Australian Agricultural Economics Society Annual Conference
Brisbane, February 1990

THE RETURNS TO AGRICULTURAL RESEARCH AND THE UNDERINVESTMENT HYPOTHESIS - A SURVEY

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Abstract:

Research on agricultural research has occupied a prominent position within agricultural economics since the pioneering work of Schultz and Griliches in the 1950s. The literature has developed from the early applied cost-benefit studies, to recent work with a distinct political-economy/public-choice flavour. Empirical estimates of rates of return to research have been consistently high. This has focussed attention on the "under-investment hypothesis", at a time when governments are trimming research budgets. This paper surveys the area, by asking the following questions: how much research to do; what research to do; who gains and loses; and what can be said concerning the role of government?

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1. Overview

1.1 Introduction

Agricultural economics has long been one of the largest and most active sub-disciplines of economics, due partly to the strategic importance of increased agricultural productivity in the early stages of economic growth. Within the sub-discipline, agricultural research continues to command much attention in the literature, because of its dominant role in increasing productivity.

There are theoretical reasons also for the continuing interest in research even today. Initially, research into research predominantly featured exercises in cost-benefit analysis, attempting to measure rates of return to applied R&D, ex post. (The difficulties increase, the nearer is the research to the 'pure' end of the spectrum.) Analysts had at least two principal theoretical techniques to employ in such studies. The first was the traditional approach utilising consumer and producer surpluses, while the second used regression analysis of aggregate agricultural production functions. Much of the subsequent literature has consisted of refinements of these methods, and will be discussed in Section 2.2. There has also been a growing emphasis on ex-ante cost-benefit studies, as setting research priorities within tight budgets becomes a more important exercise (Fox 1987; Contant and Bottomley 1988).

There are other reasons why agricultural research has proven interesting to both theoretical and applied agricultural economists. There are income-distributional issues concerning the impact of technological change on different groups within society (Section 3.1). And in a sector of the economy regarded as generally fulfilling the requirements of the competitive model, research is subject to a variety of potential market failures, incorporating both public-good and externality issues (see Section 3.1). These have resulted in high levels of public involvement in the agricultural research infrastructure in the industrialised nations of the West.

These market failures provide some theoretical explanation and justification for the major result that is consistently found in the empirical literature across different commodities and different countries, namely, that applied rural R&D is, on average, a highly profitable investment. Real rates of return to research are regularly found to be in the order of 30% to 70% per annum, and sometimes higher (see Section 2.1), suggesting that research is consistently underfunded, and that current government intervention may be inadequate.

Once public intervention is prevalent, explicit issues of political economy and public choice become important. Recent literature on agricultural research has broadened to encompass these concerns. In particular, any discussion of the "underinvestment hypothesis" must acknowledge that many of the high reported rates of return occurred within national research systems featuring a high degree of government involvement. An important question then arises as to why are there unexploited high returns even within a predominantly public research system. This is discussed in Section 3.2.

2. Ex Post Returns To Applied Research

2.1 Empirical Studies

One of the earliest investigations into applied rural research was Griliches' pioneering cost-benefit study of hybrid corn research (1958), which yielded internal rates of return of 35-40%. (All results quoted herein are in real terms, discounted for time.) Griliches also was one of the first to employ the regression analysis approach to study aggregate R&D in agriculture (1964), estimating similar rates of return. Peterson (1967) used both approaches to study poultry R&D, deriving returns of "about 20% to 30% a year from the date of investment". A comparison of empirical studies up until the late 1970s is contained in Evenson, Waggoner, and Ruttan (1979), and Ruttan (1982), which list internal rates of return to research ranging from 16% to over 100% per annum, derived mainly, but not exclusively, from studies of crop research.

Published Australasian studies are comparatively rare. Scobie (1986) derived a rate of return of 30% for New Zealand research, for the 1926-27 to 1983-84 period. Duncan (1972) evaluated pasture research in the CSIRO Division of Plant Industry. Rather than measuring changes in supply of agricultural output, he investigated the impact of increased productivity on demand for the input (improved pastures). He found high rates of return to pasture research (up to 80%), although there was considerable difference between regions. An extensive evaluation of the research conducted by the CSIRO Division of Entomology (IAC 1976; Marsden et al. 1980) indicated an average return in excess of 19%, and concluded that the overall success of the Division was due to the very large benefits of a small number of projects. This may be typical of many types of agricultural research, and is analogous to drilling for oil - a few profitable strikes more than cover the costs of the unsuccessful ones.

2.2 Theoretical Approaches

a) The economic surplus approach:

The basic analytic tools used in the surplus approach to cost-benefit analysis are presented in texts such as Just, Hueth, and Schmitz (1982). The methodology is critically examined in Wise (1975) and Norton and Davis (1981). The simplest surplus model is represented in Figure 1, which depicts the effects of successful R&D as a shift of the supply curve downwards and outwards, from S0 to S1.

(see Figure 1)

A benefit-cost ratio or a rate of return can be computed by calculating the net benefit as the present value of the sum of the consumer and producer surpluses (area ABCD) over time. Such rates are often presented as both internal and external rates of return, for purposes of comparison (see Ruttan 1982, p259). With a few exceptions (described below), surplus studies generate average rates of return to funds devoted to research - the regression analysis approach provides marginal rates.

This raises the issue of the shape and smoothness of the research production function. If it is assumed to be conventionally shaped (with a positive first derivative and a negative second derivative), marginal rates of return will decline with each project. In this case, estimates of average rates will obviously overstate the marginal return to R&D. This is one of the arguments used against the hypothesis that research is underfunded.

