THE ECONOMICS OF PUBLIC SECTOR SCIENTIFIC RESEARCH IN AUSTRALIAN AGRICULTURE

A thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy.

by

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SUMMARY

This thesis is an analysis of public sector scientific research in Australian agriculture. The study is primarily in response to the lack of attention devoted to this area despite the growing recognition of its importance internationally. The Introduction outlines the most recent contributions by overseas analysts in the area of public sector scientific research and describes the scope of the present study.

One of the major obstacles to an analysis of public sector research in Australia is the lack of relevant data. Chapter 2 describes the collection of both scientific personnel and scientific publication data for the periods 1925-1975 and 1945-1975 respectively. The utility of this data is discussed with particular emphasis being given to the validity of using publication data as a measure of research activity.

In Chapter 3, an evaluation is made of the distribution of research activity in Australia for the period 1955-1965. A model is developed which suggests that the demand for research output is a derived demand to satisfy collective wants; in particular, those which are reflected by the goals of domestic agricultural policy. These goals are investigated and publication data on a commodity basis is used to evaluate the commodity research mix in terms of the expected contribution that research is to make to the attainment of these goals.

Both publication and personnel data are utilized in Chapter 4 to analyse the contribution made by public sector research to the attainment of policy goals; in particular, its contribution to the growth of agricultural output. The publication data are again used on a commodity basis to investigate the contribution made by research to the growth of commodity production yields for the period 1955-1975. A cumulative research index is constructed using personnel data for the period 1925-1975 and is utilized to analyse the contribution of research to changes in total factor productivity.

In Chapter 5, the emphasis shifts from the determinants of and contributions made by public sector research to an investigation of the institutionalization of scientific research and its subsequent growth. The investigation is made within the framework of an induced public sector model. The theory of induced innovation is reviewed and the history of public sector research in Australian agriculture is briefly outlined. An attempt is then made to link this development to relative factor and product price changes as hypothesized by the induced innovation model.

The findings of the study are summarized in Chapter 6.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University. To the best of my knowledge and belief, this thesis contains no material previously published or written by another person except where due reference is made in the text.

Signed: ______________________________

Trevor R. Hastings

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CHAPTER 1

INTRODUCTION

1.1 The Economics of Public Sector Research

In recent times, economists have devoted an increasing amount of attention to problems related to investment in public sector agricultural scientific research. The most notable outcomes of this are evidenced in Fishel [1971], Hayami and Ruttan [1971] and Evenson and Kislev [1975]. The context of these works is briefly outlined below, followed by an outline of the proposed area of study in this thesis.

Fishel [1971] is a collection of papers presented at the Minnesota Symposium on Resource Allocation in Agricultural Research held in 1969 which was the result of

> ...a growing awareness of the increasing number of studies investigating various aspects of the returns to investments in agricultural research, both before and after its conduct ....there was a prevailing assumption that the allocation problem to a considerable extent can and should be approached within an economic framework...
>
> [Fishel, 1971, p.viii]

These papers concentrated on many areas, in particular, the overall question of research resource allocation, the accomplishment of research, historical analyses of research productivity and investigations of the procedures developed and used by various institutions to allocate research resources.

Hayami and Ruttan [1971] develop a theory of agricultural development in which they attempt to make public sector research endogenous to the economic system.

> We identify the capacity to develop technology consistent with environmental and economic conditions as the single most important variable which explains the growth of agricultural productivity of nations.
>
> [Hayami and Ruttan, 1971, p.xiii]

The authors 'test' their induced development model by making an historical analysis of agricultural productivity growth in Japan and the United States for the period 1860 to 1960 and relating this to movements in relative factor prices. Their tentative finding being that

> The success in agricultural growth in both the United States and Japan seems to lie in the capacity of their farmers, research institutions, and farm supply industries to exploit new opportunities in response to the information transmitted through relative price changes.
>
> [Hayami and Ruttan, 1971, p.135]

This model is then used by the authors to speculate on necessary conditions for the transmission of technology among countries and the policies which should be adopted to develop agriculture in less developed countries.

Evenson and Kislev [1975] is a collection of mostly previously published material, the overall aim of which is to 'attempt to explain the role of scientific research in increasing agricultural productivity.' The book includes a substantial survey of international research and extension data without which 'it was not possible to make a realistic appraisal of the distribution of resources devoted to technological discovery and diffusion throughout the world. This data is then used in a number of studies to make preliminary investigations relating to the production of research output, the determinants of research investment, the contributions of research to productivity and growth and estimates of rates of return to research investments.

The three volumes briefly outlined above indicate the type of analysis which is now being undertaken with respect to public sector agricultural scientific research; each is attempting to make this activity endogenous to the economic system. In Australia, there has been a distinct absence of research into the areas just described, although there are signs of increasing awareness of its need as indicated by the recent Industries Assistance Commission's investigations into the funding of agricultural research. Apart from this study, few others have been undertaken by economists addressing themselves to questions relating to public sector research. At an analytical level, the work of Duncan [1972] and the I.A.C. [1976] represent the only systematic attempts to analyse the contribution of scientific research to Australian agriculture. These may be regarded as partial studies in the sense that they consider the research activities of one division of C.S.I.R.O. only. At an aggregated level, no study has been undertaken in Australia to analyse the economics of public sector research.

1.2 Aims of the Study

The basic aim of this study is to undertake an analysis of public sector scientific research in Australian agriculture and so provide some preliminary findings in an area which, until now, has received little attention, despite the growing recognition that it is receiving internationally. The particular tasks to be performed are outlined below.

The I.A.C. [1976, p.22] found in their study that there was a 'lack of relevant data, on a continuing basis, from any one source.' This observation undoubtedly represents the major obstacle to an analysis of public sector research in Australia. To try and overcome this obstacle, a collection is made of data relating to scientific personnel and scientific publications for the periods 1925-1975 and 1945-1975 respectively. This represents a considerable task in that apart from C.S.I.R.O. there are no continuous data sources available for other research institutions. The collection therefore has to utilize a number of divergent sources which have to be carefully scrutinized to make the data comparable both between and within institutions. Furthermore, the publication data is not published in the form necessary for the study, meaning that all publication data was classified by individual inspection. The collection of this data is described in Chapter 2. Following a discussion of the difficulties of defining and measuring research activity the collection of the publication and personnel data is described. The data is then utilized to investigate the validity of using publication data as a measure of research activity.

In Chapter 3, an evaluation is made of the distribution of research activity in Australia for the period 1955-1965. A model is developed which suggests that the demand for research output is a derived demand to satisfy collective wants; in particular, those which are reflected by the goals of domestic agricultural policy. These goals are investigated and publication data on a commodity basis is used to evaluate the commodity research mix in terms of the expected contribution that research is to make to the attainment of these goals.

Both publication and personnel data are utilized in Chapter 4 to analyse the contribution made by public sector research to the attainment of policy goals; in particular, its contribution to the growth of agricultural output. The publication data are again used on a commodity basis to investigate the contribution made by research to the growth of commodity production yields for the period 1955-1975. A cumulative research index is constructed using personnel data for the period 1925-1975 and is utilized to analyse the contribution of research to changes in total factor productivity.

In Chapter 5, the emphasis shifts from the determinants of and contributions made by public sector research to an investigation of the institutionalization of scientific research and its subsequent growth. The investigation is made within the framework of the induced public sector model developed by Hayami and Ruttan [1971]. The theory of induced innovation is reviewed and the history of public sector research in Australian agriculture is briefly outlined. An attempt is then made to link this development to relative factor and product price changes as hypothesized by the induced innovation model.

The findings of the study are summarized in Chapter 6.

1.3 References

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CHAPTER 2

THE LEVEL OF SCIENTIFIC AGRICULTURAL RESEARCH IN AUSTRALIA, 1925 - 1975.

2.1 Difficulties of Defining and Measuring Agricultural Research Activity

2.1.1 Introduction

In this chapter an attempt will be made to construct an index of scientific agricultural research undertaken in Australia for the period 1925-1975. Traditionally, in the area of private research activity, quite extensive use has been made of patent data to construct such indexes. In this study, it will be shown that scientific research in agriculture is typically undertaken by public research institutions and that the results of such research are not normally patented. As a result, emphasis is placed on the use of both publication and scientific personnel data to construct the proposed index. The chapter commences with a discussion of the problems relating to the definition and measurement of scientific research activity and, where applicable, parallels these problems with those encountered in the use of patent data. The collection of the publication and personnel data is then described and in the final section the utilisation of this data is discussed.

2.1.2 The Definition of Scientific Research

Since in this section we are concerned to analyse the level of scientific research in agriculture, we should make explicit the definition of scientific research which we are adopting. To this end we will define scientific research as Nelson [1959a, p.299] has.

> Scientific research may be defined as the human activity directed towards the advancement of knowledge...

Admittedly this is a general definition, but it is useful in that it gives us a starting point for analysis. The definition clearly depicts scientific research as an activity described by inputs and outputs, the inputs being 'human activity', the output being the advancement of knowledge. This advancement of knowledge may be viewed as manifesting itself in several ways. With regard to agricultural scientific research, we may distinguish between a 'final' research product and an 'intermediate' research product. That is, we may regard research output as being final if it yields a direct improvement over existing production inputs or methods. Intermediate research output may be regarded as 'incremental knowledge' which is used as an input into the production of final research products.

With regard to the agricultural research process, Evenson [1971, p.164] identifies five 'final' products.

1. Improvements to tangible material inputs used in producing agricultura products,
2. Improvements in entrepreneurial 'allocative decisions',
3. The adoption of 'new' material inputs,
4. Improved worker techniques,
5. Improved agricultural product characteristics.

These 'final' outputs which relate to new or improved inputs and/or processes may be evidenced by an advancement in either mechanical or biological processes. These technologies differ in certain respects; Hayami and Ruttan [1971], for example, highlight the differences in their respective factor saving propensities, mechanical technology being primarily labor saving and biological technology mainly land saving. However, these technologies differ in at least one further important respect, that is, to the extent that they are appropriable. De Janvry [1973, p.416] highlights this difference:

> The returns from research on mechanical techniques can, in great part, be captured...Because research costs for the development of modern biological-chemical-agronomic packages are considerable and because seed or chemical companies *can only appropriate a small fraction* of the returns from this research, private firms generally will not engage in these types of innovations. (own italics)

As a result of the inappropriability of biological technology, it is likely that 'inventions' in this area will be undertaken by public, rather than private institutions and that these inventions will not be 'patentable'. In some overseas countries, Plant Variety Protection legislation has been passed which 'confers on individual plant breeders or on organizations employing plant breeders, the right to levy and collect royalties from the end user of the new cultivars which have been developed' [Edwards, 1976, p.1]. This type of legislation has not yet been introduced in Australia so that in agriculture, where inputs are not predominantly 'technical', inventive activities are clearly understated by a measure of 'technical inventions' of a patentable form.

Given the limitation of patent data in our particular area of interest, as indicated in the Introduction to the chapter, emphasis will be placed on the use of publication and scientific personnel data. This data, in particular, publication data, will enable us to include the production of intermediate research products in our analysis. This is considered important for the following reasons.

First, since much of the agricultural research output is of an intermediate and hence inappropriable form, it is largely undertaken by public rather than private institutions. In Australia, these institutions would appear to be quite highly concentrated; that is, most research is undertaken by the various State Departments of Agriculture and the C.S.I.R.O.[1] Since these bodies also produce 'final' research output, it is felt that the view expressed by Nelson concerning the nature of the research process in industrial research laboratories is applicable here, that is, 'intermediate' research is undertaken with the view to incorporatin it into 'final' research products. The implicit assumption being made here is that in publicly funded *agricultural* research institutions, 'intermediate

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1 This is not to suggest that all research is undertaken by these bodies. Clearly research is also undertaken in universities and other government departments, but this is not a significant proportion.

research activity will be undertaken with the view that it will directly contribute to a 'final' research product. If this is so, then the total of scientific research activities undertaken by agricultural research institutions should be included in an analysis of the level of agricultural scientific research. Thus in this study, our analysis will be concerned with scientific research where the 'human' activities which are required are scarce resources and the 'advancement of knowledge' is perceived of as either possessing economic value (as in the case of a 'final' research product) or as potentially possessing economic value (as in the case of 'intermediate' research output). To enable us to investigate the level of scientific research in Australian agriculture during the period 1925-1975, an attempt will have to be made to both identify and measure the relevant inputs and output.

2.1.3 Problems Related to the Measurement of Research Inputs and Outputs

As indicated above, scientific research is viewed as a process involving the use of scarce resources and that the output of this process was both 'intermediate' and 'final'. In this respect, scientific research resembles a general production process.[2] In this section, we will review some of the problems of identifying and measuring the relevant inputs and outputs. We shall first discuss the utility of scientific personnel data.

One of the characteristics usually claimed for a 'technical invention' is 'that it must be the product of a mental effort above the average...' This characteristic is advanced in order that a distinction be made of the effort required to produce an invention rather than an improvement to an existing technique. That is,

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2 As such, the inputs of research resemble those of the inputs into a material good, although the nature of the output differs in important respects. These differences will emerge in the following discussion.

> ...there are qualitative differences between the effort and capacity associated with inventions and those associated with obvious improvements, so that no shift from one to the other can be attained, no matter how much training, education or other use of reproducible resources is thrown into the scale.
>
> [Kuznets, 1962, p.22]

Within the scope of our analysis this distinction would seem to be of limited importance. In an activity where it is thought that a predominant part of the output serves as an input into further 'increments in knowledge', then the distinction between an invention and an improvement becomes most obscure. The assumption that scientific research makes incremental additions to the stock of knowledge is a different view of the way the stock of 'inventions' increases in the way described by Kuznets. In his view, inventions 'provide the basis for the improvements'. [1962, p.22]. In our treatment of the distinction, 'intermediate' output is regarded as being an 'improvement', and assuming an 'incremental' approach 'improvements provide the basis for further improvements'. If the output of scientific research is regarded as adding to the stock of knowledge incrementally, then the qualitative differences in the capacities of researchers producing 'intermediate' and 'final' research outputs are assumed to be negligible. The assumption which will be made is that the attributes of scientific personnel are distributed over some range so that the *volume* of scientific personnel is limited by population, size and available resources for providing educational and research facilities.[3] This assumption gives us a starting point for a quantitative (and qualitative) analysis of scientific personnel. If scientific personnel are going to be used as an indicator of the level of scientific research undertaken in Australian agriculture, then the following tasks would need to be performed.

First, for the period in mind, it would be necessary to determine the number of people undertaking agricultural scientific

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[3] This is essentially an alternative to the relatively rare capacity of inventors suggested by Kuznets [1962, p.31].

research. This would clearly give us an indication of the research labour force but, just as clearly, it does not necessarily give an indication of labour time. In the 'patents' literature discrepancies arising from the difference in the labour force and labour time were most acute when invention was regarded as a primarily part-time activity. However, it is presumed that, with the advent of industrial research laboratories and public research institutions, this discrepancy is much less and that in fact, the size of the labour force gives an indication of labour effort. This is not to say that the discrepancy is totally eliminated. For example, in the short run, scientific personnel may trade leisure for more scientific effort and the working of overtime would not result in the size of the labour force giving an indication of effort. Also scientists may be engaged in other activities, for example, teaching duties at universities; this again would weaken the size/effort relationship. This latter point will be relevant in the present study and will be discussed further below. The time period of analysis is an important consideration here. In our case, the period is a relatively short time span in terms usually discussed for developments in inventive techniques. During the period since 1925, there do not appear to have been substantial institutional changes in the organization of scientific research. We therefore make the assumption that the patterns of labour activity have not changed over the relevant period.

Secondly, in an attempt to establish a homogeneous labour input, some attempt would need to be made to take account of quality differences among scientific personnel. As indicated above, we assume that at a point in time, there exists a range of capabilities among scientific labour. That is, a range of factors may be operating at a particular time to prohibit us from sensibly assuming homogeneous labour units.

> It would seem that the blend of training, experience, originality, tenacity and perhaps genius which makes a man a potentially successful inventor is too 'special' to permit the economic theorist to make his customary assumption of 'homogeneity of productive resources' - unless he has very good excuses.
>
> [Machlup, 1962, p.147]

In view of the possible over-simplification in employing an homogeneity assumption, it would appear desirable that an attempt be made to identify 'equivalent' man-hours.

Again, measurement over time may present special difficulties. Sanders [1962, pp.57-8], for example, believes that 'there has been a progressive upgrading of the educational level of inventors over the course of time [and, therefore]...the progressive change in the qualitative characteristics of inventors with respect to their educational levels and probably many other particulars as well, would still be an important factor to be taken into consideration in equating inputs over time.'

Schmookler [1962a, pp.80-81], has questioned Sander's argument that the quality of inventive labour has risen over time, although he does not quibble with the argument of a range of capabilities existing at a point in time.

> ...it seems reasonable to assume that at any moment of time, the quality of inventive output in a given field varies on average with the educational level of inventors.
>
> [Schmookler, 1962a, p.81]

Schmookler sets out to show that we cannot argue that highly educated researchers working under present conditions are necessarily of a greater quality than less educated researchers in the same field, who operated in the past.[4]

> ...the reason is that the state of knowledge in X today, differs from that of X yesterday...hence the inventions in X today may be inferior to those in X yesterday...Since this is true, how can we say merely on the basis of educational level, that the inventive input of X today represents a higher quality than that in X yesterday...
>
> [Schmookler, 1962a, p.81]

Clearly the net effects of Schmookler's arguments are practically difficult to establish, but it does serve notice that the changing character of research output provides us with difficult conceptual problem

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4 Or for that matter, they are not necessarily of a higher quality than less educated researchers in a different field operating at the time.

We now turn to a discussion of the use of output measures for indicating the level of scientific research activity. As a starting point we should indicate that the output of scientific research differs in at least one important respect from that of a material good; that is, the common feature of a unit of knowledge is its 'newness', any duplication of knowledge output is instantly rendered qualitatively inferior to the initial increment of knowledge. This is clearly not the feature of a material good where successive items of that good may be qualitatively identical. For purposes of trying to measure scientific output, it is important that only one unit of an increment to knowledge is counted, even if these are independently arrived at. The characteristic of 'newness' is not such an important consideration when output is used to indicate the level of scientific activity. For example, if two 'new' identical increments to knowledge are arrived at independently, then the activity (in terms of creating a 'new' item of knowledge) is clearly greater than that associated with the production of only one of these items.

As in the case of inputs into scientific research, we have difficulty in identifying a homogeneous unit of output. Kuznets [1962, p.24], for example, points to the difficulties associated with the differing *magnitudes* of inventions. He lists four considerations on the magnitude of an invention,

(1) the technical problem overcome;

(2) the technical potential, *i.e.* the effect of the invention on further technical changes;

(3) the economic cost, *i.e.* the resources consumed in the 'production' of the invention;

(4) the economic potential, *i.e.* the contribution of the invention to cost reduction or the production of new goods in the economy.

In Kuznets' view '...if we could set down meaningful figures for each invention under each of the four heads, the problem of measuring the input and output of inventive activity would be almost entirely removed...'

[1962, p.24]. However, the author is not optimistic about the chances of obtaining these figures; that is, differences will occur in each of the four views among inventors, hence rendering the achievement of a 'homogeneous' unit of output almost impossible. It is felt that these limitations apply equally to the use of publication data for the measurement of scientific research activity. In an attempt to overcome the problem of lack of homogeneity arising from the use of patent data, Schmookler [1950, p.131] assumed that

> the inventions occurring in a particular field in a given year can be conceived of as being arranged in a frequency table according to the amount of activity required to produce them.

Thus, in any one year, there will be 'some average amount of activity per invention for the group'. On the basis of this premise and assumption, Schmookler is led to conclude that

> Our expectation is that the variations from year to year in this average amount of activity for invention per year will not be so great *ordinarily* as to prevent our concluding that there was less inventive activity in a year which produced appreciably fewer inventions than in a year which produced many more.
>
> [Schmookler, 1950, p.132]

This view is clearly not shared by Sanders.

> The second prerequisite if patents are to serve as a useful index of inventive activity is that input for average patentable invention be uniform. Here...the evidence tends to invalidate the assumption.
>
> [Sanders, 1962, p.71]

Sanders points to several factors which he believes invalidate the assumption. First, he refers to National Science Foundation studies which indicate that research and development expenditures in relation to the number of patents granted varies quite significantly among different industries. This observation by itself does not invalidate the assumption but, taken in conjunction with the claim by Sanders that the 'industrial origin of patents has varied widely over the decades', this would appear to cast doubts on the assumption. Sanders also points to changes in the education and training of inventors over time and infers from this that the quality of patented inventions has changed and that these changes are 'also associated with changing inputs for patented invention.'[5] [Sanders, 1962, p.72]. Another factor which Sanders raises is the 'marked increase in the proportion of patents with two or more inventors.' This observation coupled with the observation that the 'mean time lapse' for these patents is not significantly less than for single inventors, would seem to indicate an increased input for the average patent. These criticisms advanced by Sanders reflect the fact that the relationship between inventive effort and patents changes over time.[6] It would seem that Schmookler had already observed these difficulties and had refined his analysis to counter them. Schmookler [1954] treats the problem in the following way.[7] He observes that forces, such as those discussed by Sanders, are 'essentially long-run in character'. In view of this, he then introduces the concept of 'over-lapping' decades which achieves two purposes. First, they (decades) are long enough to 'eliminate short-term variations in the patent-inventive activity ratio which might come from the lag between the time of inventing and the time of filing an application.' Secondly, and probably more importantly

> ...because the decades overlap, any substantial difference between the two successive items in the series is probably the result of a genuine difference in the amount of inventing carried on, and not of a long-term shift in the application-inventive activity ratio.
>
> [Schmookler, 1954, p.185].

In using this method, Schmookler is arguing against using trend values in patent statistics as indicators of changes in the level of inventive activity, thus recognizing the dangers outlined above. Rather than analyse the trend values of patent statistics, Schmookler uses measures of deviation from the trend to investigate changes in the level of inventive activity.

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5 Some doubts have already been cast on this observation.

6 Problems relating to changes in the propensity to patent over time are discussed by Kuznets [1962, p.37], Sanders, [1962, pp.69-71], Gilfillan [1952, p.337] and Schmookler [1953, p.545].

7 This is not to say that Schmookler had not recognized these problems in his 1950 article, but they did not appear to get the special attention which he affords them in his'Level of Inventive Activity' [1954].

As mentioned above, the use of patent statistics for an output measure of publicly funded scientific research are unlikely to be very comprehensive and therefore not very useful. In the following section, an attempt will be made to establish the level of scientific research activity in Australian agriculture using both scientific personnel data and scientific publication data. These measures will be analysed in terms of the criteria which have been discussed in this section.

2.2 Publication Data for Australian Agricultural Research.

2.2.1 Scope of the Study

In the previous section, the difficulties of defining and measuring scientific activity were discussed. In this section, an attempt will be made to construct an agricultural research activity index for the period 1945 to 1975. The reasons for undertaking this task stem from two main considerations. First, it would seem that there has been a relatively small amount of research into the economics of research for Australian industry including agriculture.

> Few analyses of the profitability of rural research are available for Australia. Duncan estimated that for several research projects on pasture improvement, the rate of return ranged from 25 to 80 per cent. There has been no analysis of the returns to rural research in aggregate for Australia, nor of the impact of research on rural productivity.
>
> [I.A.C. Financing Rural Research, Draft Report, p.30].

Many reasons,no doubt, exist for this state of affairs, the most fundamental of which has probably been a lack of data on research activity. With regard to one possible measure of research activity, research expenditures, the I.A.C.found that there was a 'lack of relevant data, on a continuing basis, from any source' [I.A.C. 1976, p.122]. One reason, therefore, for trying to construct an index of research activity is to provide a data series which, until now, has restricted the amount of research undertaken into the economics of research in Australian agriculture To the present time, no attempt has been made to construct a series for agricultural science activity in Australia.

The second reason stems from the recent work undertaken by Evenson and Kislev [1975]. In several sections of this book, the authors make use of the number of scientific publications, in particular those in the agricultural sciences. They indicate that publication data have certain advantages and limitations as 'a measure of research activity' [Evenson and Kislev, 1975, p.20].

The authors also contend that publications 'measure research accomplishment or output rather than inputs' [1975, p.20]. It was felt that the use of publications presented a promising data source for measuring research activity and that their usefulness should be more formally investigated. A discussion of the use of publication data by Evenson and Kislev will follow below.

With these two considerations in mind, it seemed a worthwhile task to try and construct an index of agricultural research activity. It is anticipated that the index will be used in the following ways. With regard to the aggregate level of research activity, it is proposed to test certain propositions regarding the determinants of this activity. The particular treatment here will be to incorporate the research index into an induced innovation model to investigate the role of relative factor prices in determining changes in the level of research. At a more disaggregated level, the index will be used to investigate the forces determining the mix of research activities among different commodity groups. This work will resemble that undertaken by Evenson and Kislev in their investigations of the determinants of research activity [1975, pp.31-33]. The final use envisaged for the research index is to incorporate it into an aggregate production function model to investigate 'the impact of research on rural productivity.'

As a starting point to the analysis, we shall elaborate on the scope of the study. Schmookler [1950, p.123] defines inventive activity as 'the amount of attention devoted to inventing, in any particular field or in the system as a whole.' This rather broad definition gives us a useful starting point for the present analysis. We shall define agricultural research activity in an analogous manner. That is, agricultural research activity will be defined as the amount of attention devoted to agricultural research. We can now proceed to refine and elaborate on this definition to establish the scope of the present study.

In section 2.1.1, Nelson's definition of scientific research was adopted. This definition depicted research as being essentially a productive process described by inputs and outputs. We also noted that, conceptually research output may be viewed as being either 'intermediate' or 'final' in its character, but that for our purposes, the distinction would be waived mainly because 'intermediate research activity will be undertaken with the view that it will contribute directly to a 'final' research output.' We also noted that agricultural research output had different impacts; that is, it could yield 'improved' or 'new' inputs or products and new and/or improved managerial or worker techniques. *In the present study the emphasis will be on agricultural research yielding 'new' or 'improved' processes and/or products.* That is, we will not be concerning ourselves directly with research into new worker or management techniques.[1] In section 2.1.1, we also noted that agricultural technology is often divided into mechanical and biological processes, and that research into these processes will more likely be undertaken by private and public institutions respectively, mainly because of the inappropriability of biological technology. In this study, we will be concerned with biological agricultural research undertaken by public research institutions.

To summarize, we will be concentrating on the 'amount of attention' devoted by public research institutions to agricultural scientific research yielding new or improved products and/or processes of a biological nature. Although we are only concentrating on public sector research this represents the major part of agricultural research in Australia.[2]

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1 The word 'directly' is used here because research yielding new products or processes might indirectly necessitate the use of new worker or management techniques.

2 That the majority of agricultural scientific research is undertaken by the public sector is supported by evidence presented by Boyce and Evenson [1975, p.66] which suggests that in Australia the private sector provides only eight per cent of total scientific man years devoted to agricultural research activity.

It remains now to explain what we mean by the 'amount of attention devoted to'. The previous paragraphs were clearly a discussion of both input and output activities of agricultural research. By concentrating on research undertaken by public research institutions, we have specified a part of the input characteristic; that is, we are concerned with the 'amount of attention devoted' by public research institutions. Within this constraint we may define 'attention devoted to' as the total number of man-hours expended on activities yielding the relevant outputs being considered.

In this study, we will be attempting to construct an index which will reflect the total number of man-hours expended by researchers in public research institutions on activities designed to produce 'new' or 'improved' products and/or processes of a biological nature. The index will therefore be seeking to measure research inputs, *not* research output.

As mentioned at the beginning of this section, Evenson and Kislev use scientific publications as a measure of research activity and it was considered that this represented a promising data source for the present study. In the remainder of this section an investigation is made of the use of this data source by Evenson and Kislev [1975]. It is felt that in general the authors do not devote sufficient attention to the limitations of the data. It is not suggested that these limitations are easily overcome but the implied criticisms serve to help illustrate the problems associated with the present study.

Essentially the authors view the research process as an input-output activity where expenditures and scientific man-power are the inputs and new knowledge is the output. It seems clear that they intend to use publications as a measure of research output.

> As knowledge is intangible, we took as a proxy measure of its creation the number of scientific publications in particular agricultural sciences.
>
> [Evenson and Kislev, 1975, p.20]

And again on the same page:

> Publication data are utilized...as proxy measures of the creation of knowledge. *As a measure of research activity* they have certain advantages as well as limitations. (own italics).

This latter quotation would seem to indicate that the authors intend measuring the extent of research activity by estimating the level of research output. They, quite rightly, point out that the use of publications in this manner is subject to 'certain advantages as well as limitations'. Whilst appearing to recognize the existence of limitations these do not appear to be discussed; instead, the following five 'advantages'are listed.

1. They are a 'real' measure, free of exchange-rate difficulties.
2. They measure research accomplishment or output rather than inputs.
3. They provide the only available measure of commodity orientation of research.
4. The implicit definition of what research is, is contained in the standards applied by abstracting journals for inclusion. The journals chosen have as their stated purpose, international coverage of all literature of scientific significance.
5. Since they are compiled basically from only three sources, the publications data are less subject to reporting errors and unstandardized definitions.

[Evenson and Kislev, 1975, pp.20-21]

In their use of the number of scientific publications as a proxy measure for knowledge creation, the authors in a subsequent publication [Boyce and Evenson, 1975] standardize publication data to take account of the fact that abstracting journals may cover some areas of research more extensively than others, that duplication and shorter papers may be tolerated more in some areas, some areas may be more fashionable than others and that some areas may be more productive than others. In essence, these adjustments are made on a commodity or scientific discipline basis,not on a country basis.

> Of course publication standards differ by field of science and we have attempted to standardize this in our measure.

[Boyce and Evenson, 1975, p.96].

Other possible sources of bias in publication data are considered, in particular

> ...the incomplete or inconsistent application of screening standards to different countries and different languages.
>
> [Boyce and Evenson, 1975, p.97][3]

The authors point to the 'extensive' coverage of literature in foreign languages and they 'do not detect obvious cases of bias' [Boyce and Evenson, 1975, p.98].

They also point out [Evenson and Kislev, 1975, p.31] that '...our dependent variable [publications] does not measure all of the scientific output of the agricultural scientists...however, these biases are not so serious, as to alter the major implications of the regressions.'

It appears then, that the users of the publication data have placed great faith in their use of this data as a proxy for the creation of knowledge. By using international publication data in an unstandardized form (that is on a country basis) the authors are implicitly assuming a uniform 'average' quality of publications between countries. In fact, in support of this, the authors refer to the 'selection procedures' employed by the abstracting journals who include

> Only genuine scientific contributions..., instruction pamphlets and similar materials are not abstracted.
>
> [Evenson and Kislev, 1975, p.21]

This procedure was sufficient to provide'a quality standard'. The selection procedures of the abstracting journals might be questionable. Witness (Muller on Vavilvo); Priroda (*Nature*) Leningrad 1967: No.9, pp.62-67. The notes attending this reference are as follows.

> Extracts from a letter paying tribute to N.I. Vavilvo by the late geneticist, H.J.Muller, are published in the Russian language.
>
> [Plant Breeding Abstracts, Vol.XXXVIII No.2, p.219].

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[3] Boyce and Evenson [1975] and Evenson and Kislev [1975] are used interdependently in the present discussion since Boyce and Evenson [1975] essentially constitutes an upgrading and extension of the other work.

It requires some measure of judgment to regard a letter of tribute as a "genuine scientific contribution".

To assume a similar 'average' quality of publications between countries has important implications for the use of publication data. For example, it allows cross-country studies of the type carried out by Evenson and Kislev, [1973] in their study of the contribution of research to yield increases in wheat and maize. A second implication of the assumption is that it allows Boyce and Evenson [1975, p.9] to conclude that variations in the ratio of standardized (on a commodity basis) publications per scientific man year are due largely to differences in the real research skills per scientific man year.

> We conclude that the larger part of this variance is due to variance in the real research skills per S.M.Y. Some is due to imperfections in the publications measure as well, but our work with those data leads us to conclude that this source of variance is not of major significance.
>
> [Boyce and Evenson, 1975, p.9].

These claims by Boyce and Evenson place great importance on the quality of publication data. It is suggested here that some biases in publication data exist which the authors do not appear to have considered but which seem on the basis of evidence to cast some doubt on the quality of the data.

As a starting point we assume that between countries there will be a difference in the 'pressure to' or 'capacity of' scientists to publish their research results. By 'pressure to' publish we are referring to such things as the prestige attached to having material published and the account taken by institutions making decisions to either employ or promote scientists based on their publication records. By the 'capacity of' scientists to publish we are referring to the extent to which institutions, either public or private, provide publishing outlets for scientists. That is, how many journals are available for scientists to publish in. Whilst these two concepts can be conceptually separated, in practice the two would be somewhat interdependent. For example, more publication conscious employing institutions would be expected to provide more journal services for scientists. The assumption that these factors might differ among countries does not seem unreasonable.

If these differences in fact occur, then what are the implications of using research publications as a proxy for knowledge creation on a cross-countr basis? For any given country, there will be a certain 'average' quality of publications which might reasonably be assumed to differ among countries. To reject this assumption would necessitate assuming that the editorial standards set in each country were the same. If the abstracting journals used by Evenso Boyce and Kislev do, as they claim, impose a quality standard, then if average qualities differ among countries, different proportions of the total of a country's publications will be abstracted by the abstracting journals.

Now, if the pressure and/or capacity to publish differs among countries, then the number of publications per scientific man-years will vary because of this, quite apart from any skill differences which might exist between countries. If these forces cut across the whole range of publications, then the number of publications of 'average quality' (as deemed by the abstracting journals) will be less for countries with low pressures and small capacities than for countries with high pressures and large capacities. That is, biases in publication data will exist in favour of countries with high pressures and/or capacities to publish. If this bias is significant, then it makes questionable the use of publication data on a cross country basis which has not been adjusted for this bias.

In an attempt to see if these factors were an important source of variation in publications between countries, a proxy measure for the pressure and/or capacity to publish was needed. To this end, we used the number of scientific journals published in each country on the assumption that greater pressure and/or capacity to publish would be reflected by higher numbers of journals in that country. That is,

$$P_j = A(SMY)^{\alpha_1}(E)^{\alpha_2}(P_{14j})^{\alpha_3}(N_j)^{\alpha_4}$$

where P_j = total number of publications in agricultural sciences (not including plant physiology) in country j.

E_j = expenditure on agricultural research in country j.

P_{14j} = publications in plant physiology in country j.

N_j = number of agricultural scientific journals in country j.

The data relating to P_j, E_j and P_{14j} are derived from Boyce and Evenson [1975] and are described in the notes attending Table 2.1. The data regarding the total number of agricultural scientific journals was collected from Ulrich's International Periodical Directory [1975, p.vii] which

> ...includes periodicals which are currently in print, issued more frequently than once a year, and usually published at regular intervals over an indefinite period of time.

Whilst the data pertaining to the other variables are based on averages for the period 1968-1974, the 1975 edition of *Ulrich's* was used because in contrast to earlier editions

> [In] the 16th edition...Entries are sorted by country...This methodology allows for better control against duplicate entries [and] allows for the editing of titles by country...

This discrepancy in time is unlikely to bias the results of the analysis. The totals contained in column (5) of Table 2.1 are derived from the following sections contained in *Ulrich's*, Agriculture, Crop Production and Soil, Dairying and Dairy Products, Poultry and Livestock and Veterinary Science.

Quite clearly N_j is an endogenous variable in the sense that the same factors, namely SMY_j, E_j and P_{14j}, which are considered determinants of the number of publications are also likely to be determinants of the number of journals. If this is so, and if N_j emerges as a significant 'explanator' in the model, then we might conclude that the number of publications is in response to a 'higher than predicted' number of journals, which would suggest differences in the pressure and/or capacity to publish between countries.

Utilizing the data from Table 2.1, the following equation was estimated in log linear form.

$$P_j = A(SMY)^{\alpha_1}(E)^{\alpha_2}(P_{14j})^{\alpha_3}e^{U_j} \qquad (2.1)$$

where A is a constant to be estimated and U_j an error term. The other variables are as described above. The results of this test are as follows (t values in parentheses).

TABLE 2.1

AGRICULTURAL SCIENTIFIC PUBLICATION, MANPOWER AND EXPENDITURE DATA FOR 39 COUNTRIES

	Number of Publications*	Scientific Man Years**	Research Expenditure**	Plant Physiology Publications***	Total Agricultural Scientific Journal π
Austria	52	108	3,927	23	21
Belgium	129	700	9,550	43	16
Denmark	103	530	10,855	19	20
Finland	74	212	3,951	22	15
France	392	1,146	84,170	291	87
West Germany	559	2,750	99,213	343	77
Greece	15	332	3,922	6	5
Ireland	64	421	9,919	10	7
Italy	318	1,108	29,433	55	79
Netherland	243	994	36,521	96	57
Norway	64	394	9,845	29	14
Portugal	24	450	7,045	4	9
Spain	60	642	18,705	38	33
Sweden	126	252	11,939	60	24
Switzerland	95	302	31,916	51	13
United Kingdom	888	2,909	56,949	537	156
U.S.S.R.	1,881	29,583	381,904	805	30
Yugoslavia	181	1,860	11,808	15	11
Canada	551	1,423	95,880	295	60
United States	3,220	7,300	432,504	1,493	466
Brazil	111	1,667	34,791	19	41
Chile	19	175	4,779	7	5
Mexico	29	687	6,580	10	2
Uraguay	5	78	1,118	2	3
Venezuala	24	157	7,518	7	5
Israel	108	75	8,583	111	4
Ceylon	14	110	2,603	4	4
India	1,023	1,967	22,494	255	76
Japan	469	13,067	228,085	457	42
Malaysia	21	197	4,664	6	4
Pakistan	65	293	2,160	25	4
Philippines	61	573	5,797	9	12
Taiwan	52	375	2,197	8	6
Thailand	15	600	4,664	3	2
Ghana	22	133	2,636	3	3
Nigeria	47	265	15,202	16	2
South Africa	148	933	22,336	29	24
Australia	430	2,777	102,044	172	72
New Zealand	143	588	20,282	50	9

* Data on total publications are taken from Boyce and Evenson [1975, pp.206-229] Appendix II. The figures used are total average annual publications less total average plant physiology publications for the period 1969-73.

** Scientific man year and research expenditure data are taken from Table 2.1 [Boyce and Evenson, 1975, pp.21-30].

*** The number of plant physiology publications are the average for 1969-73 and are extracted from Appendix II, [Boyce and Evenson, 1975, pp.206-229].

π Derived from *Ulrich's International Periodicals Directory* [1975] as described in text.

$$\ln P_j = \underset{(0.820)}{0.437} + \underset{(2.985)}{0.268} \ln SMY_j + \underset{(0.269)}{0.025} \ln E_j + \underset{(9.203)}{0.633} \ln P_{14j}$$

$$R^2 = 0.931$$

$$n = 39.$$

All variables have the expected sign and are significant at the five per cent level except for E_j. A further test was carried out utilizing the pressure and/or capacity to publish variable, that is,

$$P_j = A(SMY_j)^{\alpha_1}(E_j)^{\alpha_2}(P_{14j})^{\alpha_3}(N_j)^{\alpha_4}e^{U_j} \quad .... \quad (2.2)$$

Again the equation was estimated in log linear form with the following results

$$\ln P_j = 0.533 + \underset{(2.787)}{0.238} \ln SMY_j + \underset{(0.194)}{0.017} \ln E_j + \underset{(6.798)}{0.530} \ln P_{14j} + \underset{(2.374)}{0.197} \ln N_j$$

$$R^2 = 0.941$$

$$n = 39.$$

These results would appear to support the hypothesis that differences in the pressure and/or capacity to publish between countries account for differences in the number of publications between countries. The inclusion of N_j in the model has increased the amount of variability in P_j 'explained' by the independent variables and the estimated coefficient is significant at the five per cent level. The estimated coefficient of 0.197 suggests that a 10 per cent increase in the number of scientific journals will result in an increase in the number of journals which is two per cent 'higher than predicted' by those variables which jointly determine both the number of scientific publications and the number of scientific journals.

If the total number of agricultural scientific journals is a reliable indicator of the pressure and/or capacity to publish, then the evidence suggests that international differences in the number of publications are explained by forces apart from international differences in 'researcher quality'. If this is accepted then there will be biases present in the use of publication data which has not been 'standardized' to take account of differences in the pressure and/or capacity to publish.

Such a standardization procedure is undertaken by Boyce and Evenson [1975, p.85] in their model designed to investigate factors relating to the productivity of agricultural scientists. In their case, the number of publications in each region is weighted by the 'publications per S.M.Y. ratios for the United States', thus expressing publications in 'constant S.M.Y. units'. [Boyce and Evenson, 1975, p.55]. However, no such procedure appears to have been undertaken by Evenson and Kislev [1973] in their international study of the effect of research on productivity growth in wheat and maize production. In this case, the results may be biased to the extent that differences in capacity and/or pressure to publish exist between countries.

A further area of concern relating to Evenson and Kislev's use of publication data is that 'they enable comparisons over time'. In the earlier discussion on patent data, the two major problem areas listed for the use of intertemporal comparisons in patent levels were that the propensity to patent inventions is likely to change over time and that the quality of patents varies one from another. While the forces relevant to patents, for example, the 'competitive influences' and 'modernized science and technology forces' are not necessarily applicable to publication data in the present study, it should nevertheless be demonstrated that on average, publications are homogeneous over time and that the propensity to publish remains the same over the considered period.

2.2.2 The Utilization of Publication Data

Despite the above limitations of using publication data as a proxy for research output, the data still has many appealing characteristics. Evenson and Kislev [1975, p.20] list as an advantage the fact that publication data can be segmented according to different commodity groupings. Lipetz [1965, p.42] relates that publication of articles is

> ...a type of research achievement, and is a practice common to most research organizations. In many research organizations, publications constitute the only tangible achievements. The counting of publications is a simple, undemanding process which is objective and reproducible.

And again, U.N.E.S.C.O. [1970, p.341]

> ...a count of papers, whether weighted or otherwise, is the only method which lends itself readily to large-scale statistical application.

The question to be discussed now is whether publication data can be utilized in a form other than as a proxy for research output? It will be argued in the remainder of this section that publication data can be utilized to give an indication of changes in the level of scientific activity where scientific activity is viewed as an input phenomenon, rather than an output phenomenon. As indicated in section 2.2.1 above, when defining the scope of research activity, we will be regarding research activity as the total number of man hours expended by researchers in public research institutions. Quite clearly this depicts research activity as an input phenomenon. As has already been observed, publications result from an act of research activity; that is, research effort is expended in a particular field and culminates with the results of that effort being published. This allows us to make the reasonably obvious observation that a relationship does exist between research effort expended and publications, even though we do not know the exact nature of this relationship. Even if we did know the exact amount of activity underlying all published articles, this would not necessarily enable us to determine the total amount of research activity undertaken. For example, not all research results might be published; to the extent that they are not, then publications will understate the level of research activity.

Research activity will not be reflected in publication data for two major reasons; first, because no attempt may be made to get the results published and second, that an attempt to get results published is unsuccessful because the article is not considered suitable for publication. To the extent that these occurrences exist, then publication data will embody only a proportion, not the entire level of research activity undertaken. Furthermore, from the viewpoint of inter-temporal comparisons in the level of research activity, there is no reason to expect that the ratio of research activity devoted to obtaining publications to total research activity has remained constant over time. Nor does it necessarily follow that a given proportion of research activity has resulted in a constant proportion of article sub-missions being rejected for publication over time. These considerations limit the use of publication data to measure inter-temporal changes in the level of research activity.

With these limitations in mind, is it still possible to utilize publication data as a proxy for the level of research activity? This question is essentially the same as that faced by Schmookler [1953 and 1954]. The following is essentially an attempt to incorporate the procedures used by Schmookler for patent data into analogous procedures for utilizing publication data.

As a starting point we should be clear that since publications in any given period need not necessarily embody the total of research activity and because we do not know precisely the amount of activity embodied in each published article, then publication data cannot be utilized to determine the absolute level of research activity. It is assumed that in any given period, there will be an observable number of published articles embodying different levels of research activity and that associated with that level of activity there will be a corresponding level of activity not embodied in published articles. This relationship is not assumed for all periods; however, for the purposes of being able to observe inter-period changes in the level of activity, it is necessary that the assumed relationship remain constant between successive periods. As Schmookler asserts with regard to patents:

> The use of patent applications as an index of inventive activity rests essentially upon the assumption that the *average* application in one period represents a quantum of inventive activity of all kinds which is equal to the amount of inventive activity of all kinds kinds represented by the average application in any other period.
>
> [Schmookler, 1953, p.542].

