THE GAINS FROM PASTURE RESEARCH IN AUSTRALIA:
AN ECONOMIC ANALYSIS OF RESEARCH IN THE
C.S.I.R.O. DIVISION OF PLANT INDUSTRY

by

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A thesis submitted for the degree of
Doctor of Philosophy
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Apart from assistance acknowledged in the Preface and in footnotes, this thesis is my own original work.
In 1969, at the request of the late Dr. J.E. Falk, then chief of the Division of Plant Industry, the C.S.I.R.O. executive made available to me a grant for a three-year study into the ways in which economic analysis could contribute to the decision-making processes within the Division. Broadly, the questions posed were: "... whether and how economic thinking can add to our decision making, and, if so, in what kinds of research situations, with what kinds of projects, can it so add". The results of the economic analysis which was carried out during the past three years are reported herein.

I wish to record my appreciation to the Executive of the C.S.I.R.O. for making the grant for post-graduate study at the Australian National University available to me. It is some measure of their awareness of the need for, and the possibilities of, improvements in the allocation of funds to research.

I acknowledge my debt to my thesis supervisors Dr. R.T. Shand and Dr. C. Tisdell. I also wish to record my appreciation to Dr. R.G. Gregory for his assistance with the econometric analysis of Chapters 5 and 6. A number of other people gave me the benefit of their comments or advice - Mrs. B. Allan, Dr. J.R. Anderson, Mr. G.W. Edwards, Mr. John Logan, Dr. F.H.W. Morley, Professor Deane Terrell, and Mr. D.G. Thomas.
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 INTRODUCTION</td>
<td></td>
</tr>
<tr>
<td>1.1 The Scope of the Study</td>
<td>1</td>
</tr>
<tr>
<td>1.2 An Outline of the Study</td>
<td>3</td>
</tr>
<tr>
<td>1.3 References</td>
<td>5</td>
</tr>
<tr>
<td>2 THE ECONOMIC ASPECTS OF RESEARCH AND RESEARCH DECISION MAKING</td>
<td>6</td>
</tr>
<tr>
<td>2.1 Definition of Research and its Uses</td>
<td>6</td>
</tr>
<tr>
<td>2.2 Investment or Consumption?</td>
<td>7</td>
</tr>
<tr>
<td>2.3 Invention and Applied Research</td>
<td>9</td>
</tr>
<tr>
<td>2.4 The Economics of Public Investment in Research</td>
<td>11</td>
</tr>
<tr>
<td>2.5 Research and Invention and Economic Growth</td>
<td>13</td>
</tr>
<tr>
<td>2.6 The Allocation of Research Funds</td>
<td>18</td>
</tr>
<tr>
<td>2.6.1 The &quot;needs&quot; approach to research funding</td>
<td>19</td>
</tr>
<tr>
<td>2.6.2 The link between academic research and science education</td>
<td>21</td>
</tr>
<tr>
<td>2.6.3 Internal and external allocation criteria</td>
<td>24</td>
</tr>
<tr>
<td>2.7 Summary</td>
<td>32</td>
</tr>
<tr>
<td>2.8 References</td>
<td>34</td>
</tr>
<tr>
<td>3 ECONOMIC CRITERIA IMPLICIT IN RESEARCH DECISIONS - C.S.I.R.O. DIVISION OF PLANT INDUSTRY</td>
<td>37</td>
</tr>
<tr>
<td>3.1 The C.S.I.R.O. and its Functions</td>
<td>38</td>
</tr>
<tr>
<td>3.2 The Division of Plant Industry, C.S.I.R.O.</td>
<td>43</td>
</tr>
<tr>
<td>3.3 The Role of Agriculture in the Australian Economy</td>
<td>44</td>
</tr>
<tr>
<td>3.4 The Role of Agricultural Research in the Australian Economy</td>
<td>51</td>
</tr>
<tr>
<td>3.4.1 Research and technical progress: the returns to producers</td>
<td>55</td>
</tr>
<tr>
<td>3.5 An Historical Examination of Decision Making in the C.S.I.R.O. Division of Plant Industry</td>
<td>68</td>
</tr>
<tr>
<td>3.6 The Economic Criteria Implicit in the Division’s Decision Making</td>
<td>79</td>
</tr>
<tr>
<td>3.7 Summary</td>
<td>84</td>
</tr>
<tr>
<td>3.8 References</td>
<td>86</td>
</tr>
<tr>
<td>4 THE MEASUREMENT OF BENEFITS FROM RESEARCH</td>
<td>89</td>
</tr>
<tr>
<td>4.1 The Value to Society of an Increase in Productivity</td>
<td>90</td>
</tr>
<tr>
<td>4.2 Sensitivity of Research Benefits to Changes in Economic Variables</td>
<td>93</td>
</tr>
<tr>
<td>4.3 Some Qualifications to the Estimate of the Returns from Research</td>
<td>96</td>
</tr>
<tr>
<td>4.3.1 Externalities in consumption</td>
<td>96</td>
</tr>
<tr>
<td>4.3.2 Externalities in production</td>
<td>97</td>
</tr>
<tr>
<td>4.3.3 Perfect competition in all markets</td>
<td>98</td>
</tr>
<tr>
<td>4.3.4 Consumers surplus</td>
<td>101</td>
</tr>
<tr>
<td>4.3.5 Consumers surplus in an open economy</td>
<td>103</td>
</tr>
</tbody>
</table>
4.4 Further Examination of the Economic Criteria for C.S.I.R.O. Decision Making

4.4.1 The relevance of some qualifications to the economic criteria used by the C.S.I.R.O.

4.5 Allocation of Research Resources Between Improvements in Productivity and Product Improvements

4.6 Summary

4.7 References

5 MEASURING THE BENEFITS FROM RESEARCH: AN ALTERNATIVE METHOD

5.1 Introduction to the Model

5.2 The Model: The Demand for a Stock of Improved Pastures

5.2.1 The rate of adjustment in a stock of improved pastures

5.2.2 The polynomial distributed lag

5.2.3 The model to be estimated

5.3 The data

5.3.1 The stock of improved pastures (K)

5.3.2 The cost of improved pastures (P)

5.3.3 The price of land (P)

5.4 Some Statistical Considerations

5.5 Results of Estimating the Input-Demand Model for Northern Tablelands, N.S.W.

5.6 The Value of an Increase in the Productivity of an Input

5.6.1 A formula

5.6.2 Research costs

5.6.3 The internal rate of return

5.6.4 The return on pasture research - Northern Tablelands, N.S.W.

5.7 Summary

5.8 References

6 THE RETURNS FROM PASTURE RESEARCH - NORTHERN AND SOUTHERN AUSTRALIA

6.1 Southern Australia

6.1.1 Southern Tablelands, N.S.W.

6.1.2 Riverina, N.S.W. (Irrigation)

6.1.3 Riverina, N.S.W. (Dryland)

6.1.4 Western Australia (Wheat/Sheep Zone)

6.2 Northern Australia

6.2.1 Townsville, Qld. (Northern Spear Grass)

6.2.2 Rockhampton, Qld. (Brigalow)

6.2.3 Rockhampton, Qld. (Southern Spear Grass)

6.2.4 Maryborough, Qld. (Wallum)

6.2.5 Maryborough, Qld. (South Queensland Dairy Pastures)

6.3 References
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>255</td>
</tr>
<tr>
<td>RETURNS FROM PASTURE RESEARCH: A DISCUSSION OF THE RESULTS</td>
<td></td>
</tr>
<tr>
<td>7.1 The Significance of the Results in Relation to Other Findings</td>
<td>255</td>
</tr>
<tr>
<td>7.1.1 The elasticity of demand for improved pastures</td>
<td>256</td>
</tr>
<tr>
<td>7.1.2 The research lag</td>
<td>263</td>
</tr>
<tr>
<td>7.1.3 The adoption lag</td>
<td>264</td>
</tr>
<tr>
<td>7.1.4 Rate of return on research</td>
<td>269</td>
</tr>
<tr>
<td>7.1.5 The effect of rainfall</td>
<td>273</td>
</tr>
<tr>
<td>7.2 The Contributions made by Different Fields of Pasture Research</td>
<td>274</td>
</tr>
<tr>
<td>7.2.1 Plant introduction and plant breeding</td>
<td>278</td>
</tr>
<tr>
<td>7.2.2 Plant nutrition and legume bacteriology</td>
<td>282</td>
</tr>
<tr>
<td>7.2.3 Research into pasture management</td>
<td>288</td>
</tr>
<tr>
<td>7.3 Summary</td>
<td>293</td>
</tr>
<tr>
<td>7.4 References</td>
<td>295</td>
</tr>
<tr>
<td>8 CONCLUSIONS</td>
<td></td>
</tr>
<tr>
<td>8.1 Summary of the Study and its Findings</td>
<td>299</td>
</tr>
<tr>
<td>8.2 Implications of the Study for Research Decision Making</td>
<td>306</td>
</tr>
<tr>
<td>8.3 Scope for Further Work</td>
<td>307</td>
</tr>
<tr>
<td>8.4 References</td>
<td>308</td>
</tr>
<tr>
<td>APPENDICES</td>
<td></td>
</tr>
<tr>
<td>I TECHNOLOGICAL CHANGE IN THE ARID ZONE OF NEW SOUTH WALES</td>
<td>309</td>
</tr>
<tr>
<td>II LISTING OF DATA USED IN APPENDIX I</td>
<td>334</td>
</tr>
<tr>
<td>III LAND VALUES INDICES FOR SELECTED AREAS</td>
<td>336</td>
</tr>
</tbody>
</table>
**LIST OF FIGURES**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Changes in industry surplus with perfectly elastic demand</td>
<td>62</td>
</tr>
<tr>
<td>3.2</td>
<td>Changes in industry surplus with perfectly inelastic demand</td>
<td>64</td>
</tr>
<tr>
<td>3.3</td>
<td>Changes in industry surplus with differing demand elasticities</td>
<td>67</td>
</tr>
<tr>
<td>4.1</td>
<td>Gains from an increase in productivity</td>
<td>92</td>
</tr>
<tr>
<td>4.2</td>
<td>Gains from research with supported prices</td>
<td>102</td>
</tr>
<tr>
<td>4.3</td>
<td>The characteristics frontier and consumer optimality</td>
<td>113</td>
</tr>
<tr>
<td>4.4</td>
<td>Comparing a process improvement with a product improvement</td>
<td>116</td>
</tr>
<tr>
<td>5.1</td>
<td>The gains from an increase in the productivity of an input</td>
<td>123</td>
</tr>
<tr>
<td>5.2</td>
<td>The gains from an increase in productivity: the effect of differences in input elasticity</td>
<td>125</td>
</tr>
<tr>
<td>5.3</td>
<td>Various price indices for bagged superphosphate (N.S.W.)</td>
<td>142</td>
</tr>
<tr>
<td>5.4</td>
<td>Area of sown pastures and superphosphate use, Northern Tablelands, N.S.W.</td>
<td>147</td>
</tr>
<tr>
<td>5.5</td>
<td>Adjustment lags in the stock of improved pastures following on research findings - Northern Tablelands, N.S.W.</td>
<td>152</td>
</tr>
<tr>
<td>5.6</td>
<td>Shift in input-demand functions: constant elasticity</td>
<td>159</td>
</tr>
<tr>
<td>6.1</td>
<td>Area of sown pastures and superphosphate use, Southern Tablelands, N.S.W.</td>
<td>181</td>
</tr>
<tr>
<td>6.2</td>
<td>Area of sown pastures and superphosphate use, Riverina, N.S.W. (Irrigation)</td>
<td>189</td>
</tr>
<tr>
<td>6.3</td>
<td>Area of sown pastures and superphosphate use, Riverina, N.S.W. (Dryland)</td>
<td>196</td>
</tr>
<tr>
<td>6.4</td>
<td>Area of sown pastures and superphosphate use, Northern Agricultural Division, W.A.</td>
<td>200</td>
</tr>
<tr>
<td>6.5</td>
<td>Area of sown pastures and superphosphate use, Central Agricultural Division, W.A.</td>
<td>201</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>6.6</td>
<td>Area of sown pastures and superphosphate use, Southern Agricultural Division</td>
<td>202</td>
</tr>
<tr>
<td></td>
<td>W.A.</td>
<td></td>
</tr>
<tr>
<td>6.7</td>
<td>Area of sown pastures and superphosphate use, Wheat/Sheep Zone, W.A.</td>
<td>203</td>
</tr>
<tr>
<td>6.8</td>
<td>Area of sown pastures and area of pastures fertilized, Townsville</td>
<td>221</td>
</tr>
<tr>
<td></td>
<td>Statistical Division, Qld.</td>
<td></td>
</tr>
<tr>
<td>6.9</td>
<td>Area of sown pastures, superphosphate use and area of pastures fertilized,</td>
<td>226</td>
</tr>
<tr>
<td></td>
<td>Rockhampton (Brigalow)</td>
<td></td>
</tr>
<tr>
<td>6.10</td>
<td>Area of sown pastures, superphosphate use and area of pastures fertilized,</td>
<td>233</td>
</tr>
<tr>
<td></td>
<td>Rockhampton (Spear Grass)</td>
<td></td>
</tr>
<tr>
<td>6.11</td>
<td>Area of sown pastures, superphosphate use and area of pastures fertilized,</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>Maryborough (Wallum)</td>
<td></td>
</tr>
<tr>
<td>6.12</td>
<td>Area of sown pastures, superphosphate use and area of pastures fertilized,</td>
<td>248</td>
</tr>
<tr>
<td></td>
<td>Maryborough (Dairy Pastures)</td>
<td></td>
</tr>
</tbody>
</table>
### LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Research Personnel Employed by Areas of Interest in C.S.I.R.O., 1968-69</td>
<td>41</td>
</tr>
<tr>
<td>3.2</td>
<td>Source and Disbursement of C.S.I.R.O.'s Agricultural Research Funds, 1968-69</td>
<td>57</td>
</tr>
<tr>
<td>3.3</td>
<td>Demand Elasticity/Reduction of Costs Matrix</td>
<td>60</td>
</tr>
<tr>
<td>5.1</td>
<td>Estimated Equations: Demand for a Stock of Improved Pastures - Northern Tablelands, N.S.W.</td>
<td>151</td>
</tr>
<tr>
<td>5.2</td>
<td>The Demand for Superphosphate Fertilizer (Alternative Model) - Northern Tablelands, N.S.W.</td>
<td>155</td>
</tr>
<tr>
<td>5.3</td>
<td>Research Expenditure per Scientist, 1935-36 to 1968-69 - Division of Plant Industry (C.S.I.R.O.)</td>
<td>164</td>
</tr>
<tr>
<td>5.4</td>
<td>Research Expenditure per Scientist, 1960-61 to 1968-69 - Division of Tropical Pastures (C.S.I.R.O.)</td>
<td>165</td>
</tr>
<tr>
<td>5.5</td>
<td>The Gross Benefits from Research - Northern Tablelands, N.S.W.</td>
<td>171</td>
</tr>
<tr>
<td>6.1</td>
<td>Estimated Equations: Demand for a Stock of Improved Pastures - Southern Tablelands, N.S.W.</td>
<td>186</td>
</tr>
<tr>
<td>6.2</td>
<td>Estimated Equations: Demand for a Stock of Improved Pastures - Riverina, N.S.W. (Irrigation)</td>
<td>193</td>
</tr>
<tr>
<td>6.3</td>
<td>Estimated Equations: Demand for a Stock of Improved Pastures - Riverina, N.S.W. (Dryland)</td>
<td>197</td>
</tr>
<tr>
<td>6.4</td>
<td>Estimated Equations: Demand for a Stock of Improved Pastures (Instant Adjustment Model) - Wheat/Sheep Zone, Western Australia</td>
<td>210</td>
</tr>
<tr>
<td>6.5</td>
<td>Estimated Equations: Demand for a Stock of Improved Pastures (Lagged Model) - Wheat/Sheep Zone, W.A.</td>
<td>211</td>
</tr>
<tr>
<td>6.6</td>
<td>Estimated Equations: Demand for a Stock of Improved Pastures (Lagged Model) - Wheat/Sheep Zone, W.A.</td>
<td>212</td>
</tr>
<tr>
<td>6.7</td>
<td>Gross Benefits Estimated for Successful Pasture Research in W.A. (Wheat/Sheep Zone)</td>
<td>213</td>
</tr>
<tr>
<td>6.8</td>
<td>Estimated Equations: Demand for a Stock of Improved Pastures - Townsville Division, Qld.</td>
<td>222</td>
</tr>
<tr>
<td>Table</td>
<td>Estimated Equations: Demand for a Stock of Improved Pastures - Rockhampton, Qld. (Brigalow)</td>
<td>Page</td>
</tr>
<tr>
<td>-------</td>
<td>----------------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>6.9</td>
<td>Estimated Equations: Demand for a Stock of Improved Pastures - Rockhampton, Qld. (Southern Spear Grass)</td>
<td>236</td>
</tr>
<tr>
<td>6.11</td>
<td>Estimated Equations: Demand for a Stock of Improved Pastures - Wallum Area</td>
<td>244</td>
</tr>
<tr>
<td>6.12</td>
<td>Estimated Equations: Demand for a Stock of Improved Pastures - South Queensland Dairy Pastures</td>
<td>250</td>
</tr>
<tr>
<td>7.1</td>
<td>Regional Long-Run Real Price Elasticities for Improved Pastures</td>
<td>257</td>
</tr>
<tr>
<td>7.2</td>
<td>Characteristics of Successful Research Findings</td>
<td>265</td>
</tr>
<tr>
<td>7.3</td>
<td>Regional Estimated Coefficients on Drought Variables</td>
<td>275</td>
</tr>
</tbody>
</table>
Chapter 1

INTRODUCTION

1.1 The Scope of the Study

The primary aim of this study was to estimate rates of return on investment in pasture research for a number of regions in Australia where the C.S.I.R.O. Division of Plant Industry has carried out research into improved pastures. As well, an investigation was carried out into the economic criteria underlying research decisions in the Division of Plant Industry. In undertaking this study it was also hoped to gain some insights into the economic factors which determine the returns from agricultural research.

In order to evaluate the contribution made by research into improved pastures, it was decided that, rather than estimating the benefits flowing from research by the usual residual methods [1, 3], the contribution made by particular research findings would be estimated. An econometric model is formulated which tests the impact of particular research results on the adoption of pasture improvement practices. In the model, the area of improved

1 Numbers in square brackets refer to the list of references placed at the end of each chapter.
pastures on farms in a number of woolgrowing or beef producing regions is treated as a durable input. The demand for the stock of this input is assumed to be a function of its real price, relative price, and the state of pasture technology. Polynomial distributed lag functions are fitted to estimate the lags in adjustment of the stock of improved pastures associated with changes in factor and product prices and with changes in the state of pasture technology.

Possible changes in the state of pasture technology are identified with the announcement of seemingly important research results. The emphasis in this study is on the returns from research by the Division of Plant Industry. For each of the regions selected, all of the Division's research findings which it was thought could have affected the demand for improved pastures were tested in the model. In some regions, however, research findings made by other public agricultural research organizations were also tested.

The increase in the demand for improved pastures associated with a research finding is identified with a shift of the input-demand curve, or marginal revenue productivity curve. Measurement of the welfare gains which result from a shift of the marginal revenue productivity curve, i.e., an increase in the productivity of the input, is suggested as an alternative to the method of estimating the gains from individual research findings which has been
used previously (e.g., see [2]). A formula is derived for estimating the gains to society from an increase in the productivity of an input, given knowledge about the increase in demand due to the shift and the elasticity of demand for the input.

In the study by Griliches [2], the method of analysis was an examination of the consequences of a shift of the supply curve for the product. This type of analysis is not appropriate in the present circumstances, as the results of adopting new pasture technology are not directly observable in yield responses. However, the method of analysis used by Griliches is discussed in some detail, for two reasons. First, the assumptions underlying the economic analysis of productivity increases will be the same for this analysis as for any other method used. Second, it was found that prior to the 1940's the C.S.I.R.O. had explicitly used an economic criterion for the allocation of research funds in agriculture which conformed closely to this method of estimating the benefits from research. The use of this criterion by the C.S.I.R.O. is discussed in the light of the examination made of the assumptions underlying it.

1.2 An Outline of the Study

An introduction to the economic aspects of research and to the role of economics in research decision making is given in Chapter 2. There is also a brief review of the empirical research which has attempted to establish the
importance of the role of research in economic growth.
In Chapter 3 the economic basis for the decisions made by the C.S.I.R.O. about agricultural research, in particular those relating to the Division of Plant Industry, are outlined and discussed. It is seen that in the past the C.S.I.R.O. has explicitly incorporated economic factors into its decisions. A method of measuring the gains to society from productivity-increasing research is outlined and discussed in Chapter 4. The economic basis underlying research decisions made by the C.S.I.R.O., which is discussed in the previous chapter, is subjected to further examination within the framework of this model.

An alternative framework for assessing the benefits from productivity-increasing research, based on shifts in the marginal revenue productivity curve for an input, is suggested in Chapter 5. A formula for calculating the value of a shift in the MRP curve is derived. An econometric model is formulated which is to be used for estimating the demand for improved pastures as a function of real and relative prices and changes in pasture technology. In order to demonstrate the application of the model, the contribution of pasture research on the Northern Tablelands, N.S.W. is investigated.

In Chapter 6, empirical analysis of the economic contribution which pasture research by the C.S.I.R.O. Division of Plant Industry and other research organizations has made in a number of regions in northern and southern
Australia is described. The results of the empirical analysis are discussed and related to the findings from other studies in Chapter 7. Finally, in Chapter 8 a summary of the findings of the study is presented.

1.3 References


Chapter 2

THE ECONOMIC ASPECTS OF RESEARCH AND RESEARCH DECISION MAKING

In this chapter the activity of research is defined and the broad economic principles relating to research in an economic system are outlined. A review is made of studies which have attempted to evaluate the contribution which research and invention have made to economic growth.

The subject of research decision making is discussed within the framework of the literature on science policy. Most of the discussion about the allocation of research resources has been carried on between non-economists and an attempt is made to isolate the important economic aspects of decisions about research.

2.1 Definition of Research and its Uses

Research is the activity of extending the bounds of our understanding of nature. As so defined there is no distinction between research and science (as used in its broadest sense), and these terms will be used synonymously. New knowledge is valued for the contribution which can be made to the material well-being of society through the application of such knowledge. Some new knowledge has immediately apparent worth in terms of making a contribution
to the material goals of society. At the other end of the scale there is some knowledge about which it is possible to be almost certain that it will never contribute to an increase in material welfare. But over the whole range, between and including these extremes, one can only predict with varying degrees of certainty whether the knowledge gained will help to make a contribution to material well being. The extent of any contribution can be predicted with even less certainty.

All new knowledge is also valued by society for its contribution to the bill of fare of "... our insatiable curiosity about the natural world" [25, p.205] - a non-material end. New knowledge gained can also help to satisfy our other non-material ends, e.g., defence, prestige among nations, understanding of social behaviour (which can also have material applications), and so on.

2.2 Investment or Consumption?

In recognition of the fact that not all human endeavour and resources are directed towards the material ends of society, research should be divided into investment and consumption. As Williams says [25, p.204]:

"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. Much defence and space R & D is in this latter category."
But to suggest, as many do, that all so-called basic research need only be justified on the grounds that it contributes to new knowledge, i.e., that it should be a consumption good, is to understate the case for basic research. Obviously, where economic growth ranks high as a social goal society is likely to give more support for basic research as an investment good than as a consumption good.

It is reasonable to argue that society should support some research purely for the sake of the non-material satisfaction derived from the results of such research. However, it is clearly unreasonable to argue, as Polanyi [19, p.67] does, that: "There is no reason to suppose that an electorate would be less inclined to support science for the purpose of exploring the nature of things, than were the private benefactors who previously supported the universities". Almost certainly for society as a whole there will not be the same preference between present and future consumption and between consumption of material and non-material goods as for those individuals who bestow gifts on universities.

Economic growth and research have become such catch-cries in recent years that it would be a difficult job indeed to judge from a country's actions and expressed ideals if it was in fact acting in accordance with its goals function. Some countries appear to go too far in conspicuous consumption of research. Other countries may express a desire for economic growth, but by their actions
in not sacrificing heavily now, are not in fact acting to achieve this end.

2.3 Invention and Applied Research

As stated previously, it is only through the application of new knowledge that research makes its contribution to society's material well-being. The manipulation of knowledge into materially-useful forms is called invention. The planned organization of inventive activity is commonly called applied research, i.e., where inventive effort or the manipulation of knowledge is directed into certain avenues which are considered desirable. This is not to say that all inventive effort is confined to organizations; Nelson [14] holds that the private inventor is still playing an important role.

Of course, inventions do occur without the deliberate act of the manipulation of known principles, or even without knowledge of the underlying principles. For instance, an empirically-based experiment may lead to an improved management practice without gaining an understanding of the physical laws involved. Arrow [2] has recently provided, in the language of Bayesian statistics, a general formulation of the knowledge production process which covers the special case of invention. Consider the situation where the outcome of an activity is not known with certainty, and where there is an underlying unknown parameter upon which the probability distribution of outcomes depends. Any
observations of outcomes will affect the subsequent expectations in accordance with Bayes's theorem.

"Thus, an activity will in general have two valuable consequences: the physical outputs themselves and the change in information about other activities" [2, p.31].

Arrow suggests that the classical research situation is at one end of the scale where "... the actual output (e.g., of nylon) is of negligible importance compared to the information gain - a posteriori the probability that a substance with the properties of nylon can be produced is now 1, whereas a priori it may have been a small figure" [2, p.31]. The other end of the scale may be shown in the case of learning by doing where "... the motivation for engaging in the activity is the physical output, but there is an additional gain, which may be relatively small, in information which reduces the cost of further production" [2, p.31]. Arrow holds that the bulk of research and development activities can be represented as intermediate cases between these polar cases.