In reality, research at the individual project level is often an uncertain venture, even when the hoped-for end result is clear. There may also be unforeseen spin-offs, where results may give rise to highly profitable applications that could not have been anticipated before the project started. Thus the assumption that marginal rates of return decline smoothly, with the most productive projects tackled first and the least productive last, seems unrealistic. Evidence on this issue is presented in part (b) of Section 2.2.

In the studies surveyed by Norton and Davis, refinements to methods of estimation involved, for example, relaxing elasticity restrictions, specifying different forms of supply shift, accounting for resources released as a result of the technical change, and identifying the distribution of the gains from technical change (for instance, between consumers and producers).

Since the publication of Norton and Davis's article, considerable theoretical refinement in the methods of estimation has occurred. In some cases it is now suggested that previous results have been overestimates, while in others they have been underestimates. With interest in the "underfunding debate" continuing, it is therefore necessary to examine the theoretical methods used in these studies, and the issues that have been raised about them.

Lindner and Jarrett (1978) (discussed in Norton and Davis) argued that insufficient attention had been paid to the nature of the shift of the supply curve of the relevant agricultural output, and that there were important implications for the size of research benefits. In particular, some authors assumed parallel shifts, others proportional ones (either divergent or convergent). They concluded that the measured level of gross benefits were highly sensitive to the assumptions made about the supply shift, and argued that many previous studies had overestimated returns to research as a result of mis-specifying the supply shift. Rose (1980) and Wise and Fell (1980) corrected and generalised their analysis. (Footnote 1)

Edwards and Freebairn (1981, 1984) provided a general model for evaluating ex-post or ex-ante benefits, allowing for the international transfer of new technology. Since research results are available for exploitation by foreign producers, higher foreign (as well as domestic) production will tend to lower the world price. This biases benefits away from producers and towards consumers, and generally lowers aggregate domestic benefits.

Fox (1985) questioned whether the underinvestment hypothesis appropriately characterised the United States, raising two points which he believed weakened the case for increasing research funding. Firstly, he argued that some comparisons between alternative (i.e. rural and non-rural) rates of return were erroneous and misleading, in that social rates of return to rural research had been compared with private rates of return to other parts of the economy. On this point, it is true that total benefits to society will be greater than the prevailing private rates of return, to the extent that there are positive externalities from R&D, or scientific spin-offs (discussed further in Section 3.1). However, few if any of the empirical studies have attempted to include such externalities.

Second, Fox pointed out that computed rates of return to public investments need to take into account the deadweight loss that arise from tax collection. Since this was not common practice, all available estimates had to be regarded as overestimates. This is essentially an empirical issue - how big are the deadweight losses associated with taxation, and what will the effect be on rates of return of incorporating them into the analysis? Tentative answers to the first part of the question were provided by Browning (1976, 1987) and Ballard, Shoven and Whalley (1985). Findlay and Jones (1982) suggested that, in Australia, a dollar of government expenditure from taxation might cost $1.40. Fox and others, in applied studies of research in Canada, have attempted to incorporate the welfare cost of taxation into their cost-benefit analyses. These studies are described at the end of this section.

According to Norton, Ganoza, and Pomerada (1987), none of the previous empirical rate of return studies considered the effects on research payoffs of demand shifts caused by population and income growth over time. Ignoring this effect would tend to underestimate the rate of return.

Alston, Edwards, and Freebairn (1988) examined the effects of market distortions on the size of research benefits, and concluded that particular distortions could increase or reduce the aggregate benefits to research. In some cases the effect is obvious. For instance, since output quotas prevent any increase in output from technological change, consumers will not benefit from research. Although producers will benefit from lower production costs, aggregate gains will be lower than in the absence of the quota by the area G in Figure 2.

(see Figure 2)

The question of distortions was raised again by Oehmke (1988). He argued that Alston et al. had not analysed the issue completely, because, while they had examined the impact of distortions on research benefits, they had ignored the effect on the costs of research. He argued that some distortions will increase the costs of research, and gave the example of a per unit output subsidy. If research enables production to increase, then the amount of output to be subsidised will rise, and thus the overall subsidy costs will correspondingly rise.

It is not clear from a cost-benefit standpoint that Oehmke is correct on this point; it depends on the price used to value the extra output induced by research. Conventionally in cost-benefit analysis, an appropriate shadow (i.e. net-of-subsidy) price is employed when such distortions are present; if this is done correctly, any extra subsidy costs count only as a transfer item. Oehmke seems to be implying that some unidentified previous studies have used the distorted price to value output, and not subtracted the appropriate amount of increased subsidy costs before computing a rate of return (which would thus be artificially high). The crucial issue is the size of the total net deadweight loss arising from the distortion before and after the research. It seems likely that in many cases the difference will be relatively slight, as is shown in Figure 3, for the case of a subsidy on a traded good in a small economy.

(see Figure 3)

Without any research, the subsidy causes a deadweight loss of ABC; with the research, it causes DEF. Thus the difference between research benefits with and without the subsidy will be correspondingly small, as shown by Voon and Edwards (1989). (Alston, Edwards, and Freebairn, 1988, established the equivalence between evaluating welfare losses from a distortion before and after research, and evaluating net research benefits with and without the distortion). McLaren (1989) pointed out that Oehmke's numerical calculations were incorrect (conceded by Oehmke in a communication), which explains the inconsistency between his results and Voon and Edwards'.

