234	63
1989	40.5	31.7	9.7	130.4	132	126	223	55
1990	48.0	35.3	10.3	127.0	135	126	231	66
1991	55.1	38.9	10.9	118.7	135	127	231	49
1992	58.4	39.3	10.3	114.8	142	132	268	50
1993	62.9	41.6	11.6	118.8	153	139	293	50
1994	64.1	42.5	12.4	117.8	158	142	324	50
1995	63.7	41.6	12.4	114.5	171	154	323	50
1996	65.6	42.4	13.2	113.9	173	157	323	50

Appendix Five

Output From 'E-Views' Regression Analysis

Key to Tables

Variable	Description
C	Intercept
W	Weather Index
EDAL	Education Index
ADVICE	Advisory Expenditure Series, £ million in 1970 prices
PBRD	Total Public Agricultural R&D Expenditure Series, £ million in 1970 prices
APPLIED	Total Public Applied Research and Development Expenditure Series, £ million in 1970 prices
BASIC	Total Public Basic Research Expenditure Series, £ million in 1970 prices
PRIV	Total Private Research Expenditure Series, £ million in 1970 prices

Equation (8)

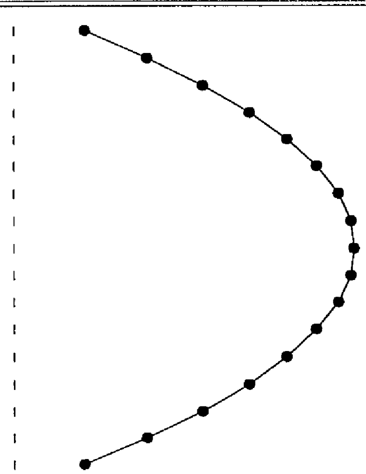
$$\ln P_t = \ln A + \sum_{i=0}^{16} \alpha_1 \ln R_{t-i}^{pbadv} + \beta_1 \ln E + \beta_2 W + \mu$$

LS // Dependent Variable is LESP
Date: 07/19/00 Time: 16:10
Sample(adjusted): 1964 1996
Included observations: 33 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.907986	0.236006	12.32165	0.0000
EDAL	0.254869	0.066718	3.820121	0.0007
W	0.003798	0.001556	2.440392	0.0210
PDL01	0.001310	0.000295	4.434370	0.0001

R-squared	0.966334	Mean dependent var	4.842683
Adjusted R-squared	0.962851	S.D. dependent var	0.258567
S.E. of regression	0.049836	Akaike info criterion	-5.884817
Sum squared resid	0.072026	Schwarz criterion	-5.703423
Log likelihood	54.27452	F-statistic	277.4688
Durbin-Watson stat	2.127005	Prob(F-statistic)	0.000000

Lag Distribution of PBADV



i	Coefficient	Std. Error	T-Statistic
0	0.00124	0.00028	4.43437
1	0.00233	0.00053	4.43437
2	0.00327	0.00074	4.43437
3	0.00407	0.00092	4.43437
4	0.00473	0.00107	4.43437
5	0.00524	0.00118	4.43437
6	0.00560	0.00126	4.43437
7	0.00582	0.00131	4.43437
8	0.00589	0.00133	4.43437
9	0.00582	0.00131	4.43437
10	0.00560	0.00126	4.43437
11	0.00524	0.00118	4.43437
12	0.00473	0.00107	4.43437
13	0.00407	0.00092	4.43437
14	0.00327	0.00074	4.43437
15	0.00233	0.00053	4.43437
16	0.00124	0.00028	4.43437
Sum of Lags	0.07051	0.01590	4.43437

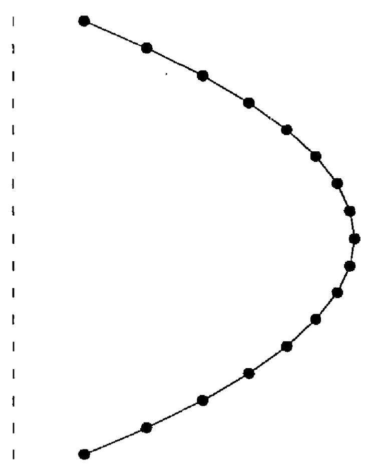
Equation (9)

$$\ln P_t = \ln A + \sum_{i=0}^{16} \alpha_1 \ln R_{t-i}^{pbadv} + \sum_{i=0}^{7} \alpha_2 \ln R_{t-i}^{pv} + \beta_1 \ln E + \beta_2 W + \mu$$