In view of the forces discussed above, it is not clear that this relationship can be substantiated over time; that is, the forces mentioned above will be working to change the amount of research activity embodied in publications over time. What is difficult to establish is the length of time which elapses before these forces significantly alter the publication/research activity relationship. Schmookler's conclusion in this regard is that each of the various forces discussed is essentially of a long-run character, '...it seems extremely probable that their combined effect upon the application inventive activity ratio, if any, has been gradual' [Schmookler, 1953, p.550]. If this conclusion can be made with respect to the forces relating to publications, then it would seem admissable to make comparisons in the number of publications between relatively short periods of time and to make corresponding inferences as to the associated changes in research activity.

In the following section, we will try and establish that the forces affecting the publication-research activity ratio are in fact long-run forces and that publication data can be used to estimate short-run changes in research activity.

2.2.3 Publications and Public Research Institutions.

In the previous section, we noted that published articles will embody only a proportion of research activity, that some research work will not be intended for publication and that some research work will not be deemed suitable by editors for publication.

Whilst it is difficult to be quantitatively conclusive in these matters, there is certain evidence to suggest that in the case of Australian public agricultural research systems a high proportion of research activity is embodied in published articles. In broad terms, we may agree with Underwood [1973, p.156] that:

> ...this effort...[government controlled and government funded agricultural research] has been shared almost entirely among three types of organization, namely several Commonwealth bodies, the State departments of agriculture and the agricultural and veterinary faculties of the Universities.

Taking these three organizations in turn, of the Commonwealth bodies, C.S.I.R.O. is by far the largest contributing body to research activity. In 1948-49, under the provisions of the *Science and Industry Act,* the present structure of C.S.I.R.O. emerged. The act listed a number of pursuits and functions, two of which were 'the collection and dissemination of information relative to scientific and technical reports and periodicals; [and] the *publication* of scientific and technical reports and periodicals' [Annual Report, C.S.I.R.O., 1949, p.1]. This directed function clearly orientates C.S.I.R.O. activities towards fostering publications. That the organization has responded to the directive of the Act can be supported by observing the number of Journals published by C.S.I.R.O.[4] Also, C.S.I.R.O. publish the *C.S.I.R.O.Abstracts* which lists all the material published by the organization's research staff. These observations suggest that a high priority is placed on publishing research results.

Turning now to the State Departments of Agriculture, each State agricultural department publishes its own Journal; this in itself suggests that these bodies are keen to report their research results in a published form. The departments also publish various bulletins reporting the results of various research projects. Another piece of evidence that the State Departments are publication conscious is found in the cases where annual reports contain bibliographies of the publications gained by the Department during the year. This suggests that publications are viewed by the Department as measures of 'achievement'.

That universities encourage research results to be published is probably manifested most strongly in the criteria used for both appointment and promotion decisions. In both these activities, publications gained by the people involved are an important factor in determining the success of their application. That this encouragement is responded to by people undertaking agricultural research within Universities is again supported by the fact that annual reports of

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4 The various journals published by C.S.I.R.O. are listed in its *Annual Reports*.

agricultural departments and agricultural research institutes invariably contain a list of publications gained by department staff.

The above observations, while not conclusive, would seem to support quite strongly the claim that a major proportion of agricultural research activity undertaken by public research institutions is recorded in a published form. Furthermore, the forces have been in existence throughout the period covered in the present study; that is, there does not appear to have been any moves by any of the organizations to discourage research results from being published. This leads us to conclude that publications are an appropriate source of data which warrant consideration as a possible indicator of research activity. It now remains to discuss the character of the forces which might affect the publication-research activity ratio.

In the case of the 'modernized science and technology' forces discussed above, it is contended that the nature of these forces will be similar to those affecting the patent-inventive activity ratio. That is, it is thought unlikely that the 'forces of modernized science' would have large short-term effects on the ratio. To the extent that a large amount of published research output is 'intermediate' research output would seem to indicate that publications are less subject to those forces than patents. According to Schmookler [1950, p.124] a patentable invention '...must yield a direct physical result and of necessity therefore must consist of either an art, machine, manufacture, composition of matter...' That is, patents are confined more to 'final' research outputs; the 'intermediate' inventive activity is not manifested in a separate patent. Thus, as science becomes more complex, the 'inventive activity' required to produce a patentable invention increases. In the case of publications, where research output does not necessarily need to be 'final', then the complexities of modern science manifest themselves in more published 'intermediate' results relative to 'final' research publications. It follows then, that relative to patents, the effects of 'modernized science' forces on the publication/research activity ratio are even more gradual and long-term.

The remaining consideration concerns the rejection rates of the various journals. If these varied considerably in the short-run, then publications would not represent comparable levels of research activity. It is difficult to quantify this effect but the following considerations suggest that rejection rates are unlikely to be an important short-run influence on the publication/research activity ratio in the present case. The first, and probably most important consideration in this respect, is the large proportion of agricultural research articles which are contained in journals published by public research institutions.[5] That is, a large number of the journals contain the results of research work undertaken by the publishing body; such a situation seems unlikely to be characterized by short-term fluctuations in the rejection rates of submitted articles. Moreover, most agricultural research articles appear in specialist agricultural journals eliminating the possibility of a general bias by editors against publications in the area of agricultural scientific research. A further consideration which suggests that this factor is relatively unimportant is reflected in the growth in the number of journals publishing agricultural research articles. Thus, if a long standing journal displayed an upward trend in its rejection rate, then it is possible that a proportion of the 'rejected' articles would find their way into newly introduced journals. To the extent that this happens the effects of changes in rejection rates on the publication/research activity ratio are made more gradual.

In an attempt to substantiate these claims regarding short-term movements in rejection rates, the editors of various journals were contacted. Following these contacts a minimal amount of data was

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5 See section 2.2.4 below.

acquired. In Table 2.2 the ratio of rejected to published papers for three major agricultural science journals for the period 1967 to 1975 are presented. Overlapping five year averages of the overall average ratios were calculated to investigate whether substantial differences existed between them in the short-run. These averages were found to be

Period	Overall Average Ratio
1967/71	0.36
1969/73	0.34
1971/75	0.38

Since the data is limited to only three journals, any observations must be tentative, but the three overlapping five year averages would seem to indicate that the rejection rates do not vary significantly in the short run. Whilst not conclusive, this observation lends support to the arguments outlined above suggesting that short-run changes in rejection rates are unlikely to affect the publication/research activity ratio.

In summary, we have argued in this section that publication data is appropriate for consideration as an indicator of research activity and that any forces likely to affect the relationship between publications and research activity are likely to be long-term rather than short-term. This being so, it is felt that publications provide an appropriate source of data with which to construct an index of agricultural research activity.

2.2.4 The Number of Publications in Australian Agricultural Sciences, 1945-1975.

In the preceding section, we argued that publication data would be used as an indicator of scientific research activity provided that long-term comparisons were not made between numbers of publications and corresponding inferences made about long-term changes in the level of research activity. In this section, the method used to collect agricultural scientific publication data is described and an index indicating short-term changes in the level of research activity is

TABLE 2.2

RATIO OF REJECTED TO PUBLISHED PAPERS

IN THREE AGRICULTURAL SCIENCE JOURNALS

Journal \ Year	1967	1968	1969	1970	1971	1972	1973	1974	1975
Australian Journal of Agricultural Research	.32	.43	.33	.45	.33	.20	.37	.28	.23
Australian Journal of Soil Research	.28	.50	.29	.18	.91	.35	.15	.37	.62
Australian Journal of Exp. Agric. and Animal Husbandry	.29	.19	.28	.35	.25	.31	.32	.38	.59
Overall Average Ratio	.30	.37	.30	.33	.50	.29	.28	.34	.48

constructed. The collection of data falls into two time sections, 1959-1975 and 1945-1959. This time sequence is adopted since the main data source used, *The Australian Science Index* was first published in 1957. This source provides a framework for collection which is then used to extend the collection of publication data back to 1945, hence the sequence of the two time periods adopted.

1. 1959 - 1975.

Since 1957, the C.S.I.R.O. has published *The Australian Science Index* (hereinafter called *The Index*) which

> ...is intended to provide an up-to-date subject and author guide to Australian scientific research issued in serial form by scientific and technical associations and societies, research institutions, government and other institutions.
>
> [*Australian Science Index*, Preface,1957]

From 1959 (Vol.3) onwards, *The Index* has been presented in a consistent form. That is, it has consisted of three major sections; General; Physical Sciences, Engineering, Technology; and Biological Sciences, Agriculture. Each of these sections are further subdivided, for example, the Biological Sciences, Agriculture section contains the following subsections; general, microbiology, botany, zoology, medical services and agriculture, forestry and fisheries. Yet another group of sub-classifications are attached to each of these subsections. The following is a list of the classifications within the agriculture, forestry, fisheries subsection;

1. General
2. Soils and Fertilizers
3. Pastures
4. Field Crops
5. Horticulture
6. Plant Pathology and Protection
7. Domestic Animals, including specific diseases
8. Fisheries

9. Forestry
10. Farm Equipment and Power Farming
11. Water Supply and Irrigation
12. Economics
13. Extension.[6]

The Index allocates articles among the classifications, but the methods of allocation are not made explicit. However, inspection allows us to make general comments on the criteria which appear to be implicitly used. Appendix 2.7.1 gives a single example of the type of publication entered under each classification. An implicit allocation rule would seem to dictate that an article will be assigned to a particular subgroup on the basis of the information contained in its title; that is, a title which has reference to a particular type of pasture in its title is included in the 'Pasture' subgroup. In some instances, the title would indicate a possible multiple classification; for example, the title 'Types and times of application of nitrogen for wheat' would lend itself, on the basis of title, to both the Soils and Fertilizers and the Field-crop subgroups. Again, the title 'Wildfire and bacterial blight on soybeans in Queensland' would lend itself to classification in both the Fieldcrop and the Plant Pathology and Protection subgroups. Inspection suggests that the majority of these 'dual' titled articles have reference to either Soils and Fertilizers or Plant Pathology and Protection. That is, a 'dual' title would rarely include both, say, horticulture and pasture references. In these cases, it appears that the classification rule is to allot these articles to either of the two subgroups just mentioned.

The Index therefore provides us with a list of articles abstracted from various Australian publications which are classified according to title on a consistent basis for the period 1959-1975. For

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6 From 1971 onwards, a further section, Weeds and Weed Control, was introduced. It appears that publications in this category were included in the General subsection before this. Because of the lack of continuity, this section has been deleted.

this list to be deemed useful for the present study, it is necessary to try and demonstrate how comprehensive it is in terms of the articles included.

For *The Index* to be totally comprehensive, it would clearly need to contain all articles published by Australian based scientists undertaking agriculturally related research. It is a difficult task to establish absolutely how comprehensive *The Index* is, but some guide-lines can be established as follows. The comprehensiveness of an index can be viewed as being a function of both the proportion of journals containing agricultural science articles which are included in the index and the extent to which articles in the selected journals are included. The first of these determinants presents some difficulties, since it is difficult to determine objectively the number of journals containing agricultural science articles. However, the following observations are suggestive of the fact that a high proportion of journals containing agricultural references are included. First, as can be observed from Appendices 2.7.2 and 2.7.3, there are a number of journals which are not specifically 'specialist' agricultural journals. This observation suggests, at least, that the procedure adopted in constructing *The Index* was not merely to include only 'obvious' agricultural journals. A further guide to the coverage of journals indexed can also be had by observing the list of 'specialist' agricultural journals indexed. Independent observation by agricultural scientists suggest that no 'notable' omissions have been made.[7] Whilst these observations do not represent objective proof, they nevertheless do suggest that the first criterion of comprehensiveness is largely fulfilled; that is, the index covers, at least, a high proportion of the journals containing agricultural research publications.

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7 The independent observation was carried out by various staff members at the Waite Agricultural Research Institute.

The second determinant of the comprehensiveness of the index can be more objectively investigated. In this regard, random volumes of the various 'specialist' agricultural journals were selected and the total number of articles which they contained were counted. These totals were then compared to the comparable total derived from the index. The largest discrepancy discovered was of the order of only four per cent which suggested a complete coverage of the journals. While this does not constitute a statistically significant test, it again gives us confidence that the index satisfies the second criterion of comprehensiveness.

Before leaving this question of how comprehensive *The Index* is, it is worth noting that it lacks somewhat in that only Australian serials are included. That is, it omits articles published in overseas journals by Australian researchers. It will be assumed, not unreasonably, that these articles represent a small proportion of the total and that the proportion of these articles does not change substantially over short periods of time.

In view of the belief that *The Index* is comprehensive in its coverage of scientific publications, it was decided to utilize the source. The collection of data proceeded with the following considerations in mind. First, *The Index* only provided data from 1959 onwards;[8] since the subsequent analysis was to utilize an index for the period 1945 to the present, it was important that the data be collected in a form which would allow it to be extended from primary sources. Secondly, because *The Index* included publications issued by 'research institutions, government and *other institutions*', then the data had to be collected in a manner which would enable publications of 'non-government' research institutions to be omitted. Finally, it seemed desirable that the journals indexed were done so on a continuing basis. On the basis of these considerations,

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8 That is, on a consistent basis. As mentioned above, *The Index* was first published in 1957.

it was decided that the data should be classified according to the publishing journal. It was also decided to retain the subgroupings used in *The Index* in view of the fact that we were seeking to construct an index of 'biological' type research activity. Clearly, not all articles indexed would be a contributor to this end. The publications were also to be collected according to the year of publication. Thus the publications contained in the various issues of *The Index* were classified according to:

(i) The Index Subgroupings

(ii) The Journal in which they appeared

(iii) The year they appeared in the published Journal.

This being done for the years 1959-1975, a decision had to be made as to what subgroupings would be included in the index and bearing in mind that we are concerned with public research activity, what journals or publications would be included.

With regard to what subgroups to include, it was decided to omit from the 13 listed above, subgroups (1), (8), (9), (10), (11), (12), and (13); that is, the index would include the following:

Soils and Fertilizers

Pastures

Field Crops

Horticulture

Plant Pathology and Protection

Domestic Animals, including specific diseases.

This selection is necessarily somewhat arbitrary, clearly some scientific biological research will be embodied in articles contained in the omitted subgroups, however it is felt that these would largely embody 'non-biological' research activities.[9]

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9 The Fisheries and Forestry subsections were not omitted for this reason. They were omitted on the grounds that the associated production activities were fundamentally different from land based agriculture.

With regard to what journals or publications should be included in the analysis, the main consideration was that the index was intended to be a public research activity index. This meant that only publications embodying this type of research should be included. In general, the publications indexed are published by three major groups; those published by private corporations or representatives of private corporations, those published by scientific institutes, societies and associations and those published by governments or government agencies.

In selecting which journals to include, the procedure is again somewhat arbitrary in that it is difficult to objectively identify which publications embody public research activity. For present purposes, it was decided to omit those articles published by private corporations or representatives of private enterprises (e.g. Grower organizations). It was considered that these publications, in general, would not directly embody public research activity and that their function was more directly related to extension activities. Appendix 2.7.2 lists the publications published by private enterprises or private enterprise representatives.

With regard to the second group of publications, those of scientific institutes, societies and associations, the selection procedure was as follows. Within this group, we can identify bodies which represent agricultural scientific pursuits and those which are not specifically agricultural. The non-agricultural specific institutes etc., whose publications are indexed, are listed in Appendix 2.7.3. Quite clearly, these bodies could include publicly employed agricultural scientists among their membership and to the extent that these people publish their research findings in these serials, then these particular publications embody public research activity. However, as is indicated by Appendix 2.7.3, the total number of publications indexed in the relevant subgroupings from these serials is small. Because of this, it was decided to omit these publications from the index.[10]

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[10] Another related reason for omitting these publications is that it is difficult to establish that the particular journals were indexed on a continuing basis.

The other serials in the second group are those published by agricultural science institutes, societies etc.; these are listed in Table 2.3. Again, the same qualification applies to publications in these serials; that is, it is difficult to identify objectively the extent to which these are contributed to by publicly employed researchers. On the assumption that the majority of agricultural biological scientific research is undertaken by public institutions, then it seems reasonable to assume that the scientists contributing to these journals are public researchers. For this reason, it was decided to include these publications in the index.

The final group of articles are those contained in government serials and publications. Again we can make a distinction between those articles contained in specialist agricultural publications and non-specialist agricultural serials. Just as the non-specialist publications in the previously discussed category, the non-specialist government publications account for only a small number of publications. This is confirmed in Appendices 2.7.4 and 2.7.5, which contain the number of indexed articles contained in non-specialist government serials and non-specialist C.S.I.R.O. serials respectively. The features of the non-specialist publications are the small numbers involved and the infrequent observations pertaining to the various serials. In comparison, the specialist government publications, as portrayed in Table 2.4 contain a large number of articles and, in almost all cases, they display continuity in representation.

2. 1945 - 1958.

For the period 1945 to 1958, it was necessary to resort to primary sources for the number of agricultural scientific publications. The procedure adopted was as follows. Using the data collected from *The Index* for 1959, we were able to ascertain which serials were being indexed at that time. This information is contained in Table 2.4.

TABLE 2.3

NUMBER OF ARTICLES PUBLISHED BY AGRICULTURAL SCIENCE INSTITUTES, SOCIETIES, ETC., 1959 - 1975

Journal*	Year First pub-lished	Publishing Institution	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Australian Journal of Exp.Agric. & Animal Husbandry	1961	Aust.Inst. of Ag. Sci.			27	26	47	58	67	72	79	104	104	107	104	93	105	110	125
Australian Veterinary Journal	1925	Aust. Vet. Association	90	77	91	98	116	98	98	116	72	98	109	86	115	126	92	89	84
Journal Aust. Inst. of Ag. Science	1935	Aust. Inst. of Ag.Sci.	39	47	21	8	6	10	22	31	33	24	23	31	36	31	37	40	10
Tropical Grassland	1967	Tropical Grassland Soc.Aust.									17	15	24	18	30	34	35	28	19

* Three other journals which fall into this category were:

(1) Journal Entomological Soc. Aust. (1 publication in 1965)

(2) Aust. Soc. Soil Science (1 publication in 1967)

(3) Proc. Weed Society N.S.W. and Vic. (3 publications in 1968)

TABLE 2.4

NUMBER OF ARTICLES PUBLISHED IN SPECIALIST GOVERNMENT SERIALS

1959 - 1974

Journal*	Year first published	Publishing Institution	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975***
Aust.Journal of Agricultural Res.	1950	C.S.I.R.O.	48	61	54	41	21	21	27	41	30	46	61	55	72	93	77	61	80
Aust. Journal of Soil	1961	C.S.I.R.O.					17	20	5	14	23	20	26	16	11	17	17	16	20
Agricultural Gazette N.S.W.	1890	N.S.W.Dept. of Ag	64	82	83	80	104	105	99	116	118	135	144	101	73	81	66	53	53
A.M.R.C. Review	1971	Aust.Meat Res.Ctee.													3	6	4	4	
Aust.Tob.Growers' Bulletin	1961	Aust.Field Crops Div. Tob. Sect.								1	0	9	5	3	5	4	0	5	
Cane Growers'Quart. Bulletin	1933	Q'ld Sugar Expt.Stns. Bureau of	28	38	39	23	28	32	33	42	39	16	27	22	31	30	27	33	27
Chiasma	1963	Uni.of New Eng., Rural Sci.Dept.					-	-	-	12	20	-	8	9	8	8	18	12	
Dairyfarming Digest	1954	Vic.,Dept. of Ag.	38*	30*	32*	28*	20*	32*	39*	31*	33*	24	17	31	9	9	23	13	9
Journal, Dept. of Ag., S.A.	1897	S.A.Dept.of Ag.	71	119	90	40	55	48	37	55	52	66	52	10	10	7	7	12	12
Journal, Dept. of Ag., Tasmania	1929	Tas., Dept. of Ag.	32	38	33	26	21	22	17	20	26	35	36	41	25	34	35	39	33
Journal, Dept. of Ag., Victoria	1902	Vic., Dept. of Ag.	46	72	81	45	44	40	35	35	43	53	37	47	48	52	70	34	34
Journal, Dept. of Ag., W.A.	1899	W.A., Dept. of Ag.	59	85	80	80	56	71	78	54	36	51	68	52	66	16	19	23	15
Mallee Horticultural Digest	1954/55	Vic., Dept. of Ag.	35*	47*	49*	37*	26	23	20	37	28	20	25	34	38	8	25	19	23
Q'ld. Journal of Ag. / Q'ld. Journal of Ag. and Anim.Sci.	1897 / 1943	Q'ld., Dept. of Prim.Ind. / Q'ld. Dept. of Prim.Ind.	93	121	121	106	111	81	87	104	119	96	168	113	81	107	109	108	73
Rural Research	1952	C.S.I.R.O.	22	22	20	16	19	22	18	20	18	20	17	15	23	25	26	24	23
Tech.Communication, Q'ld.Bureau of Sug. Expt. St.			1	3	5	2	5	6	1	1	2	2	0	3	1	0	0	0	0
Various C.S.I.R.O. Tech. Bulletins			19	17	10	22	23	33	25	23	15	19	19	23	22	35	22	15	21
Various State Ag. Dept.Papers & Bulls.			0	1	2	0	4	0	2	2	0	1	9	19	24	17	11	8	3
Vic.Hort. Digest	1956	Vic.,Dept. of Ag.	25*	21*	35*	30*	24	40	32	22	27	17	36	33	26	16	16	17	20
Wool Tech.& Sheep Breeding	1954	Uni.of N.S.W. Sch.of Wool & Past.Sci.	12	17	14	7	8	12	10	11	11	11	10	6	6	3	2	2	8

* Figures obtained from primary sources.

** Other publications in this category: (1) Agricultural Record (4 publications in 1974); (2) Tasmanian Fruitgrower & Farmer (1 publication in 1962 and 1964); (3) Horticultural Research Record (3 publications in 1959); (4) Report Plant Div., Vic. Dept. Ag. (1 publication in 1973)

*** 1975 figures subject to revision since not all serials published in 1975 have been indexed as yet.

Of the serials being published in 1959, five are not included in the present section for the period 1945 - 1958.[11] These are left out essentially because of difficulties encountered in locating them but it is not felt that their omission will bias the proposed index in any way.[12] The serials included for this period and the number of articles indexed for each are included in Tables 2.5(a) and 2.5(b). The number of articles was arrived at using the implicit criteria adopted by *The C.S.I.R.O. Index* which were discussed at the beginning of the section. That is, for each year, the articles in each of the journals were classified according to their titles into one of the subsections used by the C.S.I.R.O. Index.

Changes in the Level of Publications

To utilize the relevant data which has been collected as an indicator of changes in the level of research activity, the following procedures were adopted. The data contained in Tables 2.3, 2.4, 2.5(a) and 2.5(b) were utilized.[13] In section 2.2.2, when discussing how publication data might be utilized, we concluded that if forces affecting the publication/research activity ratio were long-run in character, then comparisons could be made between the number of publications over relatively short periods of time and inferences made about corresponding changes in the level of research activity. Subsequent discussion indicated that these forces were, in fact, likely to be long-run in

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11 These are *The Cane Growers' Quarterly Bulletin, Technical Communications: Qld. Bur. Sugar Expt. Stations*, 'Various' C.S.I.R.O. *Technical Bulletins*, 'Various' *State Agricultural Department Papers and Bulletins* and *Wool Technology and Sheep Breeding*.

12 For the four years 1959 - 1962, articles from these journals accounted for a constant eight per cent of the total of articles contained in Tables 2.4 and 2.5.

13 Reasons for the omission of the other serials have been given above.

TABLE 2.5(a)

NUMBER OF ARTICLES PUBLISHED IN SPECIALIST GOVERNMENT SERIALS

1945 - 1958

Journal	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958
Australian Journal of Agricultural Research						39	38	30	36	59	64	48	58	67
Agricultural Gazette of N.S.W.	96	105	68	82	74	60	62	52	43	61	58	41	48	54
Dairyfarming Digest										22	28	35	34	46
Journal, Dept. of Agriculture, S.A.	48	43	39	39	29	44	48	38	45	32	50	68	51	70
Journal, Dept. of Agriculture, Tas.	27	17	20	24	28	27	21	25	38	19	23	28	22	18
Journal, Dept. of Agriculture, Vict.	45	58	61	61	64	57	50	51	47	50	47	34	38	56
Journal, Dept. of Agriculture, W.A.	40	32	22	27	21	20	26	53	47	52	51	54	44	51
Mallee Horticultural Digest											42	27	45	39
Queensland Journal of Agriculture / Queensland Journal of Ag. and An. Sciences	189	141	112	91	107	73	82	79	61	120	113	89	124	111
Rural Research									20	25	21	14	20	17
Victorian Hort. Digest												43	44	33

TABLE 2.5(b)

NUMBER OF ARTICLES PUBLISHED BY AGRICULTURAL SCIENCE INSTITUTES, SOCIETIES,ETC.

1945 - 1958

Journal	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958
Australian Veterinary Journal	28	32	57	53	68	61	52	55	56	68	77	63	68	74
Journal, Australian Institute of Agricultural Science	15	18	20	22	23	21	26	25	18	37	35	38	33	45

character, enabling us to conclude that publications were an appropriate data source for constructing an index of research activity.

The selection of an appropriate short-term period for comparisons between the number of publications is somewhat arbitrary. Schmookler [1954] chose overlapping decade averages when analysing patent data because the periods

> ...are long enough to eliminate short-term variations in the application-inventive activity ratio which might come from a lag between the time of inventing and the time of filing an application. Second, and more important, because the decades overlap, any substantial difference between two successive items in the series is probably the result of a genuine difference in the amount of inventing carried on...
>
> [Schmookler, 1954, p.185]

In the present study, we will be using overlapping five year periods starting from 1945/49. The shorter periods here are mainly chosen because of the shorter over-all time period being considered.[14] The percentage change in the number of publications between these periods are contained in Table 2.6. (The publications making up the relevant totals in Table 2.6 are contained in the serials listed in Appendix 2.7.6). For each five year period being compared, the number of serials included is constant; that is, any new journal appearing say between the years 1946 and 1952 is not included in the totals contained in Table 2.7 for the period 1945/49 - 1948/52. Any new journals which so appear are included in the following overlapping period.[15] This procedure was adopted because it was felt that the inclusion of a new journal within a given overlapping period would tend to bias upwards the extent of the change in research activity. The *initial* effect of the publishing of a new journal will be that the results of already completed research work which

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[14] The short term variations in the application inventive activity ratio mentioned in the preceding quotation from Schmookler are not thought to be very important in the present study. Because the publishing bodies are in the main the institutions carrying out the research, then it seems unlikely that there would be short term variations in the lag between the completion of a research project and the publication of its results.

[15] This accounts for the difference between the total number of publications in 1951/55 totals in Table 2.7, and for similar differences through to 1963/67.

TABLE 2.6

PERCENTAGE CHANGE IN THE NUMBER OF ARTICLES PUBLISHED 1945 - 1973

Overlapping 5-year periods	No. of Publications*	Percentage Change in Publications
1945 - 1949	2,146	
1948 - 1952	1,921	-10
1948 - 1952	1.921	
1951 - 1955	1,993	+ 4
1951 - 1955	2,220	
1954 - 1958	2,511	+13
1954 - 1958	2,773	
1957 - 1961	3,211	+16
1957 - 1961	3,584	
1960 - 1964	3,481	- 3
1960 - 1964	3,832	
1963 - 1967	3,377	-12
1963 - 1967	3,779	
1966 - 1970	4,340	+15
1966 - 1970	4,340	
1969 - 1973	4,240	- 2
1969 - 1972**	3,560	
1971 - 1975	3,091	-13

* For details of the figures contained in this column see Appendix 2.7.6.

** Note here that we have departed from the use of a five year overlapping period. This is essentially because data for 1976 are not available.

TABLE 2.7

INSTITUTIONS CONTAINED IN THE

C.A.B. LIST OF RESEARCH WORKERS IN AGRICULTURAL SCIENCES

Departments of Agriculture		
1.	New South Wales	1947
2.	Queensland	1947
3.	South Australia	1947
4.	Tasmania	1947
5.	Victoria	1947
6.	Western Australia	1947
C.S.I.R.O.		
7.	Division of Animal Genetics	1956
8.	Division of Animal Health	1947
9.	Division of Animal Physiology	1956
10.	Division of Nutritional Biochemistry	1947
11.	Division of Entomology	1947
12.	Division of Food Research	1947
13.	Division of Horticultural Research	1959
14.	Division of Fodder Conservation	1962
15.	Division of Irrigation Research	1947
16.	Division of Land Research	1953
17.	Division of Plant Industry	1947
18.	Division of Soils	1947
19.	Division of Tropical Pastures	1959
20.	Division of Wildlife Research	1953
21.	Division of Mechanical Engineering	1962
22.	Division of Soil Mechanics	1956
23.	Division of Protein Chemistry	1975
24.	Division of Textile Industry	1975
25.	Division of Environmental Mechanics	1972
26.	Division of Maths. Statistics	1956
27.	Division of Chemical Technology	1975
Universities		
28.	Adelaide	1947
29.	Australian National	1959
30.	James Cook	1972
31.	MacQuarie	1972
32.	Melbourne	1947
33.	Monash	1966
34.	New England	1959
35.	New South Wales	1962
36.	Queensland	1947
37.	Sydney	1947
38.	Tasmania	1950
39.	Western Australia	1947
Agricultural Colleges		
40.	Hawkesbury	1947
41.	Queensland	1947
42.	Roseworthy	1947
43.	Wagga	1947
44.	Yanco	1947
Commonwealth Departments		
45.	Commonwealth Serum Laboratories	1950
46.	Department of Health	1950
47.	Department of the Interior	1956
48.	Department of Primary Industry	1950
Other State Institutions		
49.	N.S.W. Department of Conservation	1947
50.	S.A. Institute of Medical and Veterinary Science	1947
51.	Victoria. Department of Crown Lands and Survey	1962
52.	Victoria. Soil Conservation Authority	1959
53.	Victoria. State Rivers and Water Supply Commission	1962
54.	Queensland. Bureau of Sugar Exp. Stations	1947

otherwise would not have been published will now be published.[16] This, in effect, means that the research activity/publication ratio will have increased during the relevant period. In order that this bias is reduced, only journals which published throughout the whole of the successive periods are included.

The percentage changes revealed in Table 2.6 should not be thought of as representing changes in research activity for the corresponding periods. Quite clearly actual changes in research activity will not be immediately transmitted to changes in the number of publications. For example, a given increase in the number of man hours devoted to research will be reflected in publication numbers only after the following lags. First, there will be the lag associated with the increase in man hours and the generation of research output. Second, there will be a lag between the completion of the research project and the submission of an article for publication and thirdly there will be a lag between submission and final publication. It is difficult to be precise about the extent of these lags but clearly they will vary among projects and journals. For any given period, this means that we must refer to an 'average' lag between an actual change in research activity and its reflection in a change in the number of publications. In order that we may make some estimate of this 'average' lag and to seek some supportive evidence for the use of publication data as an indicator of research activity, we now proceed to try and estimate the number of agricultural scientists undertaking agricultural 'biological' research for the period 1945-1975.

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16 Not necessarily in the new journal but if the new journal attracts potential publications away from established journals, then previously unpublished work will find its way into the established journals.

2.3 Agricultural Scientific Personnel Data.

2.3.1 Scope of the Collection

One of the possible measures of research activity mentioned in section 2.1 was the use of statistics on scientific personnel. It was mentioned that an obvious obstacle to the use of this measure is that of actually identifying people undertaking research activities. This problem has essentially two parts, first to identify those public institutions carrying out agricultural scientific research and secondly, how many researchers were employed by each.

One source which may be useful in providing the number of research workers undertaking public agricultural research is the *List of Research Workers in the Agricultural Sciences* published approximately every three years by the Commonwealth Agricultural Bureaux.[1] This list

> ...contains the names...of research workers in the agricultural sciences, at Government and State-aided institutions contributing to the Commonwealth Agricultural Bureaux.
>
> [Commonwealth Agricultural Bureaux, 1972. Introduction]

In 1936, the British Commonwealth Scientific Conference laid down the principles underlying the list which included that

> ...the scheme should be *strictly* limited to those who were engaged in research or actually concerned with its organization; that only the more senior workers need be mentioned to the exclusion of junior technical assistants.(own italics)
>
> [Commonwealth Agricultural Bureaux, 1972. Introduction]

In an attempt to try and establish how comprehensive *The List* is in terms of institutions covered, it is necessary to once again resort to crude indicators, as was the case when discussing the comprehensiveness

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1 It would appear as if this publication was first published in 1929. It is difficult to ascertain how frequently it was subsequently published. For example, reference to the *Consolidated List of Government Publications* (London, H.M.S.O. Various issues) suggests that it was not published between 1938 and 1947. In the present section, we will concern ourselves with the post-1947 period during which *The List* was published every three years.

of the C.S.I.R.O. Science Index. Table 2.7 lists the institutions covered by *The List* and the years when each first appeared.[2] As a first impression, *The List* does not seem to contain notable omissions in that it includes various C.S.I.R.O. Divisions, each of the various State Departments of Agriculture and all the major Australian Universitie A further observation may be made concerning the coverage of institutions this relating to the coverage of C.S.I.R.O. Divisions undertaking agricultural research. C.S.I.R.O. publish the *Research Index of C.S.I.R.O. Rural Divisions*, which

> ...lists the main lines of research currently in progress in the Divisions and Sections of C.S.I.R.O. concerned with rural sciences.
>
> [1961, p.(ii)].

In this publication, the Divisions and Sections listed to be 'concerned with rural sciences' correspond almost exactly with the Divisions 7 to 20 listed in Table 2.7, the only difference being the inclusion of the Division of Food Research and the Horticultural Research Section in the *C.A.B. List*. This would suggest that in the case of C.S.I.R.O., the list was comprehensive. Of the remaining Divisions in Table 2.7, (12) and (13) and (21) to (25) and (27) are included in the 1964 edition of *Research Index of C.S.I.R.O. Rural Divisions*, as Divisions which were carrying out related work.[3] That is, the 1964 edition included Divisions which were not wholly engaged in rural science research but which devoted a proportion of their resources in this direction. The inclusion of these partially engaged Divisions again suggests a comprehensive coverage of the *C.A.B. List*.

Several difficulties emerge concerning the use of the *C.A.B. List* for the collection of scientific personnel data. One set of

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2 That is, in the post-1947 period.

3 The remaining division, that of Mathematical Statistics, appears in the *C.A.B. List*, but is not found in the C.S.I.R.O.'s *Research Index of Rural Divisions*. It is therefore not included in the ensuing analysis.

problems relate to the definition of a research worker and the relationship between labour units and *labour time*. First, on the definition of a 'research worker' the *C.A.B. List* is not very informative; it merely distinguishes between more 'senior workers' and 'junior technical assistants'. Clearly at any point in time, the quality of 'senior workers' (however defined) will not be homogeneous, that is, the research ability of people both within and between institutions will vary and furthermore the distribution of these abilities could alter over time. This means that just as we were reluctant to make long-term comparisons in the number of publications, we should also be guarded in making long-term comparisons in the number of research workers to measure changes in the level of research activity. However, just as it was argued that short-term comparisons could be made with publication data, so also can personnel data be similarly utilized. That is, in the short-term, say three years, it is unlikely that there will be major shifts in the quality distribution of research workers either within or between institutions.

Secondly, on the relationship between labour units, (or the size of the scientific labour force) and labour time, similar problems arise with regard to long-term comparisons. The main problem arising in the long-term relationship between the size of scientific labour force and the corresponding 'scientific' effort would be the amount of time taken by research workers in liaison and extension work. Clearly the amount of extension work undertaken by the various bodies can be expected to differ; for example, we would expect a greater proportion of extension work to be undertaken by State Departments of Agriculture than by scientific staff employed by universities. While the *C.A.B. List* has attempted to 'exclude people in extension and advisory services as distinct from research', there nevertheless are still references to 'Extension Services' groups in their lists. Also, it is probable that some people are engaged in *both* research and extension programmes and will be included in the list as a research worker. Again, we will resort to the not unreasonable assumption that the labour size/labour time relationship is not likely to change to any great extent in the short run.

A further problem concerning the use of the *C.A.B. List* as a data source is the fact that it has been published at three yearly intervals only; that is, the data are an incomplete series.

Despite these limitations, the *C.A.B. List* is useful in that it gives us a comprehensive list of research institutions which should be included in the present study. Furthermore it provides us with personnel data for some institutions for which no other sources of personnel data appear to exist. Of the six groups of research institutions listed in Table 2.7, only C.S.I.R.O. and the universities provide continuous information on the number of scientific personnel employed. In the absence of other data sources, the *C.A.B. List*, even if only on a three yearly basis, does provide us with data on the other four groups. The estimates of scientific personnel in these four groups, the State Departments of Agriculture, the Agricultural Colleges, Commonwealth Departments and other State Institutions follow. Wherever possible, specifically named extension sections or divisions have been omitted. Specific divisions included and omitted from the estimates are described in Appendix 2.7.7. Estimates of agricultural scientific personnel employed by C.S.I.R.O. and the universities are then described. All estimates in this section relate to the period since 1947, the year from which the *C.A.B. List* is published on a consistent three yearly basis.

2.3.2 Estimates of Agricultural Scientific Personnel 1947-1975.

1. State Departments of Agriculture.

The estimates of scientific personnel in the various State Departments of Agriculture are contained in Table 2.8. Appendix 2.7.7 lists the various divisions and sections of each Department which make

TABLE 2.8

SCIENTIFIC PERSONNEL EMPLOYED IN STATE DEPARTMENTS OF AGRICULTURE, 1947 - 1975

	Year									
Department	1947	1950	1953	1956	1959	1962	1966	1969	1972	1975
New South Wales	155	172	206	130	131	165	207	291	335	388
Queensland	93	108	181	162	106	167	276	304	378	427
South Australia	35*	38*	38[e]	39	37	64*	83	97	118	123
Tasmania	11	21	32	36	31	44	50	54	50	69
Victoria	88	106	134	150	133	161	210	245	336	311
West Australia	27*	33*	35	60	37	49	70	92	117	122

* Total is not the sum of separate Divisions but rather an overall total.

e estimate.

up the totals in Table 2.8. These divisions have undergone some degree of re-organization over the period, but the basic structure of each department has remained essentially unchanged. In fact, Wade [1965, p.129] states with regard to agricultural research in Australia that

> By 1939, the general pattern of research organization was established and subsequent changes have mainly been in the form of growth and in the methods of finance rather than fundamental re-organization.

2. Agricultural Colleges.

The figures in Table 2.9 do not accurately reflect the number of people in these institutions undertaking agricultural scientific research. This is mainly because the figures entered in the *C.A.B. List* are total staff figures and are not broken down into various departments, except in isolated years for the Hawkesbury and Queensland Agricultural Colleges. The figures presented are totals of all departments including, for example, staff members in the Department of Agricultural Engineering at Roseworthy and the School of Food Studies at the Brisbane Agricultural College. Again, because we are concerned with short term changes, rather than absolute levels, this problem is overcome if we assume that the proportion of staff members in agricultural science departments is constant in the short run.

3. Commonwealth Departments.

Table 2.7 indicates that the *C.A.B. List* contains four Commonwealth departments, however it is contended here that two of them, the Department of Primary Industry and the Department of Health do not

TABLE 2.9

AGRICULTURAL SCIENTIFIC PERSONNEL EMPLOYED IN AGRICULTURAL COLLEGES, 1947 - 1975.

	1947	1950	1953	1956	1959	1962	1966	1969	1972	1975
Hawkesbury	13	24	29	11	16	23	21	16	23	24[π]
Queensland	6	5	4[e]	4	6	8	10	18	26	27
Roseworthy	16[e]	16	18	15	9	11	11	10	8	7
Wagga[*]	5	15	13	7	10	17	17	20	27	27[*][e]

π This figure was derived from the Hawkesbury Agricultural College Calendar, 1975.

e estimate.

* The figures here represent the combined total of the Wagga Agricultural College and the Wagga Agricultural Research Institute. The Institute was officially opened in 1954 and, according to Farquhar [1966, p.66]

> 'The major function of the College is now the provision of training in the science and practice of agriculture. Investigation work is undertaken at the Agricultural Research Institute which shares the College property.'

undertake scientific agricultural research. The I.A.C. [1976, p.99] contends that

> Although the Department's [Primary Industry] function is primarily administrative, it undertakes some research through B.A.E....and, to a much lesser extent, through its fisheries and forestry divisions...

With regard to the Department of Health, the Animal Quarantine and Plant Quarantine Branches are not listed among the 'laboratories and research organizations' in the Reports of the Director General of Health. Their function is regarded as administrative rather than as research bodies.

The number of people undertaking agricultural scientific research in the remaining two bodies, the Commonwealth Serum Laboratories and the Department of the Interior are contained in Table 2.10.[4]

4. Other State Institutions.

Of the six 'other state institutions' which are contained in Table 2.7,only three are included in the present study, these being the South Australian Institute of Medical and Veterinary Science, the Victorian Department of Crown Lands and Survey and the Queensland Bureau of Sugar Experiment Stations. Table 2.11 gives the estimates of the research personnel in these institutions. Reasons for excluding the other three institutions are given in Appendix 2.7.8.

5. C.S.I.R.O.

As indicated above, data on scientific personnel employed in C.S.I.R.O.are available on a continuous basis; the information being contained in *C.S.I.R.O. Annual Reports* and the Annual Reports of the various divisions. These personnel included in the table are those who are classified as various classes of research affairs; experimental officers, technical assistants and laboratory assistants are not included.

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4 For a description of the research work undertaken by The Department of Interior see Aust., Department of Territories, N.T., *Annual Report*, 1964/65.

TABLE 2.10

AGRICULTURAL SCIENTIFIC PERSONNEL EMPLOYED IN COMMONWEALTH DEPARTMENTS, 1947 - 1975

	1947	1950	1953	1956	1959	1962	1966	1969	1972	1975
Commonwealth Serum Laboratories*	20	2	2[e]	3	4	6	5	8	14	12
Department of Interior (N.T. Admin. Div.)**				14	14	14	27	38	21	17

e estimate.

* 'C.S.L. is a statutary body primarily concerned with the production and sale of vaccines. It also carries out a small amount of veterinary research relating to the development of new vaccines, sera and diagnostic agents.' [I.A.C. 1976, p.113] The figures contained in the table relate only to veterinary research.

** These figures do not include the Scientific Services section of the Animal Industry and Agricultural Branch as its function is related mainly to extension work, nor do they include the Forestry, Fishery and Wildlife section.

TABLE 2.11

AGRICULTURAL SCIENTIFIC PERSONNEL EMPLOYED IN

'OTHER STATE INSTITUTIONS', 1947-1975.

	1947	1950	1953	1956	1959	1962	1966	1969	1972	1975
Queensland Sugar Expt.Stations*	17	18	18	16	14	14	18	21	20	19
South Australia Institute of Med. & Vet. Science**	5	2	3	4	4	4	6	7	10	
Victorian Dept. of Crown Lands & Survey***						5	4	13	16	14

* These totals are made up of research personnel in the Divisions of Plant Breeding, Entomology, Pathology and Soils and Agronomy. The Division of Mill Technology has been omitted. The figures for 1947 and 1950 were abstracted from the Annual Reports of the Bureau.

** Totals made up from the Veterinary Pathology Section and the Animal Science Division which was established in 1966. These figures were not included in the *C.A.B.List* on a continuing basis. The figures contained in the Table are derived from the Annual Reports of the Institute.

*** Totals derived from the Research Section of the Vermin and Noxious Weed Board.

Table 2.12 contains the estimates of agricultural research personnel employed by C.S.I.R.O. It can be seen that the table contains only those divisions which have been previously designated as being 'principally' engaged in rural research. Some minor re-organization has taken place with respect to these divisions during the period, but again, the changes do not reflect major changes in structure. The divisions contained in Table 2.7, but not included in Table 2.12, are those which are only marginally involved in rural research. The principal reason for omitting these divisions is because it is difficult to establish the proportion of people employed in those divisions who are actually performing rural research. It will be assumed that the number of people involved here is relatively small and that their relative importance does not alter significantly in the short run.