Gardner (1988) analysed the reasons that research and distortions coexist (even in markets characterised by over-supply) - research benefits may often accrue largely to consumers, and that intervening in the market may be a way of redistributing those benefits back towards producers. The net effect is usually that aggregate benefits fall, but producers gain more than they would otherwise. Bouchet, Orden, and Norton (1989), empirically analysed the comparative effects of new technology versus artificially high (distorted) prices as a source of growth in the rural sector. In France, they concluded that technical change, either imported or domestic, is the primary influence.

A comparative static approach is often employed in analysing R&D, with an implicit or explicit assumption that the adoption of new technology is instantaneous and complete so that the full supply shift occurs immediately the research is completed. Some empirical studies employ particular lag structures for benefit streams to approximate reality. An inportant question raised by the presence of distortions is, will there be a systematic effect on rates of adoption caused by these distortions? Protectionist price policies may increase the speed of adoption by reducing risk and increasing the farmers' investible surplus. The resultant increase in the profitabilty of R&D would be an offset to the social cost of the distortion. According to Miller and Tolley (1989), price policies (in their analysis, an output subsidy and an input subsidy are compared) "can affect the rate of adoption but still have only a minor effect on social welfare". They suggest that there is no substantial case on welfare grounds for employing price policies to encourage earlier adoption. (Footnote 2)

Four articles have recently appeared which investigate particular research programs in the light of the issues of product market distortions and the welfare costs of raising tax revenue. Zachariah, Fox, and Brinkman (1989) investigated broiler chicken research in Canada. Allowing for the effects of an output quota and a 20 per cent increase in costs reflecting excess tax burdens (see Fox 1985), and using a statistical formulation to derive a marginal rate of return instead of an average one, they concluded that the research was highly profitable. Internal rates of return were computed to be between 52% and 60% per annum. A similar analysis of beef cattle research in Canada by Widmer, Fox, and Brinkman (1988) derived marginal rates of return in the order of 63%. A study of sheep research (Horbasz, Fox, and Brinkman 1988) yielded marginal returns of 20% when the costs of public funds were included. Finally, Enamul Haque, Fox, and Brinkman (1989) investigated laying-hen research, also accounting for output controls and excess tax burdens, and derived internal rates of return under several scenarios, almost all of which were in excess of 80%.

b) The production function approach:

The major alternative method of evaluating rural research is the production function (regression analysis) approach. In this case, the input of interest is expenditures on research, and the output is some measure of agricultural productivity (or value of agricultural output). This procedure enables the derivation of marginal rates of return (unlike most surplus studies which only yield average figures). Advocates of this approach argue that it also enables analyses of aggregate research programs, unlike the surplus approach which concentrates on particular projects (and may lead to biased results if only successful projects are chosen).

The two empirical surveys noted above list the results of most pre-1980 regression analysis studies, and for the most part they tell a similar story, with marginal returns of up to 110%. The areas of debate and refinement are largely technical ones such as functional form, accuracy of data, the length and shape of the time lag reflecting the impact of research spending on output, the appropriate method of determining the rate of return from the estimation, and the quality of indexes used as the dependent variable (see Norton and Davis 1981).

Scobie (1986) provided a non-technical presentation of a production function study of all New Zealand agriculture from 1926-27 to 1983-84. Five variables are presented as major influences on productivity. They are weather conditions; spending on extension services; the number of recent graduates in agricultural science; the economic conditions of the agricultural sector; and the expenditure on rural research for each of the past 30 years. According to Scobie, "on average, research results are slowly incorporated into practice and their impact on productivity increases reaching a peak after 11 years, and finally tailing off after a total of 23 years." Using that time lag, Scobie derived a rate of return of 30%. Altering the total length of the lag from 8 years to 29 years yielded a range of rates of return between 15 and 66% (the shorter the time lag, the higher the rate of return).

Some of the "underinvestment" policy debate in the U.K. has recently occurred within the regression analysis framework. Wise (1986) followed on from Davis (1981) in looking at the issue of correctly calculating the marginal internal rate of return from a production function. Outlining a general framework within which to assess previous production function studies, he argues that they are likely to overestimate rates of return, and that high rates will not necessarily be sustained in current research.

Harvey (1988) presented a general critique of current evaluations of rural R&D, particularly in the context of regression analysis. While identifying issues which may bias reported rates of return to rural R&D downward, he also expressed some scepticism about the assumption of diminishing marginal returns to R&D expenditure, citing the possibility of major scientific breakthroughs such as the microchip. Given the alternative, that there may be increasing returns to R&D, consideration needs to be given to the appropriate role for government, which may include exploiting economies of scale. He also emphasised the dynamic and interdependent nature of R&D activity.

Thirtle and Bottomley (1988) examine U.K. research expenditure, and in contrast to Wise, generate quite high rates of return. Depending on the productivity indices used, returns vary from 53 to 84%, and they conclude that the evidence supports the underinvestment hypothesis for the U.K. Subsequent correspondence (Beck, Upton, and Wise 1988; Thirtle 1988) seemed to imply a degree of talking at cross-purposes, with Thirtle still defending his analysis, and pointing out that to make a case for underinvestment, it is not important whether returns to research are 30% or 300% - if they are higher than returns prevailing elsewhere, then there is a case for increased funding.