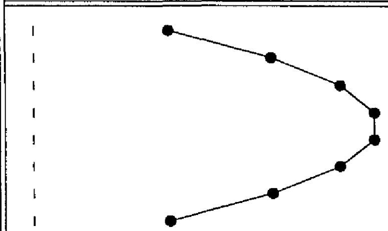
LS // Dependent Variable is LESP
Date: 07/19/00 Time: 16:14
Sample(adjusted): 1964 1996
Included observations: 33 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.079462	0.237623	12.95944	0.0000
EDAL	0.180311	0.072373	2.491415	0.0189
W	0.003595	0.001475	2.436775	0.0214
PDL01	0.000950	0.000328	2.898012	0.0072
PDL02	0.006801	0.003234	2.103237	0.0446

R-squared	0.970927	Mean dependent var	4.842683
Adjusted R-squared	0.966774	S.D. dependent var	0.258567
S.E. of regression	0.047132	Akaike info criterion	-5.970894
Sum squared resid	0.062199	Schwarz criterion	-5.744150
Log likelihood	56.69477	F-statistic	233.7751
Durbin-Watson stat	2.540136	Prob(F-statistic)	0.000000



Lag Distribution of PBADV i	Coefficient	Std. Error	T-Statistic
0	0.00090	0.00031	2.89801
1	0.00169	0.00058	2.89801
2	0.00237	0.00082	2.89801
3	0.00295	0.00102	2.89801
4	0.00343	0.00118	2.89801
5	0.00380	0.00131	2.89801
6	0.00406	0.00140	2.89801
7	0.00422	0.00146	2.89801
8	0.00427	0.00147	2.89801
9	0.00422	0.00146	2.89801
10	0.00406	0.00140	2.89801
11	0.00380	0.00131	2.89801
12	0.00343	0.00118	2.89801
13	0.00295	0.00102	2.89801
14	0.00237	0.00082	2.89801
15	0.00169	0.00058	2.89801
16	0.00090	0.00031	2.89801
Sum of Lags	0.05112	0.01764	2.89801



Lag Distribution of PRIV i	Coefficient	Std. Error	T-Statistic
0	0.00605	0.00287	2.10324
1	0.01058	0.00503	2.10324
2	0.01360	0.00647	2.10324
3	0.01511	0.00719	2.10324
4	0.01511	0.00719	2.10324
5	0.01360	0.00647	2.10324
6	0.01058	0.00503	2.10324
7	0.00605	0.00287	2.10324
Sum of Lags	0.09068	0.04312	2.10324

Equation (10)

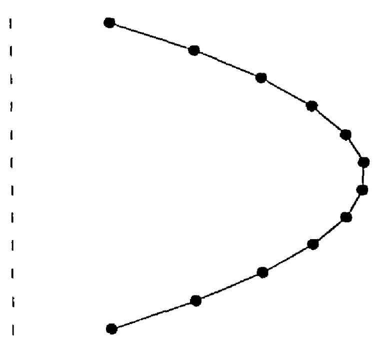
$$\ln P_t = \ln A + \sum_{i=0}^{11} \alpha_1 \ln R_{t-i}^{apadv} + \beta_1 \ln E + \beta_2 W + \mu$$

LS // Dependent Variable is LESP
Date: 07/19/00 Time: 16:19
Sample(adjusted): 1959 1996
Included observations: 38 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.758539	0.255507	10.79634	0.0000
W	0.003239	0.001382	2.343709	0.0251
EDAL	0.306910	0.067344	4.557336	0.0001
PDL01	0.003166	0.000798	3.966339	0.0004

R-squared	0.971988	Mean dependent var	4.771288
Adjusted R-squared	0.969517	S.D. dependent var	0.304172
S.E. of regression	0.053107	Akaike info criterion	-5.771598
Sum squared resid	0.095892	Schwarz criterion	-5.599220
Log likelihood	59.74069	F-statistic	393.2600
Durbin-Watson stat	1.763039	Prob(F-statistic)	0.000000