6. Universities.

The totals contained in Table 2.13 are made up from universities offering Agricultural Science and Veterinary Science courses. The specific departments included for each university are listed in Appendix 2.7.9. Again, by only including those departments which are specific to agriculture, there will necessarily be an omission of people undertaking agricultural scientific research. These people will normally be found in the various departments of Botany and Zoology where some research work will be at least marginally regarded as agricultural. For present purposes, it will be assumed, as in the case of the marginally related C.S.I.R.O. Divisions, that the amount of agricultural research undertaken by academics in departments which are not specialist agricultural departments is relatively small and unchanging in the short run.

Another consideration with regard to universities, is the research undertaken by graduate students in the agricultural science

TABLE 2.12

SCIENTIFIC PERSONNEL EMPLOYED IN C.S.I.R.O. 1947-1974

	Animal Health & Productn.	Anim. Genetics	Anim. Physiology	Nut. Biochem.	Entomology	Irrig. Research	Hort. Research	Plant Industry	Land Research	Trop. Pastures	Soils	Wildlife Research
1947	45			12	24	23		51			31	
1948	47			16	21	23		55			30	
1949	48			17	23	21		60			34	
1950	57			19	23	21		66			35	5
1951	61			19	24	21		67	8		36	5
1952	66			20	25	18		74	10		41	6
1953	65			21	26	14		84	10		44	9
1954	64			18	26	13		87	11		46	12
1955	67			17	30	16		94	13		46	13
1956	73			18	29	18		100	13		47	14
1957	76			18	31	17		101	13		44	15
1958	81			19	31	16		110	13		48	13
1959	83			19	32	16		116	23		47	12
1960	33	22	27	18	33	17		94	28	17	48	13
1961	30	24	37	19	35	18		94	28	17	51	12
1962	32	22	35	19	36	19		105	34	21	58	15
1963	33	23	39	18	42	11	14	106	36	24	57	14
1964	32	23	39	19	45	11	14	106	34	28	59	14
1965	37	23	44	19	45	9	14	102	32	31	58	14
1966	34	24	42	19	47	7	15	105	35	35	58	15
1967	34	24	45	17	50	10	16	113	36	34	60	15
1968	35	29	47	15	53	11	17	113	35	38	64	17
1969	40	28	48	16	51	10	16	114	36	35	68	15
1970	40	30	47	18	57	13	18	112	35	38	72	18
1971	43	32	48	19	62	14	17	111	36	40	70	17
1972	48	36	47	17	60	13	20	87	56	39	67	20
1973	46	34	45	16	60	12	21	87	63	45	59	20
1974	46	33	38	14	67	13	19	93	64	53	63	22

TABLE 2.13

AGRICULTURAL SCIENTIFIC PERSONNEL EMPLOYED IN

AUSTRALIAN UNIVERSITIES 1947 - 1975

	University of Melbourne	University of Sydney	Waite Ag. Research Inst.	University of Q'ld	University of W.A.	University of New England	University of Tasmania	La Trobe
1947	12	27	23	10	11			
1948	11	30	23	9	11			
1949	11	32	22	12	10			
1950	11	31	24	14	10			
1951	12	40	26	19	11			
1952	12	36	27	21	12			
1953	13	35	28	17	13			
1954	12	35	31	19	13			
1955	13	42	26	19	10			
1956	13	37	28	21	10			
1957	15	32	35	22	13	5		
1958	15	42	43	20	13	9		
1959	17	45	47	20	8	15		
1960	19	48	51	20	8	20		
1961	19	50	52	20	8	20		
1962	20	56	55	20	10	22	1	
1963	22	61	50	28	13	21	2	
1964	31	64	52	30	13	22	2	
1965	44	64	53	35	15	24	4	
1966	54	63	53	39	14	29	5	
1967	58	61	52	43	15	32	5	
1968	57	67	53	46	21	34	6	1
1969	58	75	51	46	22	38	8	3
1970	56	74	51	44	22	36	8	8
1971	59	74	49	47	22	36	8	10
1972	59	75	49	50	23	38	8	11
1973	59	79	50	56	23	38	8	12
1974	54	85	52	52	23	39	7	12
1975	54	92	54	66	23	39	8	13

faculties. Here we make the assumption that over the short period, the ratio of graduates to staff members is approximately constant, such that a change in the number of staff members, over say, a three year period, reflects a similar change in the number of graduate students.

Again the data on scientific personnel employed in the universities is available on a continuous basis, the information being included in the University Calendars of the various institutions and the *Commonwealth Universities Year Book*. The calendars were used as a primary source, but in latter years, staff lists were not published. When this occurred, the Year Books were used. Only full-time staff have been included; all part-time lecturers and tutors have been omitted.

2.3.3 Estimates of Agricultural Scientific Personnel 1925-1946.

In order that some statistical tests could be performed to analys the use of scientific publication data as a measure of research activity, and due to the need for a longer series of scientific personnel data for an aggregative study of the relationship between research activity and agricultural productivity, it was necessary to extend the scientific personnel data. In view of this,personnel data has been collected on a more limited basis for the period 1925-1946. The choice of 1925 as a starting point is somewhat arbitrary but it does correspond to the origin of C.S.I.R. and the Waite Agricultural Research Institute which both signify major developments in the institutionalization of Australian agricultural research. Reference to Tables 2.8 to 2.13 indicates that throughout the period 1947-1972, the personnel of the State Departments of Agriculture, the C.S.I.R.O. and the Universities accounted for over 90 per cent of the total. In view of this and because of the difficulties of data collection, these three groups are the only ones included in the present section. As indicated in section 2.2.4,the *C.A.B. List* does not appear on a regular basis prior to 1947,meaning that all data in the present section had to be collected from alternative sources.

1. C.S.I.R.

The estimates of C.S.I.R. agricultural scientific personnel are contained in Table 2.14. The collection procedures used are the same as those described in the previous section for the collection of data for the period 1947-1975. The major sources were the various *Annual Reports* of C.S.I.R.

2. The Universities

Table 2.15 contains the estimates of agricultural scientific personnel in the universities. Again the procedures and the data sources used are similar to those for the period 1947-75. However, for this earlier period the data was not always available in the University Calendars on a regular yearly basis. In particular, staff numbers were not available for the Sydney University for the period 1942-46 and for the University of Queensland for 1937-42. In these cases a simple linear interpolation was carried out to obtain estimates for the missing years. In occasional years when staff numbers were not published,averages of numbers in neighbouring years were used.

3. The State Departments of Agriculture

The collection of data for these institutions for this period proved to be much more difficult. For the period 1947-75, the *C.A.B. List* was utilized, however, as has already been indicated, this source was not available before 1947. As a result of this, we had to resort to the use of *Public Service Lists* published by the various State Governments. The use of this alternative source presented two major

TABLE 2.14

AGRICULTURAL SCIENTIFIC PERSONNEL

EMPLOYED IN C.S.I.R., 1927-1946

	Division of Animal Health & Production	Division of Plant Industry	Division of Entomology	Division of Soils	Irrigation Settlement	Division of Biochem. & Gen. Nut.
1927	14	1	-	-	3	
1928	13	6	-	2	4	
1929	14	12	12	5	5	
1930	16	14	15	6	5	
1931	17	15	15	6	5	
1932	19	15	20	7	5	
1933	23	19	20	7	5	
1934	22	23	15	7	6	
1935	21	28	15	9	9	
1936	27	32	17	7	10	
1937	30	28	20	9	10	
1938	31	28	20	7	11	
1939	34	31	19	16	11	
1940	35	32	13	17	12	
1941	38	32	15	18	12	
1942	32	30	12	11	10	
1943	28	35	11	11	12	
1944	32	31	12	18	13	
1945	30	37	14	20	19	13
1946	37	47	22	26	19	12

TABLE 2.15

AGRICULTURAL SCIENTIFIC PERSONNEL EMPLOYED

IN AUSTRALIAN UNIVERSITIES 1925-1946

	University of Melbourne	University of Sydney	Waite Agric. Res. Inst.	University of Queens-land	University of West. Australia
1925	3	9	2	1	4
1926	3	11	3	1	4
1927	4	11	3	1	5
1928	3	14	4	1	6
1929	3	16	6	4	5
1930	3	16	9	7	7
1931	4	17	9	7	7
1932	5	17	14	7	7
1933	7	17	15	7	7
1934	8	18	15	7	7
1935	8	18	15	7	7
1936	8	18	15	6	7
1937	10	19	15	7	8
1938	10	19	19	8	7
1939	9	20	18	8	10
1940	11	25	21	9	14
1941	11	23	14	10	10
1942	12	23	14	10	14
1943	10	24	21	11	10
1944	14	25	22	8	8
1945	14	25	23	8	10
1946	13	26	23	8	10

problems. First, the collection had to be such that the series was comparable with that derived from the *C.A.B. List* and secondly, *Public Service Lists* were published in many cases on an irregular basis.

To ensure that the series would be comparable with the 1947-75 series, information contained in the 1947 edition of the *C.A.B. List* was utilized. The information was of two types; first, the particular divisions or sections of the various departments included in the *C.A.B. List* were noted (these are listed in Appendix 2.7.7) and second, the occupational status of officers included were also noted. This information was then used in conjunction with the *Public Service Lists* to generate a continuous series, these estimates being contained in Table 2.16.

Public Service Lists were not published by the Tasmanian Government for the period 1925-46 and because of this no estimates have been made for the Tasmanian Department of Agriculture. Since the data are to be utilized for measuring short-term relative changes in the level of research activity, the omission of Tasmania will not seriously affect the quality of the series.

TABLE 2.16

AGRICULTURAL SCIENTIFIC PERSONNEL EMPLOYED IN

STATE DEPARTMENTS OF AGRICULTURE, 1925-1946

	New South Wales	Victoria	West Australia	Queensland	South Australia
1925	58	16	8	31	18
1926	59	19	8	30	23
1927	73	23	8	31	23
1928	78	22	9	34	24
1929	86	21	10	41	23
1930	88	21	10	45	19
1931	90	21	10	44	19
1932	100	21	10	44	19
1933	108	21	11	44	20
1934	111	27	11	50	21
1935	109	33	12	53	21
1936	112	35	12	52	21
1937	115	37	12	55	21
1938	123	40	12	57	22
1939	124	46	13	60	22
1940	127	45	13	63	24
1941	128	46	17	65	25
1942	131	47	17	65	25
1943	131	47	17	69	26
1944	130	45	20	73	26
1945	130	54	20	75	28
1946	129	69	21	83	32

2.4 Publications as an Index of Research Activity

2.4.1 Some General Observations.

A summary of the data contained in Tables 2.8 - 2.13 is contained in Table 2.17, which shows the total number of agricultural scientific personnel employed by public research institutions in Australia for the period 1947-1975. The table also shows the percentage change in numbers employed for each successive three year period. In our discussion on the utility of publication data in section 2.2.2, we concluded that to give meaningful estimates of short-term changes in the level of research activity, publication data should be lagged in order to reflect the actual timing of these changes. In order that some estimate can be made of this lag and to provide some support for the use of publication data we now proceed to broadly analyse the relationship between changes in the level of scientific personnel employed and changes in the level of publications.

With regard to the relationship between research activity and the number of agricultural scientific personnel employed, we would expect that the level of research activity would vary in proportion to the number of scientists employed, especially when the number of scientists employed is carefully estimated. If this is accepted, then if publications were to reflect the level of research activity, we would expect the number of publications to vary in proportion with the number of scientists employed. Furthermore, we would expect that relationship to be lagged as explained in section 2.2.4. In order that we may observe the nature of the relationship between the number of scientists employed and the number of publications we compared the percentage change in the number of publications for successive *overlapping* periods with the percentage change in the number of scientists employed for successive three year periods; the figures being in

TABLE 2.17

TOTAL AGRICULTURAL SCIENTIFIC PERSONNEL

1947 - 1975

	1947	1950	1953	1956	1959	1962	1966	1969	1972	1975
State Departments of Agriculture	409	478	626	577	475	650	896	1083	1334	1440
C.S.I.R.O.	192	241	273	312	348	396	426	477	510	
Universities	72	90	106	109	152	184	257	298	313	349
Agricultural Colleges	40	60	64	37	41	59	59	64	84	85
Commonwealth Departments	2	2	2	17	18	20	32	46	34	29
'Other'State Institutions	22	20	21	20	18	18	28	41	46	
TOTAL	737	891	1092	1072	1052	1372	1698	2009	2321	
% change		+21	+23	-2	-2	+30	+24	+18	+16	

Tables 2.6 and 2.7 respectively. Because of the expected lagged relationship, and given the total time period covered, it was considered necessary to include personnel data back to the three year period centred in 1938.

The information containing percentage changes both in the number of publications and scientific personnel are brought together in Table 2.18. In an attempt to estimate the approximate lag between changes in personnel and changes in publications a search was made for a 'best association' between the two series using as criteria both the simple correlation coefficient and the Student t-test. The following equations were estimated:

$$P_t = a + bSP._{t'}$$

$$P_t = a + b_1 SP_{t'-1}$$

$$P_t = a + b_2 SP_{t'-2}$$

$$P_t = a + b_3 SP_{t'-3}$$

where P_t = the percentage change in publications in period t.

SP_t = the percentage change in scientific personnel in period t.

t = five year overlapping period.

t' = three year period.

The estimates of these models utilizing data from Table 2.18 are (t values in parentheses):

$$P_t = 2.016 - \underset{(-0.312)}{0,094}\ SP_{t'} \qquad r = 0.117$$

$$P_t = 6.332 - \underset{(-1.643)}{0.475}\ SP_{t'-1} \qquad r = 0.527$$

$$P_t = -9.537 + \underset{(1.814)}{0.471}\ SP_{t'-2} \qquad r = 0.566$$

$$P_t = -1.751 + \underset{(0.640)}{0.187}\ SP_{t'-3} \qquad r = 0.235$$

On the basis of the correlation coefficient and the Student t-statistic, the model incorporating a two period personnel lag seems the most appropriate. That is, on the basis of a 'best association' lag estimate, we might conclude

TABLE 2.18

SUMMARY OF DATA ON CHANGES IN THE LEVELS OF SCIENTIFIC PERSONNEL AND SCIENTIFIC PUBLICATIONS

Period relating to Personnel Change	Percentage Change in Scientific Personnel	Percentage Change in Publications	Centre Years of Overlapping five year periods relating to changes in the number of Publications
1941/44	2	-10	1947/50
1944/47	36	4	1950/53
1947/50	21	13	1953/56
1950/53	23	16	1956/59
1953/56	-2	- 3	1959/62
1956/59	-2	-12	1962/65
1959/62	30	15	1965/68
1962/65*	18	- 2	1968/71
1966/69	18	-13	1971/74
1969/72	16	-	

* Personnel figures for 1965 have been interpolated.

that the average lag between changes in scientific personnel and subsequent changes in publications is approximately five to six years. Several pcints can be made regarding this estimate.

First, the estimation of the lag undertaken here highly simplifies the actual lag structure. One notable simplification concerns the effect of age distribution on the productivity of scientific personnel. A number of studies have indicated that, at least, the productivity of scientists varies with age. A study by Lehman [1953], for example, suggested a 'decrement in creative production rate subsequent to ages 30 and 39' while studies by Dennis [1956] and Pelz [1964] found different patterns of productivity according to age but still nevertheless found varying levels of productivity. These studies do not suggest that the apparent decline of productivity at certain ages is a function of declining intellectual competence but rather seek reasons in terms of changed environments, problems of motivation and rewards. Furthermore, there appears to be some evidence that scientific productivity differs according to scientific discipline and that the age 'peak' in productivity is later in development -orientated laboratories than in basic research-oriented laboratories, [Pelz, 1964, p.28]. To this stage, the data necessary to adjust thelag structure to take account of differences in age, discipline and the type of research being undertaken are not available and are therefore not included.

Secondly, the simple correlation coefficient of 0.566 reported above is quite small. It is suggested that this is largely a result of the construction of the data series. In the first place, the changes in personnel are generated from only two observations while the changes in publications are generated from changes in five year aggregates. As a result the personnel data are more likely to be influenced by random disturbances than publication data, hence resulting in a lower than expected correlation coefficient.

While two observations do not allow for confident predictions, it is interesting to note from Table 2.18, that percentage increases in personnel for the periods 1962/65 and 1966/69 are matched by percentage decreases in publications for the periods 1968/71 and 1971/74. This observation is interesting for at least two reasons. First, they suggest that there are forces which might invalidate the presumption that publications are a suitable indicator of research activity *at all stages* in the development of institutional research work. In the particular case here, a large proportion of the decrease in publications in the period 1966/70 - 1969/73 is accounted for by the fact that some of the more significant journals contained in Table 2.4 were published less frequently in the post-1970 period. In particular, the Agricultural Gazette of New South Wales was published on a monthly basis until 1970, but has subsequently been published bi-monthly; the Journals of the Departments of Agriculture of South Australia and Western Australia, previously published monthly have been published quarterly since 1970 and 1972 respectively. While a number of reasons may bring about this change, the Departments contacted indicated that the major reasons for reducing the number of issues were the increased labour and printing costs associated with publishing.

This suggestion that the research activity/publication ratio might be influenced by increasing costs has its parallel in the literature on the use of patents as an index of inventive activity. Studies by Boyle [1919] and Greenberg [1929] found positive correlations between patenting and business cycles, leading them to conclude that depressed economic conditions adversely affect the volume of patent applications and the number of patents granted. In our particular case, taking into account the postulated 'average' lag of five years between changes in personnel and publications, then it seems plausible to suggest that increased cost conditions prevailing in the early 1970's have had an effect on the number of articles published which does not reflect changes in research activity which took place in the mid 1960's. That is, the use of publication data as an index of research activity may be constrained by the influence of general economic conditions on the policies adopted by publishing institutions regarding the frequency of their issues.

Some further statistical tests were performed in an attempt to substantiate and support the above findings. One test utilized the aggregat data in Table 2.18 and involved the use of a non-parametric test. The second involved some parametric tests on C.S.I.R.O. data.

The non-parametric test used on the aggregate data was the Mann-Whitney U Test described by Siegel [1956, p.116] as

> ...one of the most powerful of non-parametric tests and... [is]...a most useful alternative to the parametric t test...

This particular test was considered appropriate because two independent samples were being considered and because the sample sizes were quite small.

The null hypothesis H_0 is that changes in the level of scientific personnel are the same as changes in the level of scientific publications. The alternative hypothesis H_1 is that changes in the two samples are different. The data used for the test are those contained in Table 2.18 for those periods where observations exist on both changes in scientific personnel and scientific publications.

The Mann-Whitmey U test involves combining observations from both samples and ranking them in order of increasing size. The statistic U is then calculated for each sample.

where $$U_A = N_a N_b + \frac{N_a(N_a+1)}{2} - R_A \quad \ldots\ldots\ldots\ldots\ldots \quad (2.3)$$

and $$U_B = N_a N_b + \frac{N_b(N_b+1)}{2} - R_B \quad \ldots\ldots\ldots\ldots\ldots \quad (2.4)$$

where N_A and N_b are the respective sample sizes

R_A = sum of the ranks assigned to changes in scientific personne

R_B = sum of the ranks assigned to changes in scientific publications.

The calculated values of R_A and R_B are 114 and 45 respectively. By applyin these values to equations (2.3) and (2.4)and with $N_a = N_b = 9$, the computed values of U_A and U_B are 12 and 81 respectively. The smaller of the two values $U_A = 12$ was then compared to the critical value of U for a two tailed test at the .05 level of significance. The critical U value for the stated level of significance and for two samples each with nine observations is 17. [Siegel, 1956, p.276]. The observed value U_A (= 12) < $U_{crit.}$ (= 17) which enables us to reject the null hypothesis H_0. We are therefore led to conclude that a significant difference exists between changes in the level of scientific personnel and changes in the level of scientific publications.

A further test was made, this time omitting the observations relating to the 1962/65 and 1966/69 changes in personnel and the 1969/71 and 1971/74 changes in publications. In this case the calculated values of R_A and R_B are 61 and 39 respectively. Applying these values to equations (2.3) and (2.4) and with $N_a = N_b = 7$, the computed values of U_A and U_B are 16 and 38. The null hypothesis H_0 and the alternative hypothesis H_1 are the same as for the previous test. With sample sizes smaller than nine, probabilities rather than critical values are tabulated. Reference to Siegel [1956, p.272] indicates that $U \leq 16$ (the observed value of U) has a probability of occurrence under H_0 of p = .318 at the .05 significance level. Since p (= .318) > α (.05) the data does not justify rejecting the null hypothesis. That is, in this case there appears to be no significant difference between changes in scientific personnel and changes in scientific publications.

The above two tests provide results which are not inconsistent with the arguments developed on the basis of inspection of Table 2.18. That is, for the period up to around 1970 changes in publications are not significantly different from changes in personnel. The inclusion of the periods in the 1970's results in us being unable to make the same conclusion. This would seem to support our previous arguments that labour and printing cost conditions prevailing in Australia during the early 1970's have affected the publication/scientific personnel ratio.

A second set of statistical tests were performed using publication and personnel data for C.S.I.R.O. The personnel data are those contained in Tables 2.12 and 2.15. A separate count was made of C.S.I.R.O. publications utilizing C.S.I.R.O. *Annual Reports* and the Annual Reports of the various divisions. These data are contained in Table 2.19.[1] In particular, the data were used to

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[1] Considerable care had to be exercised in collecting C.S.I.R.O. publication data from the various annual reports to avoid double entry, as a number of articles were indexed on more than one occasion.

TABLE 2.19

C.S.I.R.O. PUBLICATIONS 1945-1974

	Plant Industry	Entomology	Animal Health & Nutrition	Animal Genetics	Animal Physiology	Biochem. and Gen. Nut.	Soils	Land Research	Wildlife Research	Tropical Pastures	Horticulture
1945	19	8	12			5	3				
1946	28	17	16			3	11				
1947	20	22	13			6	14				
1948	13	11	24			21	7				
1949	23	13	23			7	10				
1950	28	22	27			7	20				
1951	31	17	40			16	16				
1952	42	21	45			14	6	5	4		
1953	57	41	59	5		15	23	9	4		
1954	75	33	55	7		12	31	12	4		
1955	61	40	47	10		5	27	2	14		
1956	55	22	55	8		12	39	10	34		
1957	99	38	75	9		12	20	11	17		
1958	100	41	70	15		17	37	7	18		
1959	91	32	83	30		6	40	18	23		
1960	117	52	41	33	48	9	45	36	18	14	
1961	91	31	43	32	56	14	43	26	22	5	
1962	134	55	43	37	74	11	86	44	38	17	13
1963	160	55	44	26	50	6	56	46	40	12	22
1964	167	46	59	33	77	13	46	79	42	36	20
1965	135	57	36	37	47	16	50	72	44	20	22
1966	176	60	32	39	81	7	56	34	53	45	22
1967	169	88	49	34	74	17	47	85	44	57	22
1968	186	83	45	36	107	17	93	90	38	50	33
1969	228	100	70	20	110	16	63	54	37	47	50
1970	208	88	62	n.a.	149	25	93	82	41	75	31
1971	179	89	61	n.a.	104	20	90	n.a.	30	80	37
1972	169	81	78	n.a.	118	16	95	n.a.	38	86	42
1973	145	104	88	n.a.	102	12	104	n.a.	33	73	43
1974	144	153	69	n.a.	n.a.	21	92	n.a.	53	53	46

investigate whether there were long-term changes in the publication/personnel ratio and to investigate whether there were short-term differences in the publication/personnel ratio.

To investigate whether the publication/personnel ratio changed over time the average number of publications per scientist was calculated for four divisions of C.S.I.R.O. for successive five year periods. The ratios are presented in Table 2.20(a). The publication data are averages for the years specified in the table while the personnel data relate to the preceding five year period. This procedure was adopted to allow for an adjustment to take account of publication lags. The hypothesis tested was $H_0:U_1 = U_2 = U_3 = U_4$ using an F test described by Ostle [1963, pp.133-136]. The null hypothesis is rejected if

$$F \geq F_{(1-\alpha)(V_1,V_2)}$$

where α is the level of significance

V_1 is the degrees of freedom among the groups

V_2 is the degrees of freedom within the groups

The estimates for the samples contained in Table 2.20(a) are included in Table 2.20(b). In this case

$$F = 8.67 > F_{.95(5,18)} = 2.77$$

thus the hypothesis $H_0:U_1 = U_2 = U_3 = U_4$ is rejected at the five per cent significance level. We can conclude then that the overall publication/personnel ratios which increase in each of the successive periods do differ significantly from each other.

The second test performed using C.S.I.R.O. data was concerned to investigate whether there was any significant difference between overlapping five year periods of the publication/scientist ratio. The method employed here was to calculate the average number of publications per scientist for successive overlapping periods for these divisions for which the data are available. Again, the personnel figures pertain to

TABLE 2.20(a)

AVERAGE NUMBER OF PUBLICATIONS PER MAN C.S.I.R.O. 1945-1974

	1945/49	1950/54	1955/59	1960/64	1965/69	1970/74
Division of Plant Industry	.64	.93	1.07	1.28	1.77	1.54
Division of Entomology	1.13	1.29	1.41	1.56	2.03	2.09
Division of Animal Health	.53	1.09	1.09	1.54	1.93	2.35
Division of Soils	.60	.68	.87	1.19	1.13	1.54
Overall Average	.73	1.00	1.11	1.39	1.72	1.88

TABLE 2.20(b)

ANALYSIS OF VARIANCE USING DATA OF TABLE 2.20(a)

TO TEST $H : U_1 = U_2 = U_2 = U_4$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F. Ratio
Mean	1	40.77	40.77	
Among Groups	5	3.90	0.78	8.67
Within Groups	18	1.63	0.09	
Total	24	46.30	....	

an earlier period. These average ratios and the divisions included are listed in Table 2.21. In this case we are concerned to test the hypothesis $H_0: U_1 = U_2$ and we do so using the following t-test:

$$t = (\bar{X}_1 - \bar{X}_2) \;/\; S_{\bar{X}_1 - \bar{X}_2}$$

where $\bar{X}_1$ and $\bar{X}_2$ are the respective sample means

and $S_{\bar{X}_1 - \bar{X}_2}$ is a pooled estimate of the population standard deviation.

For this test we reject $H_0: U_1 = U_2$ if

$$t \leq -t_{(1-\alpha/2)(N_1+N_2-2)}$$

or if $$t \geq t_{(1-\alpha/2)(N_1+N_2-2)}$$

where α is the significance level

and N_1 and N_2 are the respective sample sizes.

The respective t values and the critical t values for each overlapping five year period are included in Table 2.21. In each case, when $\alpha = .05$

$$-t_{(1-\alpha/2)(N_1+N_2-2)} \leq t \leq t_{(1-\alpha/2)(N_1+N_2-2)}$$

That is, in all cases we are able to accept the null hypothesis that $U_1 = U_2$ for each of the periods considered. Therefore we are able to conclude that for overlapping five year periods, no significant changes occur in the publication/scientist ratio.

It would appear then that evidence based on C.S.I.R.O. data is at least consistent with the claims made in sections 2.2.2 and 2.2.3; namely that long-run changes may occur in the publication/scientist ratio (the propensity to publish) and that the forces bringing about these changes are essentially long-run in nature, an argument supported by the evidence suggesting that no significant differences occur in the ratio when overlapping five year periods are considered.

TABLE 2.21

AVERAGE NUMBER OF PUBLICATIONS PER SCIENTIFIC PERSONNEL FOR C.S.I.R.O. FOR SUCCESSIVE OVERLAPPING FIVE YEAR PERIODS

Period relating to Publications	Period relating to Personnel	Ave. Publications/Scientific Personnel						Overall Average	$t = \frac{\bar{X}_1-\bar{X}_2}{S_{\bar{X}_1-\bar{X}_2}}$	Critical t values α=.05
		Plant Indus-try	Ento-mology	Animal Indus-try	Soils	Wild-life	Land Use			
1945/49	1940/44	0.64	1.13	0.53	0.60	n.a.	n.a.	0.73	-0.239	±2.447
1948/52	1943/47	0.68	1.01	0.78	0.56	n.a.	n.a.	0.77		
1948/52	1943/47	0.68	1.01	0.78	0.56	n.a.	n.a.	0.77	-1.340	±2.447
1951/55	1946/50	0.95	1.35	1.05	0.66	n.a.	n.a.	1.00		
1951/55	1946/50	0.95	1.35	1.05	0.66	n.a.	n.a.	1.00	-0.019	±2.447
1954/58	1949/53	1.11	1.44	1.04	0.81	n.a.	n.a.	1.10		
1954/58	1949/53	1.11	1.44	1.04	0.81	1.87	1.34	1.27	-0.785	±2.228
1957/61	1952/56	1.13	1.43	1.32	0.83	2.50	1.72	1.49		
1957/61	1952/56	1.13	1.43	1.32	0.83	2.50	1.72	1.49	-0.912	±2.228
1960/64	1955/59	1.28	1.56	1.54	1.19	2.39	3.08	1.84		
1960/64	1955/59	1.28	1.56	1.54	1.19	2.39	3.08	1.84	-0.325	±2.228
1963/67	1958/62	1.55	1.83	1.60	1.01	3.43	2.51	1.99		
1963/67	1958/62	1.55	1.83	1.60	1.01	3.43	2.51	1.99	-0.236	±2.228
1966/70	1961/65	1.88	2.06	2.18	1.24	3.09	2.08	2.09		
1966/70	1961/65	1.88	2.06	2.18	1.24	3.09	n.a.	2.09	0.286	±2.306
1969/73	1964/68	1.72	1.93	2.42	1.49	2.38	n.a.	1.99		

2.5 Summary

We are now in a position to summarize our discussion on the utility of publication data. It was argued that publication data might be appropriate for indicating the direction of short-term changes in the level of research activity. A careful count was then made of agricultural scientific publications for the period 1945 - 1975. Estimates were also made of the number of scientific personnel engaged in agricultural scientific research for the period 1925-1975. On the basis of the assumption that research activity was likely to vary directly with the number of research personnel, an investigation was made of the relationship between changes in research personnel and changes in the number of publications.

An 'informal' investigation of the data suggested that at least until the 1970's publication data served as a useful tool for estimating short-term changes in research activity. It was speculated that in the post-1970 period, general economic conditions were such that cost-savings were having an effect on the publication/personnel ratio.

Some relatively simple statistical tests were then performed utilizing aggregate data and a set of data relating only to C.S.I.R.O. These tests provided results which appeared to be consistent with arguments previously advanced concerning the usefulness of publication data as an index of short-term changes in the level of research activity.

In the following chapter publication data on a commodity basis will be used in an attempt to evaluate the mix of Australian agricultural research activity during the 1960's.

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2.7 APPENDICES

2.7.1 Examples of *C.S.I.R.O. Science Index* Classifications.

The following references are entered here to give an example of the nature of articles contained in each of the classifications of the *C.S.I.R.O. Science Index.* The particular examples listed here have been extracted from the *C.S.I.R.O. Science Index,* Vol.17, No.1, Jan. 1973.

I. General; 'Some aspects of Australia's role in overseas agricultural development' L.R. Humphreys, *J.Aust. Inst. Ag.Sci.* 38(3): 198-201 S'72

II. Soils, Fertilizers; 'Soil conservation structures for marginal arable areas: diversion spreader banks and tank drains' J.A. Quilty, *J.Soil Conserv. Ser.* N.S.W. 28 (4): 169-80 O'72

III. Pastures; 'Modified procedure for large-scale pasture evaluation by digestibility' D.M.R. Newman, *J. Aust. Ag. Sci.* 38(3): 212-3 S'72

IV. Field Crops; 'Quantitative reduction of triphenyl tetrazolium chloride on a measure of viability in cereal seeds' R.L. Hately, L.P. Paleg and D. Aspinell, *Aust. J. Exp. Agric. Anim. Husb.* 12(58): 517-22 O'72

V. Horticulture; 'Thinning Golden Queen peaches with chemicals' A. Selimi, *J. Aust. Inst. Ag. Sci.* 38(3): 205-7 S'72

VI. Forestry; 'Immediate resumption of growth by radiata pine after five months of minimal transpiration during drought' K.W.Cremer, *Aust. Forest Res.* 6(1): 11-16 '72

VII. Plant Pathology and Protection; 'New life blight threatens maize crops ' K.J. Moore, *Agric. Gaz. N.S.W.* 83(5): 280-1 O'72

VIII. Domestic Animals, including specific diseases; 'Bone biopsy in cattle and sheep for studies of phosphorus status' D.A. Little, *Aust. Vet. J.* 48(12): 668-70 O'72

IX. Farm equipment, power farming; 'Wimmera farm's study: The right machines can halve the costs' T.J. Ryan, *J. Dep. Agric. Vic.* 70(10): 362-70 O'72

X. Farm Management; 'Pastoral Problems as seen by a Visiting Sociologist' *J. Aust. Inst. Ag. Sci.* 38(3): 194-7 S'72

XI. Water Supply and Irrigation; 'Slide failures in small earth dams' K.D. Nelson, *Irrig. Fmr.* 7(9): 9-10. Je/Jl '72

XII. Economics; 'Overview of modelling in agricultural management' J.R. Anderson, *Rev. Market Agric. Econ.* 40(3): 111-22 S'72

2.7.2 Serials Published by Grower and Private Organizations

(a) Grower Organizations

Serial	Publishing Organization
Agricultural Review	Australian Primary Producers' Union
A/asian Bakers' & Millers' Journal	A/asian Bakers' & Millers' Assoc.
Australian Citrus News	Aust. Citrus Growers' Federation
Australian Grapegrower	Fed.Grapegrowers' Council of Aust.
Australian Sugar Journal	Aust. Sugar Producers' Assoc.
Australian Oil Seed Grower	Linseed Crushers' Assoc. of Aust.
Meat Industry Bulletin	Meat & Allied Traders' Federation
Producers' Review	Queensland Cane Growers' Association
Rice Mill News	Rice Growers' Co-op. Mills Ltd.

(b) Private Organizations

Serial	Publishing Company
Australian Food Manufacturer	Lawrence Pub. Co. Ltd.
Australian Country Magazine	Australian Country Magazine Pty. Ltd.
Australian Timber Journal	Australian Forest Industries Pty. Ltd.
Commonwealth Agriculture	Imp.Chem. Industries of Aust. & N.Z.
Commonwealth Fertilizers	C/w Fertilizers & Chemicals Ltd.
Fruit World	Fruit World Pty. Ltd.
Irrigation Farmer	Gardner Printing & Pub. Co.
Pastoral Review	Pastoral Review Aust. Pty. Ltd.
Power Farming	Agricultural Press Ltd.
Science Australia	Res. Publication Pty. Ltd.
Textile Journal of Australia	The Textile Industries of Australia.

2.7.3(1)Serials Published by Non-Agricultural Scientific Institutes and Societies Indexed by the *C.S.I.R.O.Science Index* 1959-1974.

Serial	Publishing Institution
Australian Geographer	Geographical Society of N.S.W.
Australian Geographical Studies	Institute of Australian Geographers
Aust.Journ. of Instrumental Tech.	Institute of Instrumentation & Control
Australian Physicist	Australian Institute of Physics
Aust.Refrig. Air Cond. & Heating	Aust. Inst. Refrig. Air Cond.& Heat.
Food Tech. in Australia	Aust.Inst. of Food Sci. & Tech.
I.E.S. Lighting Review	Illuminating Engineers'Soc. of Aust.
Inst.Foresters of Aust.Newsletter	Inst. of Foresters of Australia
Journ. Proceedings Royal Soc. N.S.W.	Royal Society of N.S.W.
Journ.Proceedings Royal Soc. W.A.	Royal Society of W.A.
North Queensland Naturalist	North Q'ld Naturalist Club
Papers Royal Soc. Tasmania	Royal Society of Tasmania
Plastic News	Plastic Instit. of Australia
Proc.Ecological Soc. Australia	Ecological Society of Australia
Proc. Royal Aust. Chem. Inst.	Royal Aust. Chem. Inst.
Proc. Royal Soc. Australia	Royal Society of Australia
Proc. Royal Soc., Q'ld	Royal Society of Queensland
Proc. Royal Zoological Soc.N.S.W.	Royal Zoological Soc. N.S.W.
Queensland Geographer	Royal Geographical Soc. Australia
Record Aust. Acad. Science	Australian Academy of Science
Reviews of Pure & Appl.Chem.	Royal Aust. Chem. Inst.
Search	A. & N.Z. Assoc. for Adv. of Science
Standards Assoc.of Aust.Stand.Spec.	Standards Assoc. of Australia
Trans. Royal Soc.S.A.	Royal Society of South Australia
Victoria's Resources	Nat. Resource Cons. League
Wildlife Australia	Wildlife Pres. Soc. Aust.

2.7.3(2) Total Number of Articles Indexed from Serials Listed in (1) Above.

Year	1959	'60	'61	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74
No.of Articles	6	1	2	5	4	2	2	3	3	6	10	11	7	9	6	3

2.7.4 Number of Articles Indexed from Non-Specialist Government Serials 1959 - 1974.

Journal	Publishing Institution	1959	'60	'61	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74
Animal Quarterly	Aust., Dept. of Health																1
Atomic Energy	Aust., Atomic Energy Com.								1			1					
Aust. Forest Research	Aust., Forest & Timber Bur.													4			
Aust.Journ. of Exp.Biol & Med.Science	University of Adelaide								1								1
Aust.Meteorological Mag.	Aust., C/w Bur. of Met.					1											
Aust. Natural History	Australian Museum	1															
Bulk Wheat	Grain Elevators Board of N.S.W.																4
Def.Standards Lab.Report	Aust., Dept. of Defence							1									
Forest & Timber	N.S.W. Forest Commission						1										
Health	Aust., Dept. of Health				1												
Living Earth	N.S.W.Soil Cons. Auth.							1			2			2			
Met.Bureau, Work.Paper	Aust., C/w Bur. of Met.						1	1									
N.S.W. Forest Com., Div. Res. Note	N.S.W. Forest Commission				1												
N.S.W.Soil Cons.Service, Journal	N.S.W.Soil Cons.Service	4	2	3	2	2		1	2	2		4		5	5	17	20
Pathology	Roy.Col.of Path of Aust.																1
Petrol Gazette	Petrol Info. Bureau								1								
Port Melb. Quarterly	Melbourne Harbour Trust					1											
Q'ld.Uni.Bot.Dept.Paper	University of Queensland							1									
Q'ld.Uni.Ent.Dept.Paper	University of Queensland			1													
Report, W.A.Govt.Chem.Lab.	W.A., Govt. Laboratory												1				
Res.Paper, Q'ld Dept.of For.	Q'ld., Dept. of Forests																1
Riverlander	Murray Valley Dev.League					6	4	1									
State Wildlife Adv.News Serv.	W.A.Dept.of Fish. & Fauna													1			
Tas.For.Com., Bulletin	Tas., Forest Commission													1			
Tech.Pap., N.S.W.Div.Wood Tech.	N.S.W.Forest Commission												1				
Vic.For.Com., Tech.Paper	Vic., Forest Commission	1	1	3	1												
Vic.Geol.Survey, Bulletin	Victoria, Dept.of Mines			1													
Vic.Soil Cons.Auth. Publ.	Vic., Soil Cons. Auth.					1											
Water Australia	Aust., Water Res. Found.																
W.A.For. Dept. Bull.	W.A. Forest Dept.																1
	TOTAL	6	3	8	5	11	6	6	5	2	2	5	2	13	5	17	29

2.7.5 Number of Articles Indexed from Non-Specialist C.S.I.R.O. Serials, 1959 - 1974.

Serial*	Year first published	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
Australian Journal of Biological Science	1948	5	1	1	3	1	6	2	5	6	2	4	6	2	4	9	
Australian Journal of Botany	1953					1				1		3	1	1	1	5	7
Australian Journal of Zoology	1953	1			1										1		
Australian Journal of Plant Physiology	1974																2
Ecos																	1
Industrial Research News	1957														1		

* Each serial was indexed in *The Index* for all years after they were initially indexed.

2.7.6 Notes Attending Table 2.6.

1. For the periods 1945/49-1948/52 and 1948/52-1951/55, the following serials are included:
   (a) Agricultural Gazette of N.S.W.
   (b) Journal, Department of Agriculture, South Australia
   (c) Journal, Department of Agriculture, Tasmania
   (d) Journal, Department of Agriculture, Victoria,
   (e) Journal, Department of Agriculture, Western Australia.
   (f) Queensland Journal of Agriculture
   (g) Queensland Journal of Agriculture and Animal Science
   (h) Australian Veterinary Journal
   (i) Journal, Australian Institute of Agricultural Science.

2. For the period 1951/55-1954/58, The Australian Journal of Agricultural Research is added to the list of included serials.

3. For the period 1954/58-1957/61, Dairyfarming Digest and Rural Research are added to the list.

4. For the period 1957/61-1960/64, Mallee Horticultural Digest and The Victorian Horticultural Digest are added.

5. For the period 1960/64-1963/67, the Cane Growers' Quarterly Bulletin, Technical Communication, Qld. Bureau of Sugar Expt. Stations, Various C.S.I.R.O. Technical Bulletins, Various State Agricultural Papers and Bulletins, and Wool Technology and Sheep Breeding are added to the list of included serials.

6. For the period 1963/67-1966/70, The Australian Journal of Soil Research and the Australian Journal of Experimental Agricultural and Animal Husbandry are included.

2.7.7 Information Relating to Table 2.8

The following provides a list of the divisions and sections which underlie the totals presented in Table 2.8. Those listed represent only the major divisions and sections, in many cases these have become divided into a greater number of sub-groups over time, nevertheless, they still reflect the major components of the various Departments.

1. NEW SOUTH WALES

The following divisions are included in the totals.

(a) Division of Animal Industry.
(b) Division of Dairying.
(c) Division of Horticulture.
(d) Division of Plant Industry.
(e) Division of Science Services.*
(f) Division of Research Services.

* In 1972 and 1975, this Division appears under the name of the Biological and Chemical Research Institute.

The *C.A.B.List* provides information on the Division of Extension Services, the Division of Marketing and Economics and the Royal Botanical Gardens and National Herbarium; these have been omitted from the present study.

2. QUEENSLAND

The following divisions are included in the totals.

(a) Division of Animal Industry*
(b) Division of Dairying
(c) Division of Plant Industry**

* The Slaughtering and Meat Inspection Board totals are omitted from the Division of Animal Industry for 1966-1975, the years when it appears in the *C.A.B. List*.

** The Food Preservation Research Branch of the Division of Plant Industry is subtracted when it appears in the *C.A.B. List* in 1962-1969.

Two further divisions included in the *C.A.B. List*, are the Division of Marketing and the Division of Land Utilization (formerly the Division of Development Planning and Soil Conservation). The latter Division is omitted because it is not considered to represent biological scientific activities, a major proportion of the Division being employed in the Development Planning Branch.

3. SOUTH AUSTRALIA

The following branches are included in the totals:

(a) Animal Health Branch
(b) Livestock Branch
(c) Dairy Branch
(d) Soils Branch
(e) Horticulture Branch
(f) Agronomy Branch
(g) Research Centres Branch.

The above segmentation appears in the List from 1962 onwards. In fact, the branches existed throughout the period 1945-1975 but for some time during the 1950's and early 1960's, these were grouped into two divisions, the Plant Industry Division and the Animal Husbandry Division.

The *C.A.B.List* also included the Extension Services Branch and the Agricultural Economics Section; these are omitted from the present study.

4. TASMANIA

The following divisions are included.

(a) Agronomy Division
(b) Animal Health Service*
(c) Dairy Division
(d) Entomology Division
(e) Horticultural Division
(f) Plant Pathology Division

* Known as the Veterinary Division 1947-1953.

Omitted from the *C.A.B. List* are the Extension Service and the Agricultural Economics Section. Also the Piggery Section and the Sheep and Wool Section are omitted. The Piggery Section had only one person assigned to it in each year while the Sheep and Wool Section was not entered on a continuing basis; it also had only two to three people assigned to it.

5. VICTORIA

Divisions making up the totals are:

(a) Victorian Plant Research Institute*
(b) Division of Agriculture
(c) Division of Chemistry
(d) Division of Animal Health**
(e) Division of Animal Production**
(f) Division of Dairying

(g) Division of Horticulture.

* Up to 1962 was named the Biology Branch.

** For years prior to 1969, these two divisions were combined as the Livestock Division.

The Division of Agricultural Education was included in the *C.A.B. List* but is omitted here.

6. WESTERN AUSTRALIA

The following divisions are included.

(a) Animal Division
(b) Biological Services Division
(c) Dairy Division
(d) Horticultural Division
(e) Soils Division*
(f) Plant Research Division
(g) Wheat and Sheep Division**

* Prior to 1959 was known as the Soil Conservation Division.