There is limited and inconclusive evidence regarding declining rates of return to rural R&D. As discussed above, Davis (1979) has argued that marginal returns to research have diminished since the 1950s, but Scobie's study of New Zealand agriculture found no such evidence. The persistence of high rates of return in published studies (both cost-benefit and regression analyses), as well as the 'discontinuous' nature of research, suggests that rural R&D will be likely to remain a good investment in the future.

c) Summing up:

The net effects of theoretical advances in the techniques of ost-benefit estimation on the reliability of earlier estimates are ambiguous; some suggest earlier rates of return were over-estimates, others under-estimates. Final conclusions can only be drawn empirically. More recent empirical work (Thirtle and Bottomley 1988; the papers co-authored by Fox, Brinkman, and others) has generally resulted in high returns of a similar order of magnitude as the earlier studies. Other empirical questions still to be conclusively resolved are the diminishing returns to research, the costs of public funds, and the correct rates of return to other sectors of the economy, with which rates of return to rural research can be contrasted. However, the underinvestment hypothesis appears to still be an important topic for both applied economists and policy makers to address.

3. Further Issues In Research

3.1. Gainers, Losers, and Market Failures

In the literature, it is recognised that productivity improvement is not the only desirable outcome of successful research; other, more specific goals have been identified (see e.g. Schuh and Tollini 1979), such as increasing consumer welfare, increasing the farm sector's net income, improving conditions for farm workers, or preserving the environment. As they pointed out, some of these goals may be incompatible, and they have different effects on more general goals like increasing economic growth or improving equity. The last goal, environmental protection, has become particularly important from the viewpoint of policy-making in more recent times, given the widespread public concern over environmental issues generally, and environmental degradation from rural land use (for example, soil acidity and salinity) in particular.

Thus, focussing purely on (essentially private) rates of return is only one dimension of a full analysis of the impact and worth of rural research. When identifying gainers and losers from research, there is a further set of aggregate issues, concerning the role of market failures, as well as the disaggregated issues of which groups and sectors benefit or suffer most. This is the focus of this section.

The factors that determine the beneficiaries of R&D are, while conceptually straightforward, numerous and possibly confusing. However, it is important to distinguish between the various distributional issues as they have a direct bearing on the question of who should pay. There are three distinctions of interest when identifying gainers and losers from R&D. First is the issue from the research agency's point of view - that is, can the agency which develops a technology or process from R&D capture all the financial gains from it, or are other firms able to "free ride" by exploiting the process without being compelled to pay for it? Secondly, there is the issue relating to the income-distributional effects of the implementation of technological change. When a new process is introduced and adopted, the expected result is that supply of the product will rise and its price will fall. Factor use may change, and particular regions or groups may benefit. The third broad issue is that of the general social benefits (or costs) of new innovations, over and above those already mentioned. New production processes may bring with them side effects (for instance on health or the environment), which may be considered good or bad. These three topics will be dealt with in turn.

a) The appropriability issue:

One major reason for believing that private markets would be inefficient at doing R&D is the appropriability problem; "pure" knowledge is almost a pure public good, and users of this knowledge have a strong incentive to free-ride. As long as the knowledge would be provided anyway, this situation is fine, since aggregate knowledge does not decrease as individuals make use of it. However, the private sector understandably expects to see a return from investments in R&D. If the users of R&D results cannot be compelled to pay for the new technology or process they employ, the private sector has inadequate incentive to conduct R&D that would be beneficial to society. This is a major reason for believing that, from an economic point of view, private markets, left to themselves, would underproduce research.

The problem stems from the issue of property rights - that is, defining who "owns" the research results. Obvious ways of assigning property rights to knowledge include patents and copyright laws. "The objective of intellectual property rights is to increase the rate of technological change and the dissemination of knowledge by rewarding the output of research investment." (Stallmann and Schmid 1987). The subject of property rights in agricultural R&D has not been widely investigated, but it is almost folklore that so-called basic scientific research will tend to exhibit inappropriability, while applied R&D projects with specific goals and results will usually be protected by patents and copyright. Therefore (the folklore contends), private R&D will be biased towards highly applied work, but the basic bread-and-butter research, which forms the foundation of all applied work, will languish unless publicly conducted or subsidised.

Stallmann and Schmid (1987) examined the difficulty of patenting new breeds of plants in biotechnology research and extension. Evenson (1983) also looked at the issue of intellectual property rights, and provides some data on patent awards since the 1960s.

However, there is little hard data on how effective intellectual property rights are within Australia, and how severely private research bodies are affected by inappropriability. The general presumption that applied rural research is less appropriable than other applied research is probably correct, but clear empirical evidence seems to be lacking. The role of the government in addressing this problem is discussed below.

b) Income distribution effects:

As Harvey (1988) stresses, technological change tends to create gainers <u>and</u> losers, and agricultural R&D is unlikely to be an exception. Improved productivity, under normal circumstances, increases farm output, which results in a lower price for the product. Consumers will unambiguously gain, but producers will only be better off in certain circumstances - since they are trading off higher sales with a lower price, their income may rise or fall. There are other effects also, on inputs (especially labour) and between regions and income groups (Scobie 1979; Schuh and Tollini 1979). The distribution of gains for research will also be affected by whether the good is tradable or not (Edwards and Freebairn 1984); whether market distortions are present (Alston, Edwards and Freebairn 1988); and also where in the production/marketing chain the research occurs (Freebairn, Davis, and Edwards 1982; Alston and Scobie 1983; Holloway 1989; Mullen, Alston, and Wohlgenant 1989). (These last topics are treated in Section 2.2).

Scobie (1979) argues that awareness of these distributional effects has increased due to the skewed effects of certain innovations, such as the introduction of high-yielding cereals. As a result, increased efficiency is now regarded as being a necessary condition for evaluating alternative investment strategies, but a more equitable distribution of the gains is also being seen as being of equal importance.