In terms of this formulation there can be no hard-and-fast rule of what is research and what is not except as defined by the stated purpose of the activity. Invention, or applied research, is primarily concerned with the use of existing knowledge and the output of potentially practical products or processes; it is less concerned with the output of new information than is so-called basic or pure research. Basic research has been seen by many writers to be made up of "uncommitted basic" or "pure basic" research,
which is carried out solely to increase scientific knowledge (a consumption good), and "committed basic" or "objective basic" research, which is basic research in a field with potential technological importance (investment-oriented research).

2.4 The Economics of Public Investment in Research

Nelson [15, p.298] argues that in a private-enterprise economy the private sector will finance a socially-optimal amount of research only if ". . . all sectors of the economy are perfectly competitive, if every business firm can collect from society through the market mechanism the full value of benefits it produces, and if social costs of each business are exclusively attached to the inputs which it purchases . . ." According to Arrow [1] these conditions are not sufficient unless firms can offset the inherent riskiness of research and invention. He argues that in the absence of offsetting insurance the large firm can reduce the risk by running a number of projects, but this is an imperfect solution.

Arrow shows that owing to the indivisibility, inappropriability and uncertainty features inherent in the process of research and invention, the private sector will invest less than is socially optimal in these activities. According to the tenets of welfare economics, society should therefore invest in research and invention up to the point where the expected marginal social benefits equal the
expected marginal social benefits from investment in alternative uses. With regard to the practical aspects of public financing of R and D, Arrow holds little hope that we can do better than adjust current expenditure accordingly as the estimated return from past expenditure varies around some general rate of return.

Once the products of research and invention are in existence, information about them can be transmitted at almost zero cost. Any restriction on the use of the results, therefore, will mitigate against the optimal allocation of resources. But without legal protection, the owner of the information loses his monopoly power once the information is transmitted. In an endeavour to find a way out of this impasse society gives legal protection over inventions through patents,\(^1\) while not allowing any restriction to be placed on facts and natural laws. Society is thereby forced to undertake considerable investment in research, especially so-called basic research, to compensate for the under-investment in research which must occur. Or to put it another way, through the patent system society encourages inventive activity by private enterprise and so reduces the contribution which society itself is obliged to make. In general, only the large diverse firms can expect to capture a big share of the total benefits which may accrue to

\[1\] Because of the difficulties of making laws to encompass something so nearly intangible as information, it is certain there will always be transgressions of patents by firms on both sides of the fence.
fruitful basic research. The development of many of these types of firms seems to provide in part an explanation for the fact that while in recent years private expenditure on research and development has been increasing steadily, the rate of increase of registered patents has been decreasing. The presumption is that these firms tend to substitute secrecy for patenting. An increase in the proportion of chemical processes to mechanical systems could also be an important factor in the decline of patents; generally, chemical processes are more difficult to copy.

2.5 Research and Invention and Economic Growth

The present state of knowledge about the main-springs of aggregate economic growth leads Nordhaus [17, p.18] to conclude:

"At the present time there is no compelling empirical evidence pointing toward technological change rather than associating increases in productivity with economies of scale, learning by doing, errors of measurement, or even sunspots. The failure to explain the residual may be due to the absence of an adequate theory . . . of the generation and transmission of knowledge. Once a reasonable model of the inventive process has been developed and tested, it should be easier to sort out the sources of productivity change among the different claimants."

Nordhaus goes on to attempt to establish an empirical relation between aggregate inventive activity and the growth of productivity, but fails, as did Sanders [20].

The establishment of a relationship between inventive activity, productivity increases, and economic
growth is vital to a study of this nature where the prime concern is with the economic benefits generated by investment in research. The failure to establish such a relationship at the aggregate level does seem, as Nordhaus implies above, to be due in large part to the difficulty of taking adequate account of the rate and level of diffusion of innovations. Another problem encountered has been the difficulty of measuring the aggregate output of inventive activity. As Nordhaus and Sanders, and others, have experienced, the number of patents has proved to be an unsatisfactory index of inventive activity. But perhaps the biggest failure of these studies is that they do not recognize that research is an important competitive tool in private industry; that some of the benefits generated are not reflected in measured gross national product but still result in increased welfare to consumers. Product competition effects the transfer of part of the benefits (whether real or imagined) to society [21, p.7].

At the level of the individual firm there is some scattered empirical evidence for the assumption of a direct relationship between research and material gains, in the following terms: (a) profit-oriented firms are more involved with research [10]; (b) the rate of growth of productivity of firms is positively correlated with their research and development expenditure [12]; and (c) the rate of diffusion of an innovation between firms is largely governed by the profitability of the innovation [6, 10, Part IV]. It must
be recognized that for the first two of these relationships the chain of causality is not at all clearly established.

In between these two extremes, viz., sorting out the contributions to economic growth at the aggregate level and measuring the results of research and development achieved by the individual firm, there have been a wide variety of studies made of research and inventive activity. These range from evaluations of the returns from a single successful research project, over evaluations of the returns from research in individual sectors of both primary and secondary industry, to the calculation of the returns from research in the whole of the agricultural sector.

There have been a number of studies made of the benefits generated by individually-successful research projects. In isolation, this is, as Minasion [12, p.84] observes, "... a procedure which is on a par with estimating returns to the acting profession by looking at the earnings of movie idols". For research on hybrid corn Griliches [7] estimated an external rate of return of 700 per cent (which converts to an internal rate of return of between 35 and 40 per cent). In answer to criticisms in the terms of that by Minasion, Griliches observes that this reasoning reduces ad absurdum to the point where it would be considered that the only rate which has any meaning is the rate of return on research for the economy as a whole. This may well be true. It is interesting to note that while Griliches takes into account all research expenditure
on hybrid corn, both public and private, since 1910, in fact the initial breakthrough in hybrid corn research was achieved quite accidentally and independently of research financed by the expenditures which he totals.

A recent study by Brown [3] estimated the benefits generated to date from one successful research effort by the C.S.I.R.O. to be approximately $22 million, when discounted at 10 per cent. The accumulation of benefits over the next 10 years were calculated to add at least another $100 million to that figure. Besides this study, little has been published in the way of estimates made of the returns to research in C.S.I.R.O., as a whole, or for any of its many divisions.\(^2\)

Peterson [18] has estimated the rate of return to investment in poultry research in the United States since 1915. The gains made in feed efficiency were used to

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\(^2\) When he was Minister in charge of C.S.I.R.O., Lord Casey furnished the Federal Parliament with estimates on the returns from research done by the C.S.I.R.O. He said that in the period 1926 to 1956 total expenditure had been $66 million. As at 1956 the payoff from this research was worth more than $200 million annually. Half of this was due to agricultural research; in particular rabbit control by myxomatosis (worth $50 million p.a.), see [4]. The Division of Dairy Research in 1970 published a brochure which lists its research accomplishments and calculates that these are worth between 1.5 and 2.0 million dollars annually. The method of calculation is not shown, but, on the face of it, it is very likely that there has been substantial double counting, while there has been no allowance made for the fact that dairy products are subsidised.
measure the benefits generated. One approach, which estimated the downwards shift in the long-run supply function, gave an internal rate of return of approximately 20 per cent (an external rate of return of 89 per cent) for the average rate of return on all past investment. A production function approach gave an estimate for the marginal rate of return of approximately 30 per cent (an internal rate of return). This study made no attempt to separate the contributions from economies of scale, education, and so on - all are lumped together as resulting in the first place from research. Moreover, all innovations are assumed to emanate from organized research. Much the same criticisms apply to a study by Evenson [5] which estimated the returns to research for U.S. agriculture as a whole. Evenson does attempt to account for improvements in education over time. He also mentions that some recognition should be given to the social costs imposed by technological change. It is presumed that he means the problems of adjustment in agriculture. Research and technological change do appear to speed up the occurrence of these problems, but it is hardly reasonable to charge all the costs of adjustment against research.

In summary, the aggregate studies which have included the manufacturing sector have failed to take account of the large part which research and development plays in product competition. Because agricultural research of the kind discussed above does not have such an
emphasis on new products, the concentration in studies of
the agricultural sector on the relationship between
research and productivity is justified. None of the
aggregate studies have satisfactorily explained the
various contributions by economies of scale, education,
learning by doing, etc., as distinct from the direct
collection by research and inventive activity. Certainly
the gains from the "residual" are large, and since the
gains from some individually-successful research projects
appear to be so large it has to be concluded that the
economic benefits of R and D do appear to be considerable,
but that the substantiation of this conclusion leaves
something to be desired.

2.6 The Allocation of Research Funds

In its broadest context, discussion about the
allocation of research resources comes under the heading
of what has come to be known as Science Policy. A
discussion of research decision making would not be
complete if it did not at least briefly examine what has

3 This must be less true in the U.S. than in Australia.
In the U.S. the proportion of total research and
development in agriculture carried out by private
enterprise is much greater (over 50 per cent of total
R & D) and there must, therefore, be greater product
competition, viz., in new machinery, plant varieties,
fertilizers, veterinary supplies, etc. While in
calculating the returns to productivity-increasing
research in agriculture we are not plagued by the
non-measurability aspects of product improvement, there
are still other problems of measurement which are
discussed later.
been said in the science policy literature. The principal way in which this topic has been covered has been in discussions of the manner in which government support for research should be distributed. In the main, the contributors to the debate have been scientists in positions where they have felt concern about the allocation of funds. There have been few contributions by economists. Of course, a driving force in the debate in the United States has been the pressures of budget stringency on research work since 1964, and particularly since 1968. The slow-down in the rate of growth of research funds has been accompanied by new political demands for evaluation and justification of research programmes.

Three concepts have been advanced, either singly or together, as the basis for science resource allocation: the "needs" of science; the link between academic research and graduate education; and reliance on "internal" and "external" criteria for scientific choice.

2.6.1 The "needs" approach to research funding

The "needs" approach to the research allocation problem, expressed in its simplest form, is that funds should be provided in amounts sufficient to permit scientists in research institutions to pursue their chosen

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4 For reviews of the science policy literature by two economists writing in Australia, see [8, Ch.8] and [21, Ch.10].
research activities. Proponents of this point of view assert: (a) that there is a calculable minimum amount of support "needed" by science; (b) that this amount can be determined in relation to demographic data; and (c) that the government should provide a sufficiently large annual increase in support to meet this need as it increases with rising prices and with the growth of the relevant population.

As pressure on research budgets has mounted in recent years and as political demands have intensified for fuller and more specific justification of claims for research support, scientists have been less inclined to assert "needs" in such absolute terms. More frequently, scientific leaders have espoused the position that budgets should continue to provide "the same relative level of support". This means that starting with the existing level of funding, expenditures for science should increase at a rate equal to the combined rates of increase of research costs and the number of researchers. The rate of 15 per cent per annum seems to have reached sacred-cow status in the U.S. in the writings of the proponents of this viewpoint, see [22].

What interpretation can be given to these assertions of needs? What guidance do they provide for decision making about resource allocation at the highest level? First, what does "needs" mean in connection with resource allocation? The concept of "needs", as used in the above context, is not found in economic theory and is
not consonant with an economic view of what resource allocation involves, turning as it does on the notion of scarce resources and competing wants of different intensities. The needs approach does not illuminate the problem of choice, which is here one of deciding the balance between research and other avenues for funds. In fact, the needs approach appears to deny the concept of choice at least in relation to funds for science.

The needs approach does appear, superficially, to provide a basis for looking at allocations between fields of science. Of course, if the total budget turns out to be adequate to meet the independently calculated needs of each discipline, there is no difficulty. But in any less favourable situation the approach gives no guidance on how to allocate the funds when all needs cannot be met. A rationale for resource allocation, to be helpful to decision makers, must provide a framework for action in the context most likely to be met; one in which a limited budget has to be allocated among alternative, scientifically worthwhile, research possibilities.

2.6.2 The link between academic research and science education

Another rationale for allocation of research support relies on the educational motivation for funding of university research. Perhaps the most pragmatic reason for the prominence given to graduate education is that of
all the benefits attributed to research - economic, technological, cultural, national prestige, etc. - only the education benefits can be translated into quantifiable measures of output and need.

The proposition that provides the connection between research funds and educational demographic variables is that academic research and graduate education are inextricably linked. The two main points in this argument are (a) that participation in research is an integral part of a graduate student's education, and (b) that academics must participate in research in order to remain up to date in their fields and so to be effective teachers.

The argument that university research should expand in proportion to graduate enrolment is ultimately a circular argument. Graduate enrolment in each discipline is partly determined by past and current government support, but it is cited as justification for future support; thus, growing support for a discipline becomes perpetually self-justifying. But graduate education is not an end in itself and should not be treated as the independent variable for determining resource allocation. To the extent that graduate education supplies scientists for industry and government, manpower demand should be the starting point. To the extent that graduate education feeds back into the academic community, intellectual opportunities and utility of each discipline should be a guide to the numbers to be trained. That is, the demand
for science and scientists should determine the number of graduate students in each discipline, not the other way around. There is no reason to assume the supply of graduate students is unresponsive to the amount of support offered.

The idea that the demand for research should determine support for education rather than the other way around follows from the policy premise that support of education should be based on the government's role in the economic and manpower spheres. From this point of view, education is supported as a means to an end. It follows that the number of persons to receive graduate training in a field should be keyed to expectations about the importance, or value, of that occupation in the future.

The proponents of an education-related needs approach might begin with a different premise, namely, that government has a responsibility for providing educational opportunity to its citizens. This argument, which embraces what may be termed a consumptionist, or social demand, motive for government support of education is as oriented to the value of education to the individual as to the value of the educated individual to society. It holds that the government's goal should be to provide each individual with the opportunity to fulfil his potential by assuring him access to all the education he is able and willing to absorb. It follows from this that support should be based on the projected number of qualified students who will seek graduate training.
These two motivations for government action are not contradictory in the sense that one denies the importance of the category of educational benefits emphasized by the other. However, the two approaches are based on fundamentally different conclusions about the magnitude and direction of optimal government support. Before normative models of government support for academic research can be developed the basic assumptions which underlie government action must be made explicit.

2.6.3 Internal and external allocation criteria

Unlike the above two approaches which mainly serve to justify claims for research support, the concept of "internal criteria of scientific merit" seeks to provide the philosophical basis for a research resource allocation process. The rationale based on needs has very little to say about allocation of a budget among fields of science and it does not purport to provide any guidance on how individual projects should be selected within a field. When faced with these practical allocation problems most scientific leaders have taken the view that the necessary decisions can be accomplished best by scientists themselves primarily on the basis of so-called "internal criteria of intrinsic scientific merit". This is consonant with a strongly-held belief that autonomy and decentralization are necessary for scientific progress, and ultimately, for maximum social benefit from basic research.
The primacy of internal criteria has been proclaimed most forcefully by Polanyi [19], in a classic and extreme exposition of the case for scientific autonomy. According to Polanyi the only role for government should be to support competent scientists in the work of their own choosing. He depicts science as a self-regulating system (guided by an "invisible hand"), in which "independent, self-coordinated initiatives" of individual scientists, guided by scientific opinion, automatically yield "maximum advantage for the advancement of science as a whole". He sees any attempt to guide science into socially beneficial channels, or "towards a purpose other than its own", as self-defeating and ultimately destructive of scientific progress.

Few other writers in the continuing debate on science policy have taken so restrictive a position. Most have acknowledged that "external" criteria - primarily the expected practical benefits from research - should have some role in determining the allocation of research budgets. But agreement does not go far beyond this generalization. There are large differences of opinion about the degree to which social utility should influence allocations. There are even larger differences about how institutional practices should be redesigned to bring this influence to bear.

What exactly are the internal attributes of fields that are supposed to measure their "intrinsic scientific
merit"? According to most writers there are two: (i) the quality of people in the field; and (ii) the field's potential for significant intellectual progress. These criteria are applicable to individual projects. However, it is difficult to see how the same criteria may be used to rank an entire field. It seems unlikely that panels of scientists would be willing to attempt such judgements or, even if willing, that they would be able to reach a consensus.

Polanyi neglects the fact that society supports research because it values the results of research, and that it gives different values to different kinds of research. As has been seen, society values new knowledge for its own sake and in this sense research is a consumption good. But society also values research results for the impetus which they give to economic welfare, and in this sense research is an investment good. Research provides information which is an input in the economic system, i.e., there is a derived demand for research. So to place a value on research only as a consumption good or only as an investment good is to under-value it.

In the terms of what has been said in the previous paragraph, Polanyi is essentially discussing the nature of the research supply function, which reflects the quality and quantity of scientific resources and the input/output relationships between scientific effort and research results. But he is wrong to think the distribution of
scientific effort should depend on supply conditions alone. It is the interaction of the demand and supply relationships which should determine the research mix. He is correct to imagine that scientists are guided in their decisions by an "invisible hand", but it is the unseen hand of the price system determined by the interaction of supply and demand which guides them. Although an explicit price does not exist for each piece of research, his research output affects the future income stream of each scientist. As a rational utility maximizer a scientist selects projects which make the maximum expected contribution to his reputation and thus to his future income stream [11].

Polanyi appears to argue that when funds are given to public research organizations that these funds can and will be distributed between projects without pressures from outside, i.e., that the pricing system is not operating. The existence of an explicit price is not a necessary condition for the functioning of a market. The head of the organization is responsible to the public and he must bear the costs and gains of all decisions he makes [9]. Moreover, the scientists themselves, because there are job alternatives existing outside the organization, will make decisions about projects on grounds common to other research organizations and be loath to accept criteria which apply only within an organization. Funds for research granted by committees on a project-by-project basis, e.g., the Australian primary industry research funds, will be allocated in accordance with society's wishes insofar as
the composition of the committee accurately projects these wishes. Again, this is for the reason that members of a committee must also bear the costs and gains accruing to them as a consequence of their decisions.

So it is agreed with Polanyi that research decision making should be largely left to the scientific community, but for a different reason. As in a conventional market, if the pricing system functions without imperfections then we should expect an allocation of resources which creates the greatest total social benefit.

But in thinking about research in a market framework, the question which immediately arises is whether there are in fact any imperfections in the price system and whether the benefits to be gained from attempting to correct these outweigh the costs of doing so. The existence of externalities and monopoly power are two such imperfections. Monopoly power is such that control can be exerted over the price (of a factor or product) and so distort the allocation of resources from what it would be in the absence of such power. Total social benefits are reduced and sectors of the economy are exploited by other sectors. Externalities in the private enterprise sector are those costs which the individual decision maker does not bear and those benefits which he cannot appropriate. Another factor which gives rise to imperfections in the pricing system is uncertainty, i.e., the lack of information.
Though he apparently does not recognize it, it is essentially the development of monopolistic tendencies in Polanyi's laissez faire republic of science which is Weinberg's concern in his discussions of scientific choice. Weinberg maintains that scientific choice cannot be left to the internal criteria proposed by Polanyi but that external criteria (a) technological merit, (b) scientific merit, and (c) social merit) must also be considered. Of these three external criteria he considers that scientific merit is of most importance [24, p.56]. This criterion he proposes is such that "... that field has the most scientific merit which contributes most heavily to and illuminates most brightly its neighbouring scientific disciplines" [23, p.166]. Weinberg sees this criterion being exercised in the main by what he calls scientific critics; scientists who can stand above a specific field of research and judge its worthwhileness in relation to the fields in which it is "embedded". But Weinberg fails to distinguish between criteria relating to the supply conditions for research (scientific merit and technological merit) and the criterion relating to demand for research (social merit).

The monopolistic imperfections which arise in Polanyi's laissez faire republic arise through a tendency for scientific fields to form "closed universes" with the overlappings between fields becoming weaker. The situation is aggravated by the growing flow of scientific literature and by the formation of scientific institutions
with their inbuilt mechanism for survival, which is mainly achieved through expansion. Compared to monopoly power in the private sector, in the public sector, so it has been argued by Niskanen [16], monopoly power leads to an emphasis on a larger budget rather than higher profits. In brief, the public monopoly will not seek to restrict its output as does the private monopolist, but it will tend to expand its output inefficiently by below-cost pricing. In so doing it will, like the private monopoly, create as little consumer surplus as possible, and create a substantially larger factor surplus than competitive industry. Therefore, Niskanen says [16, p.303]

"...the primary interests in continuing the bureau (or a war) are likely to originate from the bureau itself and the owners of specific factors. ... A bureau should be expected to engage in considerable promotion, in co-operation with the owners of specific factors, to augment the demand for its output, and to reduce - through persuasion, restrictions on entry, and consolidation - the elasticity of this demand".

The primary issue from the economic viewpoint is whether mechanisms can be built into the system to improve the efficiency of resource allocation. It is obvious that what is needed is some way of comparing the rates of return on investments in the various public agencies. The difficulty lies, of course, in measuring the various outputs in a manner which allows comparisons to be made.

Up to this point, it has been suggested that there is a pricing system which guides research decisions. As with any pricing system, non-optimal conditions may hold
due to the presence of monopolistic tendencies, externalities, and uncertainties. In publicly-organized research, monopoly powers can exist at the institutional level. A concession is made to this argument. Research, or the production of knowledge, is unlike any other form of production. The scientists themselves, forming in fact a large part of the capital involved in the production process, to a very large extent are involved in the decision-making process. Because job opportunities exist outside the organization, scientists can be expected to make decisions on criteria common to all research organizations. For this reason, and because a scientist's performance is probably more closely tied to expectations about future incomes than lower-level decision makers in other organizations, the pricing system for research is likely to be less distorted than in other organizations. For this reason it is believed that a proxy for the pricing system such as ex ante benefit/cost analysis is likely to be less important in a research organization than in other public organizations dealing with projects such as water and transport to which benefit/cost analysis has come to be fairly widely applied. This does not gainsay the fact that a very useful purpose can be served by providing economic information relevant to research decisions and by an improved understanding of the role which economic factors should play in the research allocation process. It is to these two points to which the present study is addressed.
It has been shown above that the science policy discussions which have been carried on so far, mainly by non-economists, can be translated into economic relationships. The arguments of Polanyi and Weinberg, for example, can be couched in terms of the supply and demand for research, and shifts in these functions. To say that the pricing system for research should function reasonably well amounts to saying that an individual research organization such as the C.S.I.R.O. responds to shifts in the research supply function and shifts in the research demand function. This means that it must use criteria which indicate changes in demand for its services by the various industries with which it is concerned. On the supply side it must exhibit, in an explicit or implicit manner, cognizance of changes in the expected payoff to different branches of the scientific disciplines which it employs in its researches. It is in this way that Weinberg's external and internal criteria are interpreted. In other words, on the one hand the research organization is concerned about the changing economic importance of various possible research activities; on the other hand, changes in scientific knowledge lead to changes in the expected effectiveness of different fields of science.

2.7 Summary

It is becoming increasingly obvious to those involved in research that decisions about research cannot be made in an economic vacuum. It was suggested that
within public research organizations explicit benefit/cost analysis would not be so essential to the attainment of an efficient allocation of resources as in other public bodies such as those involved in investment in transport and water facilities. Scientists, individually, are closely involved in the decisions made, and their own performance is closely tied to their expectations about future earnings. They will thus tend to use allocation criteria which are common to all research organizations. However, better decisions will be made given an improved understanding of the economic aspects of research and more accurate information about the important economic variables relating to individual research projects. While to scientists such as Weinberg it is proper that researchers should be guided in part by the possible economic impact of their work, some economists, such as Arrow, are not optimistic about the possibilities for using benefit/cost analysis in helping to make research decisions. This is because of the levels of uncertainty associated with so many aspects of the research activity and its payoff.

It was seen that the roles played by research and invention, economies of scale, learning by doing, education, and so on, in economic growth is largely unknown. Efforts to measure the economic gains from research have concentrated either on very successful projects or on aggregate research; neither of which approaches are very revealing. There has been no attempt, for instance, to examine separately the results of all projects carried
through by one organization or in one field of science. One suggestion as to why we have failed to clarify our understanding of the sources of productivity change is that the processes involved in the generation and transmission of information have not been adequately taken into account. The model on which the empirical work in this study is based does go some way towards meeting this criticism. The difficulties associated with using patents as a measure of research output were mentioned. In public agricultural research, results are not patented, but there remains the difficulty of establishing the date and origin of the information.

2.8 References


Chapter 3

ECONOMIC CRITERIA IMPLICIT IN RESEARCH DECISIONS -  
C.S.I.R.O. DIVISION OF PLANT INDUSTRY

It was argued in Chapter 2 that public research organizations can be expected to respond to changing economic conditions in those industries on whose behalf they are doing research. If this is so, it should be possible to observe from their behaviour and public statements a reaction to such changes. In this chapter an attempt is made to test these arguments by an examination of published material relating to past decisions of the Division. An attempt is also made to derive from these statements the implicit economic criteria used in the research allocation process.

However, if we are to examine the directions which agricultural research in the Division of Plant Industry has taken, it is important to understand the role or roles which research administrators and agricultural policy makers expected agricultural research to fulfil. In order to judge the desirability of certain directions in agricultural research it is also important to know how effective research will be in fulfilling certain roles. So before describing the directions of research in the
Division and the role which economic criteria have played in agricultural research decisions, a brief history of the C.S.I.R.O. and the Division of Plant Industry is sketched. Following this, a brief examination of the roles of agriculture and agricultural research in the Australian economy is undertaken. Some of the economic limitations, on the effectiveness of agricultural research under particular circumstances is discussed.

3.1 The C.S.I.R.O. and its Functions

In the history of man there has always been research in the wide sense of seeking an improved understanding of nature. In the wide sense also, there has always been the invention of new products and processes. However, the widespread organization of these activities, whether by private firms or government, is a phenomenon of the twentieth century.

According to Currie and Graham [14], the idea that research leading to the discovery of new techniques and products could be a powerful instrument in a country's development was not widely grasped or accepted, at least by England and the Commonwealth, until the beginning of World War I. The idea was brought home to some by the part which the exploitation of science had played in Germany's industrial prowess. The establishment of the Commonwealth Advisory Council of Science and Industry in 1916 (in 1920 it became the Commonwealth Institute of Science and
Industry; in 1926 the Council for Scientific and Industrial Research was formed; and in 1949 the present Commonwealth Scientific and Industrial Research Organization was established) was the manifestation of the beliefs of some academics and politicians of the time of the need for a central research organization to serve the needs of Australian primary and secondary industry. From the speeches quoted by Currie and Graham it seems that a good deal of emphasis was given by some supporters to the need for self-sufficiency in times of war, which was to be expected under the prevailing circumstances.