** From 1966, the Sheep & Wheat Division was segmented into sections, one of which was an extension section; this was deleted.

2.7.8 Omitted State Institutions.

The following explains why the three 'other state institutions' have been omitted from the present study.

1. Soil Conservation Service of N.S.W.

This service is a section of the N.S.W. Conservation Department and carries out its activities mostly through its district field offices. Some of these offices have research stations attached to them which employ research officers. However, an investigation of the works programme of the Soil Conservation Service indicates that its work is only marginally related to agriculture. In the 1969/70 Annual Report of the N.S.W.Conservation Authority the following items appear in the 'Proposals Considered by the Conservation Authority 1969/70'

1. Coastal Sand Drift Experimental Areas.
2. Experimental Roadside Erosion Control.
3. Works Programme - Summit Area (Kosciusko National Park)
   - Foreshore Protection.
4. Rabbit Eradication by Aerial Baiting.
5. Burrendong Foreshores Access Road.
6. Catchment to Lake Burley Griffen.

[Conservation Authority of N.S.W., 21st Annual Report, 1969/70, Appendix 5, p.30].

Reference to other Annual Reports of the Authority reveal that the 'Proposals have remained very similar over time. It would appear from the above list that the research activities of the Soil Conservation Authority are centred on coastal sand drift and roadside erosion problems. These activities would have negligible effects on total agricultural activity.

2. Victoria Soil Conservation Authority

Similar reasons to those described for the N.S.W. Soil Conservation Authority prevail in the case of the Victorian counterpart. The Victorian body has three major divisions; a Research Division, Field Division and an Engineering Division. The activities of the Research Division which are of primary concern here are to undertake Soil, Ecological and Land Use surveys, Geomorphological Studies, Conservation Hydrology and Conservation Agronomy. These are not directly agricultural in pursuit except perhaps for Conservatio Agronomy, a section which has had a maximum of two researchers in any edition of the *C.A.B. List* since 1959. The subsequent omission of those sections is unlikely to bias the results of the study.

3. Victoria, State Rivers and Water Supply Commission

This institution is not included here because it is believed that it does not undertake biological type agricultural research. Dunk [1961, p.1] says that

> 'Scientists and agricultural scientists have been associated with many Commission problems and activities including:
> Groundwater Hydrology and Drainage,
> Efficient Use of Water Supplies,
> Channel Maintenance,
> Advisory Services to Irrigators.'

2.7.9 Information Relating to Table 2.13.

The following provides information on the various faculties and departments making up the total in Table 2.13.

1. The University of Adelaide

These totals are made up from the total staff in the following Departments of the Waite Agricultural Research Institute.

(a) Department of Agricultural Biochemistry and Soil Science.
(b) Department of Agronomy.
(c) Department of Animal Physiology.
(d) Biometry Section.
(e) Department of Entomology.
(f) Department of Plant Pathology.
(g) Department of Plant Physiology.

Each department was in existence from 1947 except for the Department of Animal Physiology and the Biometry Section which were initially included in 1966.

2. The University of New England

These totals are derived from the total staff in the Faculty of Rural Science which was established in 1956. It is made up of the following departments.

(a) Department of Agronomy & Soil Science.
(b) Department of Biochemistry and Nutrition.
(c) Livestock Production (formerly Livestock Husbandry)
(d) Department of Microbiology and Genetics (formerly Agricultural Biology)
(e) Department of Physiology.

The Departments of Biochemistry and Nutrition, and Microbiology and Genetics were established in 1961 and 1966 respectively. They first appeared in the *C.A.B. List* in 1962 and 1969 respectively.

3. The University of Queensland

The totals here are made up from the Department of Agriculture and the Veterinary School. The figures here are supplemented by information from the *Commonwealth University Year Book.*

4. The University of Sydney

These totals are the sum of staff members in the Faculty of Agriculture and the Faculty of Veterinary Science. The Faculty of Agriculture is made up of the following departments.

(a) Department of Agricultural Botany.
(b) Department of Agricultural Chemistry.
(c) Department of Agronomy and Horticultural Science.
(d) Department of Animal Husbandry.
(e) Department of Microbiology.
(f) Department of Soil Science.
(g) Department of Zoology.

5. The University of Melbourne

These totals are made up from the staff members of:

(a) The School of Agriculture.
(b) The Veterinary Research Institute.
(c) The Faculty of Veterinary Science which consists of:
    (1) The Department of Clinical Sciences,
    (2) The Department of Paraclinical Sciences,
and (3) The Department of Preclinical Sciences.

The Faculty of Veterinary Science was established in 1964 as were the three departments. The other two inclusions were in existence throughout the period from 1945.

6. La Trobe University

The School of Agriculture was established in 1968. Within the School, three areas are recognized; animal sciences, plant-soil sciences and agricultural economics. The totals contained in Table 2.13 are made up of the first two areas.

7. The University of Western Australia

For the period 1947-1962, the totals are the number of people in the Institute of Agriculture. The Institute lost its identity in 1970 and is succeeded by the following Departments:

(a) Department of Agronomy (est. 1967)
(b) Department of Animal Science & Production (est. 1970).

(c) Department of Soil Science & Plant Nutrition (est. 1963), and

(d) Department of Agricultural Economics which has not been included.

8. The University of Tasmania

These totals are gained from members of the Agricultural Science Department which was established in 1962, but did not appear in the *C.A.B. List* until 1966.

CHAPTER 3

AN EVALUATION OF THE DISTRIBUTION OF AGRICULTURAL RESEARCH ACTIVITY IN AUSTRALIA; 1955 - 1965.

3.1 Towards a Model of Research Evaluation.

3.1.1 Introduction

In the introduction to chapter 2, it was indicated that an investigation would be made of the factors determining the mix of research activities among different commodity groups. The following procedure will be adopted. Initially an outline will be made of the difficulties associated with the determination of the optimum allocation of research resources (activity). Within the constraints of these difficulties an attempt will be made to establish a conceptual model which will indicate appropriate criteria for evaluating the mix of research activities among different commodities. Use will then be made of this model to determine the implicit allocation rules underlying the allocation of research resources in Australia during the late 1950s and early 1960s.

3.1.2 The Allocation of Resources to Research

Allocation puzzles arise from the necessity to make a choice. The need to make choices in research activity stems from the fact that the opportunities to add to the stock of knowledge are practically unlimited, whereas the amount of resources available for exploiting these opportunities is relatively limited. The nature of the allocation problem is described by Nelson. [1959, pp.297-298].

> From a given expenditure on science we may expect a given flow, over time, of benefits that would not have been created had none of our resources been devoted to basic research. This flow of benefits (properly discounted) may be defined as the social value of a given expenditure on basic research. However, if we allocate a given quantity of resources to science, this implies that we are not allocating these resources to other activities and, hence, that we are

> depriving ourselves of a flow of future benefits that we could have obtained had we directed these resources elsewhere. The discounted flow of benefits of which we deprive ourselves by allocating resources to basic research and not to other activities may be defined as the social cost of a given expenditure on basic research. The difference between social value and social cost is net social value, or social profit. The quantity of resources that a society should allocate to basic research, is that quantity which maximizes social profit.[1]

To maximize the social profit from research presents considerable problems. As has already been seen (section 2.1.1), the product of research has public good characteristics and as a result the economic value of the output is difficult to appropriate. This means that much of the output of research is not priced or traded in a market situation. Arrow [1962, pp.609-610], noting these characteristics of the research process, concludes that they violate the conditions necessary for optimal resource allocation and that the free enterprise system is likely to under-invest in research as compared to a Paretian ideal. It was also stated in 2.1.1 that, in cases where it is difficult to appropriate the value of research, for example in biological research, the research was likely to be undertaken by public institutions. Thus, for purposes of allocation analysis, the flow of benefits stems from both private (profit orientated) and public (non-profit orientated) institutions. If we accept the claim by Evenson that most research is concentrated into the production of 'intermediate' products which are less appropriable than 'final' products, then we would expect a large proportion of research to be undertaken by public institutions. [Evenson, 1971, p.166]. As we are concerned with the research activities of public institutions, then we are confronted with an analysis of resource allocation in a system characterized by an inefficient, or non-existent price system.

When analysing any allocation problems, a number of decision areas emerge. Gilchrist [1971, p.3] identifies these in relation to

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1 A similar view of the allocation problem is given by Peterson [1967, p.1434].

agricultural research as follows,

> At the highest level, decisions are made on the total resources allocated to agricultural research and alternative uses of those resources...At a lower level decisions are made on allocations to major disciplines, such as biological sciences, social sciences and physical sciences which compete for resources... Within say, the biological science, plant science, animal science, entomology compete. Within the plant science, there is wheat research, barley research, alfalfa research etc. And within wheat research, there are numerous projects competing for research resources.

At the 'highest' decision level, the optimum allocation of resources to research would occur when the following marginal principles were being satisfied. That is, the optimal amount of resources devoted to research would be that which would yield a marginal rate of return on all investment in research equal to that which is earned in other forms of investment. Quite clearly, the pursuit of this condition is beset with many difficulties. For example, one would need to know how quickly diminishing returns set in in research activity, and the extent to which increased expenditures on research increases research effort or merely results in the bidding up of scientific personnel salaries. Clearly, a number of reasons make it difficult to establish the returns from increased expenditure on research.

At the next level of decision making, similar difficult problems emerge regarding the optimal allocation of resources. That is, when decisions are made regarding the allocation of resources among different research fields, a further set of difficult questions emerge. Johnson [1968, pp.169-170] lists the following

> What have been the social rates of return on past investments in basic scientific research, for particular research projects, and on average? How likely are particular proposed lines of research to produce new contributions likely to be in relation to their cost?

To achieve an optimal allocation with respect to both the 'decision' levels just mentioned, would require answers to at least the above questions. To get answers to these questions, Johnson [1968, p.169] contends that we

> ...would require calculations of an extremely difficult sort, probably impossible to effect with any reliable degree of accuracy - calculations that have so far not been attempted on any substantial scale.

The above discussion suggests that an evaluation of the allocation of research resources among different research fields is beset with difficulties when the traditional economic rules of allocation are strictly adhered to. The question then arises as to how we might make an attempt to evaluate the efficiency of research allocations by departing from the strict marginalist approach of economic theory.

As a starting point, consider the market system for material goods where the social value of the good is reflected by its price (presumably); this price being determined by interacting supply and demand considerations. If resources are being optimally allocated between the production of two goods and then the price of the one good rises relative to the other, then *ceteris paribus*, more resources will be shifted into the production of the activity experiencing the relative price increase. Thus a shift in either (or both) supply or demand conditions will provide signals directing more or less resources into one or another activity. This analysis applies also to the efficient distribution of a given amount of research resources; both supply and demand forces are important in determining the direction which research activities should follow.

Let us first discuss the influence of supply factors on the direction of research activities. One of the most recent contributions analysing the role of supply conditions in influencing the direction of inventive activity is Rosenberg [1974]. Opposing Schmookler's claim that demand conditions are the decisive determinants of inventive effort, Rosenberg claims that if it can be shown that

(i) science and technology progress, in some measure, along lines determined either by internal logic, degree of complexity or at least in response to forces independent of economic need;

(ii) this sequence in turn imposes significant constraints or presents unique opportunities which materially shape the direction and timing of the inventive process;

(iii) as a result, the costs of invention differ in different industries; then supply considerations should be discussed as important determinants of the direction of inventive effort. [Rosenberg, 1974, p.95].

This sequence of events is to some extent supported by scientific historians. Evidence by Price, [1963, pp.17-18], for example, suggests that the growth of knowledge in a particular field conforms to a logistic trend; at any point in time a discipline may be at a different stage of development.

Rosenberg extends his analysis to an analysis of supply conditions. That is, as 'scientific knowledge grows, the cost of undertaking any given science based invention declines - from infinitely high, in the case of an invention which is totally unattainable within the present state of knowledge, down to progressively lower and lower levels.' [Rosenberg, 1974, p.107]. Thus, Rosenberg claims, the growth in scientific knowledge itself leads to a gradual decline in the costs of achieving further advances in knowledge. To trace the influence of the current 'state of the arts' on the supply function of research output would involve a study of the growth of output of knowledge in particular disciplines and to relate this growth to per unit costs. To the extent that unit costs of output decrease *over* time, and to the extent that at a *point* in time, different disciplines are experiencing different rates of growth in knowledge, then the 'pool of knowledge' hypothesis advanced by Rosenberg could be tested.

The first two forces listed by Rosenberg closely coincide with the proponents of the 'Republic of Science' who argue for the case of scientific autonomy. Weinberg [1963, p.16] distinguishes between 'internal' and 'external' criteria for scientific choice. According to Weinberg, 'internal' criteria stem from within the field of science and relate to two questions,

(i) Is the field ready for exploitation?

(ii) Are the scientists in the field really competent?

These questions are also implicitly contained in the arguments for scientific autonomy advanced by Polanyi [1962, pp.54-5] who states that

> ...the activities of scientists are in fact co-ordinated... this [co-ordination] consists in the adjustment of the efforts of each to the hitherto achieved results of the others... Their co-ordination is guided as by an invisible hand... [and] the total performance will be the best if each corrective step is decided upon by the person most competent to do so.

Quite clearly, Weinberg's 'internal' criteria relate to supply considerations and closely resemble the arguments put forward by Rosenberg.

Of Weinberg's 'external' criteria, two are predominantly supply orientated. 'Technological merit' as a criterion for scientific choice manifests itself as follows. If a technological end is 'worthwhile' (an elusive concept which is not really defined) then '...we must support the scientific research necessary to achieve that end', even though the relevance of this research is not always clearly evident. The other supply orientated 'external' criterion is 'scientific merit' which is a measure of the contribution and illumination which a particular field of science provides to neighbouring scientific disciplines. According to Weinberg, this judgement is best made by judges (scientists) in the neighbouring fields rather than from within the generating field.

The third 'external' criterion which Weinberg advances is that of 'social merit' or the 'relevance to human welfare and the values of man.' The difficulties of clarifying this criterion are outlined by the author but he makes no attempt to distinguish it from the supply orientated criteria. For example, on the question of national prestige which is seen as a social value, Weinberg contends that

> Whether or not a given achievement confers prestige probably depends as much on the publicity that accompanies the achievement as it does on its intrinsic value.
>
> [Weinberg, 1963, p.166]

The suggestion here is that social merit derived after a scientific achievement has been effected. The role of society in 'demanding' the achievement appears to be neglected.

Implicit then, in the arguments of proponents of the autonomy of science are supply considerations. Whilst these considerations should not be ignored in determining the allocation of scientific resources, they nevertheless should not be the sole determining factors. As argued above, *both* supply and demand forces are relevant. Whilst Rosenberg's paper concentrates on supply forces, he is aware of the need to consider demand forces. He is merely claiming that Schmookler's reliance on demand factors to explain the direction of inventive activity is not telling the whole story.

Turning now to the demand for new knowledge, two classes may be identified. First we may identify the demand for knowledge for its 'own sake', that is, the demand is for knowledge as an end in itself. So viewed research can be viewed as a consumption activity.[2] Pointing to this aspect of research, Williams [1968, p.104] states that

> Research may be undertaken for purely scientific interest, and happen to have no spillover to industry and agriculture. Such results should be thought of not as investment which will generate economic growth, but as consumption.

Whilst society (funding bodies) would probably support some research of this nature, this conception of research does not allow us to view research as an input into the development process.

A second conception of the demand for research is the view that knowledge is demanded for the 'contributions it makes to the attainment of other ends'. That is, the production of knowledge is viewed as an investment which becomes instrumental in attaining a wider set of goals and objectives. As Kaldor [1966, p.1634] says,

> ...the demand for new knowledge is a derived demand, derived from the contributions which it is expected to make to the achievement of individual and collective wants.[3]

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2 This distinction is advanced by Kaldor [1966, p.1634].

3 This view would also seem to be taken by Evenson who states that 'the research and extension effort does not produce improved allocative decisions or water techniques directly; it simply produces the elements of information that enter into the entrepreneur's decisions.' [Evenson, 1971, pp.164-165].

This view of the demand for knowledge has more meaningful ramifications for allocation decisions than the first mentioned in a situation where the opportunities to add to the stock of knowledge are practically unlimited, whereas the amount of resources available for exploiting these opportunities are relatively limited. We turn now to a discussion of the relevant goals for agricultural research.

3.1.3 Goals for Agricultural Research

The first question which arises is which goals are the relevant ones in determining the direction which research should take. In an evaluation of the research activities of the Iowa Research Experiment Station 'it was decided that the goals that should guide station research should be those held by the supporting public.' [Kaldor and Paulson, 1968, p.1153]. This view derives from public sector theory as Merrill [1962, p.429] summarizes:

> ...government agencies are usually concerned with developing that kind of support and influence which is helpful both in the bargaining within and between government departments during the budget making period and in the political processes of getting legislative support for their programmes and the appropriation of funds to support them.

McKeen elaborates on the bargaining process within government agencies pointing out that a public official will bear a cost if his action is damaging to certain interests; that is, he will have to bargain with affected bodies. Similarly, if a public official takes action resulting in benefits to certain interests, then he can bargain for compensation. In essence, 'every decision or action involves bargaining tacit or explicit.' Extending the bargaining process to the allocation of resources within a public body, this bargaining process may generate a 'feeling' of gains and costs in view of 'crude shadow prices' which emerge from the bargaining process. [McKeen, 1965, pp.498-500].

Whether these 'shadow prices' emerge more efficiently when research organizations are subjected to research planning or when scientists within such organizations have complete autonomy, has been a subject of considerable debate. The views of the proponents of scientific autonomy rest quite squarely on the concept of peer review. Hildreth [1966, p.1648] noting that salary and status depend on professional reputation, asserts that '...a professor's goal, in the extreme case, is to obtain a good reputation quickly, and he will work on problems that he thinks are important and relevant to the profession'. That is, 'invisible hand' forces will direct research activities in the most socially desirable directions. Lindner [1976, p.14] summarizes the views of 'invisible hand' proponents as follows:

> Proponents of the *laissez-faire* solution to accountability implicitly assume that the scientific community does value social relevance (as opposed to the advancement of human intellectual activity for its own sake) and that the incentive mechanisms provided by peer review faithfully reflect society's priorities.

The proponents of the view that research activity will be more efficiently guided to socially relevant areas when subjected to a research planning system contend that 'peer group' forces in fact have several deficiencies in guiding research activities. These deficiencies are documented by Lindner [1976, pp.14-16] and relate to such things as the lack of relevance in particular fields of research, inadequate training of scientists and the lack of information necessary for the identification of social goals, the bias towards 'basic' research resulting from pressures to publish and the tendency of institutions free to pursue both 'basic' and 'applied' science to concentrate on 'basic' work.

Given these deficiencies of the 'invisible hand' in the generation of 'shadow prices', arguments have been forwarded asserting that research techniques which seek to develop the environment in which research is undertaken and therefore encompass decisions about the type and direction of research activity may improve the efficiency of the distribution of research resources. That is, it is argued certain planning techniques may result in net gains in the allocation of research measures given the particular advantages and disadvantages of particular planning methods.

It is not our intention to argue the relative merits of these opposing views, however both adhere to the view that research activities should be guided into socially relevant areas. If this can be interpreted as meaning that research activities will be responsive to the policies of the supporting government, then the stance taken by the Iowa review would seem to be acceptable. This view was also advanced by Walsh [1970, p.41] at a recent O.E.C.D. meeting in Paris.

> ...objectives for agricultural research are set within the context of national socio-economic policy as a whole

More specifically, the relevant goals for agricultural research would relate to the role played by agriculture in the context of overall economic policy. Research activity would then be evaluated in terms of its contribution to these goals.

We have already seen that research is not an homogeneous activity, it transcends a number of disciplines and subject areas. As a result, 'different research activities offer different opportunities to contribute to various social goals.' This highlights the need to specify goals in an operational and objective way. To undertake this task, it is useful to adopt a method used in the United Nations' Report 'Economic Planning in Europe' [1965]. The tasks suggested here are

(i) determination of the major economic goals and their relative priorities,

(ii) expressing these goals in a complex of explicit, consistent and quantified targets, and

(iii) choosing and applying the measures which according to the analysis, offer the possibility of realization of the targets and goals.

The third task is more relevant to a planning context rather than an evaluation measure and as such is not discussed in detail.

In general, economists have identified three economic goals, [Stigler, 1975, p.284] summarizes these as follows:

> Three goals have long dominated economic policy in this country and in the Western world. The first and most ancient goal is the largest possible output of goods and services...The second goal is the growth of the economy... The last primary goal of economic policy is a comparative newcomer. It is the reduction of income inequality.[4]

With regard to the first goal, Stigler contends that it has evolved into a 'two-pronged' goal, that is, to employ as fully as possible society's available resources and to use those resources as efficiently as possible. In the Iowa study referred to above, three general goals were specified, these included two of those mentioned above, mainly growth and equity but they also included a further goal, 'security', which was defined as 'the protection of life, health or well-being of individuals, groups or states.'

How should the goal of security be interpreted? As defined, this is not an 'economic' goal as economists have traditionally viewed policy goals, but as McCulloch and Johnson [1973, p.726] point out:

> ...we should not overlook the possibility that certain non-economic objectives are truly public goods which provide sufficient collective utility to the majority to justify their costs in terms of foregone consumption.

It is in the area of these 'non-economic' goals where Cassidy and Kilminster believe that economists have been deficient in their analyses of public policy. For example,

> In the heavily criticized field of agricultural policy..., much can be explained once the position is taken that income transfers to rural producers are a major objective. In other words, here efficiency is not as basic a goal as equity, security, or other goals.
>
> [Cassidy and Kilminster, 1975, p.17]

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4 Cassidy and Kilminster [1975, p.15] present a narrower but nevertheless similar view to Stigler, of the goals of economic policy: 'Traditionally economists have placed an over-whelming emphasis on the single objective of economic efficiency, with in limited cases, some acknowledgement that equity questions should be weighed.'

The goals referred to in the Iowa study would seem, therefore, to represent a useful starting point for an evaluation of public sector research; that is, they incorporate the major economic goals recognized by economists and they incorporate, not unjustly, a 'non-economic' goal. As a basis for evaluation, the goals were defined as follows:

(i) Growth - the increased capacity to satisfy people's wants (both individual and collective).

(ii) Equity - a fair or just sharing of things available to satisfy human wants.

(iii) Security - the protection of life, health or well-being of individuals, groups or states.

[Mahlstede, 1971, p.330][5]

These goals are separated conceptually, however, in practice conflicts between goals may arise. That is, goals may be competitive rather than complementary. Whilst recognising these three broad goals, the Iowa study initially concentrated on the expected contributions of research to economic growth. Equity was not included 'because of the difficulty of measuring the research contribution to equity' while security was included to the 'extent that food safety was not to be lessened as a function of growth'. In the view of the evaluators, 'the promotion of growth undoubtedly has been the most emphasized goal of agricultural research'. [Mahlstede , 1971, p.330].

These broad goals will now be discussed in the light of the possible contribution biological research might make to their attainment. The discussion will highlight the *possible* effects that research might have on the attainment of the various goals. We are not suggesting that research is necessarily the most efficient way of pursuing these goals.

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5 See also Hartley [1943, p.164]. Hartley says that agricultural research should have the following three objectives which are analogous to the Iowa goals.
(i) to increase national income,
(ii) to stabilize incomes through stabilizing yields,
(iii) to improve income distribution.

3.1.3(a) <u>Growth</u>

Broadly interpreted, we may identify economic growth as a 'sustained increase in a nation's total and *per caput* product.' At the most fundamental level, agriculture may contribute to economic growth by the growth of product within agriculture.

> An increase in the net output of agriculture, in and of itself, represents a rise in the product of a country - since the latter is the sum of the increases in the net products of the several sectors. This type which we may call the product contribution, can be briefly examined - as a contribution first to the growth of *total* net or gross product, and second to the growth of product *per caput*.
>
> [Kuznets, 1961, p. 59]

The role played by research in this contribution can be described as follows. Research findings, when embodied in production techniques, increase the productivity of existing resources, raise total output and reduce resource costs. It is now necessary to discuss more specifically the ways in which agricultural research might contribute to economic growth.

As a starting point, it is useful to investigate the ways in which agriculture may contribute to economic growth in a more precise manner. Following Johnston and Mellor, we can distinguish five ways in which agriculture could possibly contribute to overall economic growth.

(i) by providing food supplies in line with increased demand for agricultural products,

(ii) by increasing income and foreign exchange earnings,

(iii) by providing labour for manufacturing and other expanding sectors of the economy,

(iv) by making a net contribution to the capital required by secondary industry,

(v) by demanding and hence providing a stimulus to industrial expansion.

[Johnston and Mellor, 1961].

Several comments can be made with regard to this classification. First, because of the complex set of interactions which exist between the agricultural and non-agricultural sectors, it is a difficult task to actually quantify these contributions. Secondly, just as agriculture as a whole displays a secular decline in the share of a country's G.N.P., so also do each of the contributing factors. However, at a point in time the factors will display different levels of relative importance and over time, these relative positions will change. This point, the changing relative importance of the contributions is important for the present analysis. In order to ascertain the role the contributions are performing at a point in time and over time, it would seem necessary to analyse domestic agricultural policy. This would be required because different countries display different patterns of development (due, for example, to different resource endowments *etc.*) making it difficult to make *a priori* judgements about the relative contributions.

For purposes of illustration, let us assume that a policy analysis revealed that during a certain period imports had reached a level which could not be sustained by the present levels of foreign exchange earnings, and also that population was growing quickly threatening to lift the level of imports even further (as was the case in Australia in 1951/52). Under these circumstances, it was the major aim of general economic policy to undertake programmes to expand the export sector. In Australia, where agricultural products enjoy a comparative advantage, a call to increase exports will invariably result in a call for increased agricultural production.

In the case (period) where the expansion and development of export goods is a high priority goal of agricultural policy what can be said about the direction of agricultural scientific research? It might be that an increased proportion of available research funds should be directed towards products which at the time would appear to have the greatest export potential; that is, towards those products which would seem to have an expanding world market and those which would appear to have a comparative advantage in the domestic economy. However, these are not clear cut observations and will be dependent upon institutional arrangements *vis-à-vis* the exchange rate. For example, if the exchange rate is continually over-valued then some products which would otherwise have export potential will not be regarded as significant export earners. Again, as Duncan [1972, p.83] observed,

> ...given that the balance or payments is of some concern, in short that the country's currency is over-valued, the problem can be rectified by means other than increasing exports, e.g. by devaluation. The probability that research into the problems of large export industries - or any export industries - is the most efficient way to achieve an improvement in the balance of payments is low.

With regard to growth, if this be the broad goal under consideration, then *ceteris paribus,* research should be directed towards those products which are relatively most important in their contributions to overall economic growth as identified by the growth policy being pursued by the government. Ordinarily the relative importance of these will be contained either implicitly or explicitly in the government's agricultural policies.

3.1.3(b) <u>Equity</u>.

We turn now to the second goal considered in the Iowa study; that of equity, which was defined above as meaning a 'fair or just sharing of things available to satisfy human wants.' Being more specific, it is possible to identify the following two aspects of equity problems which will be considered in turn:

(i) the distribution of the benefits of technical change between the producer and consumer;

(ii) the distribution of personal income among rural groups.

With regard to the distribution between producers and consumers, the following argument is normally advanced.

> Since there are few farm products with price elasticities greater than unity, the direct short-run effect of rapid increases in output is lower food costs for consumers and, unfortunately, reduced revenues for the farm industry.
>
> [Heady, 1971, p.124]

That is, increases in the supply of agricultural products tend to lead to proportionate decreases in price which are larger than the relative increases in output, resulting in a decline in agricultural income. The price decreases, however, represent an increase in the real income of consumers with a proportionately greater increase to low income groups who spend a high proportion of their total income on food.

This distribution effect does not necessarily hold for all agricultural products. For example, some export products of a particular country may only represent a small portion of total world supply, in which case, the demand for those products would tend to be relatively elastic. In such cases, the benefits of output increasing research will be reaped by producers. Within the agricultural sector, there will be a shift in the distribution of agricultural income towards the producers of export commodities. Also, it is conceivable that at different stages of development, some specialty type goods (e.g. beef) will have an elastic domestic demand; again in these cases, producers will reap gains of output increasing research.[6]

In the case of these goals, the contribution made by agricultural research can be visualized as follows. If incomes in agricultural sectors have fallen behind those in the non-agricultural sectors and it is thought desirable to reduce this gap, then research effort might be directed towards those products which have an elasticity of demand greater than unity. If this problem is not one of concern, it may be that policy makers are more concerned with the overall distribution of income which might be a signal to direct research resources into those products with an elasticity of demand less than unity. The resultant decline in price of these commodities will give relatively more benefits to low income groups.

Turning now to the second mentioned aspect of the equity problem; the effect of the research effort on the distribution of income

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6 For a detailed analysis on the distribution of gains from research see Duncan and Tisdell [1971] and Lindner and Jarrett [1976].

among farmer groups. New technology emanating from research activity invariably involves an act of investment by the adopting farmer. One might postulate that relatively larger holdings subject to less capital rationing (both internal and external) will be more able to reap the benefits of new technology. This can have a further adverse effect on small holders who may face a lower price as a result of the increased output forthcoming from holdings having adopted the new technology.

Whilst this redistribution would seem to be more relevant to the cases of 'lumpy' inputs such as farm machinery, it nevertheless could still be a relevant consideration for 'biological' inputs. As De Janvry [1973, p.416] points out, new 'biological' inputs tend to emerge in 'packages' - a new seed variety requires a different fertilizer input *etc.* Thus the introduction of a new seed may require increased investment in fertilizers and chemicals which may once again discriminate against the small holder.

It is rather difficult to assess the contribution of agricultural research to this aspect of distribution effects resulting from new technology. A possible outcome of the re-distribution effect is that as the income position of the small holder continues to worsen, the climate for a release of labour from the farm to the non-farm sector is enhanced. If then, policy makers are concerned with the need to 'reconstruct' certain industries then increased research in these areas could yield technologies which would eventually bring greater pressure to bear on marginal producers to leave the industry. Again, it is difficult to establish that research policy aimed at this end is necessarily a more efficient policy tool than say, the payment of subsidies or some other form of transfer payment.[7]

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7 The analysis of Duncan and Tisdell [1971] suggests limitations on productivity increasing research to effect changes in the distribution of income.

3.1.3(c) Security

In the Iowa study security was defined as the protection of life, health, personal liberties, income and property from risk or loss not associated with the due process of law. For the purpose of formulating directions for research policy, it is necessary to be more explicit regarding the nature of security. In particular, security will be regarded as being determined by the risk and uncertainty which a body (either individual or collective) faces. That is,an act which reduces risk and uncertainty will be viewed as one which increases security.

In agriculture, questions of risk and uncertainty would seem to revolve around two major components both outside the control of farmers, these being variations in yield and variations in price. With regard to variations in yield, uncertainty is manifested in the sense that a farmer cannot predict his output from a given set of inputs. The major reasons for these variations stem mainly from the dependence of agricultural yields on such things as climate, insects, diseases *etc.* A further point regarding these uncertainties is that these variations will likely differ among products and regions.

These sources of uncertainty can be felt in several ways. First the variations may impose shocks on the economy through the export sector. If this is the case, then research might assist the diversification of the export sector. This will involve similar considerations as those outlined above in the section on growth, i.e. a search for additional products in which the country may have a comparative advantage. Secondly, shocks may be imposed on the economy through instability in the domestically-oriented section of agriculture. In this case, research may help relieve the problem by developing techniques which might reduce yield instability. Campbell [1958, p.8], commenting on the belief that drought is overwhelmingly a technical, rather than economic problem, says that a scientific attack on the problem may take either of two forms.

(a) the achievement of greater adaptability of plants and animals by introduction or breeding,

(b) modification of the environment by such measures as irrigation, new tillage methods or weather modification.

3.1.4 Summary.

Scientific research has been viewed as a production process which incorporates the use of scarce resources. This means that questions of resource allocation are relevant. Resource allocation decisions are made on the basis of supply and demand considerations; in this section more emphasis has been placed on the role of demand factors in determining the allocation of scarce scientific resources. In particular, it is the derived demand for research output to satisfy collective wants which is considered most relevant. It is argued that the direction of research activity should be such that the net benefits of that activity are in accordance with the goals of domestic agricultural policy. It is implicitly assumed that agricultural policy is designed to contribute to the overall economic goals being pursued by the government of the day.

As a basis for discussion the relevant goals were considered to be growth, equity and security. It was shown that, when considered separately, research output may contribute towards the attainment of these goals. However, two problems emerge with regard to the use of research as a policy instrument to achieve these goals.

First, as indicated in the preceding section, it does not necessarily follow that research policy is the most efficient policy instrument at a government's disposal to try and attain these goals. Secondly, the use of research policy to attain one goal may result in conflicts with regard to the pursuit and achievement of other goals. Hartley [1943],for example, recognized that research aimed at increasing total product may serve to expand existing income inequalities. Research results might, for instance, apply differently to different areas creating disproportionate income gains to producers in different areas. If prices of some commodities fell as a result of increases in productivity, farmers in areas which did not gain from the particular research output will suffer a fall in income relative to other groups, both farm and non-farm.

In the following sections of this chapter, an attempt will be made to establish the goals of agricultural policy in Australia for the period 1955-65. An empirical investigation of the distribution of research resources on a commodity basis will then be made utilizing publication data. This distribution will be evaluated in relation to the existing policy goals. A further analysis will be made on the effects of this distribution on the instability and growth of yields in subsequent years.

3.2 Goals of Australian Agricultural Policy 1955 - 1965.

3.2.1 Introduction

In section 3.1, it was argued that research activity could be evaluated in terms of its contribution towards 'attaining a wider set of goals and objectives' and that the goals and objectives should reflect those 'held by the supporting public.' It was also argued that these goals could be identified by an analysis of domestic agricultural policies being pursued by the government of the day. The Iowa research evaluation study defined three major goals; growth, equity and security. In this section, an attempt is made to identify the goals of the Australian Government's agricultural policy for the period 1955-1965.[1]

The choice of this period has at least one important advantage associated with it. That is, for this period and for a considerable time beforehand, the same political parties, namely, the Liberal-Country Party coalition were governing and the Leader of the Country Party, Sir John McEwan, was the Minister for Primary Industry throughout the period. To the extent that the same parties ruled signifies a period characterized by a consistent set of objectives.

Before attempting to specify these objectives, it should be noted that policy responsibilities for agriculture are divided between the various State Governments and the Federal Government. Most importantly, under the powers of the Australian Constitution, questions relating to agricultural production rests essentially with the States.

> Except with respect to Australian Territories, the States administer such matters as agricultural education and research, advisory and extension services, internal quarantine production controls (where applicable), land tenure and settlement policy, as well as intra-state trade.
>
> [Harris, *et al.*,1974, p.3.24]

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1 It should be pointed out here that the purpose of this section is to attempt to *identify* the objectives of agricultural policy, not to argue the merits or deficiencies of the various policy instruments used in an attempt to attain them.

Among the principal powers resting with the Federal body is control over overseas trading and in this respect it is responsible for the promotion and quality of export products, and the negotiating of commodity agreements. The Federal government also affects rural policy through its taxation powers, the provision of credit and the provision of finance to States for rural purposes.

That a division of powers exists between State and Federal Governments on matters of rural policy may seemingly make it more difficult to identify national agricultural policy objectives. During the period under consideration, however, there seems to have been a great deal of co-operation between the State and Federal Governments facilitated mainly by the operations of the Australian Agricultural Council. This body was formed in 1934, following a conference convened by the Prime Minister and Commonwealth and State Ministers of Agriculture. The Council consisted of the Commonwealth Ministers for Primary Industry, Trade and Industry, Interior and External Territories and the State Minister of Agriculture. According to Grogan [1958, p.1]

> Problems on both the production and marketing sides of Australian agriculture have, within the constitutional and financial framework of Commonwealth-State relations, necessitated co-operation between governments. The Australian Agricultural Council with its permanent advisory committee, the Standing Committee on Agriculture, has over twenty-three years of existence developed into an effective instrument for achieving this co-operation. It is perhaps not an exaggeration to suggest it is the most successful example of such co-operation in Australian Commonwealth-State relationships.

The Council has no statutory powers, but in practice, it appears that measures adopted by it are adopted by the various governments. This was particularly so of the production aims and policies recommended by the Council in 1952, where it was clearly evident that all states and the Federal Government were co-operating to ensure that the aims and policies would be carried out. The fact that the period under consideration was characterized by a general policy of over-all expansion of agricultural production (as outlined in detail below) may have itself been a contributing factor to the harmonious relationships between the State and the Commonwealth as effected by the Council. That is, insofar as the problems confronting the Council during the period have been related to expanding agricultural production rather than with the 'more contentious and difficult ones of acreage restriction and quota allocations' may have been a contributing factor to the high degree of co-operation between the various bodies. Whatever the reasons, it appears that we can meaningfully discuss national agricultural policy objectives despite the Constitutional restraints on the Commonwealth Government.

3.2.2 Explicitly Stated Policy Goals.

> The usual difficulties of identifying the objectives of government agricultural policy apply to Australia where white papers or official manifestos expressing government policy about agriculture are rare.
>
> [Lewis, 1968, p.299]

In the post World War II period up to 1965, only two major statements on agricultural policy had been made. In 1946, Prime Minister Chifley issued *A Rural Policy for Post-war Australia: A Statement of Current Commonwealth Policy in Relation to Australia's Primary Industries.* In this statement, the following general objectives were stated.

(i) To raise and make more secure the levels of living enjoyed by those engaged in and dependent upon the primary industries.

(ii) To secure a volume of production adequate to meet domestic food requirements, to provide raw materials for our developing secondary industries, and to enable an expanding volume of exports to pay for necessary imports.

(iii) To encourage efficient production at prices which are fair to the consumer and which provide an adequate return to the producer.

(iv) to develop and use our primary resources of water, soil, pastures and forests in a way which conserves them and avoids damaging exploitation.

As indicated, these aims are stated in general terms but, nevertheless, the goals used in the Iowa study are present. For example, objectives (i) and (iv) are essentially security goals, (ii) a growth goal and (iii) an equity goal. This is obviously a rather loose classification and it is difficult to assign priorities to them. This is probably not surprising in view of Crawford's [1952, p.8] observation that the

> ...statement was couched in terms of a post-war world expected to be characterized by peace and the opportunities for the leisurely pursuit of economic progress.

The second major statement of objectives came in 1952 with the publication of *Agricultural Production Aims and Policy*. These aims reflected the attitudes of the then ruling Liberal-Country Party Coalition and contained the following passage from a statement made by the leader of the Country Party (Mr. McEwan) to the Australian Agricultural Council.

> The Commonwealth Government has decided to adopt as its policy objective a Commonwealth-wide programme of agricultural expansion, not only to meet direct defence requirements, but also to *provide food for the growing population, to maintain our capacity to import,* and to make our proper contribution to relieving the dollar problem. (own italics)

As Crawford [1952, p.8] comments, the policy objective is 'clearly a production one', and in its presentation closely relates to the production goal as described by Stigler. More specifically, the italicized sections of the extract from McEwan's policy statement indicate the precise nature of the contribution that agriculture's growth was intended to make to the economy's overall growth; that is, by the provision of food supplies and by increasing foreign exchange earnings.[2] In pursuit of this overall goal of increased production, The Agricultural Council presented its views on the necessary conditions which would facilitate its achievement, that is, the need for price incentives and the need for 'closer' settlement.

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2 These two contributions are among those listed above from Johnston and Mellor [1961], Crawford [1952, p.8] expressed the belief that '...the 1952 policy is really one which makes enhanced agricultural production a matter of urgency because it is a principle means to the wider ends of *national interest*' (own italics)

With regard to price strategies, the Council was clearly concerned with the role played by prices in fostering increased production; viz. prices must be such as to 'avoid distortions in production patterns' and 'where commodities are in short supply...special consideration must be given to price relationships with the object of attaining the required level of production' and again, '...any announcement regarding prices of wheat intended to stimulate production...' [*Production Aims and Policies*, p.6].

On the issue of closer settlement, the predominant thoughts were its contribution to increased production

> ...the acceleration of present closer settlement activities offers a way of stepping up production quickly...Ways and means should be devised to ensure the full effective use of under-developed or idle land which offers ready scope for immediate development.

The above discussion seems to clearly indicate that the predominant goal of agricultural policy was an output goal and that the other goals of equity and security assumed lesser importance. Crawford [1952, p.21] adheres to this view.

> To the extent that...welfare goals have a place in federal policy, they do so as both ends and means. [In] the setting of a production drive, family farms are important if they are commercially efficient units...Their intrinsic social and political values are not denied but here the emphasis is certainly on their contribution to the expansion of export income.

As indicated at the beginning of this section, the issue of statements resembling the above major policy statements are rare, meaning that the identification of policy goals in subsequent times is a more difficult task.

3.2.3 Implicit Policy Goals

We might start our search for policy goals for the early 1960s with the following observations regarding the continuation of the production goals set down in 1952. In 1959, in an address to the A.C.T. Branch of the Institute of Agricultural Science, Sir John McEwan said of the then present approach to policy,

> On the production side present policies are essentially a continuation of those described...as being developed to meet the situation in 1952.
>
> [McEwan, 1959, p.254]

In 1965 McKay, commenting on the goals of stabilization schemes in Australia said that,

> Limitation of production has not been an objective of post-war stabilization arrangements. Nowhere has any statement been made that stabilization includes stabilization of acreage or production
>
> [McKay, 1965, p.31]

That is, indications are that for the period up to 1965, the goal of output growth was still, at least implicitly, a part of domestic agricultural policy.

While the goal of output growth received explicit recognition in the policy statement of 1952 and appears to have remained a goal through to 1965, the other goals mentioned in the preceding section, equity and security, have received little, if any, explicit recognition in major policy statements. In an attempt to ascertain if these goals were relevant to Australian agricultural policy in the period considered, an investigation will be made of the 'reasons' why particular policy measures were taken. This, of course, will not be an easy task, as Williams [1957, p.1] pointed out.

> ...our rural policy is now a somewhat heterogeneous collection of seemingly unrelated measures taken at different times.

In the remainder of this section, an attempt will be made to categorize these measures with the intention of assigning objectives to them. As a starting point for the analysis, a section of Table 13 taken from *Agricultural Policy in Australia* (O.E.C.D. Agricultural Policy Reports, Paris, 1973, p.55) is reproduced here in Table 3.1 and indicates the types and amounts of assistance, excluding research and promotion offered to the agricultural sector for the financial year 1966/67.

TABLE 3.1

COMMONWEALTH FINANCIAL ASSISTANCE TO THE AGRICULTURAL SECTOR

Type of Assistance	1966/67 $A,000
1. Direct Payments to industry.	
Dairy Industry	27,899
Wheat Industry	16,154
Cotton bounty	2,813
Subsidies on Inputs	48,952
2. Taxation concessions	
(est. value foregone)	14,000
3. Special payments to the States	38,677

Source: O.E.C.D. *Agricultural Policy in Australia* (Paris, 1973) p.55.

Of the 'direct payments to industry' in 1966/67, we can distinguish between those which are product specific and those which accrue to the agricultural sector in general. We shall initially start with commodity specific assistance. The three industries included in Table 3.1 are those which operate under what Lewis [1958, p.1] classifies as *Guaranteed Price Stabilization Schemes,* which is but one of six price support systems which Lewis identifies, the others being,

1. two price schemes without guarantee,
2. tariff protection,
3. manufacturing quotas,
4. international agreements, bilateral and multi-lateral,
5. orderly marketing arrangements and other government action in support of group marketing action by primary producers.

Quite predictably, these schemes differ in their applicability to different commodities and the objectives to be met by those schemes change over time, depending on circumstances at different points in time. With these factors in mind, McKay [1965] undertook a comprehensive study of the various schemes to

> ...look at the stated objectives of stabilization ... [where] stated objectives are defined as those made by Ministers responsible for policy.
>
> [McKay, 1965, p.36]

His investigations led him to conclude that pricing arrangements appear to incorporate three major objectives

1. Income Objectives.

   (a) To raise the level of living of farmers.

   (b) To make more secure the levels of living of farmers.

   (c) To provide comparability of income between incomes in the farm sector and the non-farm sector.

With regard to (c) in these income objectives, McKay [1965, p.37] observes that,

> In more recent years, the direct expression of the objective of raising farm incomes relative to that in other sectors is seldom heard. *The security objective is still very prominent.* (own italics)

2. Price Objectives.

   (a) To guard against ruinous prices.

   (b) To give prices fair to producer and consumer.