Lag Distribution of APADV



i	Coefficient	Std. Error	T-Statistic
0	0.00292	0.00074	3.96634
1	0.00536	0.00135	3.96634
2	0.00731	0.00184	3.96634
3	0.00877	0.00221	3.96634
4	0.00974	0.00246	3.96634
5	0.01023	0.00258	3.96634
6	0.01023	0.00258	3.96634
7	0.00974	0.00246	3.96634
8	0.00877	0.00221	3.96634
9	0.00731	0.00184	3.96634
10	0.00536	0.00135	3.96634
11	0.00292	0.00074	3.96634
Sum of Lags	0.08866	0.02235	3.96634

Equation (11)

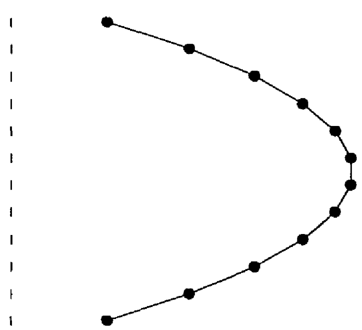
$$\Delta \ln P_t = A + \sum_{i=0}^{11} \alpha_1 \Delta \ln R_{t-i}^{apadv} + \sum_{i=0}^{7} \alpha_2 \Delta \ln R_{t-i}^{pv} + \beta_1 \Delta \ln E + \beta_2 W + \mu$$

LS // Dependent Variable is LESP
Date: 07/19/00 Time: 16:21
Sample(adjusted): 1959 1996
Included observations: 38 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.059207	0.248338	12.31874	0.0000
W	0.003319	0.001236	2.685943	0.0112
EDAL	0.179140	0.073062	2.451889	0.0197
PDL01	0.002078	0.000796	2.610078	0.0135
PDL02	0.009341	0.003026	3.087405	0.0041

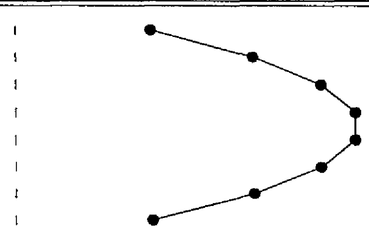
R-squared	0.978266	Mean dependent var	4.771288
Adjusted R-squared	0.975632	S.D. dependent var	0.304172
S.E. of regression	0.047482	Akaike info criterion	-5.972717
Sum squared resid	0.074401	Schwarz criterion	-5.757245
Log likelihood	64.56196	F-statistic	371.3424
Durbin-Watson stat	2.281232	Prob(F-statistic)	0.000000

Lag Distribution of APADV



i	Coefficient	Std. Error	T-Statistic
0	0.00192	0.00073	2.61008
1	0.00352	0.00135	2.61008
2	0.00480	0.00184	2.61008
3	0.00575	0.00220	2.61008
4	0.00639	0.00245	2.61008
5	0.00671	0.00257	2.61008
6	0.00671	0.00257	2.61008
7	0.00639	0.00245	2.61008
8	0.00575	0.00220	2.61008
9	0.00480	0.00184	2.61008
10	0.00352	0.00135	2.61008
11	0.00192	0.00073	2.61008
Sum of Lags	0.05818	0.02229	2.61008

Lag Distribution of PRIV



i	Coefficient	Std. Error	T-Statistic
0	0.00830	0.00269	3.08740
1	0.01453	0.00471	3.08740
2	0.01868	0.00605	3.08740
3	0.02076	0.00672	3.08740
4	0.02076	0.00672	3.08740
5	0.01868	0.00605	3.08740
6	0.01453	0.00471	3.08740
7	0.00830	0.00269	3.08740
Sum of Lags	0.12455	0.04034	3.08740

Equation (16)