Early adopters (usually larger farmers) of new technologies will improve both their absolute and relative positions in the market, particularly if they are fairly small in number (Scobie 1979). Further aspects of this issue include whether the new technology is "scale-neutral", and whether there are particular contractual arrangements (such as tenant farming) which affect incentives to adopt new technology.

With regard to the distributional effects between landholders and labourers or owners of other inputs, there are both price and output effects to consider. Improved productivity usually results in increased output, which would tend to increase the demand for inputs. The net effect may well be positive.

However, the implicit assumption above is that technological change is "factor-neutral", affecting demand for all factors equally. In fact, most technological change is biased towards saving more of one factor than another. The induced innovation hypothesis (see Just, Schmitz, and Zilberman 1979) suggests that the direction of the bias would be toward saving the relatively scarce factor (land in Japan, for example, and labour in the U.S.). However, even with factor-neutral technology, it should not be assumed that factor incomes will rise equiproportionately, mainly because the supply of land is usually highly inelastic (unresponsive to changes in prices). Since labour can migrate to a region in response to a change in demand, one would expect the relative increase in the wage rate to be considerably less than that of land values. Thus, even if the absolute incomes of both groups rise, the relative distribution becomes more unequal.

However, as discussed in detail below, if demand for output is inelastic, demand for inputs is likely to fall, and net returns to producers may fall overall. In such cases, land, whose supply is relatively inelastic, suffers the greatest relative loss. The net result is that the relative income distribution between landholders and labour improves, but some labour has been released from the agricultural sector, and its absolute total income falls. Other aspects of this issue are the dual effects of population growth; on the demand side, population growth increases demand for agricultural output (and hence inputs), while on the supply side, population growth swells the labour force, thus depressing the wage. Attention should also be paid to net employment effects, not just wage outcomes, and it should be noted that any (absolute) increase in the income to labour will result in secondary effects in other sectors of the economy, both agricultural and non-agricultural.

Huffman and Evenson (1989) have investigated the input and output bias effects of research, extension, and farmers' education in the U.S. Of particular interest here is the finding that during the period 1949-74, public and private crop research biased input usage in favour of fertilzer and away from farm labour and machinery. They note that the direction of the biases for fertilizer and labour are consistent with the induced innovation hypothesis.

An important element to consider is the distribution of gains from research between consumers and producers. Restating the argument, improved productivity from research will generally increase output, which in turn will generally reduce the product price. When the demand for the output is highly inelastic, which is often the case, consumers will be the main beneficiaries. (This has given rise to the argument that the consumer, as a taxpayer, should pay for the research, through a research subsidy - a proposition examined in Section 3.3). The net impact on producers' revenue depends on the elasticity of the demand curve for the output - and the effect of this on profits will depend on the nature of the unit cost reductions induced by the technical change.

If the commodity is traded on world markets, then the elasticity is likely to be very high, resulting in minimal price changes as output expands. Detailed analysis of this issue is contained in Edwards and Freebairn (1984). Furthermore, artificial constraints in the form of government-imposed distortions (tariffs, subsidies, quotas etc.) will affect both the absolute level of benefits to research, and the distribution between consumers and producers. For instance, floor price policies will prevent price adjustments occurring, thus depriving consumers of gains. The same result holds for output quotas (see Alston, Edwards, and

Freebairn 1988).

Various cost-benefit studies of rates of return to rural research have also examined some of the distributional issues discussed above. Schmitz and Seckler (1970) investigated the impact of the introduction of a mechanical tomato harvester, both in terms of the benefits to consumers and producers, and the losses suffered by displaced labour. Akino and Hayami (1975) analysed rice breeding programs in Japan, using the polar cases of complete autarky (no trade) and an open economy (imports creating a constant domestic price), to estimate the distribution of gains between producers and consumers. Nagy and Furtan (1978) found high rates of return (in the order of 100%) for Canadian rapeseed research, and determined that both producers and consumers gained from the research, with the producers' share rising over time. Ayer and Schuh (1972) and Scobie and Posada (1978) looked at distribution in more detail.

The division of gains between producers and consumers from research in a staple crop will also be affected when there are many subsistence or semi-subsistence farmers. Empirical investigations of this include Hayami and Herdt (1977) and Alauddin and Tisdell (1986).

(c) The externality issue:

The third important determinant of research beneficiaries is the issue of externalities, or side effects, arising from the implementation of research results. These external effects may be welfare enhancing or welfare reducing, but the benefits or costs they impose are not reflected in the market price of the product. As a result, positive externalities tend to result in underproduction, negative externalities in overproduction. For reasons given below, this description may be misleading in the case of research.

The IAC (1976, p.261) distinguished between two types of external benefits: inter-industry and inter-sectoral. "Inter-industry externalities are benefits flowing from research on one rural product to producers of other rural products...e.g. research for the cattle industry will often benefit other industries based on ruminant animals. Research for farmers in one region will flow to other regions where the new technology can be readily adapted and applied. Although these external benefits are still within the rural sector, they are nevertheless an important deterrent to adequate research investment by primary producers, either as individuals or when organised by industries as applies with the Australian RIRFS.

"Inter-sectoral external benefits are those which flow from rural research to the rest of the community. Such benefits may be direct, as when a new research application for agriculture automatically benefits human health and welfare. Many are indirect, in that a scientific breakthrough in agriculture will flow to other sectors of the scientific community and will assist in solving quite unrelated problems."

The IAC then provided two sets of examples - from entomological research in CSIRO, and from research into animal health and nutrition.