   (c) To stabilize prices to producers and consumers so as to iron out fluctuations over the long term.

   (d) To provide a minimum level of farm prices.

   (e) To give orderly marketing, i.e. to remove the competitive struggle among growers.

With regard to the set of 'objectives', the emphasis seems to be placed on stabilizing prices rather than to raise prices. Gruen [1970, p.12] states that the purpose of most schemes is to 'cushion farmers from the rigours of price competition and in particular, from the vagaries of free markets with their inevitable price instability.'

3. Production Objectives.

As we noted earlier, limitation of production has not been an objective of post-war stabilization schemes, and insofar as this is true, the production objectives explicitly contained in the 1952 policy announcement and re-affirmed by McEwan in 1959, have not been violated, in general, by the various price support schemes. However, the various price support schemes have resulted in 'the production objectives... [becoming] largely secondary to the major objectives of income and price.'

[McKay, 1965, p.38]

We turn now to non-product specific payments, namely subsidies on inputs. The figure presented in Table 3.1 is made up of funds expended on the phosphate and nitrogenous fertilizer bounties and the subsidy on freight costs of certain petroleum products from capital city to country areas. The fertilizer bounties were intended primarily for the agricultural sector, while the petroleum subsidy applied to all country areas regardless of whether the users are primary producers or not. Of the fertilizer bounties, the nitrogenous fertilizer bounty was not re-introduced until 1966/67. The payments of subsidies on superphosphate has had an interrupted history commencing in 1932 through the Financial Relief Bill of 1932. This subsidy was withdrawn in 1939 and a new subsidy was introduced in 1941 through the Superphosphate Bounty Bill. This subsidy was withdrawn in 1950 with the Superphosphate Bounty Repeal Act. For the period 1950 through to 1963, no subsidies were paid on fertilizers but payments were re-introduced in 1963 with the advent of the Phosphate Fertilizer Bounty Act. The payment of the bounty under this scheme continued with slightly changed payments until 1971.

With our relevant period being 1959-65, the objectives associated with the Phosphate Fertilizer Bounty Act of 1963, is of particular interest. The following statements were selected by the I.A.C. [1975, p.33] from the Second Reading Debate on the Bill as, perhaps, indicating the objectives.

> A Superphosphate bounty "...will encourage the most economic use of our agricultural resources and in particular, will act as a stimulus to further expansion in pasture improvement."
>
> Not only will the subsidy reduce farmers' costs and assist to increase their production but it will also increase the volume of production that Australia has for export, and thus will enable us to earn more overseas funds.
>
> Restore the profitability between the primary industries and the secondary and tertiary industries.

This last statement was isolated in its representation in the debate with the main emphasis being on the reduction of costs to farmers and to increase agricultural output and facilitate the growth of export income.

The remaining types of assistance made available to the agricultural sector in general, as distinct from on a specific commodity basis, during the period were various taxation concessions. These concessions are made available at both the Federal and State levels. At the Federal level, the major concessions were as follows:

1. averaging of incomes over five years,
2. the indefinite carry-forward of losses,
3. accelerated depreciation,
4. capital expenditure allowances.

The general objectives of these concessions are contained in prefectorial statements in various editions of *Income Tax for Farmers and Graziers*, which indicate that for the period concerned the major objectives were again the growth of output and the stabilization of farmers' incomes (i.e. security). In the 1957 edition of *Income Tax for Farmers and Graziers*, the Minister for Primary Production indicated that it was his Government's intention to 'facilitate investment by producers in essential export and import saving industries' while in the 1967 edition of the same publication, the preface contained the following:

> ... special income tax concessions have been granted to primary producers as an incentive to increased production and greater efficiency within the industry.

and again

> ...these concessions have been designed to assist the primary producer to stabilise his income and to encourage him to invest in property improvement and in plant and equipment which will lead to increased production.

Once again, the statements associated with taxation concessions emphasise the importance of fostering growth in agricultural production over the period with which we are concerned.

The last category of assistance to the agricultural sector contained in Table 3.1 is 'Special Payments to States'. These payments are primarily for regional development projects which are essentially the province of the states. One example of these special payments is the assistance provided under the Brigalow Lands Agreement Act 1962-1967 to the Queensland Government for the clearing, developing and stocking of land in central Queensland with the view to increasing the beef cattle carrying capacity of the land.

3.2.4 Summary

In the preceding discussion we have tried to identify the major objectives of Australian agricultural policy. This was done by investigating the ministerial statements accompanying various pieces of agricultural legislation passed during the period 1955-1965. In relation to the goals stated in the Iowa study, the twin goals of growth and security (stability) have been the predominant ones. There appears to have been little explicit attention given to the goal of equity during the period, although quite clearly policy measures taken to stimulate growth and/or reduce instability have equity effects.

The growth objective appears to have centred predominantly on the need to generate increased foreign earnings through increasing the volume of exports from primary industries. The contribution to growth by Australian agriculture has not focused on the release of resources from agriculture to other sectors. That is, compared with many other advanced countries, Australian agriculture during the period had not suffered from adjustment problems.

The problem of agricultural adjustment is summarized concisely by Johnson [1973]. In a growing economy, agriculture must undergo continuous adjustment for the following reasons:

(i) an income elasticity of demand for output that is less than unity and declining as real *per capita* income increases;

(ii) the direct applicability of knowledge to the farm production process;

(iii) the substitutability of inputs, including purchased inputs for land.

These forces result in an excess supply situation developing, with the result that if returns to resources are to keep in step with returns elsewhere (i.e. employed in non-farm activities), the resources typically withdrawn must be labour.

The evidence usually cited to support the argument that Australian agriculture had not suffered from an adjustment problem during the period relates to the elastic demand for Australian agricultural commodities [Standen and Musgrave, 1968, pp.72-3]. Studies by Hoffman and Hume [1965] who found little disparity between incomes of rural and non-rural sectors for the period 1952/53 - 1961/62 and Herr [1966], who presented data showing a decline in the Australian agricultural labour force of only 15 per cent over the period 1930-1959 (compared with a 52 per cent decline in the United States over the same period) provide some further evidence that the process of agricultural adjustment was not a predominant objective during the early 1960s.

Subsequent to our period of analysis, the problem of low incomes in the rural sector has received explicit government attention, as witnessed by the substantial increase in Reconstruction Assistance which rose from $7,122 in 1970/71 to an estimated $62,000 in 1972/73. Prior to 1970/71, no Commonwealth payments had been made for reconstruction purposes.

The goal of security was evidenced by the large number of price-support schemes which the government administered during the period. These schemes were designed in general to increase the stability of incomes, rather than to increase the level of incomes. Whilst the schemes have not always been regarded as successful, the evidence suggests that the government was nevertheless motivated to seek income stability.

3.3 The Commodity Orientation of Australian Agricultural Research Activity

3.3.1 Introduction

In this section we will utilize publication data to determine the commodity research mix of Australian agricultural scientific research activity. The publication data will be subjected to certain tests to see if it should be 'standardized' to take into account differences in publication behaviour relating to different commodities. An evaluation will then be made of the research mix in terms of the contribution made by the particular commodities to the attainment of the domestic agricultural policy goals discussed in the preceding section. As such, the evaluation must be regarded as partial in that supply aspects of research activity are not being included. This amount to assuming that a unit of research activity is equally productive in all fields and for all commodities. Boyce and Evenson argue that this assumption may not be unreasonable if we consider the aggregate of activity devoted to a particular commodity group.

> ...the average product of the aggregate of a number of projects may be roughly constant even though it is not constant for individual projects...over the long-term, it may not be too unreasonable to postulate plasticity of nature [ease of discovery] for broadly defined commodity groups.
>
> [Boyce and Evenson, 1975, p.84].

If this assumption is 'not too unreasonable', then an evaluation of the commodity research mix in terms of the derived demand for research output (the goals of agricultural policy) will give us a guide to the efficiency of allocation of research activity among commodities.

3.3.2 The Research Data

A count was made of the number of publications related to particular commodities or commodity groupings, for the period 1960-1969. The procedure adopted was as follows. The journals included for the count are those which were included in the aggregate publication count in section 2.2.4, in particular, those included in Tables 2.3 and 2.4. The period under review is covered by the *Australian Science Index* so this became the primary data source. As already described in section 2.2.4, the *Australian Science Index* consists of a number of subsections which relate to broad commodity groupings which are not sufficiently disaggregated to suit the present analysis. As a result, it was necessary to inspect each entry of the particular subsections used in section 2.2.4. That is, for each of the relevant subsections,each indexed article was assigned to a particular commodity or commodity grouping. This assigning was done on the basis of information contained in the title of the article. That is, if an article made explicit mention of wheat, it was assigned to that commodity. If more than one commodity was referred to in the title, an equal fraction was assigned to each. Those articles which did not have a specific commodity contained in their titles are not included in the present analysis. This resulted in only a small proportion of the total of articles not being included. In the *Australian Science Index* subsection, Domestic Animals, including specific diseases, for example, the proportion of non product specific to product specific articles for the entire period was ten per cent.

Table 3.2 contains the number of publications assigned to twenty-seven commodities or commodity groupings for the period 1960-1969. Publication data was also collected for a number of other products but have been excluded from the present analysis because of data deficiencies. These commodities and the numbers of publications are included in Appendix 3.5.1.

In an attempt to see if the publication data should be 'standardized' to take into account possible differences in abstracting, ease of publication and research productivity between commodities, the following investigation was made. Two possible areas of bias were considered. First, it was thought that the publication/scientific personnel ratio might differ between products for some of the reasons

TABLE 3.2

NUMBER OF PUBLICATIONS ASSIGNED TO PARTICULAR COMMODITIES OR COMMODITY GROUPINGS; 1960 - 1969

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1. Fruit										
Apples	20	25	16	19	27	18	20	24	13	21
Citrus	3	4	5	3	8	9	4	8	6	10
Pears	2	2	6	6	4	1	1	2	4	3
Peaches	5	7	13	8	7	9	9	3	6	10
Bananas	8	7	3	7	3	6	4	4	2	6
Pineapples	7	1	3	-	1	1	2	-	1	6
Grapes	20	26	14	13	16	18	22	20	18	23
2. Vegetables										
Potatoes	14	18	12	7	4	7	2	8	5	5
Beans	9	5	3	5	4	3	4	3	9	7
Green Peas	4	7	4	3	3	4	3	-	-	1
Carrots	-	3	2	2	1	-	1	1	-	1
Tomatoes	17	9	7	8	6	8	8	5	5	3
Onions	2	2	1	1	2	-	-	-	3	1
3. Cereal Crops										
Barley	4	5	6	2	2	5	4	2	5	5
Maize	2	2	-	4	3	3	5	2	5	6
Oats	5	5	4	9	4	8	11	7	6	8
Rice	2	4	3	3	3	4	1	5	7	8
Sorghum	3	1	3	7	1	6	4	7	5	3
Wheat	13	24	25	26	35	29	36	25	36	33
4. Industrial Crops										
Cotton	4	4	4	8	8	8	4	8	4	10
Peanuts	-	1	5	1	1	1	-	-	5	4
Tobacco	9	9	7	14	6	6	6	9	6	15
5. Animal Products										
Cattle(Beef & Dairy)	82	90	79	49	56	27	75	83	122	140
Sheep	95	81	87	75	69	76	112	112	132	128
Pigs	29	26	31	11	19	12	18	29	22	41
Poultry	45	38	19	21	16	19	18	27	27	25
Bees	8	5	1	5	7	4	1	6	5	3

just mentioned. Second, it was thought that the publication/scientific personnel ratio might differ between institutions for much the same reasons why it was thought that the ratio might differ between countries; that is, because of differences in the capacity and/or pressure to publish between institutions. To see if these factors were important, a limited amount of data were available which allowed us to see if any significant differences existed in the publication/scientific personnel ratio both between broad commodity groupings and between institutions.

The data available to carry out these investigations are limited. As already mentioned, one of the advantages of publication data are that they allow us to analyse research activity on a commodity basis. Personnel data are typically categorized in broad commodity groups, which means that our present tests can be performed only for broad commodity groupings. In fact, we are only able to identify three major commodity groupings for which both publication data and scientific personnel data exist. These are cereal grains, animal products and horticultural products. Table 3.3.(a) contains estimates of publications for scientific personnel for various divisions of three institutions, C.S.I.R.O., the New South Wales Department of Agriculture and the Waite Agricultural Research Institute. In this case, all the personnel data has been taken from the C.A.B. *List of Research Workers* in an attempt to ensure conformity in the measurement of scientific personnel. The publication data for C.S.I.R.O. Divisions are taken from Table 2.19. A further publication count was made for the N.S.W. Department of Agriculture and for the Waite Agricultural Research Institute; these are contained in Appendices 3.5.2. and 3.5.3. respectively.

The method used to determine if any significant differences existed in the publication/scientific personnel ratio between broad commodity groupings is that used in section 2.4.2. In this case, the hypothesis to be tested is H_0: $U_1 = U_2 = U_3$. The analysis of variance of the data contained in Table 3.3 (a) is presented in Table 3.3 (b). The result of the test is that

TABLE 3.3(a)

AVERAGE PUBLICATIONS PER SCIENTIFIC PERSONNEL FOR SELECTED COMMODITY GROUPINGS

Commodity Grouping		Average Publications per Scientific Personnel*
1. Cereals		
C.S.I.R.O.	Div. of Plant Industry	1.57
N.S.W. Dept. of Agric.	Div. of Plant Industry	2.45
Waite Agric.Res. Inst.	Dept. of Plant Physiology	2.42**
	Dept. of Plant Pathology	2.25**
	Overall Average	2.17
2. Animals		
C.S.I.R.O.	Div. of Animal Genetics	1.53***
	Div. of Animal Physiology	2.38
	Div. of Animal Health	1.12
N.S.W. Dept. of Agric.	Div. of Animal Industry	3.50
	Overall Average	2.13
3. Horticulture		
C.S.I.R.O.	Div. of Horticulture	2.27**
N.S.W. Dept. of Agric.	Div. of Horticulture	1.76
	Overall Average	2.02

* Publication Data are averages for 1960-70. Personnel data are averaged for 1955-65.

** Publication Data are average for 1962-1970.

*** Publication Data are average for 1960-68.

TABLE 3.3(b)

ANALYSIS OF VARIANCE USING DATA OF TABLE 3.3(a)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F. Ratio
Mean	1	45.16	45.16	
Among Groups	2	0.03	0.02	0.04
Within Groups	7	4.01	0.57	
Total	10	49.20	-	-

$$F = 0.04 < F_{.95(2,7)} = 4.74$$

We are therefore unable to reject the null hypothesis and may conclude that no significant difference exists in the publication/scientific personnel ratio for the broad commodity groups considered.

A further test was carried out to see if significant differences existed in the publication/scientific personnel ratios between institutions. The institutions considered are C.S.I.R.O., the New South Wales Department of Agriculture and the Waite Agricultural Research Institute. The ratios for these institutions are presented in Table 3.4(a). Again the personnel data are all extracted from the C.A.B. *List of Research Writers* and the publication data is the same as used for the previous test. Table 3.4(b) contains the analysis of variance of the data in Table 3.4(a) which indicates that

$$F = 0.90 < F_{.95(2,16)} = 3.63$$

Again we are unable to reject the null hypothesis, H_0: $U_1 = U_2 = U_3$ and are therefore able to conclude on the basis of evidence from three institutions that no significant difference exists between their average publication/scientific personnel ratios.

The above tests to investigate whether publication data should be 'standardized' are not to be interpreted as being conclusive. For example, the absence of significant differences in the publication/personnel ratios, both between commodity groups and between institutions, does not necessarily imply that the forces which might lead to differences in the ratios are non-existant. It may be that the averages themselves are 'camouflaging' the forces; that is, in the absence of one or other of the forces, the averages would be changed. Furthermore, the tests which are performed are constrained by the availability of appropriate data and are therefore confined to very broad commodity groups and to only three research institutions. Again, the aggregation involved in the groupings could be concealing individual product differences, and other institutions not included may exhibit differences in the capacity and/or pressure to publish.

TABLE 3.4(a)

AVERAGE PUBLICATIONS PER SCIENTIFIC PERSONNEL FOR SELECTED RESEARCH INSTITUTIONS

Institution	Average Publication per Scientific Personnel*
1. C.S.I.R.O.	
Division of Plant Industry	1.57
Division of Entomology	1.87
Division of Animal Health	1.12
Division of Animal Genetics	1.53**
Division of Animal Physiology	2.38
Division of Soils	1.05
Division of Land Use and Survey	1.68
Division of Wildlife Research	1.99
Division of Tropical Pastures	1.79***
Division of Horticulture	2.27**
Overall Average	1.73
2. N.S.W. Department of Agriculture	
Division of Animal Industry	3.50
Division of Horticulture	1.76
Division of Plant Industry	2.45
Biol. & Chem. Research Institute	1.17
Overall Average	2.22
3. Waite Agricultural Research Institute**	
Department of Agronomy	1.27
Department of Agricultural Chemistry	2.82
Department of Plant Physiology	2.42
Department of Plant Pathology	2.25
Department of Entomology	1.21
Overall Average	1.99

* Publication Data are averages for 1960-1970. Personnel Data are averages for 1955-1965.

** Publication Data are averages for 1962-1970.

*** Publication Data are averages for 1965-1970. Personnel Data are averages for 1959-1966.

TABLE 3.4(b)

ANALYSIS OF VARIANCE USING DATA OF TABLE 3.4(a)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F-Ratio
Mean	1	68.59	68.59	
Among Groups	2	0.76	0.38	0.90
Within Groups	16	6.65	0.42	
Total	19	76.00	-	-

Despite the limitations of the analysis performed on the data there seems to be some evidence to suggest that forces operating to bias the publication/scientific personnel ratio between commodities are not very strong and because of this the publications data will be used in its 'raw' form.

3.3.3 The Model

In this section, we use the publication data described in the previous section to evaluate the distribution of agricultural research activity among different commodities. The evaluation will take the form of analysing the commodity research mix in terms of the criteria established earlier in the chapter, namely that the research mix is in accordance with the goals of domestic agricultural policy. The publication data are based on the period 1960-1969 which, if our postulated publication 'lag' of five years is accepted, will mean that the relevant policy period will correspond to the approximate period 1955-1965.

In section 3.1, we argued that research activity should be directed such that it satisfies or contributes to the achievement of certain individual and/or collective needs and that this will be largely achieved if the net benefits of research activity are in accordance with the goals of domestic agricultural policy. In section 3.2, one of the major goals for the relevant period was considered to be the growth of agricultural output with emphasis on the expansion of production of export commodities to increase export income. In this regard, we make two investigations. It was noted in 3.1 that agriculture may contribute to economic growth by the growth of product within agriculture; similarly we may note that at the sector level, a commodity may contribute to the growth of agricultural output by the growth in output of that commodity. Thus our first investigation is to see whether the commodity research mix has been consistent with the goal of maximum growth of agricultural output. The approach is highly simplified and makes two major assumptions. First, it is assumed that the greater the net output of a commodity, the greater will be the 'product contribution'

TABLE 3.5

ESTIMATES OF COMMODITY RESEARCH, VALUE OF PRODUCTION, EXPORT VALUE AND PRODUCTION INSTABILITY*

	(1) Total Number of Scientific Publications 1960-69	(2) Average Gross Value of Prod. 1955/56-1959/60 $m.	(3) Average Value of Exports (f.o.b.) 1955/56-1959/60 $m.	(4) Average Variability of Area of Prod. 1945/46 - 1968/69	(5) Average Variability of Volume of Prod. 1945/46 - 1968/69	(6) Average Variability of Yields 1945/46 - 1968/69
Fruit						
Apples	203	33.9	13.600	0.05	0.15	0.13
Citrus	60	19.1	1.700	0.04	0.12	0.10
Pears	31	10.8	14.300	0.05	0.12	0.13
Peaches	77	7.0	6.900	0.15	0.21	0.09
Bananas	50	15.3	0.001	0.09	0.12	0.08
Pineapples	22	5.0	3.800	0.13	0.15	0.06
Grapes	192	31.0	18.410	0.01	0.12	0.13
Vegetables						
Potatoes	82	32.1	0.400	0.12	0.15	0.08
Beans	52	5.8	0.028	0.08	0.08	0.07
Green Peas	29	8.4	0.041	0.16	0.20	0.10
Carrots	11	3.6	0.006	0.16	0.14	0.07
Tomatoes	76	13.4	0.079	0.10	0.12	0.07
Onions	12	4.2	0.174	0.15	0.22	0.15
Cereal Crops						
Barley	40	45.3	24.400	0.16	0.28	0.18
Maize	32	8.4	0.080	0.12	0.14	0.10
Oats	67	38.8	7.700	0.12	0.31	0.21
Rice	40	7.9	5.100	0.10	0.18	0.10
Sorghum	40	6.0	1.300	0.16	0.26	0.18
Wheat	282	227.0	127.700	0.24	0.30	0.18
Industrial Crops						
Cotton	62	0.6	0.001	0.47	1.29	0.74
Peanuts	18	3.8	0.001	0.26	0.44	0.25
Tobacco	87	13.2	0.981	0.25	0.28	0.17
Animal Products						
Cattle[1]	803	638.5	152.780	0.03	-	-
Sheep[2]	967	892.3	678.900	0.04	-	-
Pigs	238	52.9	0.800	0.13	-	-
Poultry	255	111.6	7.493	-	-	-
Bees	45	4.3	1.841	0.09	-	-

* All production export and area data are derived from Bureau of Agricultural Economics, *Trends in Australian Agricultural Commodities*, various numbers.

1 Gross value of production is the sum of Wholemilk used for Butter, Cheese, Processed Milk Products and Other Purposes, and Cattle Slaughtered.

2 Gross value of production is the sum of Wool and Sheep Slaughtered.

of that commodity to the aggregate growth of agricultural output. Secondly, it is assumed that the 'productivity' of research activity is, on average, the same for all commodities. The 'productivity' of research activity relates to the same types of considerations which Kuznets [1962, p.24] made regarding the differing magnitudes of invention. On the basis of these assumptions, we can conclude that the commodity research mix is consistent with the goal of maximizing aggregate agricultural output growth if, *ceteris paribus*, relatively more research is devoted to those commodities which contribute relatively more to total agricultural output.

To test this proposition with regard to the Australian situation for the period 1955-1965, the following model was used.

$$R_i = a\, Y_i\, U_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

where (1) $R_i = \sum_{t=0}^{10} P_i$ where P_i is the sum of publications relating to commodity i and t = 0 = 1960.

(2) Y_i = average gross value of production of commodity i for 1955/56 - 1959/60.

(3) a is a constant to be estimated

and (4) U_i is an error term.

By summing publications over the ten year period, R_i represents a stock of research activity embodied in the particular commodity. Data on R_i and Y_i are contained in columns (1) and (2) respectively of Table 3.5. The use of Y_i as a measure of the 'product contribution' to aggregate output is limited in two important respects. First, value added data is a far superior measure of the 'net' output of a particular commodity, but is not available on the scale required. Secondly, by using current rather than future estimates of 'product contribution' it is possible that, say, future shifts in demand might change the relative contribution of commodities to aggregate output. Since research activity is embodied in production techniques only after quite significant lags, then matching current research activity with current product contribution may not be optimal in the sense being considered here.

Bearing these limitations in mind, equation 3.1 was estimated in the log-linear form to be

$$\ell n\ R_i \;=\; \underset{(10.37)}{2.600} + \underset{(7.53)}{0.577}\ \ell n\ Y_i$$

$R^2 = 0.69$

t values are in parentheses

$i = 1 \ldots n$ = number of cases = 27

The estimated coefficient of 0.577 suggests that ten per cent increases in product values are associated with increases in research activity of approximately six per cent; that is relatively more research activity, is devoted to those products with relatively greater gross values of production. If average gross value of production serves as a meaningful proxy measure for the net output of commodities then the evidence suggests that research activity during the period has been proportionately greater in those commodities making relatively larger contributions to aggregate output. Under our assumption that a commodity's contribution to growth will be greater, the greater is its net output, then the commodity research mix is consistent with the goal of maximizing the growth of agricultural output.

Our second investigation regarding the objective of economic growth concerns the precise nature of the contribution that agriculture is expected to make to overall economic growth. In the Australian case for the relevant period it was established in 3.2.2 that the agricultural growth objective was mainly to facilitate increased foreign earnings through increasing the volume of exports from primary industries. To investigate the distribution of research activity in terms of this contribution, the following equation was estimated.

$$R_i \;=\; a\ Y_i \left(\frac{X_i}{Y_i}\right) U_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

where X_i = average value of exports (f.o.b.) of commodity i for 1955/56 - 1959/60

Y_i = average gross value of production of commodity i for 1955/56 - 1959/60.

Using data on X_i from column (3) of Table 3.5, equation (3.2) was estimated to be

$$\ell n\ R_i = \underset{(6.523)}{2.523} + \underset{(6.572)}{0.589}\ \ell n\ Y_i - \underset{(-0.268)}{0.014}\ \ell n \left(\frac{X_i}{Y_i}\right)$$

$$R^2 = 0.695$$

$$i = 1 \ldots n = 27.$$

The estimates provide little evidence to suggest that the research mix has been influenced by the relative export intensities of the various commodities. As indicated in 3.1 in the general discussion on the direction of research activity, it is not clear cut that research activity should necessarily be directed to those products having the greatest export potential; it might be that currency movements (devaluation) may be a more efficient means of effecting an improvement in the balance of payments. Thus the failure here of export intensities to emerge as an explanator of the research mix does not necessarily imply an inefficient allocation of research activity.

In addition to the growth goal, consideration was also given to the security goal. In section 3.1.3(c) we indicated that security was increased by an act which reduced risk and uncertainty faced by the farmer. It was concluded that research might contribute to the achievement of this goal by reducing yield instability by producing more adaptable plant and animal species and by modifying the environment in which these exist. In our discussion on the goals of domestic agricultural policy, we suggested that the pursuit of more stability was a relevant goal during the period under discussion. In so far as increased stability of yields contributes to income stability then increased research into those commodities where instability is greatest might contribute to the achievement of the security goal. Estimates of instability were made with respect to volume of production and yields. The coefficient of instability was defined as the standard deviation of the residuals estimated from a straight line trend, fitted by the least squares method, expressed as a percentage of the mean of the observations for the entire period. These estimates for the period 1945/46 to 1968/69 are contained in columns (5) and (6) of Table 3.5.

To investigate whether the distribution of research activity was influenced by the degree of production instability, two approaches were adopted. The first considered the relative instability of the various commodities. The second took into account the wider effects of instability on the economy as a whole. With regard to the first of these approaches, the following equations were estimated.

$$R_i = a\, Y_i\, VV_i\, U_i \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.3)$$

and $$R_i = a\, Y_i\, YV_i\, U_i \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.4)$$

where VV_i = coefficient of instability of volume of commodity i for 1945/46 - 1968/69

YV_i = coefficient of instability of yield of commodity i for 1945/46 - 1968/69.

In the sense that VV_i is not wholly determined by variation in climatic conditions, diseases, etc., and is to a greater extent a function of farmers' decisions than VY_i then (3.4) represents a superior model. As indicated above, the estimates of VV_i and YV_i are contained in columns (5) and (6) for Table 3.5. The estimates of equations (3.3) and (3.4) are respectively.[1]

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1 The reason why the number of observations is 22 for equations (3.3) and (3.4) as compared to 27 for equations (3.1) and (3.2) is because no reasonable volume and yield figures could be obtained for the five commodities listed under 'Animal Products' in Table 3.5.

$$\ell n\ R_i = \underset{(7.41)}{3.256} + \underset{(3.98)}{0.121}\ \ell n\ Y_i + \underset{(1.21)}{0.300}\ \ell n\ VV_i$$

$$R^2 = 0.44$$

$$i = 1....n = 22$$

$$\ell n\ R_i = \underset{(6.93)}{3.622} + \underset{(4.22)}{0.480}\ \ell n\ Y_i + \underset{(1.73)}{0.417}\ \ell n\ YV_i$$

$$R^2 = 0.48$$

$$i = 1....n = 22$$

In both models the coefficients on both explanatory variables are of the predicted sign and in the case of the estimate of equation 3.4, the estimated coefficients are both significant at the 10 per cent level.

A further set of estimates were made incorporating both the growth components, that is, total value of output and share of exports, and the instability variables. That is,

$$R_i = a\ Y_i \left(\frac{X_i}{Y_i}\right) VV_i\ U_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.5)$$

and $$R_i = a\ Y_i \left(\frac{X_i}{Y_i}\right) VY_i\ U_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.6)$$

The estimates being respectively

$$\ell nR_i = \underset{(5.18)}{3.313} + \underset{(3.166)}{0.474}\ \ell n\ Y_i + \underset{(0.214)}{0.013}\ \ell n \left(\frac{X_i}{Y_i}\right) + \underset{(1.178)}{0.307}\ \ell n\ VV_i$$

$$R^2 = 0.450$$

and $$\ell nR_i = \underset{(5.18)}{3.669} + \underset{(3.266)}{0.469}\ \ell nY_i + \underset{(0.183)}{0.011}\ \ell n \left(\frac{X_i}{Y_i}\right) + \underset{(1.60)}{0.41}\ \ell n\ VY_i$$

$$R^2 = 0.481$$

Again the results coincide with the finding of the earlier models. That is, the value of production and the degree of yield variability emerge as significant explanators of the commodity research mix but not the share of exports.

A second approach to the question of instability was to try and take account of the wider economy effects of instability. That is, we make the assumption that instability will be of greater importance, the greater is the relative contribution to aggregate income of a commodity. To investigate whether this view of instability had influenced the distribution of research activity, the following equations were estimated.

$$R_i = a\ Y_i\ (VV_i\ W_i)\ U_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.5(a))$$

$$\text{and} \quad R_i = a\ Y_i\ (YV_i\ W_i)\ U_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.6(a))$$

where $W_i = \frac{Y_i}{Y}$ = the share of gross value of production of the i^{th} commodity in the total gross value of production of commodities.

and $Y = \Sigma Y_i$

The estimates of these equations are respectively

$$\ell n\ R_i = \underset{(4.09)}{4.344} + \underset{(0.675)}{0.153}\ \ell n\ Y_i + \underset{(1.44)}{0.335}\ \ell n\ (VV_i\ W_i)$$

$$R^2 = 0.48$$

$$i = 1 \ldots . n = 22$$

$$\ell n\ R_i = \underset{(4.26)}{4.950} + \underset{(0.25)}{0.058}\ \ell n\ Y_i + \underset{(1.85)}{0.422}\ \ell n\ (YV_i\ W_i)$$

$$R^2 = 0.49$$

$$i = 1 \ldots . n = 22$$

In the cases of the weighted volume and yield instability coefficients, no precise conclusions can be made because of the high degree of multi-collinearity present. For example, the correlation coefficient between Y_i and $(VV_i\ W_i)$ is 0.88.

3.3.4 Summary

In section 3.1.4, it was summarized that research resource allocation patterns may be analyzed on the basis of supply and demand considerations. The demand factors were viewed as derived demand in accordance with the goals of domestic agricultural policy. Three major goals, growth, equity and security were identified and the possible, though not necessarily most efficient, contribution of research output to their attainment was discussed.

The goals of agricultural policy in Australia for the period 1955-65 were investigated in section 3.2 where it was found that the predominant goals were growth of output, in particular to facilitate increased export earnings, and to reduce the instability of rural incomes. It was concluded that during the period, the equity goal was not predominant.

In the preceding section, an empirical investigation was carried out to investigate whether the commodity research mix during the period was consistent with the identified goals. The commodity research mix was determined on the basis of the number of scientific publications pertaining to the various products. This data was investigated for bias between commodities and on the basis of limited evidence, it was decided to use it in its 'raw' form.

An analysis of the research mix revealed, under certain restrictive assumptions, that it was consistent with the goal of maximizing agricultural output. Within the constraints of the assumption, this result suggests that the allocation of research activity among commodities was an efficient one. The goal of security was also investigated in relation to the research mix with some evidence emerging to suggest that these commodities exhibiting relatively greater volume and yield instability had relatively more research activity devoted to them.

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3.5 Appendices.

3.5.1 Number of Publications Assigned to Particular Commodities Not Included in the Analysis of Chapter 3.

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Fruit										
Pawpaws	1	-	2	-	-	2	2	-	5	3
Passionfruit	1	4	-	-	1	2	1	2	1	-
Raspberry	1	-	-	-	-	1	-	-	-	1
Strawberry	2	6	4	1	3	2	4	3	4	2
Vegetables										
Lettuce	1	4	4	3	2	1	2	1	-	2
Cauliflowers	2	1	1	1	-	1	-	1	-	-
Cabbages	2	2	3	1	2	1	-	-	-	2
Brussel Sprouts	1	-	-	1	-	-	1	-	-	1
Parsnips	-	1	-	-	-	-	1	-	-	1
Industrial Crops										
Hops	-	-	1	-	-	1	-	1	1	-
Linseed	2	-	2	1	3	1	-	3	2	4
Rapeseed	-	-	-	-	1	-	-	-	-	-
Safflower	2	3	1	4	1	2	1	-	5	3
Soybeans	1	-	1	2	1	1	-	1	1	1

3.5.2. Number of Publications of Various Divisions of the New South Wales Department of Agriculture 1957-1972.*

	Div. of Animal Industry	Div. of Dairying	Div. of Horticulture	Div. of Plant Industry	Biol. & Chem. Res. Inst.**		
					Biol.Br.	Chem.Br.	Ento. Br.
1957	29	13	12	30	33	7	21
1958	30	17	14	30	29	7	16
1959	32	15	13	19	26	3	51
1960	38	14	10	34	25	2	25
1961	43	13	10	51	32	4	26
1962	70	10	18	38	27	2	34
1963	63	9	20	52	16	8	32
1964	80	21	20	54	14	10	38
1965	82	25	28	38	12	10	25
1966	112	11	36	57	27	10	19
1967	122	24	24	31	26	14	20
1968	86	32	30	43	29	3	8
1969	89	25	30	52	30	10	11
1970	94	52	50	62	61	14	15
1971	69	45	20	47	24	14	4
1972	70	49	23	35	29	11	2

* Source: Annual Reports, N.S.W. Department of Agriculture.

** Excludes the Botany Branch.

3.5.3 Number of Publications of Various Departments of the Waite Agricultural Research Institute, 1962-1973*

	Agronomy Dept.	Agric.Chem. Dept.	Pl.Physiol. Dept.	Pl.Path. Dept.	Entomology Dept.	An.Physiol. Dept.
1962	13	21	15	13	8	-
1963	14	31	12	11	8	-
1964	20	33	9	21	9	4
1965	12	34	9	19	11	2
1966	17	39	11	15	16	6
1967	8	32	18	27	14	11
1968	28	43	22	26	5	23
1969	19	35	14	17	10	12
1970	32	44	10	24	12	14
1971	20	43	6	23	10	32
1972	24	25	18	20	10	9
1973	19	26	9	15	8	20

* Source: Annual Reports, Waite Agricultural Research Institute.

CHAPTER 4

THE CONTRIBUTION OF AGRICULTURAL SCIENTIFIC RESEARCH TO AGRICULTURAL PRODUCTIVITY

4.1 Introduction

In this chapter we investigate the contribution made by scientific research to the attainment of major policy goals. In Section 4.2, we analyse the relationship between research activity and increases in product yields which are components of increases in agricultural output. Section 4.3 investigates the role played by research in reducing production instability which would enhance the attainment of the goal of income stability for primary producers. In Section 4.4, the emphasis shifts from the commodity level to the aggregate level. In particular, we investigate the relationship between research activity and movements in aggregate productivity or technical change.

The analyses involve the use of both scientific publication and scientific personnel data. Since this data has not previously been available, the models tested in this chapter represent the first attempt to analyse the contribution of total research activity to agricultural productivity for Australian agriculture. Previous studies, Duncan [1972] and I.A.C. [1976] have tried to estimate rates of return to particular areas of research, for example, pasture research and entomological research. Because a meaningful research expenditure series has not yet been developed for Australian agricultural research, we do not attempt to estimate rates of return in the present study. Rather we test fundamental propositions regarding the expected contribution of agricultural scientific research to the abovementioned areas.

4.2 The Contribution of Scientific Agricultural Research to Increases in Product Yields.

In this section, we again utilize publication data at the commodity level; in particular, to investigate the relationship between scientific agricultural research and product yields. In the previous chapter, 3.3.3), we suggested that the commodity mix of scientific research was consistent with the goal of maximizing agricultural output. The analysis in this section is again carried out at the commodity level and seeks to analyse, in part, the contribution research has made to the growth of agricultural output. The procedure adopted resembles that used by Evenson and Kislev [1973] who test the hypothesis that there '...is a strong and persistent relationship between agricultural research and biological productivity-yield in wheat and maize' [p.1324]. Their study was an international combination cross-sectional, time series analysis involving two products which were analysed separately. In this study the procedure will be to start by testing very basic propositions and then to systematically refine the models as the hypotheses are further developed. This procedure is used essentially because of the lack of previous investigation into this area; by building the models from very basic hypotheses we will be able to observe the relative importance of the various refinements.

In section 2.1.1, we referred to the division of agricultural technology into biological and mechanical processes and indicated that biological technology was likely to be predominantly land saving. That is, increases in biological research would result in increases in output per unit of labour. The present analysis is confined to biological research and its effect on the level of output per unit of land. In particular, we will be investigating the contribution of research activity to the average rates of growth of yields of various commodities.

In view of the fact that data on 'biological' inputs such as fertilizer, rainfall, soil types etc. are not available for individual commodities, the analysis will concentrate only on the contribution of biological research activity to yield increases. Quite clearly, such an approach will bias the estimate made of the contribution of research. To this end, the model will be constrained in the same manner as the work of Evenson and Kislev [1973] was. These authors confront the constraint in the following way.

> The omission of fertilizers, water, and perhaps also an index of seed quality, pesticides, and similar biological inputs is, of course, more serious. However, to the extent that the adoption of these inputs is due to agricultural research (the development of fertilizer responsive varieties, for example), their omission is justified. We are interested in the total effect of research, including the indirect contribution through other inputs. However, these omissions will bias the estimates of research contribution upward...However, to the extent that 'paper counts' measure research [activity] with an error (random), the regression estimates are biased downwards.
>
> [Evenson and Kislev, 1973, p.1312 and p.1318]

Bearing in mind these sources of possible bias, the following tasks were performed. First, average rates of yield increase were calculated for twenty-two commodities. Two estimates were made, the first an exponential time trend with yields as the dependent variable and time the independent variable, that is, we estimated for each commodity

$$y_t = a\, e^{gt} u_t \qquad \text{.....................} \qquad (4.1)$$

where y_t = yield in year t.

a = a constant to be estimated

g = average rate of growth of yield parameter

t = time values with values of 0 to 19 corresponding to 1955/56 - 1974/75

and u_t = a disturbance term.

A second growth coefficient was estimated to take account of 'area effects' on yields. That is, as the area of a particular crop increases or decreases, the yield of the product might either decrease or increase. Russell [1973, p.156] summarizes the effect

> ...in comparing different crops in the same environment over time, statistical yields of specific geographic areas may be affected by changing areas - either increasing, possibly to a less favourable environment, or decreasing to a more favourable environment.

To take into account these area effects, the following equation was estimated.

$$y_t = a\, A_t\, e^{ht} u_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.2)$$

where y_t, a, t and u_t are defined as in equation (4.1).

A_t = area planted to the particular commodity at time t

h = average rate of growth of yields after allowing for area effects.

The estimates of g and h are contained in columns (1) and (2) respectively of Table 4.1.

The research variable is based on the publication counts for individual commodities, the data for which are contained in Table 3.5. The first research variable resembled that used in section 3.3.3, that is, research is viewed as the stock of publications for the period, 1960-69, relating to the particular commodity. That the stock of research activity of the i^{th} commodity is

$$R_i = \sum_{t=0}^{10} p_i$$ where p_i is publications relating to commodity i and t = 0 = 1960.

With R_i as the research variable, the following models were tested

$$g_i = a\, R_i\, u_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.3)$$

and $$h_i = a\, R_i\, u_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.4)$$

where g_i = estimated average rate of yield growth of the i^{th} commodity

h_i = estimated average rate of yield growth of the i^{th} commodity with area effects included.

a = a constant

and u_i = a disturbance term.

In order that the above models could be tested in the log linear form, the growth coefficients which were not significant at the five per

TABLE 4.1.

ESTIMATED AVERAGE RATES OF YIELD GROWTH: 1955/56-1974/75.[π]

	(1) Average Rate of Yield Increase 1955/56 to 1974/75	(2) Average Rate of Yield Increases Accounting for Area Effects 1955/56 to 1974/75	(3) Average Area 1960/61 to 1965/66 '000 h.a.	(4) Average Rate of Yield Increase 1945/46 to 1959/60	(5) Average Rate of Yield Increases Accounting for Area Effects 1945/46 to 1959/60
Apples	.031	.032	27.06	.026	.062
Citrus	.033	.036	19.46	.018	.020
Pears	.027	.030	7.64	.051	.050
Peaches	.031	.029	7.66	.038	.038
Bananas	.021	.022	10.66	.028	.027
Pineapples	.021	.020	3.20	.039	.031
Grapes	.010*	.029	49.80	.007*	.009*
Potatoes	.030	.031	41.34	.032	.030
Beans	.018	.020	7.18	.038	.040
Green Peas	.048	.046	20.40	.058	.052
Carrots	.008	.016	2.04	.037	.033
Tomatoes	.015	.017	6.70	.038	.041
Onions	.027	.026	3.90	-.002*	-.001*
Barley	.002*	-.006*	941.60	-.003*	-.069*
Maize	.013	.014	81.28	.024	.021
Oats	.017	.014	1131.20	.013	-.017
Rice	.009*	.062	21.00	.024	.055
Sorghum	.005*	-.026*	133.33	.028	.028*
Wheat	-.001*	-.004*	5769.20	.026	.040
Cotton	.131	.074	14.80	.033	.028*
Peanuts	.001*	.014	18.92	.010	-.023*
Tobacco	.041	.037	11.38	.015*	.019*

π All yield data taken from various issues of the *Rural Industries Bulletin* and the *Primary Industries Bulletin*.

* Indicates estimates which are not significant at the five per cent level.

cent level were assigned a value of zero. One was then added to all growth coefficients to avoid zero values. The estimates of equations (4.3) and (4.4) are respectively

$$\ell n\, g_i = \underset{(0.59)}{0.017} + \underset{(0.21)}{0.001}\, \ell n\, R_i$$

$R^2 = 0.01$

t values in parentheses

n = number of cases = 22

$$\ell n\, h_i = \underset{(0.93)}{0.018} + \underset{(0.36)}{0.002}\, \ell n\, R_i$$

$R^2 = 0.01$

n = 22

The estimates presented indicate that these particular models are poor predictors. Although the research coefficients have the expected sign, they lack statistical significance; moreover, the research variables in each case 'explains' only one per cent of the variability in yield growth rates. In the specification of equations (4.3) and (4.4), it is postulated that a proportionate increase in research activity will, *ceteris paribus*, result in a proportionate increase in yield growth rates. One of the *ceteris paribus* assumptions is that production conditions do not vary between different commodities. White it might be argued that assumptions need not reflect 'reality', if a model is not a good predictor, then the premises of the model must be re-examined.

With regard to production conditions, it is apparent that these will be more variable for some commodities than others. The production of say, carrots, which are relatively labour intensive, and which are produced in relatively homogeneous geographical areas may be contrasted with the production of wheat which is relatively land intensive, and which is produced over a relatively wide range of geographical areas. With regard to the contribution of research to yield increases, it would seem plausible to assume that a given amount of research activity will result in a greater increase in yield, the more homogeneous are the production conditions relating to a particular product.

In an attempt to take account of differences in the variability of production conditions between commodities, the research variable is weighted by the area planted to the particular commodity on the assumption that commodities commanding large areas will be characterized by more variable production conditions than those commanding relatively small areas. Of course, this assumption is not always valid, as Evenson and Kislev [1975, p.64] remark with regard to their use of an area deflater to account for variations in production conditions between countries.

> Clearly some countries have varied production conditions with small areas, while others have huge homogeneous areas.

The same observation can also be made with respect to commodities.