It has been seen that research can be consumption-oriented or investment- or growth-oriented.

The role of the C.S.I.R.O., as it was initially envisaged, was growth-oriented. According to Prime Minister W.M. Hughes, in a speech made to a meeting which led up to the formation of the Advisory Council in 1916 [14, pp.43-4]:

"We must create conditions which will attract and maintain a virile population of whom a sufficient number must settle upon the land and I know of no way of settling people on the land except to make rural industry attractive, and to this science can lend a most powerful aid. Science can make rural industries commercially profitable, making the desert bloom like a rose; it can make rural life pleasant as well as profitable. Science can develop great mineral wealth of which, after all, only the rich outcrop has yet been exploited. It can with its magic wand turn heaps of what is termed refuse into shining gold; and by utilization of by-products make that which is unprofitable to work profitably.

"Science will lead the manufacturer into green pastures by solving for him problems that seemed to him insoluble. It will open up a
thousand new avenues for capital and labour, and lastly science thus familiarized to the people will help them to clear thinking; to the rejection of shams; to healthier and better lives; to a saner and wider outlook on life".

Apart from the period of the second World War when the then C.S.I.R. carried on some defence research, the organization has been almost wholly concerned with gains in material welfare, with emphasis on the agricultural sector of the economy. Of the nine research areas suggested to the Advisory Council in 1916 as warranting its consideration, four were agricultural topics, four related mainly to the mineral processing industry, and the remaining one was of importance to manufacturing industry. A breakdown of the activities of the C.S.I.R.O. in 1968-69 in essence shows a similar weighting of research interests today, with agriculture and mineral extraction and processing being given most importance. Table 3.1 gives the numbers of research scientists and other professional staff employed in 1968-69 in various areas of interest (not by divisions).

According to the views expressed in the introduction to the 1968-69 Annual Report [13, p.8] the executive of C.S.I.R.O. recognized a need to increase the proportion of minerals processed in Australia before export. They hope to see the development of improved techniques of mineral processing which could give Australia an incentive to expand processing industries. While concerned about the derivative nature of Australian
<table>
<thead>
<tr>
<th>Areas of Interest</th>
<th>Research Scientists</th>
<th>Other Professional</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>454</td>
<td>249</td>
<td>703</td>
</tr>
<tr>
<td>Fisheries</td>
<td>21</td>
<td>20</td>
<td>41</td>
</tr>
<tr>
<td>Environment</td>
<td>99</td>
<td>69</td>
<td>168</td>
</tr>
<tr>
<td>Wildlife</td>
<td>16</td>
<td>13</td>
<td>29</td>
</tr>
<tr>
<td>Textiles (Wool Research Lab.)</td>
<td>82</td>
<td>81</td>
<td>163</td>
</tr>
<tr>
<td>Food Processing</td>
<td>73</td>
<td>65</td>
<td>138</td>
</tr>
<tr>
<td>Engineering and Construction</td>
<td>83</td>
<td>110</td>
<td>193</td>
</tr>
<tr>
<td>Chemistry and Mineralogy</td>
<td>161</td>
<td>145</td>
<td>306</td>
</tr>
<tr>
<td>Physics (incl. National Standards Lab.)</td>
<td>82</td>
<td>83</td>
<td>165</td>
</tr>
<tr>
<td>Computing &amp; Statistical Services</td>
<td>31</td>
<td>48</td>
<td>79</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>1,102</strong></td>
<td><strong>883</strong></td>
<td><strong>1,985</strong></td>
</tr>
</tbody>
</table>

manufacturing, the executive sees the organization's role in manufacturing research primarily as one of collaboration with industry as private research and development activity grows (helped along by Government assistance through the Australian Industrial Research and Development Grants Board). Stubbs [26] provides adequate proof of the high level of dependence of Australian firms on overseas research and development. The bulk of Australian private industrial research and development expenditure (estimated at $35 million in 1967) is devoted to the adaptation of overseas inventions to suit Australian conditions. This policy is reasonable, given the cost of undertaking research, if the development research is good enough to make Australian firms competitive on international markets. The worrying point is whether there are favourable Australian conditions for certain activities being neglected through the want of home-grown research.

In the early years of the organization the research effort was definitely problem-oriented, e.g., cattle tick, sheep blowfly, prickly pear, and so on; problems which were common to all States. This necessarily meant an overlapping with research being carried out by the States. In fact, according to Currie and Graham, in 1918 opposition to the Advisory Council by the State Premiers (apparently stirred up by personnel in the States Departments of Agriculture) raised real doubts about its
future. Over the years the organization has tended to concentrate more and more on basic research - a policy which recognizes that research is not necessarily problem-oriented. This change in emphasis has obviously generated less concern by the States over duplication of research.

3.2 The Division of Plant Industry, C.S.I.R.O.

The Division of Plant Industry, originally the Division of Economic Botany, was established in 1928. Its headquarters and main laboratories are located in Canberra, with other laboratories and field experiment stations in Western Australia. It also has research personnel located at a number of other research establishments. In the current financial year there has been considerable organizational change in the C.S.I.R.O. In the process the Division of Plant Industry has lost a number of sections, as follows: Tobacco Research Institute, Mareeba, Qld., and Riverina Laboratory and Falkiner Memorial Field Station Deniliquin, N.S.W., now in the Division of Land Research; Tasmanian Regional Laboratory, Hobart, now in the Division of Horticultural Research; Baas Becking Geobiological Laboratory now in the Division of Applied Mineralogy; and the Agricultural Physics Section which is now the Division of Environmental Mechanics.

In 1969-70 the Division employed 115 Research Scientists and 67 other professional staff. Expenditure totalled $4.0 million of which $2.7 million was
contributed by the Commonwealth Government and $1.3 million by outside sources - mainly primary industry research funds of which the Wool Research Trust Fund provided the bulk. (With the abovementioned organizational changes, however, the total research staff has been reduced to 155 as at December 1971.)

According to the late Dr. J.E. Falk, in a description of the functions of his Division, the overall objective of the Division is to increase the scope, productivity and efficiency of agriculture in any aspect involving plant growth. Since the growth of plants is the primary process, whether the final product sold is plant or animal, the work of the Division relates to the whole range of Australian agricultural production. It is considered that the Division is in a better position to engage in long-term projects, and especially team projects, than other organizations such as the States Departments of Agriculture. For this reason longer-term and more basic work receives considerable emphasis. A policy of active co-operation with the States Departments of Agriculture and Universities departments concerned with the rural industries is encouraged, and a large number of joint projects with States Department officers are current.

3.3 The Role of Agriculture in the Australian Economy

Because of its external market orientation and because of the factor proportions involved, Australian
agriculture has not made the same type of contribution to economic development as has agriculture in other Western countries and Japan, i.e., through the transfer of resources (both labour and capital, including capital invested in labour) from agriculture to other industries. Moreover, if agriculture maintains its external markets Australia will not experience the same relative reductions in the agricultural labour force as say the U.S. (from 50 per cent of the work force in 1870 to 8 per cent of the work force in 1960) and the U.K. (from 15 per cent of the work force in 1870 to 4 per cent of the work force in 1960). Agriculture in Australia has, however, made a considerable contribution to economic growth primarily through its export activity.

There are other economic goals besides economic growth which are pursued through economic policy (e.g., price stability, more equitable distribution of income, etc.), and there are non-economic goals which may be pursued by society which involve agriculture. A largely non-material goal to which agriculture has contributed is that of land settlement. Whether for reasons of defence, or because we feel we have some sort of international moral obligation to fulfil, land settlement as such continues to merit a positive weighting in the social objective function; but perhaps it is not so important today as in the past.

1 Figures quoted by Heady [21, Ch.I].
In the past society has been prepared to make some trade-off between economic growth and, say, settlement of Northern Australia. As the Vernon Report states [1, p.52]:

"As we have suggested, the attitude to be taken towards the development of the north cannot depend on economic aspects alone. There may be many other factors based on particular considerations, such as defence, national prestige, or the desire to provide better living conditions and greater employment opportunities for the existing population, including the native population, of the areas concerned. It is not for us as a committee to say what weights should be attached to such considerations. We urge, however, that proposals for development of northern areas should be examined in the light of all the probable costs and benefits, economic and non-economic alike."

The nature of the competing goals and the size of the trade-offs which society is prepared to make are matters of interest. For instance, in the recent debate in Victoria about the so-called "Little Desert Scheme" the Minister for Lands in his statements emphasized the importance of the scheme for land settlement and economic welfare. This scheme, in the sense of its being a marginal shift in resources, provides a means of estimating the trade-offs society is prepared to make between the goals of economic welfare, land settlement, conservation and recreation. The rejection of the scheme highlights the declining value attached to woolgrowing owing to the falling price of wool, and probably more important, the increasing value attached to recreation and conservation as population and land use expands and incomes increase.
Heady [21] has described the changes in the agricultural sector which have been experienced by countries moving to a high level of economic development. Briefly, technological advance leads to an increase in capital goods in relation to labour. As a result of this and hence the changing factor price ratio, capital goods are substituted for labour in the agricultural process. The greater efficiency of these new inputs and new resource combinations and the fact that opportunities for larger scale production are now possible leads to increases in output without a corresponding increase in the input of resources. In fact, output increases faster than population growth and in the face of price and income inelasticity of demand for foodstuffs, farm-gate prices decline. On the other hand, manufactured goods, including the processing inputs to foodstuffs, are not generally subject to such demand inelasticity. Consequently, factor prices to agriculture are raised, leading to the wide-spread cost/price squeeze in advanced agriculture. In the absence of government interference the net result is that the consumer gains through a larger supply of foodstuffs at a lower price. In the farming sector there are some who earn short-run profits because they react quickly to changes in relative prices for inputs or outputs, but on the whole the total receipts to the farming sector fall. There should be an incentive for labour resources to move out of agriculture. However, owing to an educational gap which intensifies as technological development proceeds there is immobility due
to asset fixity. There is also a problem of asset fixity with other non-human capital resources.

Donaldson [17] and Standen and Musgrave [25] have shown that Heady's thesis does not hold for all Australian agricultural industries. The external market orientation of the important industries, wool, beef, and wheat, means that these are not subject to the limitations of an inelastic demand which may apply if they relied mainly on the domestic market. Moreover, while Australian agriculture has experienced considerable technological change, the main form of capital intensification has been of a biological nature; and because the important industries have always been land-extensive, there has not been the movement of considerable manpower out of agriculture. However, while the pressures for change in Australian agriculture are not so intense as in other developed countries, they do exist, and the conflicting goals in the role of agriculture must be seen in the light of such pressures for change.

As mentioned previously, the goal of economic welfare is in fact seen as a number of competing sub-goals. For instance, a community may have to weigh a higher rate of economic growth against the cost of the greater likelihood of a recurring balance of payments problem or an increase in the likelihood of inflation. The role of agriculture may not be seen to be solely to increase the supply of foodstuffs at a lower real price. Agriculture,
in its role as a foreign exchange earner, and therefore as an indirect source of increase in real incomes and indirect source of inputs for other sectors (imported capital goods, etc.), seems to have been more important to Australia than as a direct source of higher real incomes or as a direct source of labour and capital resources for other sectors. There has been some trade-off between these two economic roles.

In the past it was probably as an export earner that agriculture was felt to be most important, judging by the way other goals were traded off in order to maintain this role. Because international trade of agricultural products is a small proportion of total world output (except for wool), prices received for exports can vary widely. If left open to such variability agricultural industries would have trouble in maintaining viability. Consequently, price support schemes have been constructed to act as a buffer against this instability; which means consumers are not able to take full advantage of the potential for higher real incomes, directly through lower food prices, and indirectly through the transfer of resources out of agriculture. It is now more than ever open to question whether the role of agriculture as an earner of foreign exchange should receive such a high weighting. At present, Australia does not have the problem with its balance of payments which plagued it previously. Moreover, mineral exports are now almost as great as, and will almost certainly soon be greater than, agricultural exports.
As stated previously, expansion of agriculture has also been seen as a means of achieving the goal of land settlement. A consequence of this is that problems of resource immobility have not been so enthusiastically attacked through government policy as might seem necessary to those advocating the maximization of economic welfare. The policy of education of the farming population has a cost of either losing population from settled areas or having to support decentralization of industry. The existing policy of agricultural price supports may be a politically attractive way of keeping these areas settled.  

Problems of adjustment raise the question of another sub-goal of economic welfare - improved income distribution. Heady [21, p.34] maintains that the goal of agricultural policy should be to guarantee "... positive-sum outcomes from farming progress over all major groups." (That is, farmers should also benefit from technological progress in farming.) But it is not realistic to abstract this problem from all of the above. For instance, problems of adjustment and income redistribution could probably be minimized by minimizing economic growth - not a very

2 Geoff Edwards (private communication) argues that the most efficient way of bringing about decentralization is likely to take the form of some sort of uniform subsidy. This argument for a uniform effective rate of assistance for decentralized activities is comparable to Corden's argument for a uniform rate of effective protection for activities protected against competition from imports by tariffs.
positive approach. Heady's overall thesis is difficult to follow. It is not clear whether he is maintaining that it is already a goal of society to compensate farmers for welfare losses which accompany economic development (i.e., all groups must benefit for it to be said that there has been a welfare gain). If this is the case then he should be concerned wholly with evaluating the effectiveness of society's policies for doing this. In fact he states over and over that society should make compensation to ensure a positive-sum outcome. But there is no evidence that society does not realize that some farmers suffer losses. The important question is - why should society make such compensation? Heady does not supply the answer. It is not generally an accepted tenet of private-enterprise economies that displaced resources should be compensated from the gains which their displacement by a more efficient resource has generated. This problem has now been raised in relation to agriculture, but it could soon become a general problem.

3.4 The Role of Agricultural Research in the Australian Economy

In this section the roles demanded of agricultural research, specifically public research, and its capacity to fulfil these various roles is examined. To

3 For a careful definition of the economic aspects see Edwards [19].
some extent in all agricultural industries, because of the increase in purchased inputs used, there has been an increase in the amount of research into new and improved processes undertaken by commercial firms such as fertilizer and seed companies. In particular industries, such as poultry and pigs, where the size of firms has increased markedly and where there is now a large degree of vertical integration, the farming enterprises themselves have the incentive to undertake research. As a result of these developments the need for public investment in agricultural research is reduced.

Agricultural research is seen by many almost as a policy tool - as a means of helping agriculture fulfil its various roles. As the roles of agriculture have changed consequent on economic and other developments, so the directions of agricultural research are expected to change. Heady [21] examines the role of agricultural research in developed countries and presents an argument for less emphasis on productivity-increasing research and more emphasis on product research. The basic premise of his argument is that in the situation where demand is inelastic the farming community does not capture enough of the gains from research. Therefore, if the product can be changed to take advantage of those characteristics of the product which are more price- and income-elastic, farmers will capture a larger proportion of the total gains from research.
As implied in the previous section, by doing this the total gains could be reduced. Heady's approach has to be seen as an attempt to use research as a tool to solve the so-called "farm problem" of developed countries by making a trade-off between maximization of national income per head and an improved (in line with Heady's value judgements) income distribution. There is no evidence that the use of agricultural research in this way would be a more efficient means of distributing an increase in income than by way of subsidies or other transfer payments. The more inelastic is demand for the product the more stress is placed upon resources to move out of the industry, for any given improvement in productivity. From society's viewpoint the "farm problem" is one of too many farmers. Society as a whole can benefit from improvements in productivity (though not always, as will be seen shortly) and product improvements. The really important question is how to optimize the allocation of research resources between these two avenues. 4

Hartley [20] recognized that agricultural research could have three economic objectives: (i) to increase national income, (ii) to stabilize incomes through stabilizing yield, and (iii) to improve income distribution. He also recognized that these goals are not always compatible. Often, research serves to aggravate income inequalities. Research findings may not apply equally to all regions

4 Some attention is given to this question in Section 4.5.
within an industry, and this will create inequalities between farming groups. If the increase in productivity results in a fall in product price, producers in those regions which did not benefit from the research will also be worse off in relation to the rest of society. Further, new practices are not as profitable for all farmers within a region. Hartley recognized that the problems of marginal producers or marginal regions would be greater the more inelastic the demand curve. He went on to question whether research which attempts to increase productivity should be carried on in those industries where demand is inelastic, because of its adverse effects on income distribution. But he saw "ample justification" for research designed to improve the lot of the marginal producer. In Section 3.4.1 below, an examination is made of the payoff to both consumers and producers under different demand elasticities from research aimed to have differential effects on the costs of production of marginal and infra-marginal units of production. This analysis shows the limitations on productivity-increasing research to effect changes in the distribution of income.

It should also be noted that it may be extremely difficult to lower costs of production in so-called marginal areas through research, particularly biological research.

Donaldson [17, pp.206-7] was concerned with the Australian situation where conflicts of interest may arise
with both society and farmers contributing to research through the industry research levy schemes. He argued that research to benefit society as a whole should be aimed primarily at increasing productivity, while "... the greatest benefit to producers will come from research which increases the price elasticity of demand for their product". In the latter category is included: "... research to aid promotion and to develop new products, greater utility of products, and alternate uses for farm produce". But, as can be shown by some simple propositions, producers or consumers may not always benefit from increases in productivity. Moreover, consumers can also benefit from new products and improvements in products. So really no simple hard-and-fast rule can be given in the terms which Donaldson has laid down.

3.4.1 Research and technical progress: the returns to producers

The general influence of technical progress on rent and profit has interested economists for a considerable time. David Ricardo [24, p.83] enunciated the fundamental influence which he summarized as follows:

"Without multiplying instances, I hope enough has been said to show that whatever diminishes the inequality in the produce obtained from successive portions of capital employed on the same or new land, tends to lower rent, and that whatever increases the inequality, necessarily produces an opposite effect, and tends to raise it."

5 This section was developed in co-operation with Dr Clem Tisdell and has been published, see [18].
He emphasizes that the differential effect rather than the absolute one is important. The models that are used below confirm this but they differ from Ricardo's and indicate circumstances in which rent and profit may rise even though the inequality in the cost of additional units of output diminishes.

Australian farmers are keenly interested in this issue since they are contributing by levy funds to support research for agricultural improvements. Most of these funds are employed by C.S.I.R.O. The Commonwealth government also contributes funds for this purpose - indeed it contributes the major portion. It would be ironic if these contributions supported research that reduced the incomes of farmers and the national welfare. The argument below indicates that under certain circumstances this is the outcome but that under other conditions the opposite is the case. These matters ought to be carefully weighed before allocating research funds.

The source and disbursement of agricultural research funds of C.S.I.R.O. for 1968-69 are set out in Table 3.2. Column 1 shows C.S.I.R.O.'s expenditure on technical agricultural research which may be expected principally to reduce the cost of the farm product, and column 2 shows its expenditure on research into the processing of agricultural products.
### Table 3.2

Source and Disbursement of C.S.I.R.O.'s Agricultural Research Funds, 1968-69

<table>
<thead>
<tr>
<th>Source of funds</th>
<th>Technical research ($m.)</th>
<th>Processing research ($m.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treasury</td>
<td>12.7</td>
<td>1.9</td>
</tr>
<tr>
<td>Contributory (mainly industry funds)</td>
<td>5.3</td>
<td>4.4</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>18.0</strong></td>
<td><strong>6.3</strong></td>
</tr>
</tbody>
</table>

It has been seen that Donaldson urged that funds provided by the government should be mainly allocated to research which leads to increased productivity and lower prices, while funds contributed by farmers should be concentrated on research leading to innovations that increase the elasticity of demand for their products. But this is debatable even if one believes "that he who benefits ought to pay". The conditions under which productivity improvements benefit producers (as well as consumers) or fail to do so are discussed below.

The industry demand curve is taken as given and is assumed not to be influenced by research. Technical progress is imagined to shift the industry's supply curve downward. The variation in the difference between the industry's total revenue and total cost is of most interest here. The difference is a surplus (a rent) which accrues to the industry. Total cost is assumed to be equal to the area under the supply curve plus a constant. Depending upon the circumstances, the situation may be interpreted as short run or long run without or with entry. Relative to the particular circumstances, production is supposed to be so organized that the cost of any level of industry output is at a minimum. A number of propositions can be shown to hold.

If as a result of technical progress an industry's marginal cost of production is reduced by equal amounts for both infra-marginal and marginal units of output
(i.e., a parallel shift of the supply curve), its surplus never diminishes and certainly increases if demand is not perfectly inelastic. A fortiori, if infra-marginal costs fall by more than costs at the margin, the industry's surplus definitely increases.

But if costs at the margin fall by more than infra-marginal costs, the surplus may fall. It falls if demand is perfectly inelastic or sufficiently inelastic. It rises if demand is perfectly elastic or sufficiently elastic.

Hence, it can be seen that the differential effect on marginal costs and the elasticity of demand for the product are important in assessing the influence of cost-reducing technical progress on an industry's profit. These propositions can be represented succinctly in a matrix. The columns of the matrix represent the nature of the elasticity of demand and the rows indicate the differential effect of technical progress on marginal cost. The signs in the body represent the variation in the industry's surplus. The question-mark indicates that the outcome will only be known given precise specification of the demand curve and the shift in costs. The relevant matrix is shown in Table 3.3.

The propositions implicit in this matrix can be clearly confirmed by means of some simple diagrams. It is of interest to note that the propositions can be confirmed
Table 3.3

Demand Elasticity/Reduction of Costs Matrix

<table>
<thead>
<tr>
<th>Reduction of costs at margin compared with infra-margin</th>
<th>Nature of demand curve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Perfectly elastic</td>
</tr>
<tr>
<td>Less</td>
<td>+</td>
</tr>
<tr>
<td>Equal</td>
<td>+</td>
</tr>
<tr>
<td>Greater</td>
<td>+</td>
</tr>
</tbody>
</table>
by taking a row at a time or by taking a column at a time. The propositions first stated above correspond to the assertions in the rows of the matrix. Below, however, three propositions corresponding to the columns are shown to hold. It is only necessary to give one approach.

Proposition 1. If the demand curve for the product is perfectly elastic, technical progress that leads to any shift downwards in the supply curve always increases the industry's surplus. This is illustrated in Figure 3.1. The shift from $S_0$ to $S_1$ or $S_2$ increases the area between the supply curve and the demand curve. The original surplus is shown by the hatched triangle (less a constant). Clearly, a movement downwards in the supply curve, which indicates the marginal cost of industry production, must increase the surplus if the constant-cost term does not increase. As a result of the downward shift, industry output is at least not decreased and variable costs of producing any output decrease. Hence, with the constant-cost term not increased, the surplus rises.

Note that the increase of the surplus is not dependent on differential effects in this case. The increase still comes about if the reduction in cost for producing the marginal unit is much greater than for the infra-marginal units.

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6 Throughout, the constant-cost term is assumed not to increase as technical progress takes place.
Figure 3.1  Changes in industry surplus with perfectly elastic demand.
Proposition 2. If the demand curve is perfectly inelastic, a shift downwards in the supply curve can lead to a fall in the industry's surplus. The result depends on differential elements.

(i) The surplus falls if the reduction in costs at the margin is greater than that on infra-marginal units of production.

(ii) The surplus is unchanged if the reduction in costs (in absolute terms) is the same for marginal and infra-marginal units.

(iii) The surplus increases if the reduction of costs on the infra-marginal units is greater than for the marginal units.

These cases are illustrated in Figure 3.2. Imagine the supply curve initially to be $S_0$. The initial surplus is indicated by the hatched area. If the supply curve falls to $S_1$, the reduction of cost at the margin is greater than infra-marginally and the surplus, as indicated by the dotted triangle, falls. The supply curves $S_2$ and $S_3$ correspond respectively to circumstances (ii) and (iii) above and it is easy to see that the propositions hold.

Proposition 3. If the demand curve is not perfectly elastic, technical progress can decrease the industry's surplus and is more likely to do so (a) the greater is the reduction in cost of producing marginal units as compared with infra-marginal ones, and (b) the more inelastic is the demand curve. The converse also holds. The industry's
Figure 3.2 Changes in industry surplus with perfectly inelastic demand.
surplus is more likely to be increased by technical progress (a) the less is the reduction in the cost of producing marginal units as compared with infra-marginal ones, and (b) the more elastic is the demand curve.

This can be seen by considering Figure 3.3. An initial equilibrium point is shown at \((X_0, P_0)\). If the demand curve is perfectly inelastic, the demand curve is \(D_0\) and the results mentioned under proposition 2 hold. If the demand curve is perfectly elastic through this point, the results stated in proposition 1 hold. If its elasticity is intermediate and the demand curve is say like \(D_1\), the surplus clearly increases if the reduction in costs of the marginal units is less than (as shown by supply curve \(S_3\)) or is equal to (as shown by supply curve \(S_2\)) that for the infra-marginal units. In both cases the inelastic demand situation can be taken as a point of reference. Note that the surplus in both cases increases as a result of moving beyond \(X_0\) if \(D_1\) is the demand curve. If the reduction in costs of the marginal units exceeds that for the infra-marginal ones, the industry's surplus may but need not decrease. This depends upon the elasticity of the demand curve and the exact differential effect. In the case shown by \(S_1\), the surplus falls; but as \(S_1\) approaches \(S_2\), the reverse position becomes more likely.

These propositions indicate that the differential effect of technical progress on costs as well as the elasticity of the demand curve are important factors in
determining whether cost-reducing research increases an industry's surplus. The marginal units of production may come from marginal land within a region or from a marginal region within an industry. Research that reduces costs more in these areas than in intra-marginal ones may very well reduce an industry's surplus.

It might be claimed that such research involves a net national benefit since consumers gain. Yet it ought to be remembered that in many cases the consumers of the products are overseas ones who make no contribution to research funds.