Evenson (1989) examined the spillover of research benefits in the U.S., and produced some tentative empirical results to indicate the extent of such spillover, concluding that there is substantial direct spillover for both crop and livestock productivity, and that there is larger spillover from similar regions for livestock than for crop production. Carlson (1989) and Capalbo and Antle (1989) focussed on external costs associated mainly with given production methods or inputs (such as pesticides). Other discussions of externalities in agriculture are contained in Dahlberg (1987). (Footnote 3)

The increasing importance of environmental issues in the public consciousness has certainly provided a strong stimulus for agricultural R&D to reflect broader concerns than the traditional one of "making two blades grow where one grew before". Environmental concerns have raised the desirability of making agriculture sustainable in the long term - that is, being able to farm an area of land indefinitely without causing damage that would render the land noticeably less fertile.

In Australia, particular rural concerns have been with the effect of historical farming practices on soil acidity and salinity. It was noted above that where there were negative externalities associated with the production of something (in this case, environmental side-effects of farming practices developed through research), the standard conclusion to be drawn is that there will be "too much" of the good produced relative to what would be socially desirable (that is, excessive rural research). However, to draw this conclusion in the current circumstances would be to view all rural research in the same light, regardless of its objectives. It could be argued that high levels of soil acidity and salinity resulted from inadequate, rather than excessive, rural research. This is because research into the long term implications of the new technologies may have brought the problems to light before they happened. Thus, both negative and positive externalities may lead to an underinvestment in rural research. This brings us to a discussion of the "underinvestment hypothesis" and its relationship with government involvement in research.

3.2. The Underinvestment Hypothesis and Government Intervention

Section (ii), above, listed two specific market failures that would lead to an a priori expectation that private markets would provide an inefficient amount of agricultural research. The first was that of inappropriability, the second that of externalities. Both of these tend to reduce the returns accruing to the research agency relative to the social returns, making such activity less profitable than it actually is to society.

This goes some way to explaining the persistently high rates of return to rural research reported in the literature, which on their own imply unexploited profitable opportunities for the private sector. The reason the private sector fails to take up such potentially high payoff opportunities may be largely a result of the market failures.

The existence of these market failures also provides one explanation for the high degree of government involvement found in many national agricultural research systems. The relevant question then becomes, are there still unexploited profitable opportunities in research, even with government intervention, and if so, why? In other words, if market failures prevent the private sector from efficiently producing research, what prevents the government from identifying all the remaining high-payoff projects, and undertaking to do (or fund) them?

The short answer would be that there are few votes in it. Governments are faced with finite budgets, and will generally be mindful of maximising the votes that they can generate with those funds, whatever other goals and constraints they face. Agricultural research is a long term and risky activity, with potentially high payoffs, some time in the future, to a diminishing group of rural producers; or worse (from a political viewpoint), accruing mainly to a large and diffuse group of consumers, who are unlikely to attribute falls in their food prices to research done years back, and transfer their voting allegiances accordingly. As a result, there is likely to be little internally generated incentive for governments to ensure that all potentially profitable research projects are undertaken.

Some writers have attempted to provide more detailed analyses of why underinvestment in R&D still persists in the presence of government involvement. Davis (1981), Ruttan (1982), Bonnen (1983), and others discuss the fragmentation hypothesis, which suggests that R&D resources are misallocated "because the research bureaucracy is fragmented and allocation decisions are made by a number of subagencies in an uncoordinated fashion" (Oehmke 1986). For example, regional spillovers (such as those described in Evenson 1989 above) provide incentives for regional (e.g. state-level) agencies to free-ride on others. Rose-Ackerman and Evenson (1985) argued in similar fashion that R&D expenditure is also determined by the political effectiveness of farm interests.

Oehmke (1986) argued that even if the public research body (and by implication, the government) acted as a "profit maximiser", that is, it intended to pursue every research project that was expected to show a profit, persistent underinvestment is still likely to be prevalent. His argument is that the demand for research rises over time, and that there is a time lag between growth in the excess demand for rural research and the increases in funding that research receives (for a variety of reasons, including recognition lags, risk aversion on behalf of administrators, and the existence of substantial indivisibilities or fixed costs for new projects). Oehmke cites White and Havlicek (1982), who examined the implications for underfunding of R&D by governments (as a budgetary measure), in terms of the long term costs, and argued that the costs to governments will be high if they try to compensate later on for past underfunding; alternatively, the costs to consumers will be even higher if the government does not compensate for earlier underfunding. Oehmke used this result to argue that incentives for governments to act as cost minimisers (or profit maximisers) were present, and would grow over time. However, this requires the government to be thinking in time frames which are, at least, greater than five years. To the extent that the government's thinking is dominated by short term considerations and expediency, it would be quite possible for it to rely on the effects of previous research, and leave it to future governments to bear the brunt of the earlier policies. Research benefits can last anywhere from fifteen to thirty years into the future, and so much of the effects of today's research will be felt by voters (consumers and producers) with a different incumbent government.

Thus, although costs will be imposed on the economy by sacrifices in government spending on research, it is not implausible to suggest that pure self-interest, in isolation, will be ineffective in ensuring efficient levels of public research expenditure. This accords completely with the intuition provided at the outset of this section. (Footnote 4)

3.3 Who Should Pay For Research?

This is the question that is likely to be uppermost in the minds of policymakers when discussing rural research. There is no objectively determinable "correct" formula for funding research, though there are some guiding principles, such as "minimising net social cost" and "user-pays".