Taking into account differences in production conditions between commodities the following equations were estimated

$$g_i = a\left(\frac{R_i}{A_i}\right) u_i \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (4.5)$$

$$h_i = a\left(\frac{R_i}{A_i}\right) u_i \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (4.6)$$

where g_i, h_i, R_i, and u_i are as described in equation (4.4),

and A_i = average area of commodity i for the period 1960/61-1965/66.[1]

Again, adding a constant, one, to all yield growth estimates to avoid zero values, the estimates of equations (4.5) and (4.6) are respectively

$$\ell n g_i = \underset{(3.42)}{0.020} + \underset{(1.63)}{0.005} \; \ell n\left(\frac{R_i}{A_i}\right)$$

$$R^2 = 0.12$$

$$n = 22$$

$$\ell n h_i = \underset{(5.99)}{0.022} + \underset{(2.37)}{0.005} \; \ell n\left(\frac{R_i}{A_i}\right)$$

$$R^2 = 0.22$$

$$n = 22$$

---

[1] The A_i values are contained in column (3) of Table 4.1.

The inclusion of an area deflater appears to have considerably improved the model. In both cases the estimated coefficient is significant at the five per cent level. Furthermore, in each case there is an improvement in the proportion of yield growth variability 'explained' by the research variable.

A further model was formulated to take into account past yield increases and their effect on the productivity of research activity. In particular, we estimated the following equations.

$$g_i = a \left(\frac{R_i}{A_i}\right)^{\beta_1} \left(\frac{R_i}{A_i} g_i^*\right)^{\beta_2} e^{U_i} \quad \ldots\ldots\ldots\ldots\ldots \quad (4.7)$$

and $$h_i = a \left(\frac{R_i}{A_i}\right)^{\beta_1} \left(\frac{R_i}{A_i} h_i^*\right)^{\beta_2} e^{U_i} \quad \ldots\ldots\ldots\ldots\ldots \quad (4.8)$$

where g_i, h_i, R_i, A_i and a are as previously defined and

g_i^* = estimated average rate of yield growth for commodity i for the period 1945/46 - 1959/60. (The estimates of g_i^* are contained in column (4) of Table 4.1)

h_i^* = estimated average rates of yield growth for commodity i allowing for area effects, for the period 1945/46 - 1959/60.
(The estimates of h_i^* are contained in column (5) of Table 4.1)

and β_1 and β_2 are the respective coefficients to be estimated.

In these cases the marginal productivity of research activity with respect to yield growth is given by

$$\frac{\partial g_i}{\partial \left(\frac{R_i}{A_i}\right)} = a(\beta_1+\beta_2)\left(\frac{R_i}{A_i}\right)^{\beta_1-1} \left(\frac{R_i}{A_i} g_i^*\right)^{\beta_2} e^{U_i}$$

and $$\frac{\partial h_i}{\partial \left(\frac{R_i}{A_i}\right)} = a(\beta_1+\beta_2)\left(\frac{R_i}{A_i}\right)^{\beta_1-1} \left(\frac{R_i}{A_i} h_i^*\right)^{\beta_2} e^{U_i}$$

If the estimated value of β_2 is negative then this would indicate that past yield increases had reduced the level of 'technological slack' and that, on average, diminishing returns to research had set in.

The estimates of equations (4.7) and (4.8) are respectively,

$$\ell n\ g_i = \underset{(2.747)}{0.021} + \underset{(1.381)}{0.006}\ \ell n\ (\frac{R_i}{A_i}) - \underset{(-0.191)}{0.013}\ \ell n\ (\frac{R_i}{A_i}\ g_i^*)$$

$$R^2 = 0.121$$

$$n = 22$$

and
$$\ell n\ h_i = \underset{(6.223)}{0.026} + \underset{(3.129)}{0.007}\ \ell n\ (\frac{R_i}{A_i}) - \underset{(-1.569)}{0.054}\ \ell n\ (\frac{R_i}{A_i}\ h_i^*)$$

$$R^2 = 0.343$$

$$n = 22$$

The estimate of β_2, in both cases, is negative and the coefficient in the case of equation (4.8) displays a 'reasonable level' of statistical significance. As suggested above, a negative value of β_2 indicates that diminishing returns to research activity with respect to yield growth have set in for the period under consideration.

The results of the analysis in this section seem to suggest that research activity has made a contribution to the goal of maximizing agricultural output. While we should be cautious of the quality of the data, the results of the model tested in the form of equation (4.6) are encouraging, they would seem to indicate that research activity is a significant explanator of yield growth. The results of equations (4.7) and (4.8) would seem to indicate diminishing returns to research activity. In all cases, the most encouraging results are achieved when both the research and yield growth variables are adjusted for area effects.

4.3 The Contribution of Scientific Agricultural Research to Reducing Production Instability.

In section 3.2.4, it was concluded that one of the major goals of domestic agricultural policy during the period 1955-1965 was the goal of security; in particular, policy was aimed at stabilizing incomes. In subsequent analysis, section 3.3.3, we found evidence to suggest that the inherent production instability of commodities was a determinant of the commodity research mix. In the present section, we investigate whether research activity has made a contribution to the reduction of production instability. The analysis will again utilize publication data at the commodity level.

To estimate the reduction in production instability, we again utilized the method adopted in section 3.3.3. That is, the coefficient of instability was defined as the standard deviation of the residuals of the estimate of a straight line trend, expressed as a percentage of the mean of the observations for the entire period. Instability coefficients for each product were estimated for two periods, 1945/46 - 1959/60 and 1960/61 - 1974/75. The coefficients are related to instability of area and instability of yields and are contained in columns (1) to (4) of Table 4.2.

The effects of research, if any, on these two coefficients will differ in the sense that research will have a more direct effect on the reduction of yield instability than on area instability. The decision relating to the area of production is largely one made by the farmer and hence any effect that research might have must necessarily be indirect. For example, if farmers are able to perceive that yields will be more stable as a result of new research output, then the uncertainty associated with their decision making will be somewhat reduced, hence enabling them to more confidently select appropriate acreages for planting. The result of this might be a more stable pattern of crop area over time.

To estimate the extent to which instability had either increased or decreased between the two periods, the proportionate change in the

TABLE 4.2.

ESTIMATES OF CHANGES IN PRODUCTION INSTABILITY; 1945/60 - 1961/75.*

	(1) Area Instability Coefficients 1945/46 to 1959/60	(2) Yield Instability Coefficients 1945/46 to 1959/60	(3) Area Instability Coefficients 1960/61 to 1974/75	(4) Yield Instability Coefficients 1960/61 to 1974/75	(5) (3)-(1) / (1)	(6) (4)-(2) / (2)
Apples	.028	.170	.071	.064	1.536	-0.624
Citrus	.027	.094	.035	.083	0.296	-0.117
Pears	.029	.089	.050	.124	0.724	0.393
Peaches	.053	.106	.149	.077	1.811	-0.274
Bananas	.098	.110	.047	.037	-0.520	-0.664
Pineapples	.092	.060	.092	.091	0.000	0.517
Grapes	.011	.122	.041	.150	2.727	0.230
Potatoes	.100	.101	.087	.051	-0.130	-0.495
Beans	.088	.086	.044	.051	-0.500	-0.407
Green Peas	.156	.059	.111	.092	-0.288	0.559
Carrots	.128	.090	.031	.051	0.758	-0.433
Tomatoes	.108	.081	.045	.068	-0.583	-0.160
Onions	.170	.166	.069	.082	-0.594	-0.506
Barley	.075	.194	.230	.155	2.067	-0.201
Maize	.110	.089	.126	.096	0.145	0.079
Oats	.154	.205	.139	.171	-0.097	-0.166
Rice	.073	.128	.204	.112	1.795	0.125
Sorghum	.169	.165	.318	.169	0.882	0.024
Wheat	.090	.173	.161	.164	0.789	-0.052
Cotton	.383	.224	.115	.389	-0.700	0.737
Peanuts	.346	.201	.230	.288	-0.335	0.433
Tobacco	.171	.193	.072	.075	-0.579	-0.611

* All data on areas and yields various volumes of *Rural Industries Bulletin* and *Primary Industries Bulletin*.

instability coefficients was calculated. That is,

$$\Delta I = \frac{I_{t+1} - I_t}{I_t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.9)$$

where ΔI = proportionate change in the instability coefficient between periods t+1 and t

I = the instability coefficient

t = period 1945/46 - 1959/60

and $t+1$ = period 1960/61 - 1974/75.

So defined, a negative value of ΔI will indicate a reduction in instability and a positive value an increase. The estimated ΔI's are contained in columns (5) and (6) of Table 4.2.

The research variables used in the present analysis are those used in section 4.2. That is, R_i will be the stock of publications relating to the ith commodity and R_i/A_i an area weighted research variable.

The general hypothesis to be examined is that, *ceteris paribus*, there will be a negative relationship between changes in instability and research activity. That is, those commodities with relatively greater amounts of research activity devoted to them will experience either relatively smaller increases or reductions in instability. The initial models tested utilized the unweighted research variable R_i and took the form

$$\Delta I_{A_i} = a + bR_i + e \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.10)$$

and

$$\Delta I_Y = a + bR_i + e \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.11)$$

where $\Delta I_{\ i}$ = the proportionate change in area instability of the i^{th} commodity

ΔI_{Y_i} = the proportionate change in yield instability of the i^{th} commodity

R_i = the stock of publications for the i^{th} commodity for the period 1960-1969

a and b are constants to be estimated

and e is an error term.

The equations are estimated in both linear and log linear form. For the log linear models a constant was added to all ΔI values to avoid negative and zero values. The estimate of equations (4.10) and (4.11) in both linear and log-linear form are largely inconclusive. The estimated coefficients lack statistical significance and only a small percentage of the variability is 'explained' by the research variable. With regard to the area instability equations, the signs of the coefficients change and therefore tell us little about the relationship. The estimates of equation (4.11) are reported below.

$$\Delta I_Y = \underset{(-0.011)}{-0.001} - \underset{(-0.75)}{0.101} R_i$$

$R^2 = 0.03$

$n = 22$

t values in parentheses

$$\ln\Delta_Y = \underset{(7.94)}{1.181} - \underset{(-0.80)}{0.030} \ln R_i$$

$R^2 = 0.03$

Whilst nothing can be attached to the statistical significance of the estimates, the signs are at least consistent with the hypothesis that research contributes to reductions in yield instability.

A further set of tests were carried out using the area weighted research variable R_i/A_i in place of R_i. Again the estimates were made in both linear and log-linear form and again the results lacked statistical significance, although the sign attached to the research variable was again negative in both cases with respect to the reduction of yield instability.

$$\Delta I_Y = \underset{(0.46)}{0.063} - \underset{(-1.31)}{0.035} \left(\frac{R_i}{A_i}\right)$$

$R^2 = 0.08$

$n = 22$

$$\ln \Delta I_Y = \underset{(33.2)}{1.070} - \underset{(-0.67)}{0.012} \ln\left(\frac{R_i}{A_i}\right)$$

$$R^2 = 0.02$$

$$n = 22$$

As is indicated by the reported estimates the results of this section are statistically unsatisfactory. No evidence exists to allow us to reasonably conclude that research has had an effect on reducing production instability. The reported results regarding the reduction in instability of yields nevertheless all have in common a negative sign which is consistent with the proposed hypothesis.

4.4 Technical Change and Scientific Agricultural Research: An Aggregate Study.

4.4.1 Introduction.

This section will investigate the nature of the relationship which exists, if any, between changes in the level of agricultural scientific research and technical change for Australian agriculture for the period 1926-1968. Interest in this relationship has broadened since the discovery, in particular by Solow [1957], that increases in the physical capital-labour ratio could explain only a small part of increases in per capita incomes. Physical capital-labour ratios could not 'explain' technical change. Following studies, for example, Denison [1962] and Jorgenson and Griliches [1967], have made attempts to 'explain' technical change by elements of efficiency increases or quality changes in traditional factors, for example, increases in education, quality changes of capital and land, and changes in utilization rates of capital and labour. The ultimate source of these changes was a type of investment which differed from the traditional Harrod-Domar investment into new units of already developed physical capital.

In this section an estimate of technical change will be made for Australian agriculture for the period 1926-1968. An attempt will then be made to investigate how much of this technical change is 'explained' by scientific research activity. The analysis will then be extended to include two other possible 'explanators'; variations in climatic conditions and changes in the education level of the community.

4.4.2 Estimate of Technical Change.

Estimates of technical change for Australian agriculture have been few and far between, the major published work being that of Herr [1964], Powell [1969] and Young [1971].[1] More recently a more extensive study was undertaken by Powell [1974] which greatly extended the data base needed for the estimation of technical change. Powell systematically extended and refined aggregated data on rural inputs and outputs for the period 1920/21 - 1969/70. These data, although not without limitations, represent the most consistent and updated series presently available and will be used in this section.

Several techniques exist for estimating technical change, the most widely used being those that utilize indexes of total inputs and total outputs. These techniques might be loosely referred to as total productivity indexes and derive from the basic assumption that output must equal total inputs. The estimate of technical change is the 'residual' or the contribution of 'unmeasured' inputs to output. As such technical change is

> ...a shorthand expression for *any kind of shift* in the production function. Thus slowdowns, speedups, improvements in the education of the labour force, and all sorts of things will appear as 'technical change'.
>
> [Solow, 1957, p.312]

The shift may, for example, be the result of any of the factors listed in 4.4.1. To this stage these factors have defied precise definition and their 'contributions' to shifts are not unambiguous.

The method of estimation used in this section will be that developed by Solow [1957]. Solow's measure assumes a Cobb-Douglas production function which displays constant returns to scale, a perfectly competitive factor market and constant elasticity of substitution between factors. With these assumptions, the production function takes the form

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[1] Other studies include Bates and Musgrave [1972], Gutman [1955] and Saxon [1963].

$$Y = A(t)\ f\ (L,K)$$

where Y = factor output

L = labour input

K = capital input

and $A(t)$ = the cumulated shifts in the production function over time.

If the production function is totally differentiated with respect to time and is divided throughout by Y, the following growth equation is derived.

$$\frac{\Delta Y}{Y} = \frac{\Delta A}{A} + w_K \frac{\Delta K}{K} + w_L \frac{\Delta L}{L} \quad \ldots\ldots\ldots\ldots\ldots \quad (4.12)$$

If all factor inputs are classified as either K or L then $W_K + W_L = 1$. On the assumption that the production function is homogeneous of degree one, if $Y/_L = y$, $K/_L = k$ and $w_L = 1 - w_K$ then equation (4.12) becomes

$$\frac{\Delta y}{y} = \frac{\Delta A}{A} + w_K \frac{\Delta K}{K} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.13)$$

where $\frac{\Delta A}{A}$ = rate of technical change

$\frac{\Delta y}{y}$ = rate of growth of output per unit of labour

$\frac{\Delta K}{K}$ = rate of growth in capital per labour unit.

and w_K = share of output payable to capital.

The neat form of equation (4.13) means that the only data needed to estimate technical change are a series for output per unit of labour, capital per unit of labour and the share of capital.

The above specification of technical change is not without important limitations.[2] For example, because the measure is a

---

2 For a review of these, see Nadiri [1970].

'residual', any errors relating to the measurement of the included variables or errors relating to the omission of relevant inputs will be reflected in the measure of technical change. At a more fundamental level the use of this specification has been criticized on the grounds that aggregate production functions have inherent conceptual limitations. For example, the practice of aggregation has met with considerable opposition, in particular, the problems of aggregating different types of capital goods. The neo-Keynesians, for example, have strongly argued that the neo-classical models do not incorporate a measure of capital which is independent of relative prices and the distribution of income. This criticism is of particular importance when aggregate functions are used to explain the share of national income between wages and profits. Other major areas of criticism of the use of aggregate production functions relate to problems of aggregating technically different micro-economic production functions and the validity of assuming a constant elasticity of substitution factors over time.[3]

Despite the shortcomings of the 'residual' method of estimating technical change, it has nevertheless remained an important analytical tool in empirical economics. In the case of this study, we adopt the Solow method of estimating technical change for much the same reasons as McLean [1973, p.564] did.

> In part our choice has been restricted by the nature of the output and input data. Also, this method has been used in studies relating to Australian farming in more recent years, so that some limited comparison would then be possible... Finally, although major advances in analytical methods have occurred over the past decade the Solow-type approach is still frequently used and would seem an appropriate first step for research in this area.

As mentioned above, we are relying on the data series produced by Powell [1974] for the present study. Powell made estimates of technical change but his results were published both graphically and in an aggregated average form which are not suitable for the present

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3 The neo-Keynesian attack is well summarized by Harcourt [1969].

analysis. In view of this, a cumulative index of technical change for the period 1926 - 1968 was estimated. The data used and the estimates of technical change are contained in Table 4.3. The cumulative index of technical change contained in column (6) of the table is derived by the following formula.

$$A(t+1) = A(t)(1 + \frac{\Delta A}{A}(t+1)) \quad \ldots\ldots\ldots\ldots \quad (4.14)$$

where $\frac{\Delta A}{A}(t+1)$ refers to the change in A between time periods t and (t+1), and letting 1925/26 = 1.

4.4.3 Derivation of an Aggregate Research Index.

The research index to be used in this section will utilize scientific personnel data, the collection of which was described in section 2.3. In that section we argued that the use of personnel data for long term comparisons in the level of research activity were subject to similar limitations to those inherent in the use of publication data. In particular, it was argued that the 'average quality' of research workers might change over time and that the relationship between the *size* of the scientific labour force and the corresponding scientific *effort* might change over time.

In view of these limitations the use of yearly scientific personnel data in a time series analysis was not considered appropriate. The procedure adopted was analogous to that used for the analysis of publication data. That is, on the assumption that the factors affecting the comparability of personnel data were not likely to be serious in the short run, then proportionate changes in personnel over short periods of time were assumed to reflect changes in research activity of the same magnitude. The practice of calculating short run changes in the data was constrained to a certain extent by the availability of the data. For the period 1925 - 1947, the data used were for C.S.I.R., the Universities and the State Departments of Agriculture which were

TABLE 4.3

ESTIMATES OF 'TECHNICAL CHANGE' FOR AUSTRALIAN AGRICULTURE; 1925/26 - 1969/70

	(1) Gross Agric. Output[1] 1949/50 Prices $m.	(2) Rural Workforce[2]	(3) Total Rural Capital[3] $m.	(4) Capital Share[4]	(5) $\frac{\Delta A}{A}$	(6) A_t
1925/26	1158	472.2	4738	0.273		1.00
1926/27	1179	471.1	4981	0.165	0.006	1.01
1927/28	1103	469.3	5130	0.167	-0.067	.94
1928/29	1258	473.4	5404	0.179	0.124	1.06
1929/30	1182	463.8	5469	0.026	-0.047	1.01
1930/31	1362	458.2	5597	-0.035	0.165	1.18
1931/32	1384	447.1	5440	0.082	0.041	1.23
1932/33	1563	464.4	5404	0.165	0.188	1.46
1933/34	1458	475.9	5357	0.344	-0.085	1.34
1934/35	1453	474.4	5356	0.295	-0.002	1.34
1935/36	1406	480.5	5340	0.375	-0.040	1.29
1936/37	1404	485.4	5408	0.462	-0.013	1.27
1937/38	1609	491.7	5407	0.412	0.137	1.44
1938/39	1512	482.2	5724	0.272	-0.075	1.33
1939/40	1546	477.8	5753	0.347	0.028	1.38
1940/41	1352	475.5	5504	0.283	-0.107	1.23
1941/42	1466	442.1	5628	0.353	0.138	1.40
1942/43	1468	406.2	5527	0.427	0.066	1.49
1943/44	1432	403.9	5399	0.428	-0.011	1.47
1944/45	1237	419.8	5178	0.234	-0.166	1.23
1945/46	1261	441.4	5086	0.325	-0.016	1.21
1946/47	1236	449.2	5081	0.349	-0.031	1.17
1947/48	1544	440.9	5090	0.675	0.266	1.48
1948/49	1518	441.8	5211	0.584	-0.034	1.43
1949/50	1607	444.6	5335	0.668	0.042	1.49
1950/51	1515	445.5	5532	0.775	-0.082	1.37
1951/52	1469	448.9	5428	0.492	-0.018	1.35
1952/53	1712	458.0	5609	0.566	0.136	1.53
1953/54	1725	461.8	5712	0.483	-0.006	1.52
1954/55	1766	459.7	5952	0.410	0.006	1.53
1955/56	1899	456.5	5961	0.436	0.079	1.65
1956/57	1947	450.9	6272	0.469	0.010	1.67
1957/58	1815	445.7	6354	0.136	-0.069	1.55
1958/59	2147	435.4	6426	0.340	0.206	1.87
1959/60	2098	425.1	6657	0.364	-0.020	1.83
1960/61	2147	415.3	6790	0.336	0.032	1.89
1961/62	2256	422.4	7150	0.271	0.021	1.93
1962/63	2375	413.4	7435	0.336	0.059	2.04
1963/64	2495	408.5	7680	0.468	0.048	2.14
1964/65	2614	406.1	8055	0.394	0.028	2.20
1965/66	2342	397.5	8434	0.178	-0.113	1.95
1966/67	2839	397.7	8798	0.393	0.205	2.35
1967/68	2620	392.1	9486	0.097	-0.101	2.11
1968/69	3125	378.4	9928	0.322	0.228	2.59
1969/70	3070	363.7	10125	0.211		

1 Source: Powell [1974], Appendix 8A, p.335.
2 Source: Powell [1974], Appendix 3F, p.299.
3 Source: Powell [1974], Appendix 9A, p.339.
4 Source: Total Wage Payments [Powell,1974, Appendix 4C, p.303]
Total Factor Output, [Powell, 1974, Appendix 8C, p.337].

available on a yearly basis.[4] The continuity of the data for this period enabled us to measure short run changes by utilizing overlapping five year averages. For the period 1947-1972, the data, in particular for the State Departments of Agriculture, are not available on a continuous basis, but rather on a three yearly basis. Short run changes in research activity for this period are calculated by taking proportionate changes in scientific personnel for successive three year periods.[5]

Estimates of short-run changes in scientific personnel for the period 1941/44 - 1969/72 are contained in Table 2.18. Proportionate changes in personnel between overlapping five year periods were calculated for the period 1925 - 1941 and are presented, together with the estimates for the latter period in column (1) of Table 4.4. The personnel data in this form resembles $\frac{\Delta A}{A}$, the rate of technical change. A procedure similar to that used to construct the cumulative technical change index was used to construct a cumulative research index. That is

$$R(t+1) = R(t)\left(1 + \frac{\Delta R}{R}(t+1)\right) \quad .... \quad (4.15)$$

where in this case $\frac{\Delta R}{R}(t+1)$ is the proportionate change in scientific personnel for overlapping five year periods (or successive three year periods.)

The cumulative research index derived by this method is contained in column (2) of Table 4.4.

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4 These data are contained in Tables 2.14, 2.15 and 2.16 respectively.

5 For this period the changes in scientific personnel utilize all the institutions reported in Chapter 2.

TABLE 4.4

ESTIMATES OF TECHNICAL CHANGE 'EXPLANATORS'

	(1) Changes in Research Activity $\frac{\Delta R}{R}$	(2) Cumulative Research Index R_t	(3) Technical Change Index A_t	(4) School Enrolment Ratio Index S_t	(5) Proxy Environmental Variable E_t
1926		100	100	100	-1
1929	0.38	138	100	101	0
1932	0.25	173	129	104	1
1935	0.17	202	132	102	0
1938	0.15	232	135	103	0
1941	0.09	253	134	102	0
1944	0.09	276	140	104	0
1947	0.38	381	129	109	-1
1950	0.21	461	143	114	-1
1953	0.23	567	147	121	-1
1956	-0.02	557	162	126	0
1959	-0.02	546	175	133	0
1962	0.30	710	195	141	0
1965	0.18	838	210	145	0
1968	0.18	989	235	146	1

4.4.4 Technical Change and Scientific Research.

With data on both technical change and scientific research activity we are now in a position to examine the relationship between the two. At the most fundamental level we might hypothesize that, *ceteris paribus*, changes in technical change will be associated with changes in scientific research activity; that is, part of the 'residual' will be 'explained' by scientific research activity. Evenson [1968] made an investigation of the time dimensions of this relationship and postulated that the time lag between research activity (in his case research expenditures) and effects on production could be divided into three separate components,

(1) a lag between research expenditures and relevant research output discoveries,

(2) a lag between these discoveries and the use of new production techniques embodying these discoveries,

(3) a lag which incorporates the diminishing impact on production of a new discovery due to the 'depreciation' of that discovery.

Evenson argued that lag (1) was likely to be of a symmetric or inverted V shape while lags (2) and (3) were likely to be exponentially declining. Each of the lags are clearly difficult to separate empirically which necessitated the use of a summary lag structure to incorporate the three. To this end, Evenson [1968, p.1421] used two different lag formulations; the exponentially declining lag and an inverted V lag. His investigation suggested that the lag between expenditures on research and relevant research discoveries was dominating the other two lags and that the mean lag between investment in research and the subsequent impact on production was six years.

In the present study the use of a distributed lag function to take explicit account of these postulated lags presents a number of difficulties. Of major importance in this respect is the small number of observations at our disposal as a result of the constraints placed on the utilization of the available data. In view of this, the choice of an appropriate lag function had to take into account not only the shape of the lag structure, but also the reduction in the number of degrees of freedom. To this end, an Almon lag structure was adopted, the particular form being as follows.[6] First, a polynomial of degree two (quadratic) was adopted, this being a formulation of an inverted-V structure and is thus consistent with the hypothesized nature of the lag. Secondly, it is assumed that the impact of the lagged variable, in this case research activity, on the dependent variable is zero in both the first and last period of the total lagged period. Given the nature of the Almon lag, this means that for varying lengths of lag, there will only be a single 'synthetic' Almon variable in the estimated equation. This restriction is not thought to be too unrealistic, especially in the case of the initial period, and it allows us to retain a maximum number of degrees of freedom which, as pointed out above, is considered most important in this case where the number of observations is quite small.

The following procedure was adopted to incorporate a distributed lagged research variable of the above nature into a model to explain changes in total factor productivity. The initial approach was to estimate the following equations, each with different lag lengths, to search for that model which resulted in the highest $\bar{R}^2$, with that model possessing the highest value being considered most appropriate.[7]

$$A_t = a + bR_t + b_1R_{t-1} \ldots\ldots + b_4R_{t-4} + e \qquad \ldots\ldots\ldots\ldots (4.16)$$

$$A_t = a + bR_t + b_1R_{t-1} \ldots\ldots + b_6R_{t-6} + e \qquad \ldots\ldots\ldots\ldots (4.17)$$

$$A_t = a + bR_t + b_1R_{t-1} \ldots\ldots\ b_8R_{t-8} + e \qquad \ldots\ldots\ldots\ldots (4.18)$$

$$A_t = a + bR_t + b_1R_{t-1} \ldots\ldots\ b_{10}R_{t-10} + e \qquad \ldots\ldots\ldots\ldots (4.19)$$

where A_t = technical change index[8]

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6 For a discussion of this form of lag structure see Almon [1965].

7 $\bar{R}^2$ is used here rather than R^2 in view of the small number of observations. For a discussion on the suitability of $\bar{R}^2$ as a criterion for selecting the best lag estimate see Thiel [1964, Chapter VI].

8 The 'technical change' data are three year averages centred on the years indicated by Table 4.4.

R_t = research index (column (2), Table 4.4)

t = time, corresponding to the three year intervals listed in Table 4.4.

The estimates from these models yielded results which were difficult to interpret due mainly to the high degree of serial correlation present, the value of $\bar{R}^2$ in each case was essentially the same, making it difficult to confidently distinguish between the respective values. In order to try and overcome this problem it was decided to take first differences of the dependent variable, thus $A_t - A_{t-1}$ was substituted for A_t in equations (4.16) to (4.19). That is, the following equations were estimated

$$A_t - A_{t-1} = a + bR_t + b_1R_{t-1} \ldots + b_4R_{t-4} + e \quad \ldots\ldots\ldots\ldots \quad (4.16(a))$$

$$A_t - A_{t-1} = a + bR_t + b_1R_{t-1} \ldots + b_6R_{t-6} + e \quad \ldots\ldots\ldots\ldots \quad (4.17(a))$$

$$A_t - A_{t-1} = a + bR_t + b_1R_{t-1} \ldots + b_8R_{t-8} + e \quad \ldots\ldots\ldots\ldots \quad (4.18(a))$$

$$A_t - A_{t-1} = a + bR_t + b_1R_{t-1} \ldots + b_{10}R_{t-10} + e \quad \ldots\ldots\ldots\ldots \quad (4.19(a))$$

where A_t, R_t and e are as previously defined

and the weights assigned to the lagged research variable were according to an Almon quadratic lag with zero weights being applied to the respective first and last research variable.

Because of the reduction in the number of observations as the length of the lag is increased, it was felt that the structural relationship between the variables might alter as the lag was changed. In view of this, the maximum number of lagged relationships was estimated for each sample size. The estimated equations, denoting the number of lagged periods, and the value of $\bar{R}^2$ are given below. In each case AV denotes the 'Almon variable.

1. Number of Observations = 12

(a) $A_t - A_{t-1} = \underset{(-1.716)}{-7.169} - \underset{(-4.246)}{0.004AV}$

$\bar{R}^2 = 0.608$

t values in parentheses

ℓ = number of lagged periods = 4

2. Number of observations = 10

(a) $A_t - A_{t-1} = \underset{(-1.920)}{-10.942} - \underset{(-3.946)}{0.005AV}.$

$\bar{R}^2 = 0.618$

$\ell = 4$

(b) $A_t - A_{t-1} = \underset{(-1.713)}{-0.586} - \underset{(-3.785)}{0.002AV}$

$\bar{R}^2 = 0.597$

$\ell = 6$

3. Number of observations = 8

(a) $A_t - A_{t-1} = \underset{(-1.794)}{-15.406} - \underset{(-3.321)}{0.006AV}$

$\bar{R}^2 = 0.589$

$\ell = 4$

(b) $A_t - A_{t-1} = \underset{(-1.523)}{-12.929} - \underset{(-3.072)}{0.002AV}$

$\bar{R}^2 = 0.546$

$\ell = 6$

(c) $A_t - A_{t-1} = \underset{(-1.415)}{-11.716} - \underset{(-3.008)}{0.076AV}$

$\bar{R}^2 = 0.535$

$\ell = 8$

4. Number of observations = 6

(a) $A_t - A_{t-1} = -15.335 - 0.006AV$
$(-2.003) \quad (-4.076)$

$\bar{R}^2 = 0.758$

$\ell = 4$

(b) $A_t - A_{t-1} = -9.485 - 0.001AV$
$(-1.246) \quad (-3.339)$

$\bar{R}^2 = 0.670$

$\ell = 6$

(c) $A_t - A_{t-1} = -7.205 - 0.064AV$
$(-0.981) \quad (-3.156)$

$\bar{R}^2 = 0.642$

$\ell = 8$

(d) $A_t - A_{t-1} = -6.656 - 0.0004AV$
$(-0.926) \quad (-3.154)$

$\bar{R}^2 = 0.642$

$\ell = 10$

These results provide a consistent finding in terms of the length of lag which maximizes $\bar{R}^2$; in all cases the 'Almon variable' incorporating four lagged periods provides the highest $\bar{R}^2$.[9] If the highest $\bar{R}^2$ is a suitable criterion for selecting the optimum lag structure, then the results suggest a lag of four periods corresponds to a lag of 12 years and a mean lag of six years. On the basis of past research in this area, notably Evenson [1968], the finding of a six year mean lag would seem to represent a plausible finding.

Quite clearly, the inclusion of only a lagged research variable in the model may give a biased estimate of the research coefficient. The exclusion of other relevant variables may bias the estimated research

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9 These models were also estimated with the inclusion of a time variable but owing to the high degree of multi-collinearity between this and other variables, the estimated coefficients were unrealistic. These estimations revealed similar results in terms of the ranking of $\bar{R}^2$.

coefficient upwards, the extent of this bias being a function both of the correlation between the included and excluded variables and of the coefficients of the excluded variables. In an attempt to try and ascertain the extent of this bias, the model is extended to include variables reflecting variations in climatic conditions and changes in the level of education.

As already indicated, the estimate of technical change is a residual measure and as such any substantial disturbances, such as a severe drought, will be reflected in the estimate. It is felt that some effects of changes in climatic or environmental factors have already been taken into account by the particular use of A_t in the model; that is, A_t is a three year average figure and as such, involves a smoothing procedure dampening the effects of such factors. Quite clearly, in an aggregate model, it is difficult to measure changes in environmental factors; all products, for example, will respond differently to given changes in say, rainfall, temperatures and soil types.

In view of these difficulties the following proxy measures were used to reflect particularly 'favourable' and 'unfavourable' years. Using Powell's [1974, p.335] estimate of real gross output for Australian agriculture for the years 1925/26 - 1969/70, we regressed this series linearly against time to enable us to observe residual values of real output from the estimated trend values. The following three part variable was then used as a proxy variable to reflect marked changes in environmental conditions. A value of

-1 was assigned to periods where real gross output was 15 per cent or more below the estimated trend values for the same period.[10]

0 was assigned to periods where real gross output was within ±15 per cent of the estimated trend values.

+1 was assigned to periods where real gross output was 15 per cent or more above the estimated trend values.

---

[10] The values again are derived from three year averages centred on the years indicated by Table 4.4. The particular values are contained in column (5) of Table 4.4.

Designating the environmental proxy variable E_t, the variable was added to the model giving

$$A_t - A_{t-1} = a + bAV + cE_t + e \quad .... \quad (4.20)$$

Using the maximum number of observations given an 'Almon variable' incorporating four lagged periods, the following estimates were made,

$$A_t - A_{t-1} = \underset{(-0.880)}{-4.131} - \underset{(-3.374)}{0.004AV} + \underset{(1.281)}{4.513E_t}$$

$$R^2 = 0.631$$

$$n = 12$$

The inclusion of the environmental proxy variable has qualitatively improved the model, the $\bar{R}^2$ value has increased from 0.608 (the first reported $\bar{R}^2$ above) to 0.631.

In an early study of the role of education in the growth of agricultural output, Griliches [1964] found that education was a significant factor affecting output. This relationship reflects the probability that increased education increases both farm management's and farm labourers' ability to *use* resources more efficiently and also to *allocate* resources more efficiently. To try and estimate the contribution of education to increases in total factor productivity for Australian agriculture we made use of a school enrolment ratio which measures the ratio of average attendance of school students to the potential number of students. The description of this data is presented in Appendix 4.7.1. The data was averaged to try and establish a variable which reflected a stock of education, for example, the ratio for say 1965, was the average of the ratio for the years 1961-1966. The index of the school enrolment ratio is contained in column (4) of Table 4.4.[11]

---

[11] This variable is deficient to the extent that it applies to the entire population rather than just to the agricultural sector. Ideally the variable should reflect the schooling of adult farmer decision makers, however data to construct such a variable is not readily available.

The data in the enrolment ratio was then included in the model to estimate the following,

$$A_t - A_{t-1} = a + bAV. + cE_t + dS_t + e \quad ....(4.21)$$

where S_t = stock of education as defined in the text and described in Appendix 4.7.1.

The estimate of this equation being,

$$A_t - A_{t-1} = \underset{(-0.530)}{-31.424} - \underset{(-0.104)}{0.001AV} + \underset{(1.304)}{5.001E_t} + \underset{(0.462)}{0.320S_t}$$

$$\bar{R}^2 = 0.595$$

$$n = 12$$

The estimates of this equation are qualitatively inferior to those of equation (4.20), all coefficients lack statistical significance and the $\bar{R}^2$ is less. The poor performance of the model is probably largely the result of the high degree of multi-collinearity between AV and S_t; the value of the correlation coefficient being -0.986.[12]

The most efficient models then, would appear to be those represented by equations (4.16) and (4.20); in each case the coefficient on the 'Almon variable' is -0.004. This value is now used to compute the respective coefficients on the lagged research variables which gives the following estimate (remembering that in the formulation of the model it was assumed that the coefficients on the first and last research variable were zero).

$$A_t - A_{t-1} = -4.131 + 0.012R_{t-1} + 0.016R_{t-2} + 0.012R_{t-3} + 4.513E_t.$$

The sum of the lagged coefficients in this case is 0.04. While this coefficient is not open to easy interpretation owing to the indexing methods employed, it suggests that over the period increases in research

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12 The models were also tested substituting first differences of the enrolment ratio for the enrolment ratio but with no qualitative improvement in the results.

activity have led to greater than proportional increases in total factor productivity, indicating that as yet diminishing returns to public scientific research activity have not yet set in in Australian agriculture.

4.5 Summary

In many respects the models tested here and the results which are reported reflect the attitude of Evenson and Kislev [1973, p.1324]

> We purposely did not follow the practice...of limiting the report to 'reasonable' results. The crudeness of the data, the lack of information, and the absence of prior work in the field justified in our mind more than the usual dose of experimentation.

The major aim of the analysis was to investigate the contribution of total scientific research activity to agricultural productivity for Australia. In section 4.2, the relationship between scientific research and increases in product yields was investigated. In some cases the statistical results were not very conclusive but in all cases, there seemed to be some evidence that increased research activity contributed to greater yield growths. For example, in all models tested the estimated coefficients had signs consistent with this proposition and when the model was refined to take account of area effects on yield growths and when the research variable was adjusted to take account of variable production conditions, a statistically significant relationship was found between the two variables.

In section 4.3, we investigated to see if scientific research activity had made a contribution to reducing production instability. In this case, the reported estimates gave us no conclusive evidence. In each of the models tested the results were statistically insignificant.

In the final section, the contribution of scientific research activity to the growth in total factor productivity (or to technical change) was investigated. Again, within the constraints of the available data, the evidence seemed to support the proposition that scientific research activity has made a positive contribution to technical change.

The utilization of a distributed lag function to describe the research/productivity relationship suggested a mean lag of approximately six years between changes in research activity and total factor productivity. As the model was expanded to account for possible 'bias' in the estimates, the research variable remained a significant 'explanator'.

We must again stress the preliminary nature of the analysis; it represents the first of its kind for Australia and as such suffers, due to both the availability and quality of data. However, in spite of the 'crudeness' of the data, the results seem to consistently support the proposition that agricultural scientific research has made a positive contribution to the growth of agricultural productivity. Whilst this conclusion must necessarily be tentative, we make the same defence as Griliches [1964, p.972] in his conclusion to his pioneering work on the contribution of education to agricultural productivity.

> None of these conclusions is very firmly established, and some may be subject to substantial bias, but the only known way of either confirming them or disproving them is the slow and expensive but cumulative process of conducting additional studies of this type on different bodies of data.

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4.7 Appendices

4.7.1 Estimates of Components of the Schooling Ratio.

Year	Average Attendance at State and Private Schools*	Estimated Number of People in Population Aged Between 5 and 19 years**
1926	911,974	1,737,370π
1929	970,341	1,806,964π
1932	1,003,241	1,876,558π
1935	992,906	1,843,675
1938	970,465	1,810,792
1941	940,954	1,772,519
1944	961,200	1,720,930
1947	1,005,886	1,725,332
1950	1,129,197	1,842,606
1953	1,369,249	2,094,676
1956	1,615,557	2,396,538
1959	1,932,949	2,681,033
1962	2,251,133	2,961,965
1965	2,436,262	3,216,101
1968	2,655,555	3,421,437

* Taken from Australia, Bureau of Census and Statistics, *Official Year Book of the Commonwealth of Australia*, various issues.

** Taken from Australian Bureau of Census and Statistics, *Demography Bulletin*, various issues.

π Linearly interpolated from 1921 and 1933 Census data.

CHAPTER 5

THE DEVELOPMENT OF PUBLIC SECTOR RESEARCH IN AUSTRALIAN AGRICULTURE

5.1 Introduction

In this chapter, the emphasis changes from the contributions made to increases in productivity by scientific research activity to an analysis of the development of institutionalized scientific research in Australia. In particular, this development will be analysed within the induced innovation theory advanced in relation to agriculture by Hayami and Ruttan [1971]. We start by reviewing the theory of induced innovation as it has developed from Hicks [1932]. This is followed by a brief discussion of Hayami and Ruttan's application of the theory to a theory of agricultural development with particular reference to the role of public sector research. The development of public sector research in Australian agriculture is then discussed and an attempt is made to link this development to changes in factor prices as predicted by the induced innovation model.

5.2 A Review of the Theory of Induced Innovation

The purpose of this section is to review the various theoretical models of induced innovation and to discuss the relative merits of each in attempting to establish biases as endogenously determined. Before proceeding with this theoretical review, it is necessary to outline the view of the production function taken here and to define bias. Conventionally the production function shows the maximum output attainable from any specified set of inputs. During the discussion which follows, it is assumed that an act of invention will result in a movement from one production function to another. This is distinct from an act of substitution which is a shift from one point to another on the same production function.[1] Thus, an act of invention will result in technical change which can be classified as either labour saving (capital using), capital saving (labour using) or neutral. Technical change will have a labour saving bias, for example, if there is a proportionate saving in labour greater than that of capital. Whilst no unique definition of bias and neutrality exists, throughout this paper Hicksian definitions will be adopted unless otherwise stated.

Hicks' [1932, pp.121-2] definition of bias and neutrality is defined as follows. At a given capital-labour ratio,

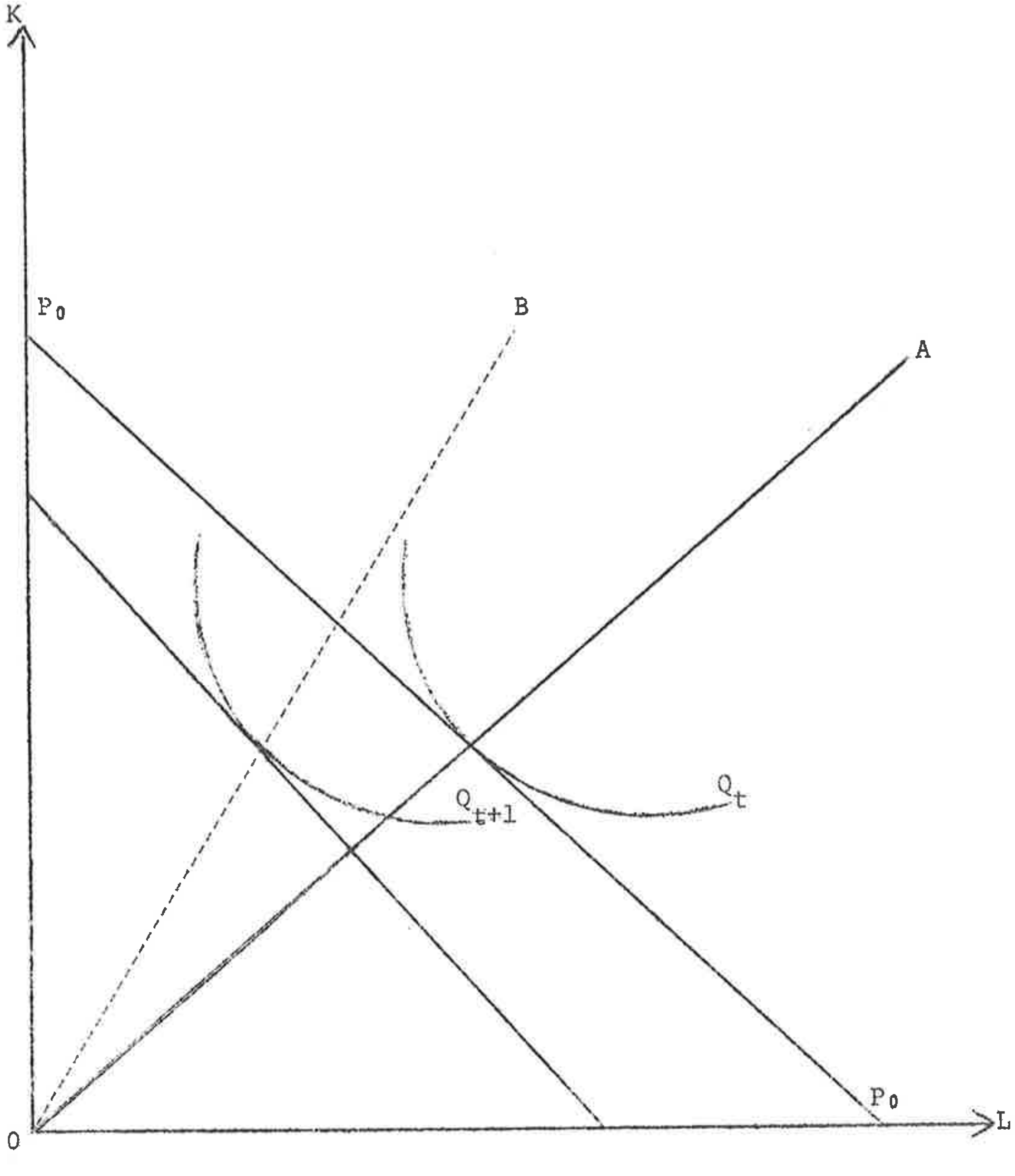
> Labour-saving inventions increase the marginal product of capital more than they increase the marginal product of labour; 'capital saving' inventions increase the marginal product of labour more than that of capital; 'neutral' inventions increase both in the same proportions.