The more elastic is the demand curve, the less need is there to be concerned with the possibility of industry research lowering the industry's surplus if the research is aimed at lowering costs. This brings us back to the point that Donaldson mentioned. Improvements of the product that shift the demand curve upward increase the surplus as do those that increase its elasticity (rotate it anti-clockwise about the existing equilibrium point) if the supply curve is shifting downward. Product research avoids the differential problem discussed above and if it makes the demand curve more elastic renders that problem of less significance. This, of course, does not prove that producers or the world cannot gain from other types of research. Yet the fact remains that under certain circumstances producers can lose as a result of cost-reducing research.
Figure 3.3 Changes in industry surplus with differing demand elasticities.
3.5 An Historical Examination of Decision Making in the 
C.S.I.R.O. Division of Plant Industry

Lamberton [22, p.28] has claimed that the 
C.S.I.R.O. has not been seen to use any criteria in the 
selection of its research activities other than the 
subjective one of "scientific excellence". This claim is 
easily disproven. It will be shown here that, at least 
in relation to the activities of the Division of Plant 
Industry, the organization has been pursuing certain 
economic goals. A number of statements have been gleaned 
from the organization's published reports and from the 
 writings of individual scientists to illustrate this and 
to show how responses to these economic criteria have 
altered the direction of research under the influence of 
various economic and non-economic circumstances.

During the period in which the organization was 
known as the Institute of Science and Industry (1920-25) 
the research emphasis was almost wholly on the losses to 
agriculture and its dependent secondary industries caused 
by diseases, pests, and parasites.

"From plant diseases alone the loss has been 
estimated at 5,000,000 pounds annually. An 
attempt to estimate the loss from the sheep-fly 
pest gives as much as 4,000,000 pounds in a bad year . . . The loss from fruit diseases and 
pests is estimated at 1,000,000 pounds annually" 
[2, p.10].

7 His failure to appreciate the extent to which economic 
criteria have been used is most likely due to a lack of 
understanding of the roles of what Weinberg has called 
"external" and "internal" criteria in the research 
decision-making process (see Chapter 2).
An awareness of the role which research could play in increasing agricultural productivity is apparent in publications of the Institute. But the only avenue mentioned for doing so was by the alleviation of pests and diseases, see Lightfoot [23].

By the time of the formation of the C.S.I.R. in 1926, there was an awareness of the part which superphosphate fertilizer and plant breeding could play in directly increasing yields per acre. According to the 1926-27 Annual Report of the Council [3, p.19] the two main areas of research for the newly-formed Division of Economic Botany (later the Division of Plant Industry) would be:

"(i) Pastoral Problems. - Research on the improvement of pastures, comprising (a) natural pastures of low rainfall areas; and (b) pastures capable of improvement by topdressing, sowing, or other means in higher rainfall areas.

(ii) Genetics. - The breeding of plants giving higher yields and resistant to drought and disease, the production of new varieties, and the reduction of variability and undesirable characters."

Encouraged by the success of introduced plants such as subterranean clover, lucerne, and kikuyu, in the 1928-29 Annual Report [4, p.12] plans were announced "... to find, test, and introduce valuable additions for the benefit of the pastoralist and agriculturist". This marked the beginning of organized plant introduction in Australia.

However, in its first year of operations, 1928-29, the Division of Plant Industry carried out research on
Tomato wilt, Bitter-pit in apples, arid flora, poison plants, and noogoora burr - almost all disease and pest problems. In the following year, with financial assistance from the Australian Tobacco Investigation Committee, the investigation of blue mould in tobacco was undertaken. This disease is caused by a fungus which destroys the beds of seedlings. The disease was so serious in some years that almost total crop loss resulted. This disease, coupled with the unattractive aroma of the leaf being produced (associated largely with soil type), had almost caused the total collapse of the tobacco industry in Australia. A form of control was achieved through the use of benzol vapour [8, p.11].

In the 1929-30 Annual Report [5, p.16] it was stated that:

"... there can be no doubt that the grass and forage plant crop is the most important in Australia and that its importance justifies very extensive and intensive studies of the areas where most sheep and cattle are depastured, with a view to arriving at definite facts regarding the present condition of pastures and their ultimate improvement."

The report went on to say that personnel for this work were not easily obtained and therefore the work had not been

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8 The point should be made that while research has enabled the tobacco industry to survive, it has received government protection from imports since 1936. Research funds are like any other resource in that distortions of the market can lead to too much research effort being given to an industry. Such distortions may be judged appropriate on "infant industry" grounds. But as with secondary industry it would be hard to find a primary industry from which protection has been removed.
commenced. In the following year the same sentiments were repeated, but again the difficulty of obtaining trained agrostologists prevented the commencement of the work. The earlier concentration on plant diseases etc., had led to the staffing of people skilled in these fields.

In the 1932-33 Annual Report it was stated that the Division had been able to make an effective beginning in the investigation of grassland problems. Reference was made to the "selection of suitable strains of grasses" and "the adoption of modern plant breeding methods", but no mention was made of legumes and soil nutrition, the factors which surely have been most important in the history of pasture improvement in Australia. By that time there existed considerable awareness of the future possibilities of these research fields in other research establishments [15].

In 1934-35 the Annual Report [7, p.13] emphasized the importance of finding a legume for the summer-rainfall regions, similar to the legume subterranean clover ". . . which has been introduced so successfully into the winter rainfall areas of south Australia". A pasture plant breeding programme was begun at Lawes in Queensland in 1935-36. The selection of Lawes was associated with an expressed concern about pasture research in "marginal areas and summer rainfall areas" [8. p.11].
In 1936 the Wool Publicity and Research Act was passed by the Federal Parliament. The Act established the Australian Wool Board to administer the funds derived from the wool levy made under the provisions of the Wool Tax Act 1936. For the C.S.I.R. the Board approved grants for research mainly in the field of animal health. Included in this were funds for the establishment of a field research station in south-western Queensland "... to enable large-scale studies and experiments to be carried out in connection with the blowfly and other problems affecting the grazing industry" [9, p.6]. "Gilruth Plains" Station, an area of about 40,000 acres near Cunnamulla was made available by the Queensland Government at a nominal rental. The decision to take up these offers is interesting in view of the earlier rejection of an offer by the Queensland Government in 1926 of 25,000 acres of land in the Barcaldine district. The Queensland Government had suggested the land be used by the Council to carry out investigations on topics such as: sheep blow-fly; worms in sheep; natural grasses best suited for wool production; artificial feeding and its effect on wool production; and conservation of fodders, including natural grasses. After extensive investigation and discussions by the Council the offer was rejected on the grounds "... that the work which could be carried out on the area would not justify the establishment of a Research Station on the lines suggested" [3, p.47]. In view of the establishment of "Gilruth Plains" ten years later in almost the same
environment the various reasons given for the rejection are interesting. Some of these are listed below.

(a) For the adequate study of natural grasses a considerable number of small areas in different parts of Australia would be required. (In the 1937-38 Annual Report it was stated that "Gilruth Plains"... will also be a valuable centre for work on pasture grasses for the drier regions of the continent" [10, p.5].)

(b) Artificial feeding was not generally necessary in that area, which would not therefore have any special value in investigations on that problem.

(c) The investigation of the problem of fodder conservation was really an economic problem and not primarily a matter for research. (The production of hay in Mitchell grass country was one of the investigations made at "Gilruth Plains").

(d) Barcaldine area was generally free from sheep diseases and parasitological diseases and it would therefore be unwise to introduce them.

In retrospect it seems that the original decision was valid - that the pastoral zone represented by these parts of Queensland did not warrant that sort of effort from the organization in preference to other areas. In the intervening ten-year period between the two proposals there was, as shown above, a growing awareness of the importance of the grazing industry, but in particular there was an emphasis given to the more extensive grazing zone. This seems to be the only
interpretation of the phrase "the areas where most sheep and cattle are depastured" if one thinks in terms of the climatic zones which the organization used as the basis for discussions of pastures.  

While in 1932-33 the Council had stated that an effective beginning had been made in the investigation of grassland problems, the expenditure on agrostological research remained a very small proportion of the total expenditure by the Division until 1938-39 when the Australian Wool Board made a grant of $4,000 for the purpose of studies in pasture management. With continuing support from the Board and increased allocations of the Divisional budget, agrostology became and remained one of the most important items of expenditure in the years following.

As stated earlier, it is apparent from the stated terms of reference of the Division that the decision-making hierarchy realized that productivity improvements could be achieved by means other than disease and pest control. But it was not until the 1929-30 Annual Report that actual decisions about projects reflected this. For instance, at this time it was stated that as wheat was the most important cultivated crop for export purposes, and as the

9 In 1936-37 [9, p.7] the major climatic zones for the consideration of pasture plant problems was said to be five: (a) the monsoonal and (b) the winter-rainfall zones with more than 30 inches of rain per annum; (c) the monsoonal and (d) the southern zones with between 15 and 30 inches of rain; and (e) the area within the 15 inches line of rainfall.
average yields of wheat were relatively low, it was decided to concentrate efforts in genetics and plant breeding on wheat problems with the object of improving quality and yield. Of course, it was also realized that in some cases productivity increases by other means may not be possible until control over disease is obtained. As in the case of the control of "take all" disease of wheat by means of improved soil nutrition the two types of productivity increase can occur conjointly.

The economic criterion for selection of research priorities in the Division was spelt out clearly in 1932-33. The Annual Report stated [6, p.8]: "In view of the economic importance of the export apple industry [7,000,000 bushels produced, 4,500,000 bushels exported], the fruit problems which are being investigated are concerned chiefly with this crop..." With respect to the wheat industry, similar comments to those contained in the 1929-30 report (see above) were made and the report then went on [6, p.9]: "The aim is to reduce losses [from drought and disease], to increase yield and to improve quality so that the cost of production may be reduced, and the producer may be enabled to compete more efficiently in the world's markets". Figures of $1,400,000 per annum loss from root rots in wheat and $800,000 loss per annum from flag smut in wheat were quoted in justification for research programmes on these

10 This was stated explicitly in relation to blue mould of tobacco after control was achieved by means of benzol vapour [8, p.11].
problems. Estimates of the gains from a one bushel/acre increase in wheat yields ($5,400,000 increase in total revenue at 30 cents per bushel and $7,200,000 increase at 40 cents per bushel), and from a one cent per bushel increase in sale price due to better quality ($2,000,000 increase in total revenue), were quoted to justify the work on improved yield and quality. In commenting on agrostological research, the report referred to an investigation by William Davies [16] of the Welsh Plant Breeding Station, Aberystwyth, who, in stating that pasture improvement was fundamental to Australia's national development, had pointed out that about 60 per cent of the total value of Australia's exports was derived directly from grasslands.

It was not until the Annual Reports of 1947-48 and 1948-49 that further statements were made from which might be extracted the economic criteria underlying the Organization's decision making. These statements heralded an increased commitment to northern Australia. The 1948-49 Report [11, p.7] included the following statement:

"Much of the intensive agricultural development in Australia has occurred in the coastal fringe of eastern, southern, and western Australia. It is generally agreed that the major agricultural development of the future will be in northern Australia, particularly in Queensland, and C.S.I.R.O. has an important function to assist in surveying and advising on projects connected with this. It is important, not only to Australia from the economic aspect, but also as a contribution to the solution of the world's major social problem, the provision of adequate food supplies."
"World food shortage of protein, and in particular the need of the United Kingdom for meat, emphasize the vital and immediate necessity for the stimulation of the beef cattle industry the present main industry of northern Australia". (my italics)

As well as increased research on pastures for beef cattle in Queensland and the Northern Territory, this upsurge of interest in northern development was manifested in the Division's investigation of (i) irrigation possibilities in the Kimberley-Ord River region of Western Australia, (ii) irrigated tobacco, and irrigated pastures for cattle fattening in the Burdekin River region, (iii) evaluation of crop, fodder, and pasture species, and tropical fruits at Katherine, N.T., and (iv) the establishment of a regional headquarters laboratory for the Division at St. Lucia in association with the University of Queensland.

The three predictions contained in the above quoted statement have all turned out to be wrong. First, the prediction that the major part of post-war agricultural development in Australia would take place in northern Australia is not true up to the present, 25 years later. Second, a "Malthusian" mistake was made in believing that improved technology in the south would not cope with the increased demand for food and that production of necessary foostuffs would have to be carried on in the north. Third, the greatly increased demand for meat from the U.K. did not eventuate. However, 10 years later there was a big stimulus from increased imports by the U.S.; so while the demand for meat did not eventuate from the source
predicted, it did eventuate and the demand for meat has continued to improve. But for other agricultural products the prospects in the north remain dim.

While the premises of the statement quoted (immediately above) have been proved false by time, the underlying motives seem to be related to maximization of economic welfare (apart from some sort of international obligation). In the statement as it stands there are no overtones of "land settlement" or "northern development". Malthus-type doubts about being able to provide enough food for our growing population were apparently widespread in the community at the time. It is important to note that there was really no long-term forecast of prices in particular markets implied in the statement.

However, the belief that if land is there it must be used or that land of low productivity must be improved was expressed repeatedly throughout the 1950's, most specifically in relation to the sheep industry. For instance, the Annual Report of 1953-54 [12, p.46], in speaking generally about research in relation to the sheep industry, stated:

"The sheep holds a unique position in the Australian economy. Wool is our major export, and primary products from the sheep industry such as wool, lamb, mutton, and hides comprise up to 45 per cent of all Australian rural production. The sheep, too, allows of the use of vast areas of marginal land which it has not so far been practicable to use for other purposes."
The same belief, which has no economic justification, also exists in the writings of one of the leading proponents of pasture development in northern Australia, the late J.G. Davies, the first chief of the Division of Tropical Pastures.

"The major problems awaiting solution lie in our summer rainfall areas, and the growing of improved pastures in the sub-tropical and tropical regions is the only basis upon which Australia can expect to use the huge tracts of undeveloped and partially developed lands" [15, pp.63-4].

There is no doubt that at the time of his writing, and to a much lesser extent today, knowledge about pasture technology in northern Australia lagged behind that in southern Australia. But whether this lack of knowledge was important depended upon the returns on other investments such as non-recurring expenditure on clearing, fencing, and watering, and on the return to other research such as animal husbandry, as well as upon the economic prospects for the product.

3.6 The Economic Criteria Implicit in the Division's Decision Making

The economic criterion underlying the organization's decision making in its earliest years has been summed up by Hartley [20, p.163] as follows:

"About a decade ago, an argument frequently advanced to justify a particular line of agricultural research ran somewhat as follows. The value of the Australian production of a particular crop is normally, say, x hundred thousand pounds per annum. A particular
disease may be estimated to cause, on the average, a loss of \( y \) per cent of the crop. Therefore - the conclusion was rarely stated baldly but was implicit in the argument - research which succeeded in eliminating the particular disease would be worth annually \( xy \) thousand pounds to the country.

"A logical consequence of this argument was that, assuming the scientific problems involved to be of comparable complexity, research was roughly justified in proportion to the existing monetary value of the production in the particular branch of agriculture concerned. In fact, agricultural research tended to concentrate, though not exclusively, on the great export products.

"During and after the depression, when the prices of Australia's agricultural exports fell heavily, and schemes were put in hand to limit production, the above argument began to sound less convincing and was less frequently heard. A tendency developed for agricultural research workers to devote their attention more to relatively minor products, particularly those in which the country was not self-supporting and in which the fall of prices had been less severe."\(^{11}\)

In economic terms, therefore, the two parameters which were seen to be important are (a) the potential percentage decrease in unit costs of production, or the potential productivity increase, and (b) the total revenue earned by the industry. As will be shown in the next chapter the choice of these as the important parameters for comparing productivity-increasing research projects has a good economic foundation.

\(^{11}\) Hartley remarked that one member of the executive drew the conclusion that more research should be devoted to the problems of gold production as gold was the one commodity which increased in price during the depression.
As Hartley makes clear, it was understood by the decision makers of the time that it was the product of these two parameters which was important. How does one explain the concern with the low-productivity areas, i.e., the so-called marginal and summer-rainfall areas? These areas certainly comprised the largest area of land; and at the time they carried a larger number of stock than the high-winter-rainfall areas. Prior\textsuperscript{12} states that during the 1930's the C.S.I.R. suffered severe financial constraints which resulted in restrictions on its research direction from those bodies offering financial support. The emphasis in pasture investigations on the arid and northern Australian areas existed before the Wool Board was formed. However, as stated previously, there was substantial concern by the State Governments that the Council's research did not overlap with research which they were doing.

Can the Division's concern with the arid and northern areas be interpreted as a belief that because existing productivity in these areas was low, a larger increase in productivity could be expected than from areas where productivity was already high? Such an interpretation implies the same sort of reasoning underlying the arguments for agricultural development in Australia.

northern Australia. Or was the rationale as follows? The size of the region or regions is very large in relation to other regions, so for an equal or even smaller increase in productivity per acre the gains from research will be larger. In both of these interpretations the expected size of the increase in productivity per acre and the area over which the research results will apply are critical. While the predictions may have been wrong, the principle is the same as that expressed by Hartley.

Another interpretation of the Division's concern for these marginal areas, but for which there is no obvious evidence in the statements quoted, is that the organization was concerned with improving or maintaining the existing income distribution. Some statements were made about "drought prone" areas and "the drier areas where native pastures had been degraded". From this could be implied some concern about the need to stabilize or improve the incomes of farmers in these regions.

Some points should be noted in relation to the emphasis which the size of exports received in the quoted statements. If, as Hartley seems to imply, the largest industries were also the largest exporters, which was probably true in Australia's case, there is no quibble. But if the emphasis was on exports as such the following points are relevant.
First, for an industry of a given size, if its output is sold mainly on the domestic rather than mainly in foreign markets, its contribution to economic welfare is no less; perhaps even larger if domestic consumers reap some consumer surplus.

Second, there would be no concern over the size of international reserves held (except for reserves to accommodate trading and risk-bearing purposes) if international exchange rates were freely fluctuating, and therefore no concern with exporting per se.

Third, given that the balance of 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.

The historical examination above was concentrated in the earlier years of the Division. So far as the recent period of the last 15 or so years is concerned, there have been no public statements on the economic criteria underlying the choice of research projects. There has, of course, been a considerable amount of discussion following the recent very large drop in wool prices and its dramatic effect on the funds available for research through the levy.
But there has been no published analysis of the decisions made as a result of the decrease in research funds. A number of reasons may account for the hiatus in statements on economic objectives. First, since the mid-1950's there has been a steady change over to basic research. There is less pressure and perhaps less need for economic justification of basic research. Second, in the early period of its development, perhaps it could be expected that an organization would be more concerned with the rationale for its existence. Third, it may be that prior to the period of the sharp decline in wool prices research priorities had remained fairly static. However, there is another reason which could be important, that is closely tied in with the change in the Division's research programme from crops to pastures. Discussion of this is left until Chapter 5 where it can be placed in proper context.

3.7 Summary

The goal of economic welfare was seen to consist of a number of sub-goals which are competitive. Societies also have non-economic goals which are competitive with their economic goals. Government policy can be seen, therefore, as attempting to maximize an objective function consisting of those arguments which reflect society's values. Agricultural policy in Australia has pursued both economic and non-economic goals with differing degrees
of enthusiasm. Among its economic objectives, agricultural policy has probably been most concerned with maintenance of a favourable external balance and with the benefits to economic growth which accrue through imports of capital goods. It has also been closely concerned with problems of income stability and income distribution.

Agricultural research is seen by some to be a tool of agricultural policy. If research is used as a selective policy instrument, it is important that the returns to research should not be assessed solely on the effect of research on national income per head. Special attention was paid to the use of agricultural research as a means of improving or maintaining the distribution of income. The use of productivity-increasing research in this way could mean a differential impact on marginal and infra-marginal units of production. An examination was made of the changes in the returns to producers (and consumers) from such differential effects under different demand elasticities. A conclusion can be drawn that, as the demand curve becomes more inelastic, in order to maximize economic benefits the emphasis in productivity-increasing research should be placed more and more on infra-marginal units of production. This has obvious implications for the use of such research to improve the relative situation of marginal groups.

There is no doubt that, at least at times of marked change in economic conditions of the industries
for which the Division of Plant Industry has carried out research, the direction of research has been reassessed. The economic parameters which have been seen by the organization to be most important for the choice of research projects are the expected reduction in unit costs of production and the total revenue (price times quantity sold) of the industry or region concerned. If these are the important parameters, the effectiveness of research decision making is subject to the effectiveness of the predictions relating to the impact of research on production costs of the region or industry, and to the future demand for the product. It was seen that for some decisions, especially about agricultural development in northern Australia and in the drier areas of Australia, the predictions made were unsoundly based. But it was in respect of these particular decisions that it seems most likely the direction of agricultural research was reflecting social aims other than pure economic growth.

3.8 References


A number of aspects of one model which has been used to estimate the economic benefits generated by productivity-increasing research are explored in this chapter. The underlying assumptions of the model are examined as to their relevance to the real world. Also, the sensitivity of the estimates to changes in various parameters is investigated. As suggested in Chapter 3, this model seems to conform closely to the economic criterion which the C.S.I.R.O. Division of Plant Industry has used in its allocation of research resources. Some further comments are therefore made on the application of this economic criterion by the Division. The behavioural aspects of decision making in the Division are discussed briefly.

While the emphasis in the present study is upon productivity-increasing agricultural research, some discussion in this chapter is given over to the research allocation problem which arises when a choice has to be made between research into new products and research into new processes. Economic theory has not until recently been able to cope with problems involving the introduction of
new or improved goods. A new approach to consumer theory proposed by Lancaster seems likely to assist in the analysis of such problems.

4.1 The Value to Society of an Increase in Productivity

Research and invention, in so much as it is directed towards gains in material welfare, is concerned with the development of innovations, and with the discovery of new resources. Innovations fall into two classes: process innovations and product innovations. In dealing with an actual innovation the distinction may be hard to make as there may be some product change associated with a new cost-reducing process, while a new product may require the development of new technology. Agricultural research in the past has been overwhelmingly oriented towards process innovations. Pasture improvement is an example of research which leads to an improved method of production, i.e., an increase in productivity. As the Division of Plant Industry has done little in the way of new product research, and as the empirical work herein concentrates on pasture research, the concern here is with measuring the value of new processes to society.

A process innovation can be defined as an improvement in the technology of production which reduces average costs per unit of output despite the fact that input costs remain unchanged [1, p.13]. The adoption of such practices has the effect of shifting the upwards-
sloping product supply curve to the right. The total gain to society, from a downwards shift of the supply curve, assuming no externalities and perfect competition, is depicted in Figure 4.1 by the hatched area. The hatched area represents the increase in consumers and producers surplus. The value of the gain is estimated by a procedure which calculates the loss to society if the productivity increase were to disappear [5].

If the supply curve is known or assumed to be infinitely elastic, a linear approximation of the loss to society from a parallel shift from $S_1$ to $S_2$ (in Figure 4.1) is given by the formula $KP_1Q_1 (1 - \frac{1}{2} K\eta)$; where $K$ is the proportionate change in the marginal (and in this case average) cost of production; $P_1$ and $Q_1$ are the equilibrium levels of price and quantity, respectively, before the shift; and $\eta$ is the absolute value of the price elasticity of demand. When the elasticity of the supply curve is zero, the formula for calculating the gain from the productivity increase is $KP_1Q_1 (1 + \frac{1}{2} K\eta)$. Clearly the latter assumption about the supply elasticity gives the higher estimate of the value of the productivity increase.

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1 The general formula for estimating the value of an improvement in productivity is given by the formula

$$KP_1Q_1 (1 + \frac{1}{2} K\eta) - \frac{1}{2} Q_2 K^2 P_1 \left(\frac{P_1}{P_2}\right) \left(\frac{\eta}{\varepsilon + \eta}\right) \left(\frac{n-1}{n}\right)^2$$

where $\varepsilon$ is the elasticity of supply, see Peterson [13]. For a given $\eta$, the upper limit of the estimate is obtained when $\varepsilon = 0$, where the third term disappears; the lower limit is obtained when $\varepsilon = \infty$, where the third term is maximized.
Figure 4.1  Gains from an increase in productivity.
An estimate made by assuming an intermediate value of the supply elasticity will lie within the range covered by these two estimates [5, p.422]. As was demonstrated in Chapter 3, the ultimate distribution of the benefits from research between producers and consumers is determined by the slopes of the supply and demand curves, and the type of shift of the supply curve.

In brief, given estimates of the supply and demand elasticities of an industry, and an estimate of the shift of the supply curve, it is possible to calculate the benefits gained from productivity improvements. This approach has been used, for example, by Peterson [13] who calculated the return on all research investment in the poultry industry in the U.S., and by Griliches [5] to estimate the return on the successful development of hybrid corn. Of course, the extent to which the prices of the products and factors reflect the real costs and benefits to society will determine the extent to which benefits calculated in this way truly reflect social gain. This problem will be examined in a later section.

4.2 Sensitivity of Research Benefits to Changes in Economic Variables

It is of some interest to show how sensitive the returns to an improvement in productivity are to changes in the parameters of the above formulae. This is of interest, for example, because if uncertainty exists about some or all
of the variables it is important to know for which variables better information would be more critical. For illustrative purposes the formula \( (KP_1Q_1 - \frac{1}{2}K^2P_1Q_1\eta) \) will be used. The comparisons may be thought of as being within an industry over time, between regions within an industry, or between industries. The above formula assumes an elasticity of supply \((\varepsilon)\) of infinity, which gives the lowest estimate of the value of an increase in productivity. Using the formula in this form also means that the sensitivity of the estimate to different values of \(\varepsilon\) is not examined here. However, Griliches [5, p.422] has shown that the estimates are not very sensitive to variations from zero to infinity in this parameter.

Suppose initially the price of the product, say wool, is 40 cents per lb.; \(Q_1\) in one region A is 100 million lb. and in another area B it is 200 million lb.; and \(\eta\) is equal to -1. The value of a shift of the supply curve representing a one per cent reduction in unit costs of wool production for area A is $398,000, and for area B is $796,000. If the value of \(K\) is doubled the productivity increase is now worth $792,000 in area A. If now the value of \(\eta\) for area A is doubled, with \(K\) still at 2 per cent, the total gain to society is $784,000.