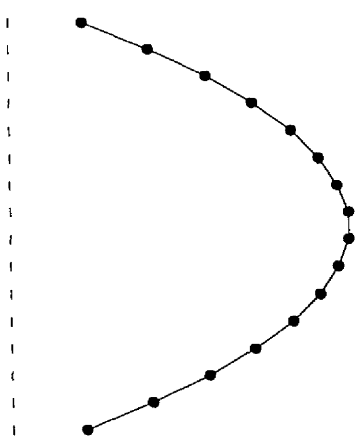
$$\ln P^*_t = \ln A + \sum_{i=0}^{14} \alpha_1 \ln R_{t-i}^{pbadv} + \sum_{i=0}^{6} \alpha_2 \ln R_{t-i}^{pv} + \beta_1 \ln E + \beta_2 W + \mu$$

LS // Dependent Variable is EXT
Date: 08/31/00 Time: 15:41
Sample(adjusted): 1963 1996
Included observations: 34 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.110282	0.204047	15.24296	0.0000
W	0.001575	0.001109	1.420536	0 1661
EDAL	0.215430	0.062173	3.465011	0.0017
PDL01	0.000976	0.000304	3.215284	0.0032
PDL02	0.005504	0.002759	1.995225	0.0555

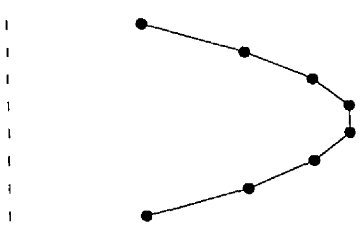
R-squared	0.978842	Mean dependent var	4.837961
Adjusted R-squared	0.975924	S.D. dependent var	0.262556
S.E. of regression	0.040739	Akaike info criterion	-6.266076
Sum squared resid	0.048131	Schwarz criterion	-6.041611
Log likelihood	63.27938	F-statistic	335.4179
Durbin-Watson stat	1.658998	Prob(F-statistic)	0.000000

Lag Distribution of PBADV



i	Coefficient	Std. Error	T-Statistic
0	0.00092	0.00029	3.21528
1	0.00172	0.00054	3.21528
2	0.00241	0.00075	3.21528
3	0.00299	0.00093	3.21528
4	0.00344	0.00107	3.21528
5	0.00379	0.00118	3.21528
6	0.00402	0.00125	3.21528
7	0.00413	0.00129	3.21528
8	0.00413	0.00129	3.21528
9	0.00402	0.00125	3.21528
10	0.00379	0.00118	3.21528
11	0.00344	0.00107	3.21528
12	0.00299	0.00093	3.21528
13	0.00241	0.00075	3.21528
14	0.00172	0.00054	3.21528
15	0.00092	0.00029	3.21528
Sum of Lags	0.04685	0.01457	3.21528

Lag Distribution of PRIV



i	Coefficient	Std. Error	T-Statistic
0	0.00489	0.00245	1.99523
1	0.00856	0.00429	1.99523
2	0.01101	0.00552	1.99523
3	0.01223	0.00613	1.99523
4	0.01223	0.00613	1.99523
5	0.01101	0.00552	1.99523
6	0.00856	0.00429	1.99523
7	0.00489	0.00245	1.99523
Sum of Lags	0.07339	0.03678	1.99523

Equation (17)

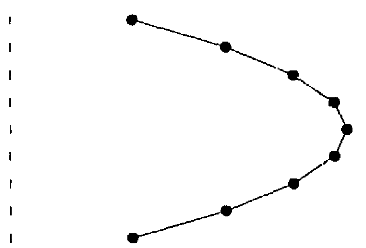
$$\ln P^*_t = \ln A + \sum_{i=0}^{8} \alpha_1 \ln R_{t-i}^{apadv} + \sum_{i=0}^{6} \alpha_2 \ln R_{t-i}^{pv} + \beta_1 \ln E + \beta_2 W + \mu$$

LS // Dependent Variable is EXT
Date: 08/31/00 Time: 15:18
Sample(adjusted): 1956 1996
Included observations: 41 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.117884	0.213585	14.59783	0.0000
W	0.001314	0.001047	1.255881	0.2172
EDAL	0.200122	0.061232	3.268276	0.0024
PDL01	0.003342	0.001161	2.879391	0.0067
PDL02	0.010554	0.002857	3.694420	0.0007