Diagrammatically Hicks' concept of bias can be illustrated as in figure 5.1. At a given point in time, t, there is a prevailing input-price ratio, P_0P_0, which results in an equilibrium capital-labour ratio (given by the ray OA) at the point where the isocost line is tangent to the isoquant, denoting output Q_t. Supposing the input-price ratio and the capital-labour ratio are instantaneously fixed and that technological change takes place (graphically depicted by an inward shift of the isoquant towards the origin), assuming that this technological shift is labour saving, (capital using) and the new isoquant is represented by Q_{t+1}, this implies a decrease in the marginal rate of technical substitution. At the given factor-price ratio there would be an incentive to substitute labour for capital; that is, an incentive would exist to shift to capital-labour ratio to OB. With fixed

---

1 This differs somewhat from the interpretation of the production function envisaged by Salter [1960]. Salter defined the production function to embrace all 'possible designs', (p.15) which would mean that an invention under his definition would not result in a shift to another production function.

FIGURE 5.1



input supplies, the capital-labour ratio cannot be changed instantaneously. However, in the long-run, the ratio will be increased. This is the meaning of Hicks' biased technological progress. Having presented a view of the production function and defined bias, the various theories of induced innovation will be reviewed. The theories will be reviewed in a chronological order since each development seems to be in direct response to the previous contribution.

5.3 A Review of the Theory of Induced Innovation

5.3.1 Hicks to Ahmad

Hicks developed his theory of induced invention in an attempt to explain 'the predominance of labour-saving inventions.' This 'predominance' seemed to be based on casual rather than empirical observation. He supported the earlier claim by Pigou that inventions have a decided bias in the labour saving direction pointing out that it was difficult to find many cases of important capital-saving inventions (with the exception of wireless) while the appearance of 'obvious' labour-saving inventions were frequent. The practice of casual observation in this case is not a particularly good one as it is difficult to tell *a priori* on the basis of appearances whether a particular invention will save relatively more of one factor than another.

However, with the belief that inventions were largely labour-saving, Hicks sought to explain this in terms of the movements in the prices of capital and labour.

> The real reason for the predominance of labour-saving inventions is surely that which was hinted at in our discussion of substitution. A change in the relative prices of the factors of production is itself a spur to invention, and to invention of a particular kind - directed to economising the use of a factor which has become relatively expensive. The general tendency to a more rapid increase of capital than labour which has marked European history during the last few centuries has naturally provided a stimulus to labour-saving invention.
>
> [Hicks, 1932, pp.124-5]

Hicks was not prepared to declare that all inventions were induced by changes in relative factor prices. He distinguished between 'induced inventions' which were the result of a change in the relative prices of factors and 'autonomous inventions' which were the residual of inventions over and above 'induced inventions'. According to Hicks there is no reason to suppose that autonomous inventions will, on balance, be either predominantly labour or capital saving; 'in the absence of special knowledge we may reasonably assume a random dispersion.' This being so, Hicks' natural conclusion is that on balance both types of invention taken together will give a predominance of labour saving inventions.

The above is, in essence, the first attempt to formalize the idea of 'inducements to invent' into a theory which seeks to explain biases in technical change. However, the theory was born to explain a belief which stemmed from casual observations which contained inherent deceptions and furthermore, the theory contained no explanation of how the 'inducement' mechanism worked. It is not surprising then, that Hicks' theory was confronted with a number of criticisms.

Probably the most damaging criticism of Hicks' theory of induced invention was levelled by Salter. Salter claimed that firms are motivated to save *total* cost for a given output. At a competitive equilibrium, each factor is being paid the value of its marginal product making each equally expensive to the firm. This being so, Salter argues that there is no incentive for competitive firms to search for techniques to save a particular factor. Salter's argument is quite concise,

> If...the theory [Hicks'] implies that dearer labour stimulates the search for new knowledge aimed specifically at saving labour, then it is open to serious objections. The entrepreneur is interested in reducing costs in total not particular costs such as labour costs or capital costs. When labour costs rise, any advance that reduces total cost is welcome and whether this is achieved by saving labour or capital is irrelevant. There is no reason to assume that attention should be concentrated on labour-saving techniques, unless, because of some inherent characteristic of technology, labour-saving knowledge is easier to acquire than capital-saving knowledge.
>
> [Salter, 1960, pp. 43-44]

As if in direct response to Salter's criticism of the Hicksian theory, Fellner sets out to 'modify' Hicks' theory to the extent that he seeks to establish a method of adjustment which results in inventive activity being more or less labour saving 'according as one or the other factor of production is getting relatively scarce on the macro-economic level.' [Fellner, 1961, p.305].

Viewed in terms of relative factor prices changing at the aggregate level, Fellner contends that these changes would not induce firms (under conventional static equilibrium conditions) to direct inventive activity in either one direction or the other.[1] In fact, Fellner seems to directly echo Salter,

> On the assumption [conventional static equilibrium] macro-economic resource scarcities express themselves to the individual firms exclusively in the ruling factor prices, none of which is either 'high' or 'low' in relation to the marginal productivity of the resource. Consequently, the firm is not interested in whether any given product-raising or cost-saving effect is achieved by raising primarily the marginal productivity of one or the other factor of production.
>
> [Fellner, 1961, p.305]

On the basis of the above dissatisfactions with the Hicksian theory, Fellner develops two models (or propositions) which seek to 'establish a presumption for the existence of an adjustment mechanism' which results in induced bias. His first proposition concerns the behaviour of atomistic firms who, through a *learning process* may act 'as if they were big enough to notice that *macro-economically* the factors of production are *not* in infinitely elastic supply.' [p.306] That is, Fellner incorporates an expectations hypothesis which suggests that entrepreneurs may expect relative factor prices to change even though they realize that their actions alone will not appreciably affect these prices. This particular model of Fellner's is best illustrated with the aid of Figure 5.2(a).

Point A represents a usual isocost-isoquant equilibrium where I-I' and XY represent the isoquant and isocost respectively. If the firm is faced with the need to develop either innovation II-II' or III-III' with the prevailing factor-price ratio X'Y' (parallel to XY)

---

1 There was a short exchange between Fellner and Ahmad on the interpretation of Fellner's claim that actual factor price changes will not result in bias. The exchange centres on the proposition by Ahmad that an *actual* change is an *unexpected* change. Fellner denies this proposition and the area of dispute is left largely unresolved. See Fellner and Ahmad [1967].

FIGURE 5.2(a)

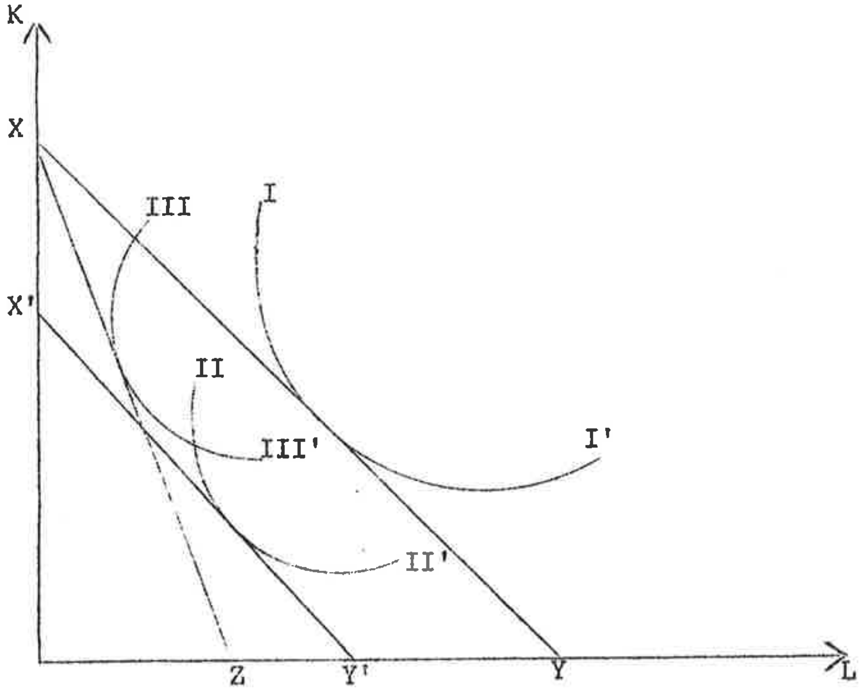
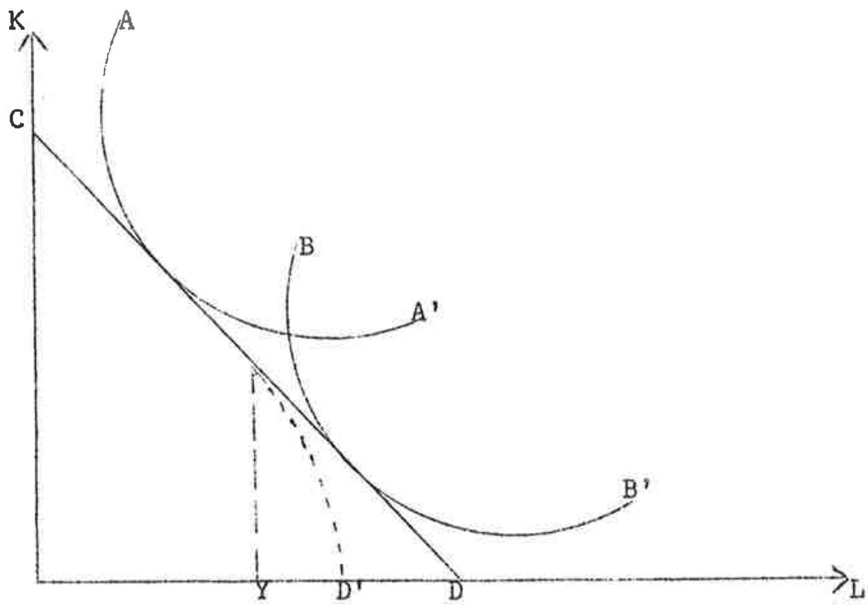


FIGURE 5.2(b)



then II-II' is clearly superior to III-III'. However, and this is the crux of Fellner's contribution, if entrepreneurs anticipate that the real wage will rise relative to interest rates then entrepreneurs will expect III-III' to become superior to II-II' 'in the future'. Referring to figure 5.2(a), if real wages are expected to rise relative to the interest rate, then XZ becomes the *expected* isocost line and III-III' becomes superior to II-II'. The inducement procedure reveals itself; if real wages are expected to rise relative to interest rates, then a labour-saving bias in technological change emerges (witnessed by III-III' being more labour saving than II-II').[2]

Fellner's second model shifts emphasis from atomistic firms to a monopsony-oligopsony situation. Figure 5.2(b) depicts a constant input price isocost curve CD, and two isoquants AA' and BB' which represent two technologies capable of producing the same level of output. In the situation where CD exists, both technologies would appear equally efficient to an entrepreneur; it is likely that both technologies would be developed and used. If however, at some level of labour usage (for example at Y), entrepreneurs *expect* the supply of labour to become less than perfectly elastic, (that is, beyond Y, he expects to become a monopsonist) then the isocost curve becomes CD'. In this case the entrepreneur clearly would prefer AA' to BB' which is labour saving in the sense described by Fellner's first model.

Essentially both the Fellner models presume that entrepreneurs have an expectation of an increase in the relative price of labour and thus will choose that technology which is relatively labour saving.

Through his concentration on Salter's criticism of Hicks, Fellner has developed models which purport to show that an expected rise in price of one factor relative to another will induce entrepreneurs

---

2 This is not labour saving in the strict Hicksian sense, as Hicks defines labour saving with respect to a given capital-labour ratio. In this case, we are comparing equilibria at different capital-labour ratios.

to select techniques which are either labour or capital saving. However, the theory still does not, in the same way as Hicks' did not, specify the mechanism by which the new techniques available for selection are made available. That is, the theory is not a real theory of endogenous technical change.

Following Fellner, there have been two major contributions to the theory of induced innovation by Kennedy [1964] and Ahmad [1966]. Kennedy's theory of induced bias (as was Fellner's) seems to have been inspired by the lack of development of Hicks' theory.

> One of the reasons why Professor Hicks' theory of induced invention has not been developed so far as it might have been is that it was tied to changes in relative factor prices. This at once brought the theory up against the difficulty of drawing a sharp distinction between the substitution of capital for labour and labour-saving invention. It will be argued...that changes in relative factor prices are not essential for a theory of induced bias in innovation.[3]
>
> [Kennedy, 1964, p.542]

Kennedy divorces his theory of induced bias from changes in relative factor prices completely by making the following assumptions.

(i) technical progress takes place only in the consumption sector,

(ii) the rate of interest is constant,

(iii) labour is homogeneous,

(iv) production functions are homogeneous of degree one,

(v) there is perfect competition in both the output and input markets.[4]

---

[3] Kennedy's major aim is to provide an alternative theory of distribution which does not require the specification of the production function. As a theory of distribution further contributions have been made, especially by Weizacker, [1966]& Samuelson[1965]. For present purposes we are concerned only with the inducement mechanism specified by Kennedy and areas of dispute in this respect with Samuelson will be considered. However, the effects of the inducement mechanism on the theory of distribution are not considered here.

[4] Of course, Kennedy does not deny that factor prices play a role in technical change. 'Such a model is, of course, not to be regarded as realistic, since there is no doubt that technical progress in the capital-goods industries does lead to a secular fall in the price of capital goods relative to labour'. Kennedy, 1964, p.542 .

Two further assumptions are made; that there are only two factors of production, labour and capital, and that only one consumption good is produced.

Then define λ as the share of labour costs in total cost and γ as the share of capital cost in total cost. In general, a technical change will reduce both the amount of labour and capital required to produce a unit of product. Let these proportionate reductions be designated by p and q respectively. Technical change will then be defined as labour saving, neutral or capital saving according to whether $p \gtreqless q$. It is assumed that entrepreneurs seek that improvement which reduces total cost by the greatest proportion. Write the proportionate reduction in unit costs (r) as

$$r = \lambda p + \gamma q \qquad \text{.....................} \qquad (5.1)$$

This indicates that the entrepreneurial choice is not merely a technological matter, it is also influenced by economic considerations.

For the entrepreneur's choice to be determinate there must be a restraint on technological possibilities; to this end Kennedy makes the assumption that the proportional factor reductions are related by an innovation possibility frontier (or trade-off frontier) of the explicit form

$$p = f(q) \qquad \text{......................} \qquad (5.2)$$

That is, innovation possibilities are of a purely technological nature and are not influenced by economic considerations.[5] The entrepreneurial maximizing problem is then to maximize (5.1) subject to (5.2). The maximizing condition thus obtained is

$$\frac{dp}{dq} = \frac{-\gamma}{\lambda} \qquad \text{......................} \qquad (5.3)^{6}$$

---

5 The merits of this assumption are discussed below.

6 For the proof of this condition see Ferguson, [1969].

Since λ and γ are both positive by definition, it follows from equation (5.3) that

$$\frac{dp}{dq} < 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.4)$$

This indicates that the larger the reduction in the unit labour requirement, the smaller will be the possible reduction in unit capital requirements. Kennedy also argues that

$$\frac{d^2p}{dq^2} < 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.5)$$

since

> ...it is clear that for p to approach its upper limit of one...very large increases in the amount of capital would be required. Similarly for q to approach one, very large increases in labour would be required.
>
> [Kennedy, 1964, p.544].

The nature of the maximizing problem in Kennedy's model can now be explained with the help of figure 5.3.[7] Equation (5.1) can be re-arranged as follows,

$$p = \frac{1}{\lambda} r - \frac{\gamma}{\lambda} q \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.6)$$

giving the slope

$$\frac{dp}{dq} = \frac{-\gamma}{\lambda} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.7)$$

Given the constrained maximizing condition in equation (5.3) and equation (5.7) the points of tangency in figure 5.3 indicate the solutions to the Kennedy propositions. For example, if λ is high relative to γ the slope of the line (equation (5.7) will be slight and the point of tangency will be at a point where p is high relative to q. If then, $p > q$ indicates labour saving bias in technological change, then the Kennedy model of inducement concludes that if the relative share of labour (λ) exceeds the relative share of capital (γ), then there will be a labour-saving bias (and vice versa).

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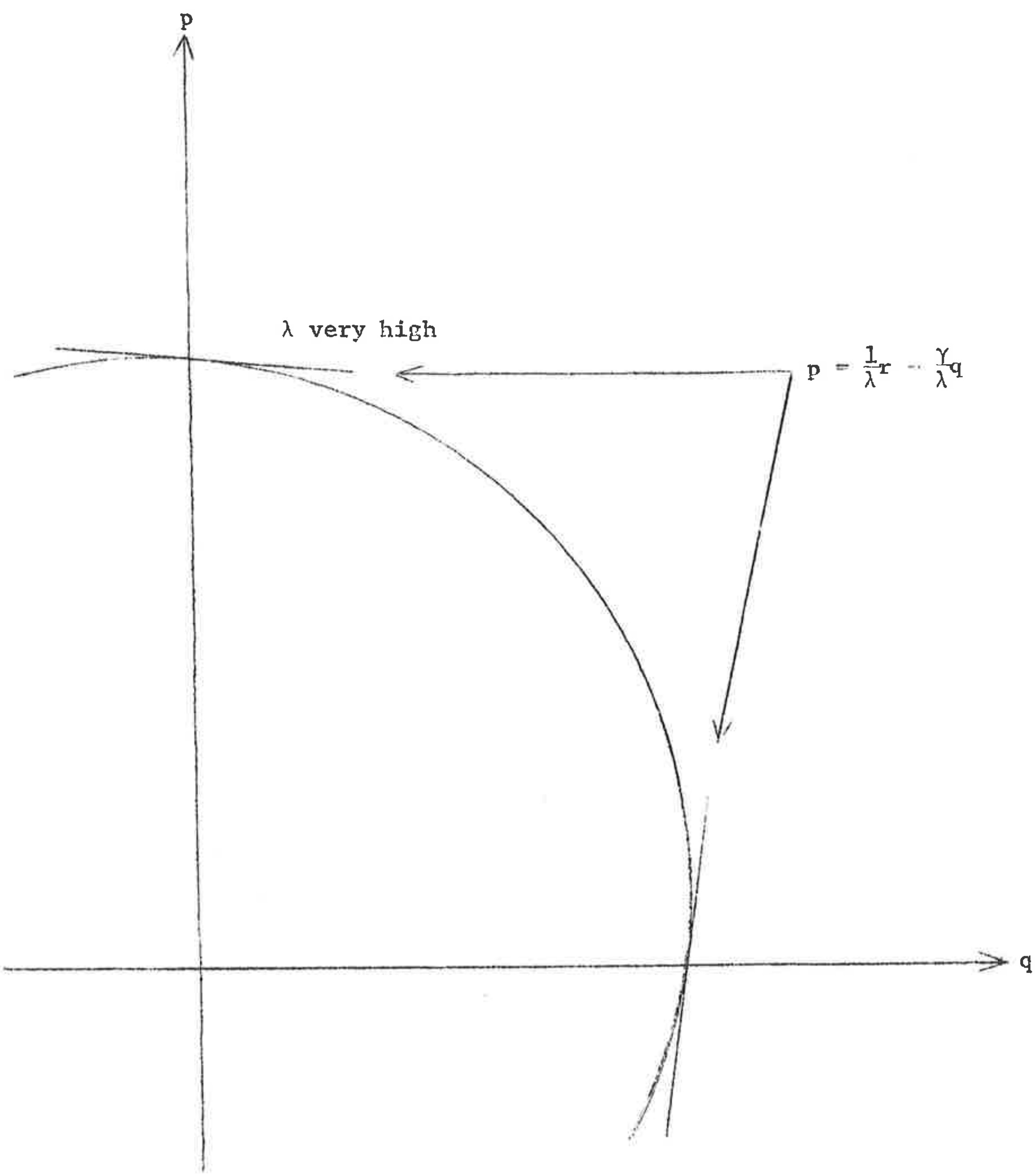
7 The frontier can enter the negative quadrants if, for example, a change occurs which reduces labour requirements while increasing capital requirements.

FIGURE 5.3



Whereas Kennedy's theory of induced bias was independent of changing relative factor prices, Ahmad's theory is based upon actual changes in relative factor prices.[8] In Ahmad's article we are introduced to an historical innovation possibility curve [I.P.C.] which is

> ...simply an envelope of all the alternative isoquants (representing a given output on various production functions) which the businessman expects to develop with the use of the available amount of innovating skill and time.
>
> [Ahmad, 1966, p.347]

This curve is 'not the result of any economic choice, it is purely a technological or laboratory question.' The only economic consideration is made when a particular isoquant is chosen from various isoquants belonging to the I.P.C. In this respect, it is assumed that the isoquant which minimizes production costs, given the relative factor prices, will be chosen.

A further assumption made by Ahmad is that the I.P.C. is neutral, that is,

> ...if the innovation in response to any given relative factor price at time n (the time when the nth innovation is contemplated) is neutral to the innovation in response to the same relative factor price at time (n-1). In terms of curves the neutrality of the innovation possibility would require that the IPCs themselves possess the characteristics of two neutral isoquants, while the respective isoquants for each factor-price ratio are also neutral to each other.
>
> [Ahmad, 1966, p.348]

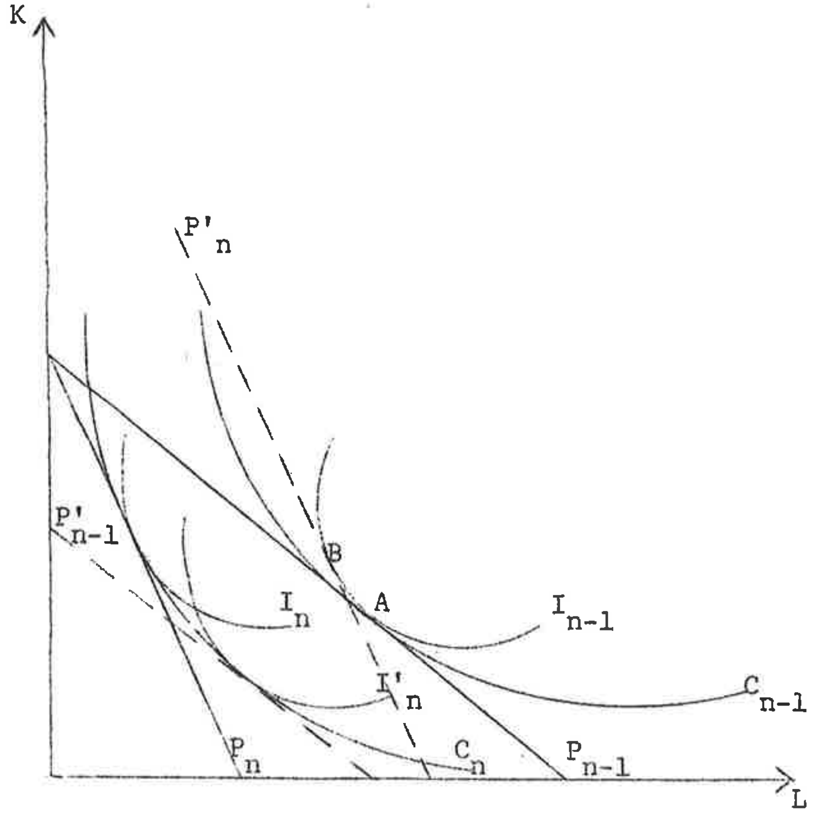
Figure 5.4 helps to analyse the Ahmad model. Capital and labour are indicated on the two axes while C_{n-1} and C_n are the IPCs for times n-1 and n respectively. Let P_{n-1} represent the original factor-price ratio; this results in point A being the equilibrium at time n-1 (A being the point of tangency between the individual isoquant I_{n-1} on C_{n-1} and the relative price line P_{n-1}).

If the price of labour increases relative to capital such that P_n is the relevant isocost line, then in the short run, the best the firm

---

8 While Kennedy's inducement mechanism was developed as part of a theory of distribution, Ahmad's model has no such wider implications.

FIGURE 5.4



can do is to move from A to B; the usual case of factor substitution.[9] However, in period n the entrepreneur will consider the range of innovations given by the I.P.C., C_n. If P_n represents the relevant factor prices, then the innovation represented by I_n will be chosen.

The major question regarding bias is answered by comparing the nature of the innovation represented by I_n and that represented by I_{n-1}. Such a comparison leads to the following conclusion. Since the I.P.C.'s are assumed to be neutral then I_{n-1} is neutral to I'_n (these being in response to the same relative factor prices). However, I_n is chosen, not I'_n and I_n is labour saving compared to I'_n.[10] Now, if I_n is labour saving compared to I'_n and I'_n is neutral to I_{n-1}, then I_n is labour saving compared to I_{n-1}. Hence it may be concluded that 'a rise in the price of labour would lead to an innovation which is necessarily labour-saving, if the innovation is technologically unbiased.' [Ahmad, 1966, p.349].

5.3.2 Criticisms of Kennedy's I.P.F. and Ahmad's I.P.C.

Like their predecessors, the theories of Kennedy and Ahmad have had their critics. Most of the criticisms are directed towards that concept which the theories innovated - the innovation possibility frontier (Kennedy) and the innovation possibility curve (Ahmad).[11]

The first criticisms levelled at the I.P.F. were regarding the assumption that the I.P.F. was a purely technological consideration. Samuelson [1965], for example, believed that economic weights should enter the trade-off function and rewrote the transformation function as follows so that it involves relative shares.

$$p = F(q, \gamma) \qquad \text{.....................} \qquad (5.8)$$

---

9 Another isoquant on IPC_{n-1} is not chosen, because it is assumed by Ahmad that "all the isoquants belonging to a particular I.P.C.except the one actually chosen become irrelevant for economic decisions after the choice is actually made." Ahmad, [1966].

10 Again, this is not strictly in the Hicksian sense.

11 The two concepts will be used interchangeably in this section as the criticisms apply equally to both.

> The whole point of this reformulation is to get away from implicit theorizing by which one assumes that the entrepreneur can have knowledge that the transformation function remains invariant over time and has naught to do with the costs and shares of the factors themselves.
>
> [Samuelson, 1965, p.352]

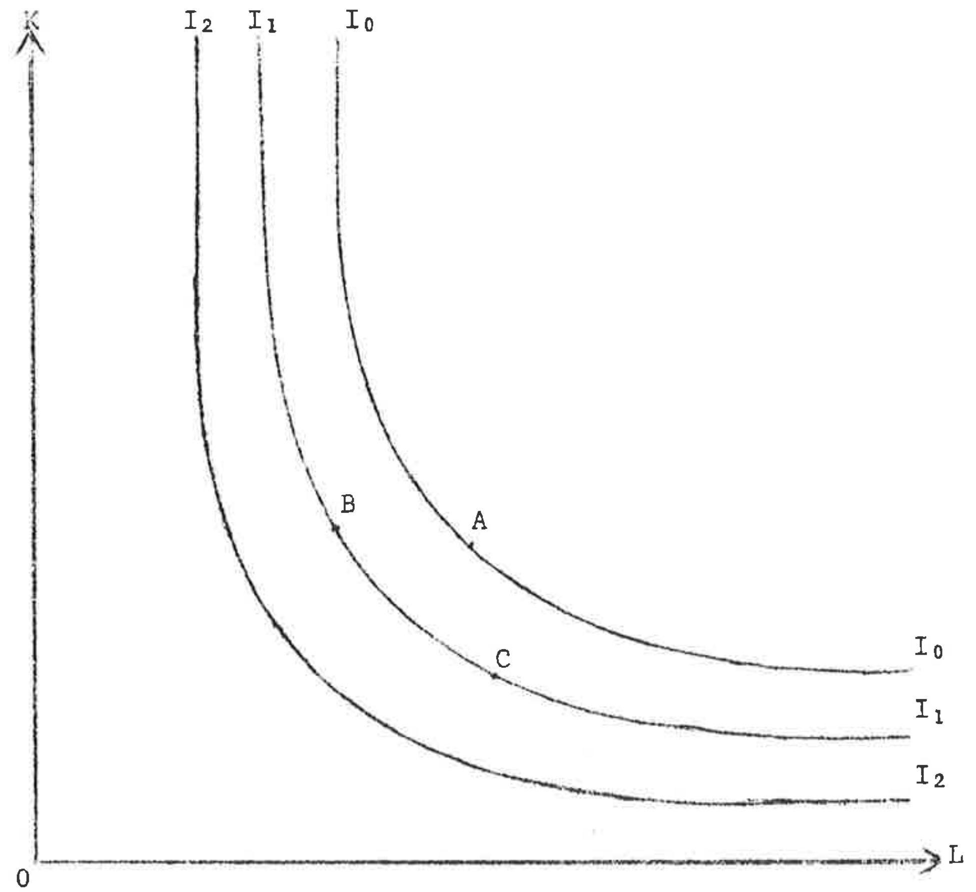
Kennedy defended his earlier assumption,

> Suppose there is a change in the price of one factor but no other change in the situation. A transformation function that involves relative shares then commits us to the view that the entrepreneur believes the change to *have altered the technological possibilities.* I cannot see how such a view can be reconciled with common sense or even rationality.
>
> [Kennedy, 1966, pp.343-4]

This caused Samuelson to 'recant some of his scepticism' although he still remained troubled by the situation where effective factor proportions have changed (because, for example, of changed efficiencies in the past). Such a change, argues Samuelson [1966, p.446], 'might well alter the prospect for *further* innovational savings in the use of that factor.' That is, at a changed factor-ratio position, the relative shares will be changed and in the above sense, changes in shares may be linked to the frontier. This concern of Samuelson's seems to reflect the major criticism of the I.P.F. put forward by Nordhaus [1973] who argues that there is 'no memory' in the process of innovation. Nordhaus argues that if research is treated as endogenous, it would be possible to assume that a change from one technique to another has an associated cost and that this cost would be greater, the 'greater' the change. In a world of certainty, it is possible to define that set of techniques attainable at a given cost (C), the C isotech. Figure 5.5 illustrates a map of such isotechs. Consider a firm currently operating at point A; by devoting resources of say $R(I_1)$ it can move to any technique on the isotech I_1I_1 (and so on for movements to I_2I_2...). With regard to these movements, Nordhaus [1973, p.212] remarks that

> ...we would generally assume that the progress of technology displays time dependence, or memory, in that the invention possibilities in time t+1 depend on whether the system has at time t moved from A to B or from A to C.

FIGURE 5.5



The implication of this is that a different isotech will emerge depending on whether the movement was to B or C.[12]

The above criticism seems to illuminate an overriding problem associated with the development of a theory of induced innovation. If technical change is to be regarded as truly endogenous then the theory should explain two activities, invention and production. The suggestion made here is that the theories of induced innovation have tended to concentrate strongly on the production activities and not on the invention activities. That is, the micro-economic interpretations given to the derivation of the innovation possibility curves, (that is, to the actual generation of new techniques) have either been neglected altogether or have been treated scantily.[13] This view is shared by both Nordhaus and Binswanger. Nordhaus reflecting on the micro-economic strength of the models concludes

> Almost the only micro-economic framework that preserves competition is one in which a book of new blueprints falls from the sky every period - the new techniques given according to the I.P.C. - and the entrepreneur chooses the best technique. In this case, it would be quite misleading to say that technical change is induced. Rather, the I.P.C. gives the technical possibilities at a point in time. The model is then a disguised version of the neoclassical model with exogenous technical change.
>
> [Nordhaus, 1967, p.343]

---

12 Both Kennedy and Ahmad recognize the time dependence nature of innovation possibilities but do not give the notion explicit recognition in their formulations. See Kennedy, [1967]. On page 960 of this note Kennedy says, 'I believe that the innovation possibilities open to one are relative to one's starting position; and that the innovation possibilities of tomorrow, will be influenced by the innovations of today.' Also see Ahmad, [1967].

13 Kennedy seems to give no micro-economic interpretation to his I.P.F. while Samuelson makes brief mention of the fact that '..presumably a limited amount of resources available for research and development can be used to get a larger decrease in $\lambda_1(t)$, only at the expense of a slower decrease in $\lambda_2(t)$, where the λs refer to the savings in the amount of the factors labour and capital.' See Samuelson [1965].

Whilst Binswanger [1974, p.956], in an even more scathing attack,has the following to say,

> In retrospect the I.P.F. appears to be one of the outstanding cases of implicit theorizing in the economic literature. The interacting problems posed by endogeneity of technical change, namely, how to determine optimal amounts of research and how to trade it off against investments in physical capital is completely neglected in the theory...It attempts to explain constancy of shares with biased technical change by means of an ingenious device whose relationship to the research process was left in the dark long after the implications of the device were explored in detail and became widely accepted. That the device cannot be generated by research as an investment process did not matter.

5.4 Induced Innovation and Agricultural Development.

In their recent book, *Agricultural Development: An International Perspective*, Hayami and Ruttan [1971, p.3]'attempt to show how a model, in which technical and institutional changes are treated as endogenous factors, responding to economic forces, can aid in the historical analysis of agricultural growth, particularly in Japan and the United States.'

An investigation into the resource endowments of the two countries revealed substantial differences. Briefly, it was observed that land area per worker is far greater in the United States than in Japan and that the difference has been widening continuously since 1880. Also, the relative price of land and labour have differed substantially between the two countries. For example, in the United States between 1880 and 1920, the price of labour rose relative to the price of land, whereas, in Japan over a similar period, the price of land rose sharply relative to the price of labour. Despite these differences, 'both the United States and Japan experienced relatively rapid rates of growth in production and productivity in agriculture' during the period 1880 to 1960.

In Hayami and Ruttan's view this finding can be explained if it is recognized that technology can be developed along particular paths, in particular they concentrate on mechanical and biological technology.[1] Mechanical technology is viewed as facilitating 'the substitution of power and machinery for labour. Typically this involves the substitution of land for labour, because higher output per worker through mechanization usually requires a larger land area cultivated per worker.' Biological technology, however, is viewed as facilitating the 'substitution of labour and/or industrial inputs for land. This may occur through increased recycling of soil fertility...through use of chemical fertilizers...

---

1 This is not a new view: see for example, Heady, [1949] and Sadan, [1970].

management systems...which permit an optimum yield response.' Using this taxonomy it makes sense to partition the growth in labour productivity into two components as follows,

$$Y/L = \frac{A}{L}\ \frac{Y}{A}$$

where Y = output

L = labour

A = land area

hence labour productivity can grow through increases in land area per worker and/or land productivity. Given that technology can develop along different paths to allow the substitution of 'relatively abundant (hence cheap) factors for relatively scarce (hence expensive) factors in the economy,' then the differences in relative factor prices observed in the United States and Japan has led to differing types of technology being adopted. In the United States, for example, where the price of labour rose relative to land, productivity growth was brought about mainly by increases in mechanization which increased land area per worker and thus saved the relatively scarce factor, labour. In Japan, on the other hand, where land is the relatively scarce resource, productivity increases have been primarily brought about by biological advances which are 'land saving'.

On the basis of the above observations Hayami and Ruttan [1971, p.122] develop the argument that

> ...the contrasting patterns of productivity growth and factor use in U.S. and Japanese agriculture can best be understood in terms of a process of dynamic adjustment to changing relative factor prices along a metaproduction function-dynamic in the sense that production isoquants change in response to changes in relative factor prices.

This idea is developed in a similar framework to the Ahmad model developed earlier. In figure 5.6(a), U represents the land-labour isoquants (U_0, U_1...) depicting different types of technology. When the prevailing factor prices are given by P_0 then U_0 is developed (for instance

FIGURE 5.6(a)

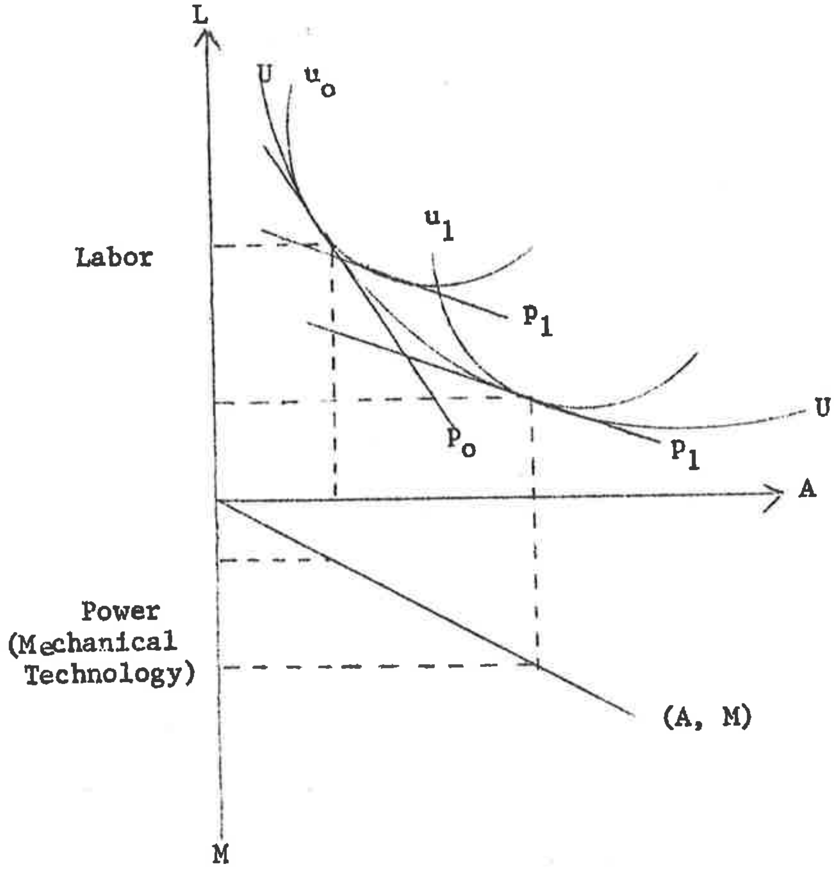
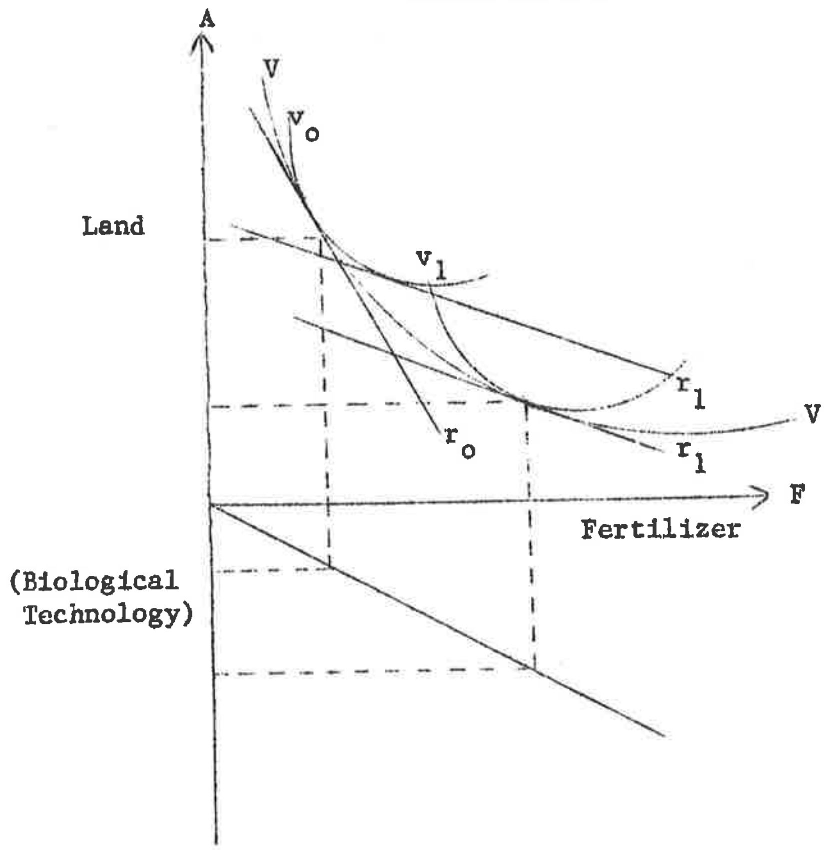


FIGURE 5.6(b)



a reaper). When P_1 represents the relevant factor price ratio another technology U_1 (a combine) is induced.[2] The 'new' technology U_1 results in an increase in land area per worker which 'generally corresponds to a higher intensity of power per worker.' This reasoning supports the complementary relationship between land and power (mechanisation) mentioned above, that is, 'mechanical innovation is conceived as the substitution of a combination of land and power [A.M.] for labour in response to a change in wages relative to an index of land and machinery prices, though, of course, in actual practice land and power are substitutable to some extent.' [Hayami and Ruttan, 1971, p.125]. Figure 5.6(b) illustrates the relation between the fertilizer-land price ratio and biological and chemical innovations.

To *test* the above model statistically, Hayami and Ruttan seek to determine the extent to which the variations in factor proportions (land-labour, power-labour and fertilizer-land ratios) can be explained by changes in factor-price ratios. They assume that at each moment of time the elasticities of substitution among factors in agricultural production is very small so that almost fixed proportions prevail.[3] Given this assumption, the induced innovation hypothesis can be 'proved' along the following lines. Using time series data, estimates can be made of the elasticities of substitutions. If these are large then the *ex post* observed substitution must have been due to biased technical change rather than to substitution along a given production function which is assumed to be very difficult. Such a test, it is claimed, would prove both the endogeneity of the biases and the predominant role of factor prices in explaining them.

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[2] This, of course, is implicitly assuming a profit maximizing objective.

[3] As support for this assumption they cite evidence from experimental studies on fertilizer response which indicates that the optimal fertilizer use in each crop does not change very much with changes in price. Examples of mechanical processes such as harvesting of grain are also presented. While this assumption of small elasticities may hold for *individual* crops and tasks, it may not hold at the *farm* level where much more flexibility is likely to exist.

Upon reflection however, it is doubtful if this substantial claim in support of endogeneity of biases is warranted. A statistical test which looks at the observed *ex post* relationship between factor proportions and factor prices is susceptible as a test of induced innovation. Factor proportions, for example, change after the introduction of either a labour or capital saving technique. What changes in factor proportions do *not* tell us is when the invention of the relevant techniques took place and whether these inventions were stimulated by changes in relative factor prices. The authors in fact spell out the mechanism of inducement which they envisage,

> Farmers are induced, by shifts in relative prices, to search for technical alternatives which save the increasingly scarce factors of production. They press the public research institutions to develop the new technology and, also, demand that agricultural firms supply modern technical inputs which substitute for more scarce factors. Perceptive scientists and science administrators respond by making available new technical possibilities and new inputs that enable farmers to profitably substitute the increasingly abundant factors for increasingly scarce factors, thereby guiding the demand of farmers for unit cost reduction in a a socially optimum direction.
>
> [Hayami and Ruttan, 1971, p.57]

To establish the endogeneity of biases, Hayami and Ruttan should have made an attempt to establish that the mechanism they have postulated in fact occurs. The statistical test incorporating factor proportions and factor prices only, in no way 'proves' the demand mechanisms (inducement mechanisms) outlined in the above quotation. That is, the tests do not incorporate a viable theory of invention, the same overriding criticism made earlier of the theoretical models.

A recent attempt to specify more rigorously the demand mechanism underlying the generation of agricultural innovations within the context of an induced innovation model has been undertaken by De Janvry, [1973]. He develops a socio-economic model of induced innovations aimed to explain the stagnation of the Argentine agricultural sector. De Janvry distinguishes between *latent* demand and *actual* demands for innovations.

Referring back to figure 5.4, if the relative factor prices change from P_{n-1} to P_n, there will be a latent demand for the innovation

I_n on the I.P.C. C_n. That is, latent demand is the demand for a 'socially optimal' technology.[4] Actual demand is that demand which 'guides the course of current public sector innovations [and] is conditioned by government and by socially and politically dominant farm interests and will diverge from latent demand, thus creating lags in the generation of socially optimum innovations.' [De Janvry, 1973, p.411].

De Janvry [1973, p.418] postulates that actual demand materializes essentially in two forms:

(i) the budget allocated for research; both in its absolute size and in its allocation restrictions,

(ii) a flow of information to Agricultural Experiment Stations.