Suppose initially the price of wool is 30 cents per lb., with \(K\) equal to one per cent and \(\eta\) equal to -1. The value of the productivity improvement for area A is now $298,500, and for area B it is $597,000. Even if the
elasticity of demand for wool is increased to -12, a value which is an upper estimate of the long-run foreign price elasticity of demand for Australian wool [3], under these assumptions the estimate of the benefits in A would be decreased only to $282,000. Clearly, within the sorts of magnitudes that might be expected of changes in the various parameters (or the magnitude or errors in the estimates of the parameters), K and $P_1Q_1$ (what might be termed the "size" of the region or industry) are the critical parameters.

The simple comparison of a wool price of 40 cents per lb. and 30 cents per lb. gives an idea of the reduced incentive for investment in research in the wool industry following the fall in wool prices over the recent period. As the industry research levy funds are geared to a percentage of gross revenue from wool sales, the wool producer's research investment was automatically reduced in line with the fall in price.

It should be noted that if there is a size difference between the industries or regions, the research project yielding the greatest improvement in productivity does not necessarily yield the highest returns. Also, the time period over which the benefits (and costs) are realized will have an important effect on the present value of past or prospective returns. The hybrid corn study by Griliches [4] showed that over 90 per cent of adoption took place within four years in those corn-growing areas where the shift from open-pollinated corn was hypothesized to be most.
profitable. In supposedly less profitable areas the time taken to reach this same level of adoption, or a lower level, was in some cases as much as 16 years. The further into the future the benefit stream extends the greater the effect of the discounting process used to calculate the rate of return. Therefore, if the Griliches hypothesis is accepted, the less profitable a prospective new practice is the greater is the effect of discounting on its expected rate of return.

4.3 Some Qualifications to the Estimate of the Returns from Research

The method of analysis described above, as it has been used by Griliches and Peterson, assumes implicitly that the economy is in a state of Pareto optimality (which assumes no external economies or diseconomies in production or consumption, and perfect competition in all markets), and that there is no spillover of research results to other regions or industries. It also assumes away problems in the measurement of consumers surplus. It is proposed to evaluate the relevance of the formula in the real world, particularly for those industries with which the Division of Plant Industry has been most involved.

4.3.1 Externalities in consumption

Pasture improvement research by the C.S.I.R.O. has been primarily concerned with the wool and beef
industries. It is difficult to conceive of any externalities in the consumption of these agricultural products. Moreover, if there are any externalities in the consumption of wool, these can be ignored as most wool is exported.

4.3.2 Externalities in production

In the case of pasture improvement it does not seem that there are production externalities of an important magnitude. But it is important to note that there may well be substantial production externalities in the implementation of other farming practices. For some practices, in particular those to do with pest and disease control, because of the nature of the problem and of the control programme the size and dispersion of the external benefits may be such that it is rational for society to undertake the control measures or to subsidize them heavily. A case in point was the myxomatosis control programme for rabbits. In other examples, such as the area control of dingoes by "1080" poison, the external benefits to be realized would appear to be lower than for myxomatosis but they may still be sizeable enough and localized enough to make for voluntary collective action by farmers in an area. However, estimates of the external costs involved, e.g., the poisoning of

2 One possible area of external costs in the use of improved pastures and cropping is the pollution of rivers and streams from run-off containing fertilizer residues.
domestic dogs and wildlife, may be so high as to prevent such collective action.

Briefly then, in some cases of external benefits they may be internalized. In other cases society may have to act - for example, to legislate to enforce adoption, or to subsidize the activity in order that there is no under-investment. In this latter case the cost to society of such subsidies must be deducted from the benefits as estimated by the formula above.

4.3.3 Perfect competition in all markets

Agricultural firms are not of equal size and efficiency, but in relation to the size of most agricultural industries these differences can be ignored. In other words there are no important differences between firms in their ability to affect costs and prices. However, according to the theory of "second best" [12], fulfilling this condition may not be relevant so long as there are imperfections in other markets, or government intervention in agricultural markets. But as the theory stands we are not in a position to make a judgement one way or the other on "second best" grounds as to whether or not the first-order conditions for optimality are affected. If the net effect of government intervention and the other distortions in various parts of the economy is to cause too many resources to be devoted to agriculture, it would be desirable on efficiency grounds that agricultural firms possessed monopoly power; this would
reduce output. But if the net effect of imperfections is to cause too few resources to be used in agriculture (or in a particular agricultural industry) it is desirable that firms in agriculture possess no monopoly power so that this particular imperfection does not add to the misallocation resulting from the others.

In Australia, government regulatory intervention in agriculture exists in the form of subsidies, tax incentives, and various price support schemes. Outside of agriculture the main regulatory measure is the tariff. It has been argued that in those industries such as wool and beef where the effective level of protection received is relatively low (approximating 10 to 20 per cent), such protection can be justified from the point of view of efficiency in resource allocation on the grounds that it offsets the direct and indirect effects on farmers' costs from tariff protection received by secondary industry [6].³

For other primary industries the effective level of protection is much higher (e.g., Gruen estimates it is greater than 50 per cent for dairying). In these cases there must be substantial misallocation of resources. Where such misallocation occurs, any shifts in the supply function no longer truly represent the value to society of an improvement in productivity.

³ The distortion in use of real resources caused by the tariff, part of which involves direction of resources into cars etc., rather than beef and wool, would occur even if it happened that these primary industries did not use inputs produced under protection and their costs were not raised by the tariff.
Because of the proportion of Australian wool to total wool traded internationally, Australian wool has a degree of international monopoly power (i.e., less than perfectly elastic demand for the product). Edwards [3] has argued that in line with the optimum tariff argument there should be an export tax on wool so that Pareto optimality in an open economy is fulfilled, i.e., domestic rate of substitution = domestic rate of transformation = foreign rate of transformation, as under free trade there would be a misallocation of resources. Within the assumptions of his model, Edwards argues that either an export tax on wool of between 8 per cent and 26 per cent should be imposed, or the various forms of protection given to wool removed. If this argument is upheld, then while the present situation exists a degree of resource misallocation may be present and the formula for estimating the value to society from research in wool production would give an overestimate. However, as a means of ordering the importance of new practices within the wool industry it would still be efficient.

With maintained prices as in the home consumption price schemes, the government has to buy, and sell overseas (usually at a lower price) the excess supplied over that

4 His model assumes free trade, full employment, perfectly elastic foreign demand for Australian exports other than wool, perfectly elastic foreign supply for imports to Australia, and the absence of divergencies between price and marginal costs except for the divergence due to Australia's international monopoly power in wool.
which can be sold domestically at the set price. In a free market situation surpluses do not exist except in the short run; price adjusts to clear the market. As shown in Figure 4.2, from the industry's point of view there is greater incentive for productivity gains under the maintained price \( P_d \) (the whole of the shaded area) than in the free market situation (the lower part of the shaded area). In this case there is no gain in consumers surplus as a result of the productivity increase. However, the sort of situation illustrated does exert increasing pressure on the government, especially if it experiences difficulty in selling the increased output resulting from productivity improvements. The growth in the subsidy puts pressure on the government to lower the domestic price (or not to raise it as fast as other prices). In this way consumers will receive some benefit from research, and at the same time such action will serve to lower the industry's incentive for research.

4.3.4 Consumers surplus

The Marshallian concept of consumers surplus has many limitations. Hicks [8, Ch.II] showed that the use of an uncompensated demand curve for measuring consumers surplus is valid only if there are no income effects. Otherwise, only an income-compensated demand curve will provide a measure of

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5 This may be an opportune point to set straight a prevalent misconception among agricultural scientists. Research per se does not lead to surpluses - government intervention in a free market does. At any given price those new practices which are profitable will be adopted. At higher than free market prices this may mean a larger research effort is demanded than at free market prices.
Figure 4.2  Gains from research with supported prices.
consumers surplus (there are four different ways of measuring consumers surplus in the Hicksian analysis). However, the income-compensated demand curve is not known. Therefore, use of the uncompensated demand curve must involve an assumption of no income effects (own-price or cross-price); which means that it must be a partial equilibrium analysis concept. Samuelson [15, pp.195-202] further showed that within the neoclassical theory of demand, which is based on the assumption of an ordinal utility function, it is impossible to aggregate individual preference functions to get a measure of total welfare.

4.3.5 Consumers surplus in an open economy

Most of the total output of the Australian wool industry is exported (90 per cent in 1968-69). The beef industry is also a large exporter (26 per cent in 1968-69). If any increase in consumers surplus goes wholly or partly to overseas consumers the benefits to Australia of a shift in the supply curve is overstated by the above formula. This will happen if foreign demand for Australian production is less than infinitely elastic. The elasticity of overseas demand for Australia's products depends on the proportion of total world trade which Australia's exports represent [14]. In most cases the proportion is small enough for world demand to be regarded as perfectly elastic. In the case of

6 For Queensland alone the export percentage is now close to 40 per cent.
wool, however, the Australian proportion of international trade is high enough to affect the price received. The long-run price elasticity of demand by overseas consumers for Australian wool has been given values by estimation or assumption within the range -3.8 to -12.3 [3]. In the absence of empirical evidence it is usually assumed that the price elasticity of demand for Australia's exports of beef is infinite.

4.4 Further Examination of the Economic Criteria for C.S.I.R.O. Decision Making

It was shown in Chapter 3 that, for the allocation of resources between applied research projects in the Division of Plant Industry, the C.S.I.R.O. had used two economic criteria - the expected reduction in unit costs, and the total revenue of the industry or region. In the present chapter it has been shown that, for the economic analysis of the returns to research, these are the two most important parameters. However, various qualifications to the application of the analysis were described. The relevance of these qualifications to decision making in the Division will now be discussed.
4.4.1 The relevance of some qualifications to the economic criteria used by the C.S.I.R.O.

(i) externalities in production:

It has been seen that, especially in the implementation of new methods of control of diseases and pests of agriculture, there may be important production externalities. It is in the control of diseases and pests that public agricultural research has made a substantial contribution. Presumably, in estimating the expected effect on productivity of a possible new method of control the research organization implicitly assumes that the government will take the appropriate action to ensure an optimal investment in the activity. However, no overt analysis of the benefits and costs of externalities in agricultural production has been carried out in Australia.

(ii) market distortions and government intervention:

On the basis of arguments which Gruen has put forward, the production incentives offered by government to industries such as wool and beef can be ignored in decisions by a public research organization. Because of resource misallocation due to the level of effective protection afforded to industries such as dairying, the criterion used is not valid for comparisons of research projects in these industries with say the wool and beef industries. However, it still has validity for ordering
the importance of research projects within say, the dairying industry.

The majority of industries in which the Division has concentrated research over the years have been those in which there has been little or no government interference with the market, i.e., wool, lamb and mutton, beef, and apples. The other industries which have received important attention are tobacco and wheat. Tobacco has been protected since 1936 and wheat since 1948. Since the 1930's wheat has received proportionately little attention by the Division.

The ability of the Division to make decisions in terms of the maximization of social welfare is, of course, limited by the fact that industry research levies finance a significant proportion of its research, and outside committees supervise the distribution of these funds. Any distortions in research resource allocation which may ensue as a result should not be attributed to the research organization so long as it can obtain scientists for all the projects for which it has funds.

(iii) open economy effects:

Given that the foreign demand for Australian wool is less than perfectly elastic, and therefore most of any increase in consumers surplus from a shift in the supply curve goes overseas, the research criterion used by the C.S.I.R.O. overstates the benefits to Australia. Again,
this does not invalidate the use of the criterion for ordering research priorities within the wool industry. But it does mean that comparisons on this basis between research projects in say the wool and beef industries are not valid.

(iv) the dynamics of decision making:

One consideration which is introduced when examining the dynamic aspects of the above method of estimating the benefits from research has already been mentioned, i.e., the period over which adoption of the new practice takes place. Another dynamic consideration is that the product price may change due, for example, to downwards shifts of the demand curve because of competition from substitutes. Like any other decision maker the research organization does not have perfect knowledge about future events. One prescription for rational behaviour in the face of such uncertainty is to maximize expected benefits. This involves the formation of price expectations. From the quoted statements of the C.S.I.R.O. it seems that either there is no attempt to formulate such expectations or that the immediate past price is considered the best estimate of future prices. The latter interpretation is often used as a behavioural assumption in econometric studies of firms.

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7 Without going too far into this area, it would seem that as public research is partly justified on the grounds that it is underwriting private risk, risk would not play a part in deciding between courses of action as it does for the private firm.
under perfect competition. The lack of long-term expectations, and the lack of discussion of economic criteria except at times of crises in the industries with which it is involved, raises behavioural questions about the organization's decision making. This type of behaviour closely resembles the behaviour of large firms as it has been described by Cyert and March [2].

Interest in the formulation of behavioural theories of firms mainly stemmed from dissatisfaction with the assumption of profit maximization as the sole objective. The principal objection was that in the absence of competitive conditions and with the advent of absentee ownership it was no longer valid to assume that profit maximizing was the overriding objective of management in large firms. Another objection arose out of the existence of uncertainty and the effect which this had on the behaviour of firms. Simon [16] emphasized the importance of replacing maximizing by adaptive behaviour. Cyert and March [2] have constructed a model of firm behaviour which is based on Simon's adaptation assumption. The firm's behaviour in the face of uncertainty is described as follows:

"To all appearances, at least, uncertainty is a feature of organizational decision making with which organizations must live... . As a result, much of modern decision theory has been concerned with the problems of decision making under risk and uncertainty. The solutions involved have been largely procedures for finding certainty equivalents (e.g., expected value) or introducing rules for living with the uncertainties (e.g., game theory)."
"Our studies indicate quite a different strategy on the part of organizations. Organizations avoid uncertainty. . . . They avoid the requirement that they correctly anticipate events in the distant future by using decision rules emphasizing short-run reaction to short-run feedback rather than anticipation of long-run uncertain events. They solve pressing problems rather than develop long-run strategies" [2, pp.118-9].

The pattern of decision-making behaviour in the Division does seem to be very like that described by Cyert and March. It does appear to react to changes in economic conditions (and only when there are marked changes) rather than maintain a continuing brief on economic events. Two mitigating circumstances are present, however. First, research projects are usually long-term undertakings and there has to be some trade-off between flexibility in a research programme and the need to push projects through to finality. Second, long-term forecasting of prices is far from satisfactory. Hartley [7], in commenting on the changes in the direction of research in the C.S.I.R.O. as a result of the depression, remarked on the upsetting effect this had on long-term research. It should be expected that basic research, because it is justified on grounds other than the expectation of economic benefits, would be less affected by changes in economic conditions. As remarked previously, the Division's work over the years has become more basic.
4.5 Allocation of Research Resources Between Improvements in Productivity and Product Improvements

It is the primary concern in this chapter to examine one suggested method for estimating the rates of return on past or prospective research projects which lead to new or improved processes. It would not be inappropriate, however, to comment on the problem of allocating resources between new-product and productivity-increasing research.

Until recently, consumer theory has not been very helpful in dealing with the problem of the introduction of new goods. The introduction of a new good required that the preference function defined on the existing goods be replaced by a new preference function based on the new set of goods. The information on preferences on the original set of goods was discarded in the process. However, Lancaster [9, 10] has presented a new approach to consumer theory based on the idea that a good is a bundle of characteristics and that an improved product may be thought of as providing the same bundle of characteristics in a different proportion. The improved product may also have more or less characteristics than the existing product. Lancaster puts forward the hypothesis that, at least in a complex consumption technology like the U.S., the total number of characteristics is less than the number of products. He admits that some revolutionary new goods may include characteristics which are not possessed by any existing goods.
The simple treatment of the theory is the two-characteristic case. Goods possess different fixed proportions of two characteristics, A and B. It is assumed that the characteristics from different goods are additive. Suppose initially there are two goods G1 and G2, that one pound of G1 contains two units of characteristic A and one unit of characteristic B, and that one pound of G2 contains one unit of A and two units of B. A consumer has a budget of $12, and the prices of both G1 and G2 are $1 per pound. The situation is represented in Figure 4.3.

By spending all his budget on G1 the consumer can purchase 12 pounds of G1, which yields 24 units of A and 12 units of B. By spending all his budget on G2 he obtains 12 units of A and 24 units of B. Therefore, as the two goods can be utilized in combination, the consumer can attain different collections of characteristics by moving along the line G1-G2. This line is the attainable characteristics frontier for the given budget and prices. If the budget is increased the frontier would move out parallel to itself, whilst its slope would change if the relative prices of the goods changed.

Since the consumer's preferences are really between collections of characteristics the indifference curves between collections of A and B can be superimposed. The preferred collection, M, is where the indifference curve is

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8 This simple example is taken from Lancaster [11].
tangential to the characteristics frontier. Corner solutions may occur at G1 or G2.

Suppose a new good G3 is produced which has the characteristics A and B but in different proportions from G1 or G2. Whether G3 becomes relevant to the consumer's choice depends on its price. If one pound of G3 yields two units of A and two units of B and its price is $1.50 per pound, by spending the whole budget on G3 the consumer could get eight pounds of the good, yielding 16 units of A and 16 units of B. This is the point Y. It would be inefficient to consume G3 at this price, since 18 units of A and 18 units of B could be obtained by spending $6 on G1 and $6 on G2. If the price of G3 is reduced to $1.20 the consumer could obtain 20 units of A and 20 units of B — the point G3. The old frontier is now replaced by the frontier G1-G3, G3-G2 which will enable the consumer to reach a higher indifference curve, say at N.

Lancaster points out that if preferences of consumers are well distributed it can be expected that all three goods will be consumed. Moreover, if a new good is introduced and sold, at least one consumer must be at a higher indifference level, and none at a lower level, so long as all original goods are still sold at the original prices.

Both income and price effects can be analysed in the Lancaster model. If real income increases, which is represented by a parallel outwards shift of the
Figure 4.3 The characteristics frontier and consumer optimality.
characteristics frontier, an income-consumption curve can be plotted. This curve will describe the proportions in which the goods are purchased and the quantities acquired of each characteristic. If the relative prices of the goods change, the net effect can be decomposed into a substitution and an income effect in the usual way by means of compensated price change analysis.

The importance of the Lancaster theory in this discussion is that it provides for the first time a means of analysing the question of the allocation of resources between productivity-increasing research and product research. In terms of the simple model used previously, an increase in productivity in G1 can be represented as a change in relative prices (see figure 4.4), i.e., the characteristics frontier moves from a,b to c,b. The consumer will move from indifference curve I₁ to indifference curve I₂.

If instead of a cost reduction in producing G1, suppose a differentiated product G3 was produced which possessed characteristics A and B in different proportions to G1 and G2. For the consumer to be as well off as with the decrease in price of G1, the price of G3 would have to push the characteristics frontier out to a tangency point.

9 For a group of consumers the price change will reflect accurately the total increase in welfare only if demand is infinitely inelastic. If demand is not then some adjustments will have to be made to allow for changes in consumers and producers surplus.
with $I_2$. Such a point might be at $d$, with the characteristics frontier now $a,d$ and $d,b$. It will be noted that to reach $I_2$ in Figure 4.4 there could have been a trade-off between a lower price for G3 or to make G3 more like G1. In general, the terms of the trade-off between these two variables will be dictated by the elasticity of substitution between A and B. If the indifference curve $I_2$ was more elastic between $c$ and $d$ the price at which a good closer to G1 could have been sold would be higher.

The above analysis suggests a way in which the value of a cost-reducing innovation and an improvement in a product may be compared for an individual consumer. Aggregation of benefits raises, of course, the problem of adding preferences, and further, there is the fact that product price is no longer exogeneous.

In Lancaster's terms what the producer is ultimately selling is bundles of characteristics. The question arises: What is the possibility of farmers being able to offer goods embodying different proportions of the same characteristics, or including additional desirable characteristics or fewer undesirable ones? In general, it appears that many of the characteristics which are included in the end product or are contained in substitute products and which have high income elasticity, cannot be put into the product on the farm. These include such characteristics as packaging in cooked and frozen form, restaurant service, and homogenized or pasteurized properties. It may be easier
Figure 4.4 Comparing a process improvement with a product improvement.
to remove some of the undesirable characteristics. One example is the attempt to produce through the feeding of "protected" feedstuffs, a polyunsaturated milk. Another possibility may be low cholesterol eggs.

Empirical work now seems to be necessary to identify the bundles of characteristics and to examine the stability of these over time. The validity of the linearity assumptions relating to characteristics will have to be queried. With this sort of information, practical application of the theory will be much nearer.

4.6 Summary

One method of analysis for estimating the benefits accruing from a past or prospective research project was discussed. The underlying assumption was that this analysis could be used as a criterion for ordering research projects so as to maximize the economic benefits from a given level of research expenditure - that is, a prescriptive method of research decision making. It was seen that the estimate of the gains from a shift of the supply curve is most sensitive to changes in the size of the total revenue already earned by the industry or region, and to the size of the reduction in unit costs. The estimate of the gains is rather insensitive to changes in the demand and supply elasticities for the product.

The economic criterion which has been used in the Division of Plant Industry conforms to the model
discussed in its simplest, static form. It was pointed out that some qualifications should be recognized. If, as a result of protection, market distortions occur, the criterion is no longer a valid basis for comparisons of research projects relating to different industries. It should also be realized that in those industries exporting a large proportion of output some of the increase in consumers surplus resulting from research may go to overseas consumers.

The decision criterion used by the Division appears to be static in nature. It was pointed out that in this, together with other aspects of decision-making behaviour, the Division appears to avoid uncertainty by behaving in a like manner to that hypothesized for large firms.

In a digression from the analysis of the returns to productivity-increasing research it was suggested that the characteristics approach to consumer theory, recently advanced by Lancaster, provides a framework for making choices between research into new products and research into new processes. A simple theoretical approach to this so-far unresolved problem was described.

4.7 References


Chapter 5

MEASURING THE BENEFITS FROM RESEARCH:
AN ALTERNATIVE METHOD

In the previous chapter the method of estimating the returns to research in terms of the shift of the supply curve was examined in some detail. It was seen that the Division of Plant Industry has used something similar to this method as a criterion for directing applied research. In this chapter an alternative, but closely related, method for estimating the gains from improved processes is proposed. It measures the gains directly through the shift of the input-demand curve. The proposed method has a number of advantages in certain situations. One of these is that in measuring the gains from past research, information is generated about the elasticity of demand for the input. It will be shown that this is useful information for making decisions about future research related to that input. In this and later chapters, empirical work demonstrates the proposed procedure by estimating the net benefits from pasture research which the Division of Plant Industry and other agricultural organizations have undertaken.
5.1 Introduction to the Model

In the method which Griliches [13] pioneered, the critical estimate which has to be made is with respect to the percentage reduction in unit costs of production. This parameter is critical because of the sensitivity of the results to errors in its estimation, and because of the difficulty of obtaining an estimate of the parameter. In Griliches' example of research into hybrid corn, the estimate could be made fairly reliably in terms of the average increase in yield per acre. However, innovations in pasture improvement have been numerous, with the adoption of a number of different practices taking place at the same time. Moreover, improved pastures are only one of many inputs which contribute to the amount of wool or meat produced. Other inputs may also have been improving in efficiency over time. Given these confounding effects, it is not possible to calculate directly by reference to yield data the reduction in unit costs to be attributed to any given improvement in pasture technology. A way of estimating the benefits generated by improvements in an input such as improved pastures is proposed as follows.

It is assumed that changes in the demand for a factor of production is a function of changes in the price of (a) the factor, (b) other factors, and (c) the product, and of changes in the state of knowledge. Changes in the demand for a factor caused by changes in prices can be illustrated as movements along a given production function.
Changes in factor demand due to changes in the productivity of the factor, i.e., changes in the state of knowledge, relate to a movement from one production function to another. If the demand curve or marginal revenue productivity curve for an input is assumed to slope downwards to the right, an increase in the productivity of the input will shift the curve to the right, as represented in Figure 5.1 by the shift from \( ID_1 \) to \( ID_2 \). The hatched area represents the gross gain to society from an improvement in the productivity of the input. It is the value of this area which is to be estimated. Of course, all of the qualifications discussed in the previous chapter in respect to the accuracy with which the shift of the supply curve method of analysis reflected welfare effects apply in equal measure to this present method.

Some dynamic aspects of the shift from \( ID_1 \) to \( ID_2 \) should be mentioned at this stage. First, the shift from \( Q_1 \) to \( Q_2 \) may not occur instantaneously. It seems, therefore, that the long-run elasticity of input demand is the relevant one to use. Second, the improvement in technology may or may not erode over time (e.g., controls over plant and animal diseases and pests such as wheat rust and cattle tick may persist only as long as it takes for resistant strains of the organism to evolve). It is felt that this problem can reasonably be ignored in relation to improvements in pasture technology. Third, while the productivity increase may continue into the future, the marginal revenue
Figure 5.1 The gains from an increase in the productivity of an input.
productivity curve will change its position if the product price changes and this will affect the size of the hatched area for a given improvement in technology. Estimation of the discounted value of future benefits therefore involves some prediction about product price.

The higher the product price, the further will the input-demand curve lie from the origin. Therefore, for a given increase in the productivity of the input, the higher the product price the larger the gain from the improvement in technology. This is another way of illustrating what has been discussed in other contexts previously; the size of total benefits from research depends upon economic conditions within the industry. The size of the gain from a given increase in productivity is also influenced by the price elasticity of input demand. It can be seen from Figure 5.2 that for a given increase in factor demand, the less elastic the demand curve the larger the productivity increase must have been and the greater the benefits generated. It can be seen that given knowledge of the elasticity of input demand, implications can be drawn about the benefits to be gained from research in different regions or industries.

A single-equation, regression model will now be described which provides the basis for empirical analysis which will (i) estimate the long-run, own-price elasticity of demand for an input, in this case improved pastures and (ii) identify important research findings and estimate the
Figure 5.2 The gains from an increase in productivity: the effect of differences in input elasticity.
increase in demand resulting from these, i.e., the increase from $Q_1$ to $Q_2$. Later, a formula is derived which uses these pieces of information to calculate the value to society of an improvement in the productivity of the input.