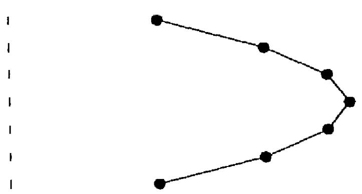
R-squared	0.985028	Mean dependent var	4.739101
Adjusted R-squared	0.983365	S.D. dependent var	0.316752
S.E. of regression	0.040854	Akaike info criterion	-6.281661
Sum squared resid	0.060085	Schwarz criterion	-6.072689
Log likelihood	75.59757	F-statistic	592.1361
Durbin-Watson stat	1.440220	Prob(F-statistic)	0.000000

Lag Distribution of APADV



i	Coefficient	Std. Error	T-Statistic
0	0.00301	0.00104	2.87939
1	0.00535	0.00186	2.87939
2	0.00702	0.00244	2.87939
3	0.00802	0.00279	2.87939
4	0.00835	0.00290	2.87939
5	0.00802	0.00279	2.87939
6	0.00702	0.00244	2.87939
7	0.00535	0.00186	2.87939
8	0.00301	0.00104	2.87939
Sum of Lags	0.05514	0.01915	2.87939

Lag Distribution of PRIV



i	Coefficient	Std. Error	T-Statistic
0	0.00923	0.00250	3.69442
1	0.01583	0.00429	3.69442
2	0.01979	0.00536	3.69442
3	0.02111	0.00571	3.69442
4	0.01979	0.00536	3.69442
5	0.01583	0.00429	3.69442
6	0.00923	0.00250	3.69442
Sum of Lags	0.11082	0.03000	3.69442

List of Publications

1) Barnes, A. P. (1999). **Commercial R&D Linkage with Public Agro-Food Institutions**. *Food Policy* **24**, 349-255.

Abstract: *Recent changes in research policy have shown an increasing reliance on the private sector as a source of funding for public sector research institutes. Accordingly, this note reveals the results of a survey into the level and type of linkage between the agro-food industries and the public research institutes. Furthermore, it addresses the motivations for linkage and whether there are any major obstructions to its growth. It concludes that the main motivation for linkage, a search for in-depth expertise, is threatened by the Government's reductions in funding.*

2) Barnes, A.P. (2001). **Towards a Framework for Justifying Public Agricultural R&D: the Example of UK Agricultural Research Policy.** *Research Policy* **30** *(4)*, 665-674.

Abstract: *Changes to the UK agricultural research service have questioned the role and purpose of publicly-funded agricultural research and development (R&D). However, traditional methods of assessment seem inadequate when analysing the diversity of agricultural R&D. This paper criticises the traditional arguments for the public support of an agricultural research system and forwards a more dynamic means to assessing agricultural research in the public sector. Overall, areas of public-good enhancing R&D carry strong support, whereas more traditional areas of productivity-enhancing R&D are questioned in terms of continued expenditure. Finally, these findings are contrasted against UK Government support for agricultural R&D and reveals a divergence between theory and policy which should be re-corrected in light of recent reductions in research budgets.*

3) Barnes, A.P. (2001). **Publicly-Funded Agricultural R&D and 'Social' Total Factor Productivity.** *Agricultural Economics*, (*in press*).

Abstract: *Most studies concerned with measuring the rate of return to publicly-funded agricultural R&D investment have found high returns, suggesting under-investment, and calls for increased expenditure have been common. However, the evaluation of returns tend to measure the effect of research expenditure against growth in Total Factor Productivity (TFP), based on market inputs and outputs. When compared against growing public unease over the environmental effects of pursuing agricultural productivity growth, TFP indices become a misleading measure of growth. This paper integrates some non-market components into the TFP index. The costs of two specific externalities of agricultural production, namely fertiliser and pesticide pollution, are integrated in a TFP index constructed for the period 1948 to 1995. This adjusted, or 'social', TFP index is measured against UK public R&D expenditures.*

The rates of return to agricultural R&D are reduced by using the 'social' as opposed to the traditional TFP index. Whilst both remain at justifiable levels, previous studies appear to have over-estimated the effect of agricultural R&D expenditures. Furthermore, with changes in policy towards more socially acceptable but non-productivity enhancing outcomes, such as animal welfare, rural diversification and organic farming, the future framework for analysing returns to agricultural R&D should not be so dependent on productivity growth as an indicator of research effectiveness.