The problem then is to identify *whose* demands affect these two variables. The author believes that in Argentina it is the demands of dominant farm interests; namely, the large land owners which are relevant in this respect. Hence,

> It is postulated that the actual demand for public innovations results from the maximization of the utility function of the dominant farm interests.
>
> [De Janvry, 1973, p.419]

De Janvry then attempts to specify the utility function on a theoretical sociological basis. Three main factors are thought to enter a lexicographic utility function.

> ...congruence [which induces innovations that are compatible with existing production structures]...that dominates expected profits maximization lexicographically and stress [defined as negative in falling profits] that dominates congruence, also lexicographically. If a risk aversion goal in the form of a survival constraint like $Pr(\pi \geq 0) = \alpha$ that also dominates congruence...
>
> [De Janvry, 1973, p.421]

Whilst this presents a dynamic approach to the interaction mechanism introduced by Hayami and Ruttan, the model still falls short

---

[4] Socially optimal in the sense that if prevailing economic and scientific conditions are optimal then the technology consistent with latent demand is socially optimal.

in that no specification is made of the activities of research institutions in response to these demands. That is, the demands of the 'dominant farm interests' might lead to the adoption of innovations from a range of possible innovations which have 'fallen from the sky'. That is, the model does not specify the mechanism which *gives* the technical possibilities. Because of this, both the Hayami-Ruttan and the De Janvry models of induced innovation in agriculture could be nothing more than a disguised neo-classical model with exogenous technical change.

5.5 Binswanger on Induced Innovation

In the preceding sections, it has been argued that the theories of induced innovation have been largely unsuccessful in providing a theory of endogenous technical change in that they fail to incorporate an analysis of the creation of new techniques. That is, the theories are really a disguised version of exogenously determined technological change, the biases being partly determined by forces not considered by the models. If we accept the view that a certain amount of research expenditure may generate a variety of processes each with different impacts on factor intensities, then some part of the rate and bias of technological change could be influenced by economic factors. To date these economic factors have not been incorporated into the models of induced innovation and hence do not provide a truly endogenous theory of technological change and bias. Undoubtedly the reason for this stems from the inadequate theories of invention in economics; inadequate in terms of development and also in terms of rigour. Probably the most widely recognised investigation of the economics of invention is the work undertaken by Schmookler.[1] In a study of four industries and encompassing the collection of hundreds of U.S. patent statistics Schmookler concludes that the incentive to make an invention is affected by the excess of expected returns over expected costs.

> Scientific progress may reduce expected costs and so increase the probability that a given invention will be sought and made. However, every invention represents a fixed cost, and the expected benefits from it vary with circumstances. These circumstances, arising from the prospective market for a commodity or process, depend not on scientific discovery, but on socio-economic change - urbanization, declining family size, changing status of women, changes in relative factor costs, increases in population and per-capita income etc. *Antecedent scientific discoveries are sometimes necessary but seldom sufficient conditions for invention.*
>
> [Schmookler, 1966, p.20]

---

[1] Schmookler, [1966]. See also Nelson, [1959].

In his recent article, Binswanger has made an initial attempt to incorporate a more realistic micro-economic framework of invention into the theory of induced innovation. To the extent that he is successful, the theory of induced innovation is more truly an endogenous theory of technological change. Basically Binswanger is disposed to

> ...develop a micro-economic model by reformulating innovation possibilities on the basis of research processes, which have expected pay-off functions in terms of efficiency improvements and by explicitly introducing research costs. This leads to the specifications of research as an investment problem in which present value is maximized.
>
> [Binswanger, 1974, p.940]

To specify innovation possibilities on the basis of research processes, Binswanger adopts an interpretation of the research process initially introduced by Evenson and Kislev; that is, research is interpreted as a sampling process. Consider the case of new seed varieties; it is assumed that there is a 'probability distribution of potential yield increases which is determined by nature, the state of basic sciences, and plant breeding techniques.' Research is then defined as drawing successive trials from this distribution. If there are such trials, the expected pay-off from the research is defined as the largest yield increase found in the sample. That is, given a probability distribution with variance σ and mean u, the expected pay-off from research is the first-order statistic of a sample, size m.

$$\text{i.e.}\quad E(\Delta\gamma_{1m}) = h(m,u,\sigma) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5.9)$$

where $E(\Delta\gamma_{1m})$ is the largest yield increase in the sample. In the model only two research processes are considered,

(i) x - amount of primarily capital-saving research,

(ii) y - amount of primarily labour-saving research,

and each of these are subject to the identical scale functions (that is, the returns to research decrease at the same rate with the number of x trials and the number of y trials). It is finally assumed that research processes are additive in the sense that the results of one research process can be implemented *independent* of research results from the other process. This is a restrictive assumption in that results from one research cannot affect the productivity of the other research.

In order to specify the implications of research processes for factor proportions and hence adopt the model to a theory of induced innovation, Binswanger specifies a factor augmenting production function of fixed proportions.

$$\text{i.e. } Y = \min.(\frac{K}{A}, \frac{L}{B}) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5.10)$$

where Y = output

K = capital stock

L = annual labour flow

A = capital augmentation coefficient $(\frac{K}{Y})$

B = labour augmentation coefficient $(\frac{L}{Y})$

To link the research processes to factor proportions it is assumed that the research activities reduce the augmentation coefficients, A and B.

With the specification of research activities outlined above and the form of the production function contained in equation (5.10), the following specification of innovation possibilities can be made.

$$A^* = u(x)\alpha^x + u(y)\alpha^y \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5.11)$$

$$\text{and } B^* = u(x)\beta^x + u(y)\beta^y$$

where α^x and α^y are the productivity coefficients of research which reduce A and where β^x and β^y are the productivity coefficients of research which reduce B. (This means that the model assumes that each research activity affects both labour and capital augmentation coefficients.) A* and B* are the proportional reductions in A and B.

Binswanger then presents a comparative static model in which the benefits of research occur during only one period. The expected bias, Q, for the fixed proportion production function is defined as,

$$Q = A^* - B^* \gtreqless 0 \rightarrow \begin{cases} \text{Capital saving} \\ \text{neutral} \\ \text{Labour saving} \end{cases} \qquad \text{.......... (5.12)}$$

Equation (5.12) can then be re-written in terms of the research pay-off functions. That is, substituting (5.11) into (5.12) gives,

$$Q = u(x)\ (\alpha^x - \beta^x) + u(y)\ (\alpha^y - \beta^y) \qquad \text{.......... (5.13)}$$

Now consider a firm which wants to build a new plant. This can be done by either buying a plant of existing design with augmentation coefficients A_0 and B_0 and the fixed capacity Y, or it can undertake research to reduce the coefficients. Since output is given (by the production function) the decision variables of the firm are x and y. Write profits as

$$u = PY - RK_0 - WL_0 + RK_0A^*(x,y) + WL_0B^*(x,y) - xP^x - yP^y \quad \text{...(5.14)}$$

where PY, RK_0 and WL_0 are the value of output, capital cost and labour costs of the plant of existing design. P^x and P^y are the prices per unit of x and y.

Since PY, RK_0 and WL_0 are constant they can be collected into a single constant term U_0 (= PY - RK_0 - WL_0) which are profits without research. Writing $C_K = RK_0 = RYA_0$ and $C_L = RL_0 = WYB_0$ equation (5.14) can be re-written as

$$U = U_0 + C_KA^*(x,y) + C_LB^*(x,y) - xP^x - yP^y \qquad \text{.......... (5.15)}$$

Substituting (5.11) into (5.15) and rearranging gives

$$U = U_0 + u(x)\ (C_K\alpha^x + C_L\beta^x) + u(y)\ (C_K\alpha^y + C_L\beta^y) - xP^x - yP^y \text{...(5.16)}$$

which is the final form of the maximizing problem.

In this initial form, equation (5.16) indicates that a firm faced with the alternative of choosing between problem techniques is not influenced by factor shares (as in the Kennedy model); nor is it concerned with factor prices only (as in the Ahmad model). Equation (5.16) indicates that it is total factor costs (C_K and C_L) and research costs (xP^x and yP^y) which are important. Since the choice between alternative techniques involves the selection of alternative isoquants and hence alternative factor intensities, then Binswanger's model is a genuine attempt to make the theory of induced innovation truly endogenous.

5.6 The Institutionalization of Scientific Research.

5.6.1 Advances in Agricultural Technology During the Nineteenth Century

In the early years of the nineteenth century there seems little evidence to suggest that new agricultural technology was domestically generated; any new technology which was introduced was invariably imported, mainly from the United Kingdom. In fact, in the early years after settlement, the role of science in agriculture did not appear to be prominent.

> ...the benefits to be derived from the application of science were not great in Australia during the period represented by the first 50 to 60 years of our history.
>
> [Watt, 1926, p.16]

This is not to say that the potential importance of science to agricultural development was not recognized. In 1821, for example, the Philosophical Society of Australasia was established for the 'purpose of collecting information with respect to the natural state, capabilities, production and resources of Australia.' In part, this society was formed in response to the observation that

> ...little has been done to awaken a spirit of research or excite a thirst for information amongst the Colonists... this country affords an opportunity to an enlightened people, of putting into practice, with all the advantages of salubrity of climate and fertility of soil, the knowledge which has been obtained, by the experience of many ages, in every branch of agriculture...but in order to render this stock of information effective, we should be well acquainted with the present physical state of the country, its capabilities and resources, and here we are compelled to admit we are lamentably deficient.
>
> [Minutes of the Philosophical Society of Australia, reproduced in Moyal, 1976, p.111]

Also in the early 1820s, Governor Brisbane, an astronomer and agriculturist who was instrumental in establishing the Philosophical Society, announced the formation of an Agricultural Society, again in order that the stock of resources could be better understood; '...I think it will be productive of much good, as all the races of animals are sadly jumbled together, without even science or system.'

Masson [1935, p.63] reported that these early societies were short-lived, especially after the stimulus of Brisbane's leadership was lost. It was not until the 1850s that scientific societies became permanently established. By the 1860s all states had established a Royal Society which represented the first stage in the development of organized research in Australia The importance of these societies was felt mainly in the establishment of libraries, museums, observatories and botanic and zoological gardens.

The principle of scientific endeavour seemed to be quite firmly entrenched by the middle of the century; in fact, by 1850 there was increased impetus given to generating new agricultural technology. During the early years of settlement at least two significant conditions existed which mitigated against the need for new and improved technology. First, the growth of population was not very great, meaning that the demand for increased food production was not great and second, the practice of squatting with its attendant uncertainty of tenure did not encourage investment in new technology. By the 1840s. however, changed conditions increased the demand for inventive and scientific activity. In particular, at this time the eastern states were experiencing depressed economic conditions which were characterized by acute labour shortages. These shortages were further accentuated by the gold rushes of the 1850s, and the attendant upsurge in activities such as railway construction.

> The immediate effect of this upsurge on the land industries was disastrous as indispensible labour was attracted away. Sheep were unshorn, agriculture could not cope with the increased demand for food, and imports of grain had to take place on a large scale.
>
> [Magee, 1968, p.205]

Although the precise effects of these changes on the generation of new agricultural technology are difficult to identify, it is clear that from the early 1840s onwards, there were a number of significant advances; perhaps the most significant being John Ridley's harvester which enabled

> ...four men to do in a single day what it took the equivalent of two men the whole harvesting season to do before.
>
> [Magee, 1968, p.206]

This invention was revealed in response to a competition held in 1842 and this particular form of the harvester was used almost universally until 1884 when a combined harvester-thrasher was invented by H.V. McKay. The 1840s also saw the introduction of the stump-jack plough invented by a South Australian,Mr. R.B. Smith. This machine greatly facilitated the cultivation of imperfectly cleared land by doing just as its name suggests; that is, it was able to jump obstructions in the ground,such as tree stumps,and resume cultivation.

The pastoral industry also benefited from new technology in the second half of the nineteenth century, particularly with regard to mechanical sheep shearing equipment. In 1968, for example, a Victorian, James Higham, filed the world's first patent for a mechanical sheep shearing device with the Patents Office of New South Wales. In 1877 further patents were taken out on mechanical shearing machines by Savage and Wolseley and by about 1880 the use of this equipment was becoming quite general.

Whilst outstanding examples of new mechanical technology were evidenced during the second half of the nineteenth century, there were also a considerable number of advances in biological technology during this period. The early practice of wheat growing in Australia involved continuous cropping, the result being that these lands eventually suffered from weed problems and insufficient moisture and plant nutrients, and in consequence, wheat yields declined. As a result of these falling yields, two new 'biological technologies' emerged. In response to the weed problem, some farmers decided not to plant crops continuously but rather cultivate it at regular intervals in an attempt to kill the weeds. It was found that after this treatment yields increased quite substantially when cropping resumed; a result which was largely unanticipated.

> The practice of cultivated fallow, which has meant so much to the Australian farmer, was thus an accidental introduction, and the scientific explanation of its favourable results came only after it was partially established.
>
> [Watt, 1926, p.21]

The second major 'biological advance' during this period was the 'discovery' of superphosphate. Although superphosphate as a fertilizer had been patented by Lawes in England in 1842, its application to Australian crops did not gain momentum until the 1890s. The use of superphosphate in this period is largely attributed to the efforts of Professors Custance and Lawrie who tested the response of wheat yields to superphosphate application at the Roseworthy Agricultural College. Summers [1899] reported the quite phenomenal increase in superphosphate usage in the South Australian Wheat belt following the work of Custance and Lawrie; the area fertilized increased from 60,000 acres in 1897 to 400,000 acres in 1899.

There were also other 'biological' investigations of considerable importance taking place in Australia during the latter half of the nineteenth century. The most notable of these probably being the wheat breeding activities of William Farrer. Farrer arrived in Australia in 1870 and after working as a surveyor in the New South Wales Lands Department became acutely aware of the problems posed to wheat growers by diseases such as rust and bunt. In 1886 Farrer, having retired to his own property, began experiments relating to rust, the progress of which were followed closely by Doctors Cobb and McAlphine, the plant pathologists employed by the New South Wales and Victorian Departments of Agriculture respectively. In 1898, Farrer joined the New South Wales Department of Agriculture as a 'wheat experimenter' but 'frustrated by the lack of researchers in the Agricultural Colleges capable of carrying out experimental work' left the Department and proceeded privately with his research until his death in 1906.

Another significant biological development during this period was the 'discovery' of sub-terranean clover. Its introduction into

Australia is generally regarded as 'accidental', its growth being discovered in Victoria, South Australia and New South Wales during the late 1880s. The 'discovery' of the economic significance of the clover is accredited to Mr. A.V. Howard, a farmer of Mount Barker, South Australia. Howard collected its seed, planted it to pasture and applied superphosphate to it, discovering quite remarkable improvements in growth. Magee [1968, p.222] said of Howard's work

> ...[He] initiated the combination 'sub' and 'super' which has contributed so phenomenally to the increase in stock carrying capacity and soil fertility to a vast region of Southern Australia.

While the above account of advances in agricultural technology are not necessarily comprehensive the discussion nevertheless would seem to indicate two significant observations. First, the second half of the nineteenth century was characterized by developments in *both* mechanical and biological technology. In fact, it would appear as if developments in one led to complementary developments in the other. As Watt [1926, p.24] noted

> The use of superphosphate for wheat brought in its train the use of the combined seed and manure drill, which has been developed to a much greater extent in Australia than in any other country. The response of our wheat crops to small quantities of superphosphate is partly accounted for by the ideal distribution of fertilizer brought about by this mechanical device...The practice of the cultivated fallow and the use of superphosphate applied by the combined seed and manure drill have been exceedingly potent factors in the success of wheat growing in Australia.

This dual development of both mechanical and biological technology in the second half of the nineteenth century provides an interesting contrast to the interpretation by Hayami and Ruttan [1971] of the development of agricultural technology in the United States for the same period. Just as in Australia, the period was characterized by a relative shortage of labour and as a result, 'mechanical technology was sought in order to increase the land area that each worker could cultivate.' In consequence,

> ...throughout the last half of the nineteenth century ...Mechanization was the most important single source of labour productivity growth...The advances in mechanical technology were not accompanied by parallel advances in biological technology.
>
> [Hayami and Ruttan, 1971, p.139]

That there appeared to be a parallel development of both mechanical and biological technology in Australia during the period might be explained by the pattern of land settlement which contrasted to that in the United States. During the period after settlement in Australia until the mid 1800s the area of land settled for agricultural purposes increased rapidly.

> From the commencement of the twenties then, there was an expansion in all directions - west across the mountains, north towards Newcastle, and especially south...
>
> [Roberts, 1924, p.165]

These lands were largely settled by squatters, 'who grazed stock within the boundaries without troubling to obtain a licence or those who could not obtain a licence because they were beyond the boundaries' [Roberts, 1924, p.187]. In 1847, the squatters were granted leases on their properties by virtue of an Order-in-Council.

> As a result of the leases, the great bulk of the good pastoral and much that was suitable for agriculture became locked in the hands of relatively few.
>
> [Magee, 1968, p.204]

That is, a majority of the quality farming land was in the hands of a few. With the great influx of population associated with the gold rushes of the 1850s, there became increased agitation for smaller settlements as farmers began clashing with the squatters. After continued agitation, led primarily by Robert Lower, two Bills were finally introduced and passed through the New South Wales Legislature in 1861, these being the Crown Lands Alienation Act and the Crown Lands Occupation Act. The Alienation Act gave people the right to select land between 40 and 320 acres from certain areas in return for paying a fixed price of one pound per acre and residing on the property.

The Occupation Act provided squatters with the opportunity to retain certain rights over their occupied land mainly in the form of pre-emptive purchasing rights.

Despite problems relating to the practicalities of the Acts [see Roberts, 1924, pp.238-9] there were several notable outcomes; in particular

> In the first year, 7389 lots, covering 445,000 acres were taken up and in the face of bad seasons and floods (1863-5), 17000 families were settled on the land in five years. In the same period, the cultivated land had increased from 250,000 acres to 460,000 acres and the number of sheep doubled
>
> [Roberts, 1924, pp.237-8]

It would appear then, that in the face of relative labour shortages in agriculture during the mid 1800s, the emigration as a result of the discovery of gold and the enactment of the Land Laws aimed at increasing the number of landowners and reducing the size of farming enterprises were large contributory factors to overcoming the labour shortage. In terms of a Hayami-Ruttan induced innovation diagnosis, while there was a labour shortage in the 1840s and 1850s resulting in a 'demand' for mechanical technology there was also an institutional response to reduce the area of land per unit of labour. This might be interpreted as a signal to increase the demand for biological technology so that output per unit of land could be increased. Hence the institutional policy with regard to land settlement might 'explain' the dual development of mechanical and biological technology during the second half of the nineteenth century.

The second major observation which can be made regarding the generation of new technology in this period is that *both* the mechancial and biological advances were made by private individuals; they were not the outcome of public research activity. During the period, although the mood for public research was emerging, little, if any, appeared to be undertaken. By the turn of the century, all states had their own departments of agriculture with four of the states having agricultural colleges as well. In these early years, the Departments were multi-functional but scientific endeavour was alluded to, although the emphasis seemed to be on extension and demonstration work. Among the listed objectives for the New South Wales Department of Agriculture, for example, were 'to complete the history of agriculture in New South Wales'; 'to introduce and distribute new seeds, cereals, plants...from other lands with climatic conditions similar to our own'; to educate farmers by means of lectures, practical demonstrations and by experimental farms...' and 'to indicate improved methods by which to learn how to turn the land to better account.' [New South Wales Department of Agriculture, Annual Report, 1891, p.4]. There seemed to be no explicit emphasis on scientific research activities. That New South Wales and the other states were not carrying out scientific research at the end of the nineteenth century is supported by the claim made in 1913 by the Federal Member for Wannon in the debate at the second reading of a bill to establish a Commonwealth Agricultural Bureau.

> Without showing any disrespect to the state authorities, I can safely say that today, there is practically no laboratory work of any real value to Australia carried out by the State Departments in connexion with the science of agriculture... they are not carrying on any real laboratory work of a highly scientific character that is likely to put the science of agriculture on as high a plane as it ought to be.
>
> [Australia, Parliamentary Debates, 1913, p.3421].

The second half of the nineteenth century also saw the establishment of Universities in Australia, the first being the University of Sydney in 1850, followed by the University of Melbourne in 1853. No agricultural faculties were established in the period up to 1900 and it seems doubtful if academic agricultural scientists were employed. Story [1861, p.153] made the observation

> I am not aware that either professors or lecturers in any branch of either landed or agricultural economy pertain to any Australian collegiate establishment at present in existence.

In summary, the nineteenth century was characterized by a number of significant advances in agricultural technology. These advances were primarily the results of individual efforts and not the outcome of public research activity. The role of science in agriculture was being recognized by the various State Departments of Agriculture but their activities were largely directed to extension and instruction rather than towards scientific research work.

5.6.2 The Growth of Public Sector Agricultural Research in the Twentieth Century.

During the first two decades of the twentieth century, although the importance of scientific research was being continually advanced, there was not a great deal of development. In the early years of the century, several of the universities established schools of agriculture, in particular in Adelaide (1901) and Melbourne (1906). In 1910, the first Chair of Agriculture in Australia was established at the University of Sydney and coincided with the establishment of the first publicly funded Veterinary School in Australia. It is doubtful, however, if these schools were research orientated at this early stage of their development. Dickson [1951, p.44] referred to the 'ad hoc' research of the schools and Schedvin and Trace [1976, p.6] reveal that

> ...the general scene was dismal: insufficient quality in depth, overcrowded lectures and hopelessly inadequate research facilities.

In 1900, the Bureau of Sugar Experiment Stations was established, but was only a quasi-government institution being largely financed by producers. The Bureau was unique in that it represented the first research organization serving the needs of a single industry in Australia. Although the advent of the Bureau and the establishment of schools of agriculture at the Universities were not insignificant developments, they can hardly be interpreted as the start of a new era in organized research.

In 1909 there was an initial attempt at the Federal level to establish a Federal Agricultural Bureau. The initial Bill was debated in the House of Representatives but after the second reading Parliament was prorogued and the Bill lapsed. The purpose for wanting to establish the Bureau was to

> ...take steps [to increase] production [and] preserve that which we are producing from injury by means of diseases or pests, and advance land settlement.
>
> [Australia, Parliamentary Debates, 1909, p.1921]

The Bill in its original form was re-introduced into Parliament in 1913. During the course of the debates following the second reading a number of scientific activities were envisaged for the Bureau particularly in relation to 'the diseases which affect our animal and plant life'. This time the Bill was passed in the Lower House but again Parliament was prorogued before the Bill was passed in the Senate.

It was not until the post 1920 period that significant advances were made in growth of public sector research. The 1920s and 1930s, for example, saw the beginning of the Waite Agricultural Research Institute (1926), the Institute of Agriculture at the University of Western Australia (1938) and the establishment of the Council for Scientific and Industrial Research (1926). The establishment of the Waite Research Institute was the direct result of a unique gift from Peter Waite, an emigrant from Scotland who became a most successful pastoralist in the north of South Australia. He purchased a property at Urrbrae, South Australia, in 1874 which was to become the site of the present Institute. The University of Adelaide adopted the following general aim for the Institute's work.

> The main objective of the Institute is to enlarge the stock of knowledge relating to agriculture in the widest sense and to pass it on to those actively engaged in production as farmers or pastoralists.
>
> [Waite Research Institute, Annual Report, 1926, p.8]

The formation of the Council for Scientific and Industrial Research in 1926 was the culmination of a long series of events aimed at involving the Commonwealth Government in organized scientific research.

As already mentioned above, the Commonwealth Government made attempts in 1909 and 1913 to establish a Commonwealth Agricultural Bureau but on both occasions the Bills were not successful in passing through both houses of Parliament. Interest, however, was maintained in the idea of Commonwealth scientific activity with the reports of the Dominion's Royal Commission of 1913 and the Interstate Commission of 1915 which claimed that

> ...a Commonwealth department operating upon the problems of secondary as well as primary production, might well be constituted with a view to the systematic application of science to Australian industry.
>
> [reproduced in Currie and Graham, 1966, p.7]

During the ensuing period, two particularly strong advocates of a Commonwealth scientific organization emerged in the persons of Hagelthorn, the Victorian Minister of Agriculture and Prime Minister Hughes. It appears that both men were motivated to some extent by the contribution of science to agricultural development and that around 1915 the State Ministers of Agriculture were in agreement with the idea.

> The Ministers of Agriculture of the different states recognized that a number of questions could be settled easier and research work done more effectively by joint action than by each state working separately...
>
> [reproduced in Currie and Graham, 1966, p.28]

In 1916 an Advisory Council was established to 'consider and initiate scientific researchers in connection with, or for the promotion of primary and secondary industry.' Among the problems which it was suggested that the Council should investigate were 'the sheep fly pest', 'the introduction of a mechanical cotton picker' and 'the eradication of the prickly pear'. The Council also initiated investigations into the problems of cattle tick. This concentration on agricultural problems is claimed to have caused some resentment within State Departments.

> These activities [those of the Council] had alerted officers of the State Departments of Agriculture to the fact that an organization for scientific research was actually competing with some of them in a few of their own cherished fields of study and this caused some resentment among State officers.
>
> [Currie and Graham, 1966, p.81]

In fact, at an interstate conference of Ministers of Agriculture in 1918, there was direct opposition to the Commonwealth Government's involvement in scientific research. The duplication of effort seemed to be the major area of dissention [see Currie and Graham, 1966, pp.81-88].

Eventually, with the continued efforts of Masson and Bruce, the Advisory Council was replaced by the Institute of Science and Industry in 1920 which was in turn reorganized as the Council for Scientific and Industrial Research in 1926. That the new Council was orientated towards agricultural research can be gauged from the fact that the first four Divisions created were related to agriculture; these being the Divisions of Economic Botany, Economic Entomology, Animal Health and Nutrition and Soils.

During the 1920s there also seems to be some evidence that the State Departments of Agriculture were also starting to carry out scientific research as distinct from experimental work. In the Victorian Department of Agriculture which was established in 1872, it is reported that

> Chemical analysis and agricultural education services were also begun in those early years, and research and advisory services followed in the mid-twenties.'
>
> [Department of Agriculture, Victoria, 1975, p.2]

Furthermore, the New South Wales Department announced in 1924 that it had decided

> ...to alter the title of the committee controlling experiments conducted on Government farms from Experiments Supervision Committee to Research Council, it being considered that this title was more suitable in view of the work carried out.
>
> [Department of Agriculture, New South Wales, 1924, p.11]

The above discussion suggests that public sector research in Australian agriculture did not become established until the 1920s, despite the establishment of the various State Departments of Agriculture in the latter years of the nineteenth century and attempts to establish a Federal Agricultural Bureau as early as 1909. This picture of the development of public sector research resembles quite closely that described by

Hayami and Ruttan [1971] of the development of agricultural public sector research in the United States. For example, the United States Department of Agriculture was established in 1862 but it was not until the latter years of the nineteenth century that the department 'achieved any significant capacity to produce the scientific knowledge needed to deal with urgent problems of agricultural development' and it was not until the 'early 1920s [that] a national agricultural research and extension system had been effectively institutionalized at both the Federal and State levels.' [Hayami and Ruttan, 1971, pp.143-44].

The authors address themselves to this apparent delay in institutionalization of research and seek to explain it in terms of induced innovation in the public sector.

> The answer must be sought in the same conditions that induced the rapid development of mechanical technology in American Agriculture before 1900. Neither movements in relative factor prices nor factor-product price ratios were such as to induce yield-increasing innovation.
>
> [Hayami and Ruttan, 1971, p.144]

This claim is not directly supported by empirical evidence by the authors. Data limitations preclude the possibility of substantially investigating this relationship for Australia but there are, nevertheless, sufficient data to allow us to make some observations regarding the institutionalization of research and possible effects of movements in factor price and product-factor price ratios. These investigations are made in the following section.

5.6.3 The Role of Factor and Product Prices in the Development of Public Sector Research.

In this section, we investigate the relationship between the growth of public sector research and movements in factor price and factor-product price ratios. The data available to carry out this investigation are limited but they do allow us to make some general observations. First we analyse the relationship between factor price ratios, in particular the land-labour price ratio and the growth of public sector research activity. In terms of the induced innovation hypothesis as advanced by Hayami and Ruttan [1971] we may postulate the following. If the price of land rises relative to the price of labour, then, *ceteris paribus*, farmers will search for techniques which will save the relatively scarce factor; in this case, they will seek biological, land saving technologies. (Alternatively, if the price of labour rises relative to the price of land, then farmers will seek labour saving, mechanical technology). According to the Hayami-Ruttan induced public sector model, farmers in their search for land saving technology will

> ...press public research institutions to develop new varieties. Through a kind of dialectic process of interaction among farmers and experiment station workers, a new variety... is developed.
>
> [Hayami and Ruttan, 1971, p.127]

Although the evidence is limited, there are reasonably strong indications that the organization of public sector agricultural research activity and its subsequent growth has not been associated with increases in the price of land relative to labour as predicted by the induced innovation hypothesis.

McLean [1975] has developed a series of unit land and labour prices and output per unit area measures for Victorian agriculture for the period 1870/71 - 1910/11. These data are presented graphically in Figures 5.7(a) and 5.7(b). As can be seen the land/labour price ratio increased throughout the period 1870/71 - 1900/01 and decreased slightly between 1900/01 and 1910/11. The increases in output per unit area, which are depicted in Figure 5.7(a), would seem to support the induced innovation hypothesis. That is, in response to increases in the price of land relative to labour farmers have introduced land saving or yield increasing technologies as indicated by the increases in output per unit of occupied land. However, it would appear that the technologies adopted were not the outcome of organized public sector research

FIGURE 5.7(a)

Movements in Relative Factor Prices and Land Productivity; Victorian Agriculture, 1870/71 - 1910/11

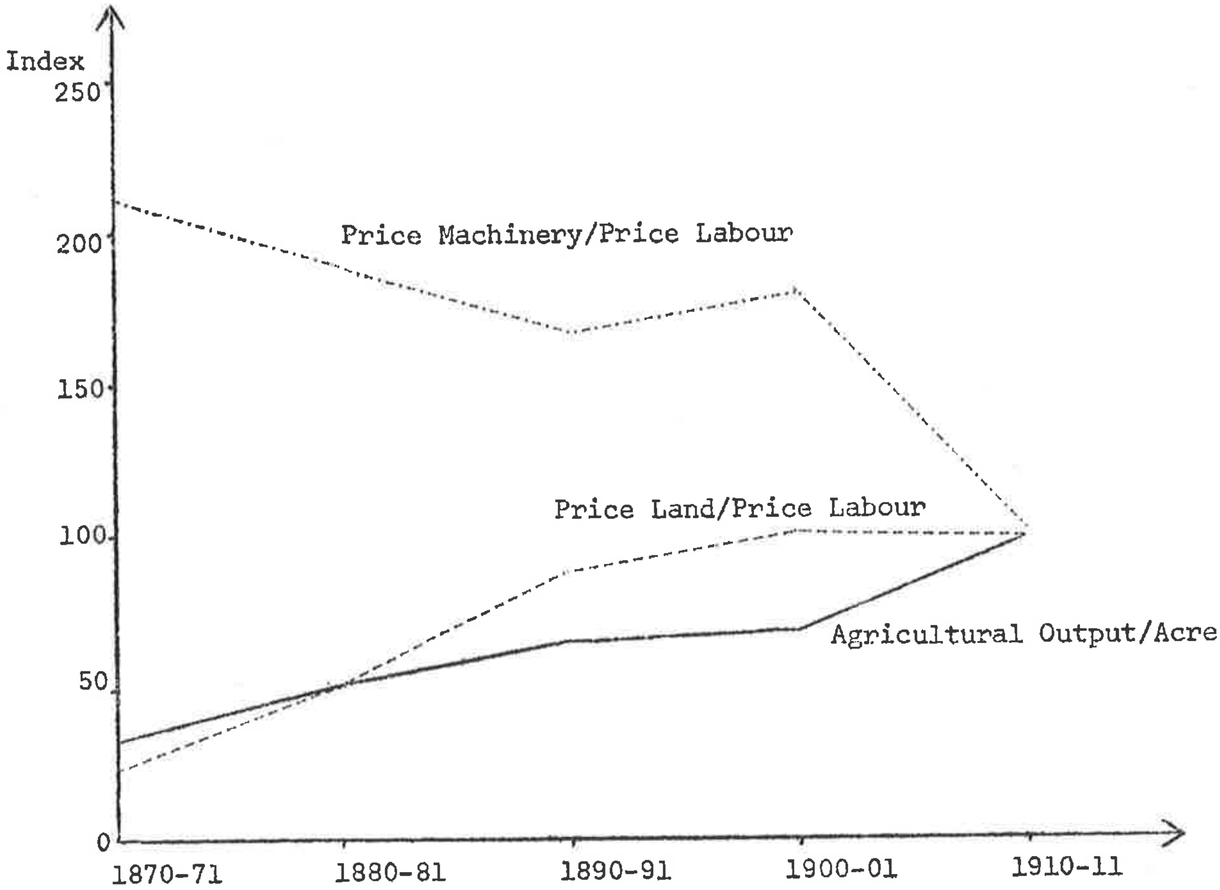
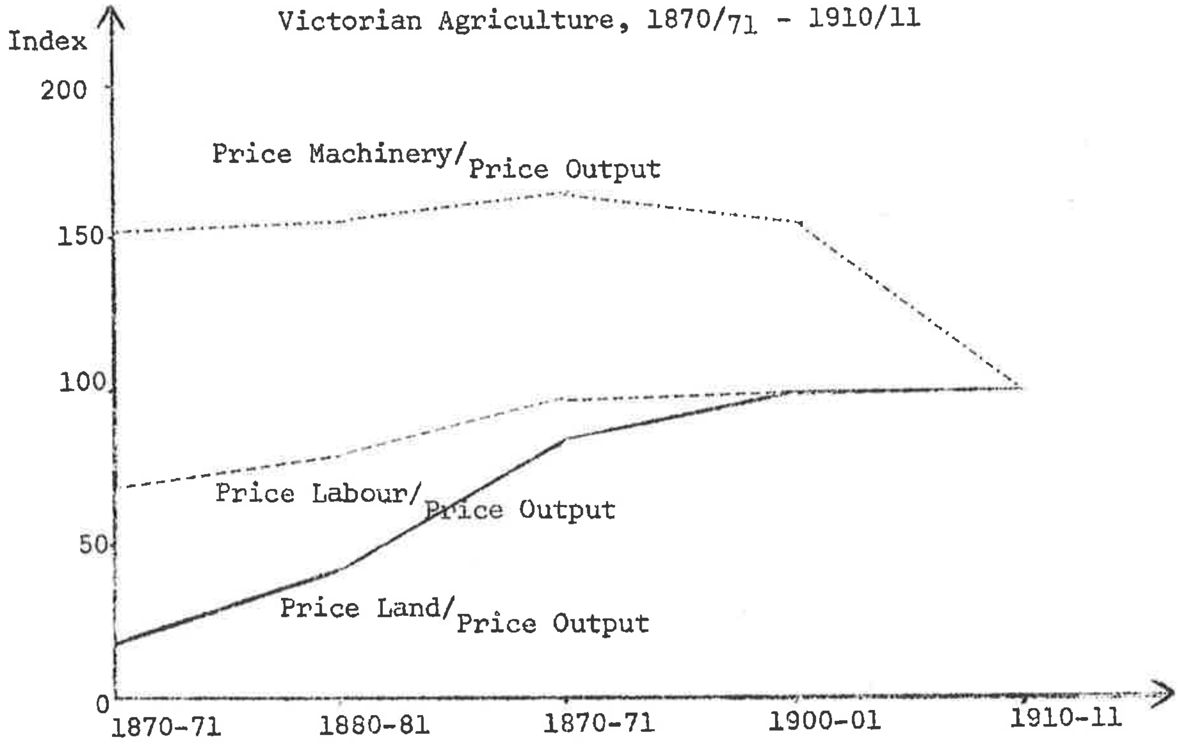


FIGURE 5.7(b)

Movements in Factor/Product Price Ratios; Victorian Agriculture, 1870/71 - 1910/11



Sources: McLean [1975 and 1977].

activities. As we saw in section 5.6.2, the Victorian Department of Agriculture, although established in 1872, did not commence undertaking scientific research activity until the mid 1920s and there was no Federal scientific activity until the same time.

With respect to the Victorian situation then, it would seem implausible to conclude that the delay in the institutionalization of research was a function of factor price movements. That is, the appropriate factor price movements were experienced during the approximate period 1870 to 1900 and although farmers responded by introducing land saving technology, this was not forthcoming from induced public sector research responses.

We turn now to factor-product price ratios to investigate if there is any evidence to suggest that the commencement of public sector research was in response to movements in these price ratios. In particular, we investigate the proposition that the institutionalisation of scientific research was in response to increases in the price of factors relative to product prices. Once again, the data available to make this investigation are limtied but it still allows some general observations to be made. In figure 5.7(b), the ratios of prices of machinery, labour and land to output are presented, the data again are derived from McLean [1976 and 1977] and relate only to Victorian agriculture. The graphs presented in figure 5.7(b) indicate that during the period 1870/71 - 1910/11, the price of machinery relative to output fell but that the price of land relative to output and the price of labour relative to output increased throughout the period. This evidence provides a similar picture to that discussed with regard to movements in the price of land relative to the price of labour. That is, if scientific research is expected to make a contribution to cost reductions, in particular by providing land saving technology, then the price evidence we have suggests that the market was providing appropriate signals for scientific research output in Victoria during the period

1870/71 - 1910/11. Again we may make a similar conclusion regarding the establishment of institutionalized research as was made with regard to the behaviour of relative factor price changes. That is, during the period 1870/71 - 1910/11, the movements of factor - product price ratios were such as to 'induce' farmers to introduce cost-saving technology; however, as we have seen, the advent of public sector research did not occur until the mid 1920s. Again, it seems impossible to conclude that the delay in the institutionalization of scientific research was attributable to inappropriate movements in factor-product price movements.

Although the above discussion must be cautiously interpreted because of the limited availability of data, it does suggest that past movements in factor and/or product prices were not primary reasons for the establishment of public sector research in the mid 1920s. This is not to deny however, that factor and product prices did not play some role. It might be argued that perceived future changes in product and factor prices rather than past changes were a primary reason for the upsurge of public sector research in the mid-1920s. Schedvin and Trace [1976] address themselves to the question: Why was C.S.I.R. established in the mid 1920s? Their main conclusion was that its establishment was a 'product primarily of the quest for Imperial Economic Co-operation' in the face of an uncertain future.

> After World War I the United Kingdom and most Dominions seemed faced with a highly uncertain economic future...The uncertainty which faced the Dominions concerned their future economic role. Were they to continue as exporters of food and raw materials largely for the benefit of the United Kingdom as in the nineteenth century, or should they develop a measure of economic independence through industrialization? In the Australian case growing national operations pointed in the direction of industrialization ...At the same time the level of economic welfare continued to depend heavily on the export of crop and livestock products. But the stability and availability of the markets for traditional exports was threatened by the search in Europe for greater self-sufficiency as a result of widespread famine and shortages of materials during the war.
>
> [Schedvin and Trace, 1976, p.4]

Within the environment of a move towards greater self-sufficiency and greater competition in export markets, future increases in factor prices and falls in export prices would characterize price expectations. If the establishment of C.S.I.R. was motivated primarily in response to the economic climate described by Schedvin and Trace, then it might be argued that perceived changes in factor and product prices were one of a wider net of factors associated with the establishment of public sector research in Australia. This explanation however, still should not be interpreted as suggesting that movements in factor and product prices were a *primary* consideration in the changes that took place during the mid 1920's.

5.7 Summary

In this chapter, the theory of induced innovation has been reviewed. Although the theory was subjected to considerable review and change it nevertheless appears to be deficient in the sense described by Nordhaus [1967] and Binswanger [1974]; that is, the theory has failed to incorporate the process of research and development as a truly endogenous variable. Hayami and Ruttan [1971] attempt to incorporate the response of public research institutions into their model of induced agricultural development but this is essentially a static analysis; the actual 'response' processes are not really analysed, they refer only to 'a kind of dialectic process of interaction among farmers and experiment station workers.' The first genuine approach to make research truly endogenous in the theory of induced innovation is that of Binswanger [1974]; this theory is outlined in section 5.4.

In section 5.6, we examined the development of public sector research in Australian agriculture and indicated that its growth can be dated from the mid 1920s. An attempt was made to reconcile this development with the 'dialectic processes' described by Hayami and Ruttan. An investigation of historical and perceived future changes in factor and product price changes and their relation to public sector research does not support the Hayami-Ruttan thesis that the development of public sector research must be explained by movements in either relative factor prices and/or factor-product price ratios.

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CHAPTER 6

SUMMARY

In this study, we have undertaken an analysis of public sector scientific research in Australian agriculture. A major reason for undertaking this investigation was the apparent lack of attention devoted to it by Australian economists in spite of the increased attention being devoted to public sector research by analysts elsewhere. In general, we have viewed the research process as a type of production process in which scarce resources are utilized. As such, it was felt that public sector research resources should be constrained by efficiency considerations in much the same way as 'normal' production processes are. To impose this constraint, however, presents difficulties in view of the fact that one of the primary reasons why public sector research is undertaken is that the economic gains from some types of research are most difficult to appropriate. This makes it extremely difficult to establish appropriate efficiency criteria for research resource allocation decisions. The approach we have adopted in this study was to try and establish some appropriate criteria and utilize them to investigate public research behaviour in the agricultural sciences.

The main obstacle to the study was the lack of an appropriate data set on research activities undertaken in Australia. In Chapter 2 we described the difficulties of generating an appropriate research activity index and highlighted the inherent limitations of possible data sources. One possible source of data were scientific publications; this was investigated and it was concluded that these might be appropriate for indicating short term changes in the level of research activity. A count of publications was undertaken for the period 1945 to 1975. To allow us to undertake a more formal analysis of the suitability of publication data, estimates of the number of scientific personnel engaged in agricultural scientific research for the period 1925 to 1975 were made. An 'informal' and a statistical analysis were undertaken which appeared to confirm that publication data was appropriate for measuring short-term changes in the level of research activity.

In Chapter 3, an analysis was made of the factors determining the mix of research activity among different commodity groups. In an attempt to identify appropriate evaluation criteria, research was viewed as a production process in which supply and demand considerations were relevant in determining resource allocation criteria. The analysis concentrated on demand forces; the derived demand to satisfy collective wants being considered the most relevant. It was argued that the direction of research activity should be such that the net benefits of that activity were in accordance with the goals of domestic agricultural policy. An attempt was then made to identify the goals of Australian agricultural policy for the period 1955-1965 by examining ministerial statements accompanying the various pieces of agricultural legislation passed during the period. The major goals were found to be the growth of agricultural output in order that increased foreign earnings might be generated, and income stability or security. An empirical investigation utilizing publication data was carried out to investigate whether the commodity research mix during the period was consistent with the identified goals. It was found that, under certain restrictive assumptions, the research mix was consistent with the goal of maximizing agricultural output. Some evidence was also found to indicate that commodities which exhibited more unstable production patterns had relatively more research activity devoted to them.

In Chapter 4, we investigated the contribution of scientific research activity to Australian agricultural productivity. The first part of this investigation utilized publication data to analyse the relationship between scientific research and increases in product yields. Not all the models yielded statistically significant results. However, when yield growth rates were corrected for 'area effects' and the research variable was adjusted to take account of variable production conditions, a statistically significant relationship was found between the two variables. An analysis was also made of the contribution of scientific research activity to the growth of total factor productivity for Australian agriculture for the period 1926-1968. A number of models were tested and, in each case, research activity appeared as a 'significant' explanator of changes in total factor productivity. It was emphasized that these results must only be accepted tentatively but in general they seemed to support the proposition that agricultural scientific research had made a positive contribution to the growth of agricultural productivity.

The emphasis changed in Chapter 5 to an analysis of the development of institutionalized scientific research in Australian agriculture; the analysis being conducted within the framework of the theory of induced innovation. The theory of induced innovation was reviewed and although it claims to make technical change truly endogenous, it was found to be deficient except for Binswanger [1974] in this respect. A brief review of Hayami and Ruttan's [1971] attempt to incorporate the response of public research institutions into a model of induced agricultural development was also undertaken. The development of public sector research in Australian agriculture was traced and an attempt was made to reconcile this with the induced institutional response hypothesis advanced by Hayami and Ruttan. A discussion of the historical movements in factor and product prices and possible expectations about their future movements did not reveal evidence that supported the hypothesis advanced by Hayami and Ruttan that the development of public sector research must be explained by movements in either relative factor prices and/or factor-product price ratios.