5.2 The Model: The Demand for a Stock of Improved Pastures

The model is a dynamic interpretation of the neoclassical theory of demand for an input. The static theory of the competitive firm assumes that the decision maker maximizes profits within a framework of known input-output relationships and price ratios, instant adjustment, and unlimited capital. Also, the individual firm's production decisions under perfect competition have no influence on prices. The demand for any input is derived from the demand for the product, the production function, and the supply of other factors. Within such a static framework it can be shown that changes in a firm's demand for an input will depend on (i) changes in the price of the product, (ii) changes in the cost of the input and in the cost of other inputs, and (iii) changes in the productivity of the input [22, pp.187-9]. It is assumed that there is no money illusion and hence the demand function for an input is homogeneous of degree zero, i.e., a doubling of product price and of all input prices will leave the equilibrium level of inputs unchanged. This means that the demand for an input can be expressed as a function of real and
relative prices.¹

The demand for a durable input such as improved pastures is the demand for a capital stock which provides a flow of services. The purchase of durable inputs implies that the producer has a planning horizon which extends beyond a single production period. It seems likely, therefore, that he will attempt to maximize the sum of discounted future profits over this horizon rather than maximizing profits in each period. However, Jorgenson [16] shows that under certain assumptions the demand for the services of a durable input also depends on its real price and relative price. The flow of services provided by durable inputs is usually not measurable, but assuming that the flow is a constant proportion of the stock it can be hypothesized that the demand for the stock of a durable input is also a function of its real price and relative prices.

So we have,

(5.1) \[ K_t = f(P_{It}/P_{Pt}, P_{It}/P_{Jt}, R_t, u_t), \] ²

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1 Expression of the function in this form, while reducing the number of independent variables, does impose a constraint that the sum of the separate elasticities of demand (own price, cross price, and product price) should equal zero, see Cowling et al., [6].

2 The assumption of unlimited capital has been maintained for the following reason. This type of analysis assumes that farmers in an industry or region will act to maximize profits like an individual firm. However, while for an individual firm it appears necessary to assume capital limitations, for a large group of firms it seems reasonable (cont'd.)
where $K_t$ is the level of the stock of improved pastures;\(^3\)

$P_{lt}/P_{Pt}$ is the real price of the input at time $t$;\(^4\)

$P_{lt}/P_{jt}$ is the relative price of the input (land was the only other input considered); $R_t$ is a shift variable denoting improvements in the state of pasture technology; and $u_t$ is an error term assumed to be random and uncorrelated with the independent variables.

Prices, especially product prices, are uncertain in the planning period; therefore some expectational assumption has to be introduced. In this case the simplest assumption has been made - that producers will expect the immediate past prices to hold in the future. In the model the product prices used were (a) for woolgrowing areas - the Australian average greasy wool price of the previous year ended 30th June, and (b) for beef-producing areas (all

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2 (contd.)

that if a profitable investment exists it will be made. If it is not made by the farmer himself, then it will be made by means of the control of the farm passing into other hands.

3 The way in which the level of the stock of improved pastures is measured is discussed in a later section.

4 Here, it is the index of superphosphate price or total fertilizer prices (whichever is the most relevant as an index of fertilizer use in a region) over the index of product price (wool or beef). A fertilizer price index was used as a proxy for the cost of pasture improvement as fertilizer is usually an important component of establishment costs and the most important component of maintenance costs. The use of the price of the durable input instead of its implicit rental assumes that the rate of depreciation and the rate of interest remain constant over time. It was partly because of the lack of any knowledge of depreciation rates for improved pastures and of marginal interest rates paid by farmers that a better index of the cost of improved pastures was not constructed.
in Queensland) - the average beef export price of the previous year ended 30th June. The fertilizer prices used were those ruling at the beginning of the year in which the pasture improvement was made.

In order to introduce some dynamic aspects into the model the assumption of instant adjustment in the stock of improved pastures was relaxed. In the following sub-section consideration is given to the way in which producers react to changes in input and product prices and to changes in pasture technology.

5.2.1 The rate of adjustment in a stock of improved pastures

The usual reason advanced for constructing distributed lag models is the existence of factors such as (a) uncertainty about the permanence of price changes, and (b) technological and institutional restraints [24, p.771]. It was decided to lag only the real price variable to test if there was a lag in adjustment in improved pastures to changes in prices. The real price variable was chosen on the grounds that the price of the product (e.g., wool) would be subject to much greater uncertainty than either the price of fertilizer or the price of land. It was expected that if adjustment was lagged in response to price changes the best-fitting lag structure would have declining weights.
A lagged response in input demand to changes in new technology can be expected because the results of research take time to become widely known, and the level of subjective uncertainty associated with a new farming practice can be expected to fall over time. While the rate of change in the level of uncertainty associated with a given product price change is a function of time, the rate of change in the level of uncertainty associated with a change in technology is a function of the number of firms adopting the practice. Technological uncertainty (i.e., the uncertainty about the results from adopting the practice, not the uncertainty inherent in the agricultural process itself - although there may be some interaction between the two) can only be reduced through putting the new practice into use. The number of operators adopting a new practice over time and the rate at which they adopt has been assumed, following Griliches [11], to be a function of the expected profitability of the practice. When a new practice is invented its expected profitability will vary from farmer to farmer depending on farm organization, other economic circumstances, and the degree of uncertainty which the operator is prepared to accept. Those for whom expected profitability is at an acceptable level will adopt the practice. Over time, as the results obtained by these farmers become generally known, the level of uncertainty

5 Or perhaps, if the practice allows it, will first undertake a trial, see Duncan [9].
about the practice for other farmers is reduced and expected profitability rises to an extent that they will adopt. The best-fitting lag structure for estimating the adjustment of input demand to an improvement in the technology of the input was expected, therefore, to have lag coefficients which are first increasing then decreasing.

Possible changes in the state of pasture technology are identified here with the publication or announcement of seemingly significant research results. Such research results were included in the input-demand equations as separate dummy variables. A value of 1 was assigned to all years following the year in which the research finding was announced. A polynomial lag was generated on each of these variables. This provided an estimate of (a) the increase in demand for the input following the improvement in technology, and (b) the rate of adjustment to this stimulus. It is obvious that this specification can give unambiguous results only if the different research results are separate in time.

A polynomial lag structure was also generated on the real price variable. The method of estimation of these lags is briefly outlined in the sub-section following.

5.2.2 The polynomial distributed lag

The procedure for estimating polynomial distributed lags, as derived by Almon [1], allows for lags of any shape to be fitted to a number of explanatory variables in the one
estimating equation. All distributed lag equations state that a dependent variable, $K_t$, is determined by a weighted sum of past values of an independent variable, $X_t$:

$$K_t = \sum_{i=0}^{n-1} w(i)X_{t-i} + u_t,$$

where $n$ is the number of periods of the lag and the $w(i)$ are the period weights or lag coefficients. Almon's estimation procedure assumes only that the weights lie on some polynomial. Using the technique of Lagrangean interpolation it is necessary to estimate a small number, $q + 1$, of the points of the polynomial (where $q$ is the degree of the polynomial) and the remaining points, or lag coefficients, can be interpolated. The $w(i)$ at the beginning or end of the lag may be a priori specified to be zero.

The matrix of values $X_{t-i}$ is transformed by the application of a matrix of Lagrangean interpolation coefficients. A regression of $K_t$ on the transformed values of the $X_{t-i}$ yields estimated values of the correspondingly transformed lag weighting function at the specified points. The values of the original lag weights, $w(i)$, are derived as a linear combination of the transformed lag weights.

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6 The number of explanatory variables on which lags can be generated may be limited by the computer programme or by the number of degrees of freedom in the regression.
5.2.3 The model to be estimated

The input-demand model has been estimated with the variables expressed as logarithms. This is equivalent to assuming a production function of the Cobb-Douglas form. Thus the estimated coefficients on the price variables can be interpreted as geometric average elasticities of the input-demand function.

The equation to be estimated thus becomes,

\[ H = P_1 X_1 + P_2 X_2 + F + \lambda (\bar{Q} - A X_1^\alpha X_2^\beta) \]

First order conditions for minimization of \( H \) are:

1. \( \frac{\delta H}{\delta X_1} = P_1 - \lambda \bar{Q}/X_1 = 0 \)
2. \( \frac{\delta H}{\delta X_2} = P_2 - \lambda \beta \bar{Q}/X_2 = 0 \)
3. \( \frac{\delta H}{\delta \lambda} = \bar{Q} - A X_1^\alpha X_2^\beta = 0 \)

From (1) and (2),
\[ X_1 = (\alpha/\beta) (P_2/P_1) X_2 \]

and substitution in (3),
\[ X_1 = (\bar{Q}/A) (P_2/P_1)^\beta (\alpha/\beta) \]

In estimation by logarithms this becomes,
\[ \ln X_1 = \beta \ln (P_2/P_1) + \ln A^*, \text{ (where } A^* = (\bar{Q}/A) (\alpha/\beta)^\beta = \text{constant}) \]
The lags in adjustment of $K_t$ in response to technological change were approximated by a polynomial of degree 4, generally with the left hand end of the lag tied to zero. The number of periods of the lag, $n$, may be known a priori, but in general has to be estimated by fitting a number of different periods and choosing the best on some suitable criterion. Almon [1, pp.184-5] suggests two criteria for choosing the optimal length of lag - the $R^2$, and the length of the lag at which relative stability in the weights appears.

Dummy variables were also included in the estimated equations to measure the effect of less-than-average rainfall on demand for the stock of improved pastures. From rainfall data in Gibbs and Maher [10] and Maher [17] three dummy variables were constructed which recorded the three deciles of below-average rainfall for each area. An area was considered to have had yearly rainfall within a certain decile if, according to the maps in the above publications, more than half of the area received an annual rainfall within that decile.
5.3 The Data

In this section the variables used in the estimation model and their measurement are described. The limitations which arise because of the data used are also noted.

In order to evaluate the economic benefits generated by pasture research in the Division of Plant Industry, the pasture research which it has carried out since its inception has been separated on the basis of the different regions in which the work has been carried out. Not all such areas were examined in terms of the input-demand model because use of the model hinges on the fact that there has been on-farm use of pasture improvement techniques in an area over a sufficient number of years to allow the application of time-series regression to the data. For some areas in the semi-arid and arid zones pasture research has been carried out, but no pasture improvement practices, in the sense of sowing new species or fertilizing existing species, have been shown to be economically feasible. In other areas, specifically in Northern Territory and far northern Queensland, pasture improvement techniques have only been adopted in recent years.

The geographical areas chosen have been defined here in terms of the statistical divisions used by the Commonwealth Statistician. While there is no doubt that
the area of influence of the research may in many cases extend beyond these boundaries, it is hoped that the boundaries chosen capture the bulk of any benefits generated. It is not denied that research done by other organizations, in particular the States Departments of Agriculture, have influenced pasture improvement activities in most or all of these areas. In some cases the research findings which are tested were made by these organizations. But the main emphasis is given to research findings made by the C.S.I.R.O. Division of Plant Industry.

5.3.1 The stock of improved pastures \( (K_t) \)

The dependent variable is the stock of improved pastures held by all farmers in a region at the same point of time each year. A capital stock at a point of time is defined as the sum of net investment over time; where net investment is gross investment minus replacement investment. The improvement of pastures is not a homogeneous practice, even in a given environment. Types of improvement vary from superphosphate fertilizer topdressing of native pastures to ground establishment of introduced grass and/or legume mixtures dressed with various types and rates of fertilizers. An ideal index of the stock of improved pastures could be constructed only if it was possible to express all areas of improved pastures in equivalent terms. For this purpose knowledge would be required of the acreage of the different types of improved pastures, the stage of
development of each area, and the relative values of the different types of improved pastures. It would also be necessary to know the rate at which the productivity of an improved pasture falls off when fertilizer is withheld. This information is not available. Annual data series are available for the following: area of sown pastures (SP); amount of superphosphate fertilizer used on sown and native pastures (SU); amount of other artificial fertilizers used on pastures; and area of sown and native pastures fertilized with superphosphate and other fertilizers (PF).

Since the productivity of a sown pasture increases over time, the area of sown pastures (SP) recorded annually is an overestimate of the level of services which that stock provides, until full productivity is reached. However, in

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8 The productivity of improved pastures increases for some time with periodic application of fertilizers. An improved pasture does not usually depreciate over time except by exploitation. However, it can be deliberately allowed to depreciate by not applying fertilizer. A pasture can also fail altogether at any stage, for biological or climatic reasons.

9 These data are presented in the Statistical Register compiled by the office of the Commonwealth Statistician in each state. The question of consistency relating to the data series for area of sown pastures is important as the terms used vary from state to state, e.g., Queensland - "introduced grasses", W.A. - "established pastures", and N.S.W. - "sown grasses and clovers". It is doubtful whether the same interpretation is placed on each term. Moreover, all of these categories must have become increasingly ambiguous for the farmer as the modes of pasture improvement have increased. For instance, should he include aerially-sown paddocks which could be just as much thought of as "sown", "introduced", or "established" as ground-cultivated paddocks?
a region with a large population of such areas, at all levels of productivity, the total area of sown pastures probably gives a reasonable indication of changes in the services provided; although it may still suffer the defect of being biassed upwards in periods when relatively large areas of improved pastures were sown, and downwards in periods when relatively few new sowings were made. Given these limitations, however, the SP series was used as one measure of the stock of improved pastures. This essentially implies a "one-hoss shay" assumption about depreciation. What this assumption amounts to is that the pasture, once sown, receives periodic dressings of fertilizer and will last forever unless some calamity occurs. Thus, changes in the stock level take place through new sowings and deaths.

The above measure of the stock of improved pastures ignores the fact that fertilizer applications may be withheld from pastures as a means of reducing the stock level, or that larger applications may be made to existing pastures to increase the level. Given this, it is clear that the stock level fluctuates with variations in the area of pastures fertilized and the amount of fertilizer used.

10 Due to the ambiguity attached to this series it may also suffer from the defect that as the practice of topdressing natural pastures has become more widespread the series understates the total acreage improved. However, because fertilized natural pastures are not as productive as pastures established by cultivation this defect may have an inbuilt compensatory factor. That is, if only part of the area of natural pastures topdressed is included as sown pastures, by getting equal weighting in the series it may offset what is left out.
Therefore, a second approach to the measurement of the capital stock was use of the SU series. This approach is not too unreasonable taking account of the fact that apparently few improved areas in Australia have reached the point where maintenance dressings of superphosphate could be discontinued, i.e., a situation of equilibrium in soil nutrition (or if farmers act as if a nutrition equilibrium situation had not been reached). While the function estimated now becomes a demand equation for superphosphate, in effect it should reflect farmers' desires to raise or lower the equilibrium level of the stock of improved pastures. Moreover, many of the improvements in pasture technology in Australia have been intimately linked to the use of superphosphate.

The SU series was preferred to the series "area of sown and natural pastures treated with superphosphate" on the grounds that the amount of superphosphate would more accurately reflect price changes. For instance, a price rise in fertilizer might not show up in the area of pastures fertilized if the amount per acre is reduced. As against this, the latter series would probably more accurately reflect improvements in technology which utilized fertilizer more efficiently.

The SU series most probably underestimates the stock of improved pastures in the years before the value of using superphosphate, or of using it regularly, was appreciated. The series over-estimates the stock level
in more recent years by giving the same weight to fertilized natural pastures and fertilized sown pastures.

Where it seemed valid, both the SP and SU series were used as alternate measures of the stock of improved pastures in the estimation of the input-demand functions. There are regions, however, where the periodic application of superphosphate is not a critical factor in pasture improvement. In these areas the PF series was also used as the dependent variable if the application of other fertilizers was a regular practice.

To allow for changes over time in the total area of rural holdings in the statistical divisions, the SP and PF series were converted to a percentage of the total area of rural holdings in the statistical division (or part thereof). The SU series was adjusted by a correction factor which was the percentage change in the total area of rural holdings since the beginning of the series.

5.3.2 The cost of improved pastures ($P_{It}$)

The superphosphate price index (or in some cases the fertilizer price index) has been used as a proxy for an index of the cost of improved pastures on the grounds that superphosphate is an important component of establishment costs and the most important part of maintenance costs. Some problems in the way of constructing an implicit price series for improved pastures have been mentioned previously. Perhaps the most important source of error from using the fertilizer
index series is the omission of the impact on the cost of improving pastures from the introduction of aerial agriculture. It was anticipated that the real price variable would perform better in those regressions where the SU series was the dependent variable, because the fertilizer index does not take account of other costs of pasture improvement.

In Figure 5.3 some idea is given of what has happened since 1926-27 to superphosphate prices as such, and in relation to other prices. The price per hundredweight bag of superphosphate for N.S.W. is the price to the farmer with subsidies deducted. Subsidies for superphosphate have had a long history in Australia. In 1932-33, 1934-35 and 1935-36 a $1.50 per ton subsidy was paid to farmers. For the next three years it was reduced to $1.00 per ton, and then removed. From 1942-43 to 1947-48 a bounty was paid to fertilizer manufacturers to keep the price to the farmer at the 1941-42 level. For the years 1948-49 to 1950-51 the manufacturers received a bounty of $4.55 per ton ($5.00 per ton for Eyre Peninsular and $5.50 per ton for W.A.). In 1951-52 the bounty was removed. From August 1963 a superphosphate subsidy of $6.00 per ton was paid to manufacturers. This was increased to $8.00 per ton as from October 1968, and increased again to $12.00 per ton as from October 1969.

To try to show the effect of the subsidies on the price of superphosphate by comparison to what has happened
Figure 5.3  Various price indices for bagged superphosphate (N.S.W.).

- Superphosphate price
- Greasy wool price
- Price per cwt. bag (minus subsidies)
- Export beef price

Price Index

25-6 30-1 35-6 40-1 45-7 49-50 54-5 59-60 64-5 69-70
to the costs of other materials in the economy, the superphosphate price index was adjusted by the Wholesale Price Index (for Basic Materials and Foodstuffs). The comparison is with a horizontal line. Of course, the validity of the comparison assumes that apart from the subsidy all influences on superphosphate prices and the prices of all other materials have been alike. The deflated price of $5.36 in 1969, following the introduction of the $12.00 per ton bounty, is the lowest for the whole period.

However, it is the real price of the input which is important to the firm, i.e., the input price in relation to the price of the product (and in relation to other inputs). Real price series for superphosphate to both wool producers and beef producers are also presented in Figure 5.3. All series are indexed to a common year, 1949-50. The impact of high wool prices in 1951-52, and of the subsidy in 1963-64 can be seen. It is obvious that the recent increases in the subsidy have not offset the decline in wool prices. The real price of superphosphate to beef producers has continued to fall steadily.

5.3.3 The price of land ($P_{jt}$)

A relative input price variable which included land was chosen as it was felt that population and production pressures on the supply of land, as well as the legislation enforcing the breaking up of large properties and land settlement provisions for maximum home maintenance
areas, have acted in some areas through increased land prices to force substitution of pasture improvement for land. An imputed rental series was not attempted. Instead, a price series for land was arrived at by adding together the unimproved capital value of non-urban land in the shires in each statistical division and dividing this by the total area of rural holdings.

These unimproved capital valuations are not made each year, and, in N.S.W. at least, they are not made by the one body (some shires are valued by the Valuer-General, and others by private valuers). For the regions of interest to this study, shires in N.S.W. are valued most frequently, and Queensland areas probably most infrequently.

A defect of the series is that there is no weighting allowance made for the proportion of freehold and leasehold land in each shire. This was not possible as the proportions of rural holdings which are freehold and leasehold are not available for all years under consideration. The land price series constructed for the various regions are presented in Appendix III. The series are indexed to a common year, 1949-50.

5.4 Some Statistical Considerations

The nature of the relationship between the demand for fertilizer and its price was considered in view of the possibility of simultaneity in the data. If simultaneity exists, which leads to dependence between the disturbance
term and the price variables, the least squares estimators will be biased and inconsistent. In common with Griliches [12] and Metcalf and Cowling [18], it is argued here that fertilizer prices to the farmer are predetermined within short periods and that any disequilibrium is expressed in sellers' inventories. On this basis the problem of simultaneous determination was ignored.

The most serious estimation problems arose from multicollinearity (i.e., linear dependence) between the price variables, and from autocorrelation (i.e., serial dependence of the error term). Griliches [12] in his U.S. study of fertilizer demand found that he was unable to separate the effects of the real and relative price variables. The same was true in this study for most of the regions investigated. As most interest centred on the real price elasticity, the relative price variable was generally excluded from the regressions. It has to be kept in mind, therefore, that the size of the coefficient on the real price variable is in some cases overstated.

For each region a number of research findings were tested in the model. Owing to programming restrictions the number of polynomial lags which could be included in each region was four, at the most. In some cases, therefore, some research findings which were important had to be left out of the regressions while other research findings were tested. Exclusion of variables gives rise to serial correlation, and this was usually found to be the case.
However, there seemed to be no way around this problem. In the presence of serial correlation the estimated parameters are not necessarily fully efficient; a factor which must be kept in mind when interpreting the results. If the serial correlation is positive the estimates may be biased upwards, and if there is negative serial correlation the estimates may be biased downwards.

5.5 Results of Estimating the Input-Demand Model for Northern Tablelands, N.S.W.

For the purposes of demonstrating an application of the model, in this section estimation of the input-demand model for improved pastures in the Northern Tablelands Statistical Division, N.S.W. is described. Empirical analysis of the remaining areas is described in Chapter 6. Data available for the SP and SU series in the Northern Tablelands Statistical Division, for the years 1925-26 to 1968-69, are graphed in Figure 5.4. These data are not adjusted for changes in area of rural holdings. For this period the peak in sown pastures was reached in 1964-65, at which time 21 per cent of the total area of rural holdings was under sown pastures.\(^\text{11}\)

\(^{11}\) According to Walker [23], white clover was first planted on the Northern Tablelands in 1841. In fact, most of the introduced grass and legume species now in use in the area were brought in by farmers in the last century. The N.S.W. Department of Agriculture was recommending the use of 2 cwt of superphosphate per acre in 1892, at which time superphosphate was $10.00 per ton. But until 1934-35 the area of improved pastures did not rise contd....
Figure 5.4 Area of sown pastures and superphosphate use, Northern Tablelands, N.S.W.

Source: Commonwealth Bureau of Census and Statistics, Sydney, *Statistical Register of N.S.W.*
From the published results of the C.S.I.R.O.'s pasture research at Armidale, three research findings have been chosen as seemingly important additions to the state of pasture technology. These are: (i) report of significant effects of superphosphate, 1947-48; (ii) success in broadcasting clovers into natural pastures, 1951-52; and (iii) success with merino breeding on improved pastures, 1953-54.

The preferred equations for the estimation of the model for the 38-year period 1926-27 to 1940-41 and 1946-47 to 1968-69 (i.e., excluding the war years) are presented in Table 5.1. The SP and SU series were used as alternative measures of the level of the stock of improved pastures. Only with the SU series as the dependent variable is the real price variable significant. The elasticity of demand

11 (contd.)
above 10,000 acres. In 1931 the Department of Agriculture began specific studies in the Northern Tablelands environment [8]. The investigation was prompted by the problem of winter malnutrition in sheep. Experiments carried out with supplementary feeds found them to be uneconomic. In the first experiment with sown, fertilized pastures, commenced in 1940 at Glen Innes, the value of improved pastures to the maintenance of health and production of dry merino sheep was demonstrated [15]. In 1945 a follow-up experiment to investigate the effect of improved pastures on merino breeding was begun on the same pasture [5]. The experiment was continued until 1954. Results of the experiment were first reported in 1953. The C.S.I.R.O. began pasture research at Armidale in 1945-46. Their activities involved pasture management studies, evaluation of introduced legumes and grasses, and assessment of soil fertility. Research on nodulation of legumes began in 1947-48.
is -1.03 and adjustment to changes in this price variable takes only two years. Taken over all the regressions run, an elasticity of -1.03 is a reasonable average. The equation estimated explains the data very well including the downturn in superphosphate use after 1964-65. These estimates are therefore preferred to those with the SP series as the dependent variable. The superphosphate price series is obviously not a suitable price index for explaining price responses in the area of sown pastures on the Northern Tablelands. None of the coefficients estimated on the rainfall variables were significant in any equations.

The evidence suggests that information with respect to the possibility of merino breeding on improved pastures had less of an impact than earlier information relating to the effect of superphosphate on clovers. The weights on the remaining research variable were insignificant. In Figure 5.5 the adjustment lags on the research variables are graphed for the SU series. They are represented in the exponential log form in which they were estimated and also in terms of the actual increases in superphosphate use.

From Figure 5.4 it can be seen that the big upswing in pasture improvement began after 1947-48. The research which the Department of Agriculture had done during the 1940's (and insofar as results are concerned its research seems to predate the C.S.I.R.O.'s work) did
not have any effect on demand for improved pastures, at least up to 1948-49. If there was a research effect beginning in 1948-49, as suggested by the regression estimates, it can be argued it was as much due to the research which the Department carried out as to the research of the C.S.I.R.O. This is because the two organizations were doing research in different areas of the Northern Tablelands, and were thus complementary. With respect to the research into sheep breeding on improved pastures, results from the two organizations were made available at about the same time. Here again the two organizations probably played a complementary role. The demonstration that sheep breeding could be successfully carried out on improved pastures was important because breeding percentages on native pastures were very low, and most flock replacements were brought in from other regions.

As stated previously, unless innovations are clearly separate in time the results from this model cannot be regarded as definite. There were other important innovations which took effect about this time, e.g., the use of legume inoculum, and the use of aerial sowing and

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12 Legume inoculation involves the application of rhizobia to the seed just prior to sowing. The N.S.W. Department of Agriculture began work with inoculums in 1905. By 1914 the Department was issuing inoculum cultures to farmers. The C.S.I.R.O. commenced research in this field in the mid-1930's and the University of Sydney in 1939. The demand for inoculums increased so fast after 1951 that the commercial production of inoculums was transferred from the Department of Agriculture to private enterprise in 1954, see Roughley [20].
Table 5.1
Estimated Equations: Demand for a Stock of Improved Pastures
Northern Tablelands, N.S.W.