"User-pays" argues that the beneficiaries of R&D should finance it. As shown above, research benefits can accrue across a wide variety of groups in society; between the innovating firm and other firms or farms (the appropriability problem), between consumers and producers, not to mention factor owners (the income-distribution effects), and to other groups in society (the externality problem).

The appropriate question is then, what form should the government action take, given the acceptance of the user-pays principle as a guideline? Scobie (1984) has outlined three broad courses of action open to the government with respect to research. They are:

(1) improve the economic/legal environment in which R&D is carried out. This would include measures designed to enhance existing intellectual property rights, such as patent and copyright laws, as well as providing tax concessions or other forms of subsidy;
(2) directly fund R&D that will then be carried out in the private sector; and
(3) establish public research facilities.

Thus, the government may alter the rules of the game, or pay for the research, or do the research itself. Various combinations of these three options may be employed in different circumstances, such as joint ventures between public and private enterprise.

One argument often advanced is based on the inelastic demand for food: since consumers stand to gain substantially from agricultural research (through lower prices), then they should, as taxpayers, be prepared to shoulder a share of the burden.

There are two in-principle objections to this, and one practical one (IAC 1976, p.42). The first is that any profitable investment, in anything, will provide benefits to consumers-otherwise, they would not demand what was being produced, and it would not be profitable. This cannot, however, be said to justify universal public subsidies for any and all private investments. The second objection follows on from the first; it is that the costs of an investment will generally come to be reflected in the price of the product anyway, to an extent determined by supply and demand elasticities, thus passing some of the costs on to the consumer. A research subsidy aimed at helping producers would accrue mainly to consumers in the long run, given inelastic demand. The third, practical, objection is that most of Australia's rural output is exported, with a world price that is largely independent of our supply. In those cases domestic consumers gain little from research anyway.

In economics texts, the public-good case (of which inappropriable research results is an example) is usually regarded as justifying public provision. However, Scobie (1984) has noted that other firms free-riding on one firm's research still results in the private sector being the principal beneficiaries. In this case, the private sector should still be responsible for financing the research. The government's role should be to facilitate this, either by changing the legal environment or by encouraging joint private sector research.

Where definite externalities can be detected, there is a clear case for government funding (and possibly performance) of research. With positive externalities, this is unambiguous. With potential negative externalities (environmental, for instance), there may be need for further government research on the long term impacts of new techniques.

In the case of Australian agriculture, which is mainly for export, the sharing of productivity gains between producers and consumers generally favours producers. The IAC (1976) suggested that, for most products, farmers obtain 60 to 90% of the gains.

Because farmers provide only a small part of the total funding, but obtain most of the benefit, a dual "gearing" effect operates. For example, if it assumed, conservatively, that:

(i) 60% of the returns to agricultural research accrue to farmers;

(ii) farmers meet 20% of the costs (they currently provide some 10%); and

(iii) the overall rate of return to research is 25% p.a.;

it then follows that a research expenditure of $100m would give a return of $25m p.a.; thereby providing $15m p.a. to farmers on their investment of $20m, <u>a rate of return of 75%</u>. Admittedly these returns are not like a cheque in the mail - they are distant in time and often hidden - but they are much larger and just as real as returns obtained from, for example, extra fertiliser. Also, the long wait for returns for research is already allowed for, since the benefits quoted earlier have been discounted at realistic interest rates.

4. Priority Setting: Ex Ante Cost-Benefit Analysis

The overall rate of return to research depends partly on the efficiency of the project selection process. Ideally, funds are allocated to the high payoff areas. Useful surveys of ex ante analysis are contained in Schuh and Tollini (1979), Scobie (1979), Norton and Davis (1981), and most recently, Fox (1987) and Contant and Bottomley (1988).

Ex ante studies of research projects involve difficult scientific judgements about the probability of success of the projects at various levels of funding. A second question is, given a successful outcome that will reduce costs of production by x per cent, what will be the likely net social benefits?

Edwards and Freebairn (1984), developed a theoretical framework for ex ante evaluation, and provided useful rules of thumb for project evaluation on tradable commodities. They stress as major determinants of profitability the size of the expected cost reduction, the size of the industry, its growth prospects, the rate over time at which cost savings are realised, and the exportability of both the technology and the final output. Davis, Oram, and Ryan (1987) extended the Edwards-Freebairn framework and evaluated the benefits of worldwide research accruing to a variety of crops. Other applied analyses of estimated payoffs to research are Norton, Ganoza and Pomerada (1987) investigating crop research in Peru, and Lemieux and Wohlgenant (1989) evaluating agricultural biotechnology.

Shumway (1981) and Anderson (1988) stressed the inherent riskiness and indeterminacy of R&D. As Anderson puts it, "estimation of future returns to agricultural research investment is something between a challenging task in applied economic analysis and a fledgling art-form."

5. Conclusion

Studies of applied agricultural R&D in many different commodities in different countries, using different methods, have generally suggested rates of return which seem unrealistically high. However, the consistency of the findings is reassuring, especially as methods of estimation have become more sophisticated recently. This article has also outlined some responses to those who profess scepticism about the credibility of the high reported returns: private research is hampered by pervasive market failure, while public research is a long-term and expensive activity which is politically "unprofitable". It would be surprising if a combination of market failure and "government failure" did not produce high rates of return.

Although the underinvestment hypothesis is not easily dismissed, some caution needs to bɔ exercised when extrapolating high previous returns into the future. However, the sorts of problems for which agricultural research seems needed show no signs of becoming less important. Nor are there clear signs that the ingenuity of our research workers is "running out".