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>ln (SP)a</th>
<th>Dependent Variables</th>
<th>ln (SU)a</th>
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<td>(0.35)</td>
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<td></td>
<td>(0.03)</td>
<td></td>
<td>(0.12)</td>
</tr>
<tr>
<td>7</td>
<td>0.21</td>
<td>2.14d</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>(0.03)</td>
<td></td>
<td>(0.11)</td>
</tr>
<tr>
<td>8</td>
<td>0.24</td>
<td>1.60d</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>(0.06)</td>
<td></td>
<td>(0.19)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>R² (adjusted for degrees of freedom)</th>
<th>d (Durbin-Watson statistic)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.998</td>
<td>2.17</td>
</tr>
<tr>
<td></td>
<td>0.990</td>
<td>2.35</td>
</tr>
</tbody>
</table>

- Adjusted for changes in the total area of rural holdings.
- The figures in parentheses are the standard errors of the estimated coefficients.
- n.s. = not significant.
- Sum of lag coefficients.

Definitions:
Research Variable (1) = Reported 300 per cent increase in clover pasture yields with superphosphate, 1947–48.
Research Variable (3) = Reported success with merino breeding on improved pastures, 1953–54.
Figure 5.5  Adjustment lags in the stock of improved pastures following on research findings
Northern Tablelands, N.S.W.
topdressing of pastures. It has been suggested that the lack of a suitable nodule bacteria prevented the more rapid spread of white clover. The C.S.I.R.O. had begun research on nodulation of legumes at Armidale in 1947-48. It seems that suitable commercial rhizobium would have been available to Northern Tableland farmers early in the 1950's [2]. The earliest recorded use of aerial topdressing of pastures in N.S.W. was by a farmer on the Northern Tablelands, see Gruen and Pearse [14]. From figures compiled by Gruen and Pearse the amount of fertilizer spread by air in N.S.W. increased from 100 tons in 1949 to 25,000 tons in 1956. Also, during the period 1956 to 1958 competitive conditions in the agricultural aviation industry led to substantial reductions in the costs of spreading fertilizer by aeroplane. Neither of these influences have been included in the price variable; it must be concluded that their effects have been captured by the research variables. Therefore, not much more can be said than that there seems to have been two clear innovative effects covering the periods 1948-49 to 1953-54 and 1953-54 to 1960-61. While the two research variables account for a large part of the increase in demand for improved pastures, it must be remembered that they cover the period of high wool prices, i.e., when we would expect innovations to be most profitable. From Figure 5.2 it can be assumed that for a given increase in productivity, the higher the marginal revenue the larger the benefits to producers.
The estimated long-run elasticity of demand for superphosphate fertilizer is -1.03, i.e., for a 10 per cent fall in the real price index we can expect a 10 per cent increase in the stock of improved pastures (or superphosphate use). For the purposes of comparison an alternative specification was estimated. This was a model which Metcalf and Cowling [18] applied to nitrogen fertilizer demand in the United Kingdom,

\[
(5.4) \quad \ln K_t = b_0 + \sum_{i=0}^{n-1} w(i) \ln \left( \frac{P_t}{P_{t-1}} \right) + b_2 T + u_t.
\]

In equation (5.4), \( T \) is a variable representing time. The coefficient on this variable is a "catch-all" or "measure of ignorance" which attempts to capture all the factors which influence productivity changes. In the model presented earlier, the main purpose is to go beyond this "residual-type" approach to technical change and attempt to estimate the importance of pieces of new knowledge. Equation (5.4) differs from the Metcalf and Cowling model in that they used the Koyck-Nerlove partial adjustment formulation which includes a lagged dependent variable [24]. The fitting of the polynomial lag to the price variable gives an estimate of the lag structure directly. The coefficients estimated for this alternative model are shown in Table 5.2. The SU series is the dependent variable. Equation (1) assumes instant adjustment, and equation (2) is the result of fitting a lag to the price variable. The price variable coefficient in both equations is close to the estimate from
Table 5.1. However, the Durbin-Watson statistic indicates a high degree of autocorrelation is present. Correction for autocorrelation was carried out after estimating $r$, the coefficient in the first-order auto-regressive error scheme. Equations (3) and (4) give the corrected estimates. Equation (3) provides the most reliable results. According to this equation the value of the real price elasticity coefficient is $-0.58$.

The fact that the real price elasticity is not large suggests the conclusion that it was not primarily the high wool prices making old research results more profitable which caused the big upswing in pasture improvement. The results here suggest that it was mainly due to research findings which occurred during the period of high prices; though no doubt this research was founded on the research which had gone before.

In the next section the results from applying the model to pasture improvement on the Northern Tablelands will be used to demonstrate the method of evaluating benefits outlined in section 5.1. Only the results from regressions on the SU series will be used. The SU series may be thought of as the demand for a current input or as a measure of the stock of improved pastures. The method used to place a price on the input does not differentiate between these.
### Table 5.2

The Demand for Superphosphate Fertilizer (Alternative Model)

Northern Tablelands, N.S.W.

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
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<tr>
<td><strong>Intercept</strong></td>
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<td>0.36</td>
<td>0.13</td>
<td>0.05</td>
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<tr>
<td></td>
<td>(0.36)</td>
<td>(0.43)</td>
<td>(0.22)</td>
<td>(0.22)</td>
</tr>
<tr>
<td><strong>ln(P_I/P_P) t-1</strong></td>
<td>-1.06</td>
<td>-0.86</td>
<td>-0.58</td>
<td>-0.11 n.s.</td>
</tr>
<tr>
<td></td>
<td>(0.32)</td>
<td>(0.37)</td>
<td>(0.23)</td>
<td>(0.36)</td>
</tr>
<tr>
<td><strong>ln(P_I/P_P) t-2</strong></td>
<td></td>
<td>-0.44 n.s.</td>
<td></td>
<td>-0.51 n.s.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.31)</td>
<td></td>
<td>(0.28)</td>
</tr>
<tr>
<td><strong>T</strong></td>
<td>0.24</td>
<td>0.22</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>(0.01)</td>
<td>(0.01)</td>
<td>(0.008)</td>
<td>(0.008)</td>
</tr>
</tbody>
</table>

| R²                     | 0.94  | 0.95  | 0.64  | 0.73  |
| d                      | 0.46  | 0.49  | 1.52  | 1.27  |
| r                      | 0.79  | 0.76  |       |       |
5.6 The Value of an Increase in the Productivity of an Input

It has been argued in section 5.1 that an estimate of the benefits from research into improved pastures can be obtained by placing a value on the industry surplus which any resulting increase in productivity creates, i.e., by estimating the value to society of the hatched area in Figure 5.1. It was stated that this estimate can be obtained from information about the long-run price elasticity of demand for improved pastures, and the increase in demand which a given improvement in pasture technology generates. The net gain to society is the value of the hatched area minus research costs, and minus any losses which result from market distortions due to subsidies, etc. These latter costs are ignored here on the basis that they are small for the wool and beef industries.

In the following sub-section a formula is derived for calculation of the value of the industry surplus. The way in which the research costs have been estimated is described and the method of calculating the internal rate of return on research projects is outlined. Following this, the rate of return is calculated on the two successful research findings for the Northern Tablelands.

5.6.1 A formula

The input-demand functions have been specified and estimated in double-log form. It is assumed that the
shift of the input-demand curve from $\text{ID}_1$ to $\text{ID}_2$ in Figure 5.1 is a parallel shift in the logarithmic function, i.e., constant elasticity. This implies a non-parallel shift of the curve in its non-linear form. More strictly, the non-linear functions do not intersect, as shown in Figure 5.6. Of course, the effect of the improvement in technology may have been to change the slope of the demand schedule, as well as moving it to the right.\footnote{The elasticity of demand for the input may also change as the proportion of total costs spent on the input changes \cite[p.190]{22}.} However, estimations made from time-series regressions in logarithmic form give only constant elasticities which relate to the geometric average of the dependent variable. Therefore, a parallel shift in the logarithmic function was the only type of shift which could be assumed.

As the movement from D to C in Figure 5.6 takes place over a number of years, in this time both the product price and the input price could have changed. For the purposes of the calculation it must therefore be assumed that the shift from $\text{ID}_1$ to $\text{ID}_2$ relates to some ID curve based on an average product price for the period of the shift from D to C. Also, it has to be assumed that the input price is some average of the cost of improving pastures during the period.

Given the elasticity of input demand and the increase in improved pastures due to the shift of the
Figure 5.6 Shift in input-demand function: constant elasticity.
curve (both of which are taken from the regression results), and given the price of the input \((P)\) and the area of improved pastures before the shift of the demand curve \((OD)\), a formula can be derived by integration which will give an estimate of the value of the area ABEF. Leaving out of the input-demand equation the relative price variable, the research variables, and the weather variables, we have in general form,

\[
(5.5) \quad K_t = a + b \ln(P_t),
\]

where \(K_t\) is the level of the stock of improved pastures at time \(t\), \(P_t\) is the price of the improved pastures at time \(t\),\(^{14}\) \(a\) is the intercept, and \(b\) is the long-run price elasticity of demand.

In linear form we can obtain price as a function of output as,

\[
\frac{K_t - a}{b} = \ln(P_t)
\]

\[
\frac{K_t - a}{b} = e
\]

With \(P_t\) fixed, and given a parallel shift of the demand function in log-linear form, this is true for,

\(^{14}\) In estimating the input-demand equations the real price of the input was used. Here the product price is assumed held constant at some average value and therefore the money price of the input can be used.
\[ \frac{K_t - a_1}{b_1} \]

\[ P_t = e \]

and \[ \frac{K_t - a_0}{b_0} \]

\[ P_t = e \]

where \( a \) is intercept \( F \) and \( a_1 \) is intercept \( A \) in Figure 5.6.

Also, \( b_0 \equiv b_1 \equiv b \) as defined.

The area \( ABEF = ABCO - [FEDO + EBCD] \)

\[ = \int_{0}^{C} e^{t - a_1/b} dK_t - \int_{0}^{D} e^{t - a_0/b} dK_t - P_t (C-D) \]

as \( \int_{0}^{C} e^{t - a_1/b} dK_t \)

\[ = \int_{0}^{C} e^{t/a_1/b} dK_t \]

\[ = e^{t/a_1/b} \int_{0}^{C} e^{K_t/b} \]

\[ = e^{t/a_1/b} (\int_{0}^{1} e^{K_t/b} \big|_{0}^{C} ) \]

and \( \int_{0}^{D} e^{t - a_0/b} dK_t \)

\[ = \int_{0}^{D} e^{t/a_0/b} dK_t \]

\[ = e^{t/a_0/b} \int_{0}^{D} e^{K_t/b} \]

\[ = e^{t/a_0/b} (\int_{0}^{D} e^{K_t/b} \big|_{0}^{D} ) \]

\[ \int_{0}^{D} e^{K_t/b} \big|_{0}^{D} = e^{(D/b) - 1} \]

\[ = b e^{(e^{D/b} - 1)} \]

\[ ABEF = b e^{a_1/b} (e^{C/b} - 1) - b e^{a_0/b} (e^{D/b} - 1) - P_t (C-D) \]

\[ C - a_1/b - a_1/b - a_0/b - a_0/b \]

\[ = b (e^{a_1/b} - e^{a_0/b}) - b(e^{a_1/b} - e^{a_0/b}) - P_t (C-D) \]
Since
\[ P_t = \begin{cases} C-a_1/b & D-a_0/b \\ -a_0/b & -a_1/b \end{cases} \]
\[ ABEF = b(e^{a_0/b - e^{-a_1/b}} - P_t(C-D)) \]

But since \( a_1 \) and \( a_0 \) are not known, then by substitution
\[ -a_1/b \quad -C/b \quad -a_0/b \quad -D/b \]
using \( e^{-a_1/b} = P_t e^{-a_0/b} \), and \( e^{-a_0/b} = P_t e^{-D/b} \)

\[ ABEF = b(P_t e^{-C/b} - P_t(C-D)) \]

That is, the area ABEF can be estimated in terms of \( D, C, b \) and \( P_t \). \( D \) is given, and \( C \) and \( b \) are to be estimated.
The next problem is to establish a value for \( P_t \). It has been seen previously that improved pasture is a durable input of a somewhat special nature, in that if the pasture is maintained with fertilizer inputs it will last in perpetuity (except for losses due to drought, disease, etc.). It is assumed that for most areas the cost of improving an acre of land to full productivity and maintaining it at that level is the initial costs of seed, fertilizer and cultivation plus the annual cost of an ad infinitum application of one cwt. of superphosphate.\(^{15} \)

In order to get an annual value for the area ABEF, an acre of improved pastures is treated like a non-durable input with the \( P_t \)

\[ 15 \text{ While this certainly does not accord with superphosphate fertilizer recommendations in most areas, it is a reasonable approximation to how farmers actually behave. The area of improved pastures in Australia has increased about 16-fold in the past 30 years, but the annual average application of superphosphate has remained steady at about 1 cwt. per acre [4].} \]
being the price of superphosphate fertilizer in any year (deflated by the Wholesale Price Index for 1938-39 = 100). It is assumed that the price of superphosphate after 1967-68 is the same price as for 1968-69.

Obviously some account must be taken of the very large fall in wool prices in recent years, and the eroding effect which this has had on the benefits accruing from research; this effect is illustrated by a movement of the input-demand curve towards the origin. It was arbitrarily decided that the annual value of the benefits of an increase in productivity occurring before 1967-68 would, after that date, be reduced by one-quarter. Though the price fall since 1967-68 (at which time the Australian average greasy price for wool was 47.38 cents per lb.) has been larger than one-quarter, some allowances should be made for the fact that improved pastures have alternative uses in cattle enterprises, and for the role which improved pastures play in wheat growing.

5.6.2 Research costs

The next problem was to make some estimates of research costs. One way of estimating the research costs which have been incurred by particular research projects or groups of projects within an institutional setting (where other research is done and scientists work simultaneously on a number of projects) is to estimate the number of scientists man-years put into the project and
multiply this by an estimate of the average cost of employing a scientist. If a new project was being evaluated, the relevant cost would be the marginal cost of undertaking the project. But in the present context of assessing the returns to completed projects, the average cost of research seems appropriate.

In many of the projects evaluated the research has been carried out from regional research stations of the Division, and it would be interesting to know whether the average and marginal costs of research are higher or lower at the smaller regional centres. A further question of interest is whether there is a cost difference between applied and basic research. In the absence of such information the annual average costs for the whole Division have been calculated (see Table 5.3). The annual average costs of research in the Division of Tropical Pastures have also been calculated and these are included in Table 5.4. The Division of Tropical Pastures was formed from a section of the Division of Plant Industry which had been operating in Queensland for some time. The comparison provided with Table 5.3 may give some support for the contention that smaller regional centres have higher average costs. It can be seen that in recent years expenditure per head in the Division of Tropical Pastures has increased more rapidly than for its southern counterpart. It might have been expected that there would have been a larger disparity in its early years of autonomy.
Table 5.3

Research Expenditure per Scientist, 1935-36 to 1968-69

Division of Plant Industry (C.S.I.R.O.)

<table>
<thead>
<tr>
<th>Year</th>
<th>Expenditure ($'000)</th>
<th>Staff (No.)</th>
<th>Expenditure/ head ($)</th>
<th>Deflated Expenditure/ head ($)</th>
</tr>
</thead>
<tbody>
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<td>35-36</td>
<td>54</td>
<td>28</td>
<td>1,921</td>
<td>2,066</td>
</tr>
<tr>
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<td>29</td>
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<td>2,088</td>
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<td>36</td>
<td>1,854</td>
<td>1,854</td>
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<tr>
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<tr>
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<td>18,850</td>
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<tr>
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<td>3,773</td>
<td>181</td>
<td>20,847</td>
<td>3,933</td>
</tr>
</tbody>
</table>

a Research Scientists and Experimental Officers.

b Expenditure deflated as follows: 68 per cent deflated by an index of C.S.I.R.O. salaries for Senior Principal Research Scientists, and the remainder deflated by the Wholesale Price Index. For both indices 1938-39 = 100.
Table 5.4  
Research Expenditure per Scientist, 1960-61 to 1968-69  
Division of Tropical Pastures (C.S.I.R.O.)

<table>
<thead>
<tr>
<th>Year</th>
<th>Expenditure ($'000)</th>
<th>Staff^a (No.)</th>
<th>Expenditure/head ($)</th>
<th>Deflated Expenditure/head^b ($)</th>
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</thead>
<tbody>
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<td>350</td>
<td>24</td>
<td>14,595</td>
<td>3,235</td>
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<tr>
<td>61-62</td>
<td>419</td>
<td>28</td>
<td>14,976</td>
<td>3,400</td>
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<tr>
<td>62-63</td>
<td>538</td>
<td>33</td>
<td>16,305</td>
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<tr>
<td>63-64</td>
<td>691</td>
<td>38</td>
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<tr>
<td>64-65</td>
<td>813</td>
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<td>19,263</td>
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<td>1,178</td>
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<td>67-68</td>
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<td>54</td>
<td>24,134</td>
<td>4,574</td>
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<td>68-69</td>
<td>1,489</td>
<td>55</td>
<td>27,080</td>
<td>5,110</td>
</tr>
</tbody>
</table>

^a Research Scientists and Experimental Officers.  
^b Expenditure deflated as follows: 68 per cent deflated by an index of C.S.I.R.O. salaries for Senior Principal Research Scientists, and the remainder deflated by the Wholesale Price Index. For both indices 1938-39 = 100.
Clark [3] has warned that those capital works carried out on behalf of the C.S.I.R.O. by the Commonwealth Departments of Works and Interior are not included in the financial statements of the C.S.I.R.O., but appear only in the statements of the Departments doing the work. These additional costs have not been included here.

Annual average costs of research per head have been calculated by dividing total expenditure by the number of scientists (both research scientists and experimental officers). The effect of price changes over time has been accounted for by deflating a given proportion of expenditure representing salaries and wages by an index of C.S.I.R.O. scientists' salaries, and the remaining expenditure is deflated by the Wholesale Price Index (1938-39 = 100). The proportion of total expenditure taken to represent salaries and wages was 68 per cent. This was a figure given by the C.S.I.R.O. [7, p. 8] for 1964-65 expenditure.

5.6.3 The internal rate of return

One measure of the return on research investment is the internal rate of return - that rate of interest which equates the flow of research costs with the flow of gross benefits, at a given point in time. Research costs are subtracted from gross benefits to derive a net flow.

16 In the post-war period the index of salaries has risen almost twice as fast as the Wholesale Price Index.
for each year. The internal rate of return is calculated by an iterative procedure to choose a rate of interest which makes the discounted present value of the positive and negative yearly net flows equal to zero at a given point of time (here 1967-68). The formula representing this procedure is given as follows [19, p.663].

\[ F_0 + \frac{F_1}{(1+r)} + \frac{F_2}{(1+r)^2} + \cdots + \frac{F_n}{(1+r)^n} = 0 \]

\( F_n \) is the net flow in the evaluation year (1967-68), plus the present value of the estimated future net flows discounted at the internal rate of return;¹⁷

\( F_0 \) is the net flow of the year the research project commenced;

\( r \) is the internal rate of return - the annual return on research expenditure.

5.6.4 The return on pasture research - Northern Tablelands, N.S.W.

Using equation (5.6) above the gross benefits from the two significant research variables in Table 5.1 were calculated in the following manner. \( P_t \) was taken to be the average superphosphate price for the period of the

---

¹⁷ The formula for calculating the present value of a stream of a constant annual sum is

\[ \int_0^t C(t)e^{-rt}dt. \]
adjustment, deflated by the Wholesale Price Index (1938-39 = 100). For 1968-69 and onwards the benefits generated annually were reduced by one-quarter to allow for the fall in wool prices. As the regressions were estimated in double-log form, the value for D in equation (5.6) was, for each calculation, taken to be the geometric average of superphosphate usage for the period over which the regressions were estimated. The value for C in each year was thus the sum of lag coefficients in that year times the geometric average for superphosphate use. The annual benefits yielded by the two research variables up to 1968-69 are shown in Table 5.5. Two sets of figures are presented to demonstrate the sensitivity of the benefits yielded to the size of the price elasticity of demand for the input. The elasticity value of -1.03 is from Table 5.1, and the value of -1.30 is from Table 5.2 which presents results from the alternative model. The value of -1.30 is taken to be an upper estimate.

It has been suggested that if the two research variables do in fact measure the contribution of the two research findings tested, the credit for these findings is shared by the N.S.W. Department of Agriculture. The research cost estimates have been made on this basis. Two cost estimates have been used. The first estimate attempts to include only the costs of those projects of the C.S.I.R.O.

---

18 After taking out 11 observations for construction of the polynomial lags, the regressions were estimated over a 27-year period 1937-38 to 1968-69 (excluding 1941-42 to 1945-46).
at Armidale and the Department of Agriculture at Glen Innes which would have directly contributed to the two research findings. The second estimate represents total pasture research costs by the two organizations up to the end of the second period of adjustment, 1960-61. Pasture research by the Department of Agriculture at Glen Innes was considered to have begun in 1939-40. Of course, if the research projects begun in 1931-32 were included, the rate of return calculated would be lower. For both research organizations the annual average costs of research per scientist as shown in Table 5.3 for the Division of Plant Industry have been used.

The internal rates of return calculated on these alternative research cost streams were as follows. On the basis of an input elasticity of -1.03 and research costs which included only those projects directly connected with the research findings tested, the internal rate of return was approximately 80 per cent. If all pasture research costs of the two research stations were included, the rate of return was approximately 68 per cent. If the elasticity coefficient of -0.58 from equation (3) in Table 5.2 had been used, the rates of return would have been higher.

The respective rates of return, given an input elasticity

---

19 Costs up to the end of the adoption period were included on the basis that research after the publication of the findings would be aimed at influencing the transmission of the results. This may also be thought of as including a component of expenditure for regional extension.
Table 5.5
The Gross Benefits from Research - Northern Tablelands, N.S.W.

<table>
<thead>
<tr>
<th>Year</th>
<th>Research Variable (1)(^a)</th>
<th>Research Variable (3)(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price Elasticity (-1.03)</td>
<td>Price Elasticity (-1.30)</td>
</tr>
<tr>
<td></td>
<td>($'000)</td>
<td>($'000)</td>
</tr>
<tr>
<td>1948-49</td>
<td>379</td>
<td>201</td>
</tr>
<tr>
<td>49-50</td>
<td>708</td>
<td>374</td>
</tr>
<tr>
<td>50-51</td>
<td>1,012</td>
<td>535</td>
</tr>
<tr>
<td>51-52</td>
<td>1,416</td>
<td>749</td>
</tr>
<tr>
<td>52-53</td>
<td>1,998</td>
<td>1,056</td>
</tr>
<tr>
<td>53-54</td>
<td>2,529</td>
<td>1,337</td>
</tr>
<tr>
<td>54-55</td>
<td>2,529</td>
<td>1,337</td>
</tr>
<tr>
<td></td>
<td>223</td>
<td>128</td>
</tr>
<tr>
<td>55-56</td>
<td>2,529</td>
<td>1,337</td>
</tr>
<tr>
<td></td>
<td>472</td>
<td>270</td>
</tr>
<tr>
<td>56-57</td>
<td>2,529</td>
<td>1,337</td>
</tr>
<tr>
<td></td>
<td>658</td>
<td>377</td>
</tr>
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<td>57-58</td>
<td>2,529</td>
<td>1,337</td>
</tr>
<tr>
<td></td>
<td>769</td>
<td>441</td>
</tr>
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<td>58-59</td>
<td>2,529</td>
<td>1,337</td>
</tr>
<tr>
<td></td>
<td>844</td>
<td>483</td>
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<td>59-60</td>
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<td>1,337</td>
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<tr>
<td></td>
<td>931</td>
<td>533</td>
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<tr>
<td>60-61</td>
<td>2,529</td>
<td>1,337</td>
</tr>
<tr>
<td></td>
<td>1,067</td>
<td>611</td>
</tr>
<tr>
<td>61-62</td>
<td>2,529</td>
<td>1,337</td>
</tr>
<tr>
<td></td>
<td>1,241</td>
<td>711</td>
</tr>
<tr>
<td>62-63</td>
<td>2,529</td>
<td>1,337</td>
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<tr>
<td></td>
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<td>711</td>
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<td>63-64</td>
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<td>64-65</td>
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<td>711</td>
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<td>65-66</td>
<td>2,529</td>
<td>1,337</td>
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<tr>
<td></td>
<td>1,241</td>
<td>711</td>
</tr>
<tr>
<td>66-67</td>
<td>2,529</td>
<td>1,337</td>
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<tr>
<td></td>
<td>1,241</td>
<td>711</td>
</tr>
<tr>
<td>67-68</td>
<td>2,529</td>
<td>1,337</td>
</tr>
<tr>
<td></td>
<td>1,241</td>
<td>711</td>
</tr>
<tr>
<td>68-69</td>
<td>1,897</td>
<td>1,003</td>
</tr>
<tr>
<td></td>
<td>931</td>
<td>533</td>
</tr>
</tbody>
</table>

\(^a\) \(P = $8.00\) per ton for superphosphate fertilizer
\(^b\) \(P = $7.73\) per ton for superphosphate fertilizer

The geometric average of the SU series over the period 1937-38 to 1968-69 was 9,850 tons.
of -1.30, were approximately 65 per cent and 58 per cent. Given that the effects of other successful innovations have been captured in the research variables, it is felt that the rate of return which is relevant is that relating to all pasture research costs and this lies somewhere within the range of a lower value of 58 per cent and an upper value of 68 per cent or higher.