Footnotes

Note 1 - Wise (1981) subsequently proposed a new approach for estimating net research benefits. It utilised the same supply-demand framework, but did not involve surpluses. Wise argued that this method avoided ambiguities inherent in the surplus method, and that published studies could be derived as special cases. The current authors know of no studies which have applied this approach empirically.

Note 2 - Miller and Tolley also note that their results may overstate the potential gains from price policies, since they did not account for the deadweight losses due to taxation, or for the possibility of inefficient farmers adopting technologies that they would not have adopted in the absence of price policies (that is, the returns would not normally have outweighed the costs of adoption).

Note 3 - For a more sociological view of the external effects of research, see the chapter by Heffernan in Dahlberg (1987). For other critical appraisals of the economics-of-agricultural-research literature, see the chapters by Aiken and Madden.

Note 4 - Some other results are worth mentioning here. Pardey and Craig (1989) argued that public R&D is determined by output, as well as vice versa; in other words, there is a simultaneity problem, and R&D spending cannot be taken as exogenous. Intuitively this seems plausible, given the arguments advanced in Section 3.2 about the dependence of public R&D spending on the political effectiveness of the farm lobby. Ulrich, Furtan, and Schmitz (1986) noted that in joint public/private research, private incentives would be to manipulate the direction of the research so as to maximise private benefits, possibly at the expense of higher social benefits.

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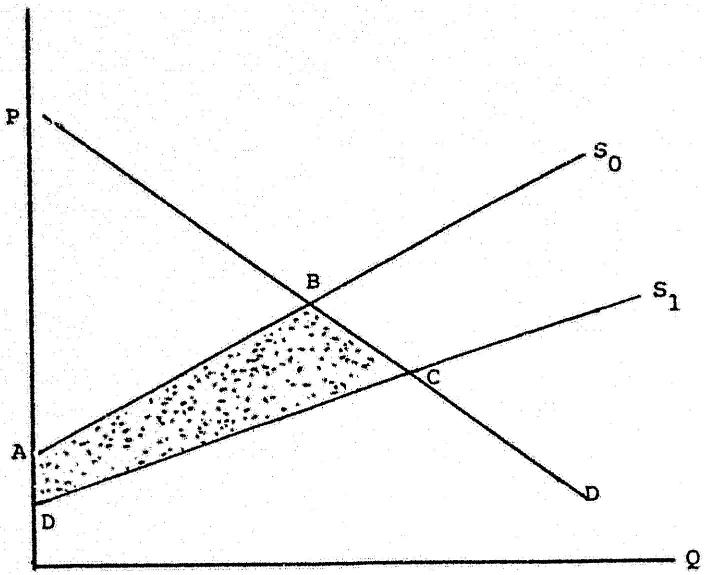

FIGURE 1
Benefits to Research

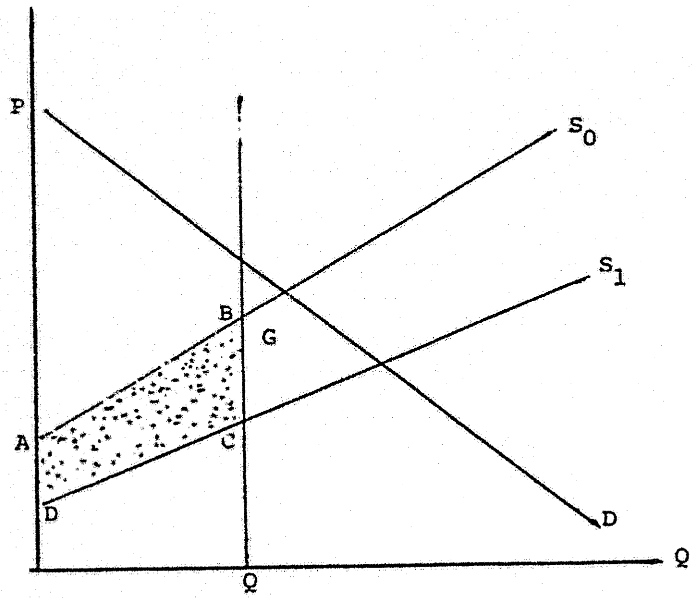

FIGURE 2
Effects of a Quota

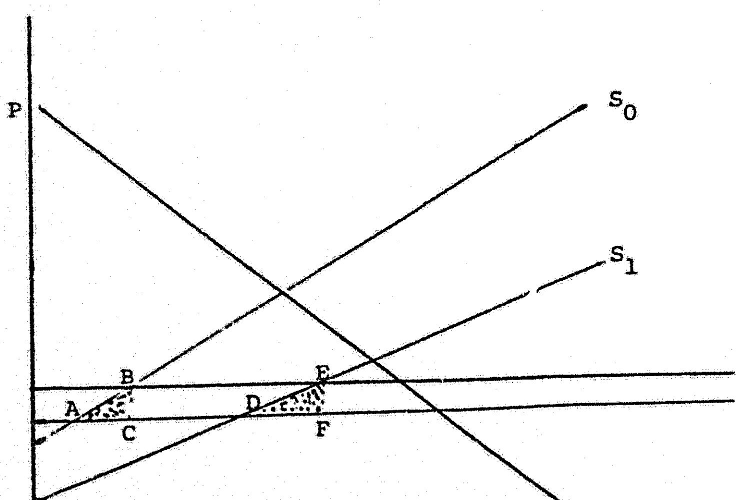

FIGURE 3
Effects of a Subsidy on an Imported Good