5.7 Summary

An alternative approach to estimating the benefits from research which increases productivity has been described. It is applicable when research directly increases the productivity of an input. The gross gain from research is measured as the industry surplus which results from the outwards shift of the marginal revenue productivity curve. A formula was derived for estimating the value of the industry surplus. The parameters in this formula are the long-run price elasticity of demand for the input, and the increase in input demand resulting from the productivity increase. An econometric model was formulated to provide estimates of the elasticity of demand for an input. In this study the model has been applied in estimating the elasticity of demand for improved pastures in different regions of Australia and for testing the effect on the demand for this input of research findings which have been made by the Division of Plant Industry and other public agricultural research organizations.
In the input-demand model, changes in the demand for improved pastures are a function of changes in real and relative prices, changes in pasture technology, and rainfall. The area of sown pastures (SP) and annual use of superphosphate fertilizer (SU) were proposed as alternative measures of the stock of improved pastures. The price index for superphosphate was proposed as a proxy for the input price. In an application of the model to data for the Northern Tablelands Statistical Division (N.S.W.) the estimated short-run and long-run real price elasticities of demand for superphosphate were -0.71 and -1.03 respectively. The adjustment period was only two years. These results were similar to those obtained from an alternative specification for the input-demand model. The relative price variable (fertilizer price/land price) was excluded from the regressions because the two price variables were highly collinear. The real price variable was not significant in explaining changes in the SP series. It was concluded that the superphosphate price index was not a good proxy for the total costs of improving pastures on the Northern Tablelands. Below-average rainfall did not have a significant effect on the demand for SP or SU.

Three research findings by the Division of Plant Industry were tested for the Northern Tablelands. Two of these were shown to be very important in explaining the increase in superphosphate use. In both cases the N.S.W. Department of Agriculture seemed to have been largely
responsible for the new information. The results cannot claim to be unambiguous, however, as there were other innovations at the time which could have had an important effect in increasing productivity and lowering costs of improving pastures. But it can be concluded that, because the elasticity of demand is not large, the increases in superphosphate use were not primarily due to the high wool prices making "old" research findings profitable. It is felt that the argument that the increase in improved pastures was primarily due to the adoption of old pasture technology in a period of high liquidity is also unacceptable. This reasoning implies that even though pasture technology was known to be profitable, capital limitations both within and without the rural sector were such as to prevent any investment taking place.

The internal rate of return was calculated for the stream of net benefits yielded by these two research variables, after deducting pasture research costs of both the Division of Plant Industry and the N.S.W. Department of Agriculture. Whether all pasture research costs incurred by both these organizations on the Northern Tablelands were included, or only that proportion thought to be specific to the two research findings, the rate of return yielded was very high. The sensitivity of the benefits yielded to changes in the value of the elasticity coefficient was also demonstrated.
5.8 References


Chapter 6

THE RETURNS FROM PASTURE RESEARCH - NORTHERN AND SOUTHERN AUSTRALIA

In this chapter it is attempted to estimate the rate of return on investment in pasture research by the Division of Plant Industry, and, in some cases, by other public agricultural research organizations. All regions in which the Division has done pasture research have been included in the study, except for those regions where the history of pasture improvement is too brief to permit time-series regression analysis. For each of the regions selected, all of the Division's research findings which it was thought could have changed the state of pasture technology were evaluated within the framework of the model described in the previous chapter. In some cases research findings made by other public research organizations have also been evaluated.

As mentioned in Chapter 3, the C.S.I.R.O. saw pasture research in Australia divided into five broad geographical areas, based on the timing and amount of rainfall. There was firstly the division into summer and winter rainfall incidence, which also served to divide the organization's activities into northern and southern
Australia respectively and, on an industry basis too, into beef and sheep respectively. These two broad categories were divided further into areas with between 15 and 30 inches of rainfall per annum and those with above 30 inches of rainfall. The fifth category was all those areas with annual rainfall below 15 inches. Within these broad zones it has been possible to select a number of distinct areas in which pasture research has been carried out by the Division for different periods and with different objectives.

Within the southern Australian or winter-rainfall zones four main areas have been selected - Southern Tablelands, Northern Tablelands, and Riverina Statistical Divisions of N.S.W., and the Western Australian wheat/sheep zone, i.e., the combined Northern, Central, and Southern Agricultural Divisions of W.A. The Riverina Division was divided into those shires in which irrigation of pastures is practised and those in which it is not. The three agricultural divisions of W.A. were examined individually, as well as collectively, to see if there were any significant differences in the adoption of new practices between divisions.

Within the northern Australian or summer-rainfall zones, five areas have been distinguished: (i) the Townsville Division, which represents the northern spear grass zone; (ii) the brigalow zone within Rockhampton Division; (iii) the remainder of the Rockhampton Division, which represents the southern spear grass zone; (iv) the
wallum zone within the Maryborough and Moreton Divisions; and (v) the remainder of the Maryborough Division, which is part of what the Division of Tropical Pastures calls the South Queensland Dairy Pastures zone. The activity of the C.S.I.R.O. in pasture research in Queensland is now the responsibility of the Division of Tropical Pastures, which was created in 1959 as a direct off-shoot of the Division of Plant Industry. However, the above Queensland areas have been selected for inclusion in this study on the basis that the research in these areas was started, and in some cases substantially carried forward, before the formation of the Division of Tropical Pastures. But, moreover, the results of pasture research in the northern beef areas provide a useful contrast to the results from pasture research in the southern, predominantly wool-growing, areas.

The results of estimating the input-demand model for improved pastures in these various areas are described below. For most areas a number of research findings have been tested in the model. The rate of return for those research results which have been found to be important is also calculated. This chapter is devoted to reporting the results obtained in each of the areas selected. In Chapter 7 there is a general discussion of the results obtained.
6.1 Southern Australia

6.1.1 Southern Tablelands, N.S.W.

Wool growing is the primary form of agricultural land use on the Southern Tablelands. Data for the SP and SU series, covering the years 1925-26 to 1968-69, are graphed in Figure 6.1. These data are not adjusted for changes in area of rural holdings. For the period shown, the peak in sown pastures was reached in 1967-68, at which time 18.5 per cent of the total area of rural holdings was under sown pastures.

Three research results were tested in the model. These findings by the Division of Plant Industry were reported at the time as being of importance for pasture technology in the Southern Tablelands. They are: (i) first reports on successful establishment and response of subterranean clover to surface cultivation and superphosphate, 1940-41; (ii) reports of success with clover nodulation problems through use of molybdenum and lime, 1947-48; and

---

1 The earliest recorded use of superphosphate on pastures in the Southern Tablelands was at Crookwell in 1917. The N.S.W. Department of Agriculture began to study improved pastures in 1919 at Crookwell. During the 1920's its research showed the importance of the use of superphosphate with subterranean clover. Research in pastures by the C.S.I.R.O. Division of Plant Industry began in 1938-39.

2 The value of molybdenum to clover growth was first recognized by Anderson [3] in South Australia in 1942.
Superphosphate used on pastures ('000 cwt.)

Figure 6.1 Area of sown pastures and superphosphate use, Southern Tablelands, N.S.W.

Source: Commonwealth Bureau of Census and Statistics, Sydney, Statistical Register of N.S.W
(iii) use of lime-pelleting of clover seed in acid soils, 1954-55 [24].

As was the case for the Northern Tablelands, the real price variable in the model was not significant in explaining changes in the SP series for the Southern Tablelands. This was likewise true for the SP series in the simple alternative model.

Thus the results reported for the Southern Tablelands are only for equations in which the dependent variable was the SU series. These are shown in Table 6.1. The model was estimated with the research variables included separately and together. Two research variables were important in explaining the changes in superphosphate use. These are the research findings relating to the use of molybdenum and lime, and lime-pelleting of clover seeds.

3 The basic idea of lime-pelleting of legume seeds was reportedly due to research in the U.S. in 1941, see Norris [27, p.A26]. As well as protecting the rhizobia in acid soils, lime-pelleting also protects the rhizobia when the seed is mixed with superphosphate for sowing.

4 For the simple model, equation (5.4), the real price variable seemed to be significant when instant adjustment was assumed, but not when a lag was imposed. The equation estimated was:

\[
\ln(\text{SP}) = -0.46 - 0.38 \ln(P_I/P_p)_{t-1} + 0.10T, R^2 = 0.89, d=0.38, (0.21) (0.19)
\]

However, following correction for positive, first-order serial correlation [21, p.194] the estimated equation was:

\[
\ln(\text{SP}) = 0.36 - 0.08 \ln(P_I/P_p)_{t-1} + 0.02T, R^2 = 0.56, d = 2.13, (0.06) (0.10) (0.004)
\]

for \( r = 0.74 \) in the regression on the least squares residuals \( \hat{u}_t = ru_{t-1} + e_t \).
The results in Table 6.1 are the estimated coefficients for those equations when these two research variables are included separately, equations (1) and (2), and when both variables are included, equation (3). On the basis of the $R^2$ and Durbin-Watson statistic, equation (3) is to be preferred. The lag in adoption of the research results is six years for both research variables in this equation.

Only in those equations where the price variable was not lagged was its coefficient significant. Which implies that landholders respond to price changes within a one-year period. The value of this coefficient in the three equations presented ranged from -0.55 to -0.94. The alternative model of equation (5.4) was also estimated, and the results were:

$$\ln(SU) = 1.46 - 0.36 \ln(P_t/P_{t-1}) + 0.028T, \quad R^2 = 0.57, \quad d = 1.49$$

$$r = 0.71,$$

after correction for positive, first-order serial correlation. The value of the price elasticity coefficient in equation (3) of Table 6.1 was accepted as being a reasonable estimate for the purposes of estimating the returns to pasture research.

On the evidence in Table 6.1 there appears to be some interdependence between the two research variables. In the absence of the other variable, the sum of lag coefficients on the included variable is much larger than when both are included in the equation. One explanation is
that the findings about lime-pelleting increased the value of the previous findings on the role of molybdenum. This conclusion seems to be borne out by reference to the results of the survey carried out by Crouch [15] in the Yass River Valley (part of the Southern Tablelands). This survey involved the usual sociological approach to the adoption of new farm practices, of recording the numbers of farmers adopting a practice over a period of time. Crouch included legume inoculation, molybdenumized superphosphate and lime-pelleting as separate recommended practices. Both legume inoculation and molybdenumized superphosphate were recommended before lime-pelleting of clover seeds. Crouch's survey data show that the adoption rate of the two earlier practices increased substantially after 1954 when lime-pelleting was recommended. This point raises the general issue of the reliance which can be placed upon the results derived in this study. If reference can be made to data such as presented by Crouch, greater confidence can be given to the results. However, it should be noted that the approach of recording which farmers adopt over time has limited usefulness for our purposes. It is also critical to know how farm investment in a practice changes over time. The obvious refinement is to test the model used here on time series data of specific aspects of pasture improvement.

5 Scientifically, the pelleting of clover seeds with lime was not important as it was previously known that 2 cwt. of lime per acre was effective in inducing nodulation. Its value was most probably in the reduction in the cost of establishing pastures which it brought about.
such as seed strains, molybdenumized superphosphate, and inoculums. Various research workers have recognized that changes in the demand for particular forms of fertilizers, plant strains, etc., do give some indication of the successfulness of research, e.g., see [34]. A further point which should be made is that, if the pay-offs to lime-pelleting and the use of molybdenumized superphosphate and inoculums were interdependent, this indicates an additional difficulty involved in forecasting the benefits from specific projects.

On the basis of equation (3) in Table 6.1, the gross benefits generated by research variable (ii) up to 1967-68 were calculated at $3.0 million. At a price elasticity of -0.36 (from the alternative model) these were $5.6 million. The gross benefits generated on research variable (iii) up to 1967-68 were $0.5 million given a price elasticity of -0.55, and $0.94 million, given a price elasticity of -0.36. Both of these findings were made by workers in the field of plant nutrition in the Division of Plant Industry at Canberra. Based on estimated research costs of two scientists per year from 1943-44 (when plant nutrition studies began at Canberra) up to 1961-62, the end of the lag on research variable (iii), the internal rate of return on the stream of benefits from these two findings was as follows: 53 per cent when the price elasticity was -0.55; and 67 per cent when the price elasticity was -0.36. This represents a possible range for
Table 6.1

Estimated Equations: Demand for a Stock of Improved Pastures
Southern Tablelands, N.S.W.

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Dependent Variable – ln(SU)(^a)</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>5.23 (0.15)</td>
<td>5.63 (0.13)</td>
<td>5.19 (0.13)</td>
<td></td>
</tr>
<tr>
<td>ln(Pi/Pp)(_t-1)</td>
<td>-0.60 (0.20)</td>
<td>-0.94 (0.24)</td>
<td>-0.55 (0.17)</td>
<td></td>
</tr>
<tr>
<td>Research Variable (ii)(_t-i)</td>
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<td>-0.05 n.s. (0.09)</td>
<td>-0.05 n.s. (0.09)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.03 n.s. (0.09)</td>
<td>0.04 n.s. (0.08)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.16 (0.05)</td>
<td>0.18 (0.05)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.27 (0.05)</td>
<td>0.29 (0.06)</td>
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<tr>
<td></td>
<td>5</td>
<td>0.32 (0.07)</td>
<td>0.33 (0.07)</td>
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</tr>
<tr>
<td></td>
<td>6</td>
<td>0.31 (0.07)</td>
<td>0.27 1.08(^b) (0.06)</td>
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<tr>
<td></td>
<td>7</td>
<td>0.23 (0.06)</td>
<td>0.12 n.s. (0.13)</td>
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<tr>
<td></td>
<td>8</td>
<td>0.14 1.42(^b) (0.08)</td>
<td>-0.09 n.s. (0.25)</td>
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<td></td>
<td>9</td>
<td>0.06 n.s. (0.09)</td>
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<td></td>
</tr>
<tr>
<td>Research Variable (iii)(_t-i)</td>
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<td>0.34 n.s. (0.33)</td>
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<td>0.47 n.s. (0.42)</td>
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<td></td>
<td>3</td>
<td>0.25 1.38(^b) (0.10)</td>
<td>0.47 n.s. (0.36)</td>
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<td>4</td>
<td>-0.004 n.s. (0.16)</td>
<td>0.39 n.s. (0.24)</td>
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<td></td>
<td>5</td>
<td>0.28 (0.13)</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.18 0.46(^b) (0.07)</td>
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</tr>
<tr>
<td></td>
<td>7</td>
<td>0.10 n.s. (0.06)</td>
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</tbody>
</table>

\(\bar{R}^2\) 0.94 0.82 0.968
\(d\) 1.30 0.76 1.74

\(^a\) Superphosphate use adjusted by total area of rural holdings.
\(^b\) Sum of significant lag coefficients.

Definitions:
the rate of return on the research costs directly involved in these projects. As was done for the Northern Tablelands, it was assumed that these two research variables captured most of the contribution by pasture research in this area. A conservative estimate of the pasture research costs incurred by the Division and the N.S.W. Department of Agriculture was 4 scientists per year from 1937-38 to 1961-62. Given price elasticities of -0.55 or -0.36, the internal rates of return calculated on this total cost stream were 22 per cent and 27 per cent respectively.

6.1.2 Riverina, N.S.W. (Irrigation)

Those shires which contain the irrigated pasture areas of the Riverina Division have been aggregated for this study. This was done with a view to seeing whether the improved pastures in these shires have been influenced by the irrigated pasture research which has been carried out at the Division of Plant Industry's Falkiner Memorial Field Station at Deniliquen and at the N.S.W. Department of Agriculture's research stations in the Riverina. The ten shires which have been included are: Berrigan, Conargo, Carrathool, Jerilderie, Leeton, Murray, Murrumbidgee, Wade, Wakool and Windouran. The SP and SU series for the period 1931-32 to 1968-69 are graphed in Figure 6.2. In 1965-66 the peak in the area of sown pastures was reached, at which time 7.2 per cent of the total area of rural holdings was improved. With respect to this percentage, it should be
noted that these shires include all the western and thus drier areas of the division. Much of the acreage under improved pastures in this area is on farms carrying on both cropping (rice and wheat) and grazing, usually in rotation.

Research relating to the performance under irrigation of summer and winter growing pasture mixtures was begun by the C.S.I.R.O. in 1940-41 at Griffith. In 1944-45 the Division of Plant Industry's research station at Deniliquin was established. The irrigated pasture research programme has included studies in plant introduction, soil nutrition, pasture management, and water use relations. However, only one research result from this programme seemed to warrant testing in the model. This was the recommendation for the addition of gypsum to irrigation water to improve pasture establishment on heavy sodic clay soils (announced in 1957-58).

The myxomatosis virus for the control of rabbits was first released in Australia in the Riverina in 1950-51. It was decided to include a dummy variable to measure the effect of this innovation on the demand for improved pastures. One further research finding was considered: the use of pasture leys to control skeleton weed in wheat.  

---

6 In 1936 skeleton weed in N.S.W. was described as "...the most insidious and drastic menace wheat farmers have ever had to contend with" [22]. In fact, a reward of $10,000 was offered for a "...practical method of eradicating skeleton weed" [1]. The recommendation for use of a pasture phase in wheat rotations came from observations on sown pastures ...cont'd.
Figure 6.2  Area of sown pastures and superphosphate use, Riverina N.S.W. (Irrigation).

Source: Commonwealth Bureau of Census and Statistics, Sydney, *Statistical Register of N.S.W.*
However, this recommendation was made in 1935-36, and the manner in which the regression programme constructed the polynomial lags precluded fitting a lag at this early point in the data series. An examination of the SP and SU data series in Figure 6.2 indicates that, at least in the Riverina Division, the recommendation to include a pasture phase in the cropping programme could have had little impact on the demand for improved pastures.

The preferred equations estimated for the 33-year period 1931-32 to 1940-41 and 1946-47 to 1968-69 are presented in Table 6.2. The real price variable is significant in explaining changes in both the SP and SU series. For the SP series there is a two-year lag on the price variable.

In both equations the research variable relating to the release of the myxomatosis virus is important in explaining changes in the data series. However, the total effect of this research variable is less for the SU series. Referring back to Figure 6.2, it can be seen that the performance of the two series have been quite different. During the first half of the 1950's the rate of increase in superphosphate use was much slower. The $R^2$ on the

6 (cont'd.)

at the Department of Agriculture's Wagga Experiment Farm. The N.S.W. government allocated $200,000 for advances to farmers to assist with reorganization of farms diversifying into grazing on improved pastures.
superphosphate demand equation is three points lower than it is for the equation estimated on the SP series, which suggests that some research findings have been omitted which could be important. A comparison of the actual and predicted values of the regression gave no hint as to the time at which an excluded variable could have been important. Because some of the improved pastures in these shires may not be in irrigated areas, it was decided to see if any of the Division's pasture research in low-rainfall areas had been effective in this area. The only seemingly important result, which was reported in 1961-62, was a recommendation for the use of heavy inoculation methods in sowing legumes into semi-arid pastures. This variable was tested in the model but found to be insignificant.

The research variable included to test the impact of the recommendation for gypsum use was not significant in either equation. This negative result is of some interest. It supports the tentative conclusions reached by research workers in the Riverina that this research finding has had only a small impact on pasture establishment on heavy soils [20].

Pasture research by the Division of Plant Industry in the dryland, wheat/sheep areas of N.S.W. has been rather limited and sporadic. A plant breeding programme began in 1936-37 and continued until 1946-47. This work was done in Canberra and was primarily concerned with improvement of the native grass Danthonia. A legume selection programme began in 1942-43, but lapsed soon afterwards, until it was recommenced in 1949-50. The emphasis in this latter project has been on selection within the medic species for a legume which is adapted to those drier areas of the wheat belt unsuited to subterranean clover.
Gross benefits have been calculated for the research variable which represented the release of the myxomatosis virus. The estimated equation on the SP series was used for this purpose. From an examination of Figure 6.2 it is apparent that on the average an application of about one-half cwt. of superphosphate per acre per annum has been the practice for most of the period. Using this figure as an estimate of the annual costs of pasture improvement, the gross benefits amounted to $170,000 per annum from 1956-57 onwards (a total of $2.5 million for the period 1951-52 to 1967-68). The costs of pasture improvement could be higher than assumed, as periodic renovation of irrigated pastures is practised. However, this underestimate may be balanced by the possibility that the estimated price elasticity on the SP series could be too low. This is due to the fact, mentioned previously, that the SP series does not reflect fluctuations in the stock level caused by farmers withholding fertilizer or applying additional fertilizer. Two other points should be mentioned. First, in the case of myxomatosis it is apparent that there can be (and has been?) a deterioration in this form of pest control. Second, the calculation of the benefits from increases in the productivity of improved pastures has assumed that the pastures are permanent. In this area pastures are used in rotation with crops. It is not clear whether this results in an over-estimation or under-estimation of the value of the productivity increase.
### Table 6.2

**Estimated Equations: Demand for a Stock of Improved Pastures - Riverina, N.S.W. (Irrigation)**

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>ln(SP)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>ln(SU)&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intercept</strong></td>
<td>0.49 (0.24)</td>
<td>11.10 (0.44)</td>
</tr>
<tr>
<td>ln(P&lt;sub&gt;i&lt;/sub&gt;/P&lt;sub&gt;P&lt;/sub&gt;)&lt;sub&gt;_t-i&lt;/sub&gt; i=0</td>
<td>-0.50 (0.13)</td>
<td>-0.90 (0.24)</td>
</tr>
<tr>
<td>1</td>
<td>-0.17 (0.08)</td>
<td>-0.23 n.s.</td>
</tr>
<tr>
<td>2</td>
<td>0.02 n.s.</td>
<td>0.18 n.s.</td>
</tr>
<tr>
<td>RV&lt;sub&gt;_t-i&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>i=1</td>
<td>0.29 (0.15)</td>
<td>0.47 (0.28)</td>
</tr>
<tr>
<td>2</td>
<td>0.33 (0.11)</td>
<td>0.50 (0.21)</td>
</tr>
<tr>
<td>3</td>
<td>0.27 (0.07)</td>
<td>0.34 1.31&lt;sup&gt;b&lt;/sup&gt; (0.12)</td>
</tr>
<tr>
<td>4</td>
<td>0.20 (0.08)</td>
<td>0.16 n.s.</td>
</tr>
<tr>
<td>5</td>
<td>0.18 (0.07)</td>
<td>0.06 n.s.</td>
</tr>
<tr>
<td>6</td>
<td>0.17 1.43&lt;sup&gt;b&lt;/sup&gt; (0.09)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.12 n.s.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>-0.12 n.s.</td>
<td></td>
</tr>
</tbody>
</table>

|<sup>a</sup> Adjusted for changes in total area of rural holdings. |
|<sup>b</sup> Sum of significant lag coefficients. |
|<sup>c</sup> Research Variable = release of myxomatosis virus in 1950-51. |
6.1.3 Riverina, N.S.W. (Dryland)

The shires for which the two series presented in Figure 6.3 have been aggregated are those shires in the Riverina Statistical Division not included in the previous sub-section. These are, Coolamon, Corowa, Culcairn, Lockhart, Narrandera, and Urana. This group of shires was included in this study to provide a comparison with the results of the input-demand functions estimated for irrigated pastures. The two areas are more or less situated in different vegetative regions. In the irrigated areas of the shires aggregated in the previous sub-section, the vegetation is predominantly semi-arid shrub woodlands [26, Map 3]. The remaining part of these shires is predominantly shrub steppe. The six shires aggregated in this present section are situated in the eastern part of the Riverina Division, where the predominant vegetative cover is temperate, sub-humid woodlands. This is the same vegetative cover which predominates in the adjacent South Western Slopes Division. In this respect, the research which is carried out by the Department of Agriculture at Wagga would be most pertinent to the so-called dryland area examined here. In turn, the price-elasticity coefficients derived here can probably be extrapolated to the South Western Slopes Division, one of the most important wheat/sheep areas in N.S.W.

In Figure 6.3 the two dependent variable series are graphed for the years 1931-32 to 1968-69. The peak of
sown pastures was reached in 1965-66, at which time 14.8 per cent of the total area of rural holdings in these shires was improved.

Only the myxomatosis research variable was included in the estimated equations. The recommendation relating to skeleton weed was not included for the reason described earlier. In this area also, it is doubtful whether the factor of skeleton weed control was directly important in influencing the acreage of improved pastures.

The preferred estimated equations are presented in Table 6.3. The real price variable is highly significant in explaining changes in both dependent variables, with an adjustment period of three years. The research variable relating to the release of the myxomatosis virus was again important in explaining changes in the demand for improved pastures. For the first time, rainfall was shown to affect the demand for superphosphate. In this case, those rainfall years in the first and second deciles (in Gibbs and Maher's terminology, "very much below average" and "much below average", respectively) have a positive effect on the demand for superphosphate. This would appear to be a compensatory effect, with a larger increase in superphosphate usage following the more severe dry period. The rainfall year is measured from December to December, whereas superphosphate usage is measured over the March-March year. Most superphosphate would probably be spread in February-March each year, seeing that subterranean clover germinates in the late-February to March period.
Figure 6.3  Area of sown pastures and superphosphate use, Riverina N.S.W. (Dryland).

Source: Commonwealth Bureau of Census and Statistics, Sydney, Statistical Register of N.S.W.
Table 6.3
Estimated Equations: Demand for a Stock of Improved Pastures - Riverina, N.S.W. (Dryland)

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Dependent Variables</th>
<th>ln(SP)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>ln(SU)&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intercept</strong></td>
<td></td>
<td>1.07</td>
<td>10.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.12)</td>
<td>(0.33)</td>
</tr>
<tr>
<td><strong>ln(P_I/P_P)&lt;sub&gt;t-i&lt;/sub&gt;</strong></td>
<td>i=0</td>
<td>-0.46</td>
<td>-0.69</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.11)</td>
<td>(0.20)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 -0.35</td>
<td>-0.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.09)</td>
<td>(0.12)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 -0.21</td>
<td>-1.01&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.07)</td>
<td>(0.12)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 -0.09</td>
<td>0.01 n.s.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.11)</td>
<td>(0.16)</td>
</tr>
<tr>
<td><strong>RV&lt;sub&gt;t-i&lt;/sub&gt;&lt;sup&gt;c&lt;/sup&gt;</strong></td>
<td>i=1</td>
<td>0.24</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.10)</td>
<td>(0.12)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 0.33</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.07)</td>
<td>(0.16)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 0.34</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.05)</td>
<td>(0.10)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 0.30</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.07)</td>
<td>(0.12)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 0.25</td>
<td>0.26 1.80&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.06)</td>
<td>(0.11)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 0.20</td>
<td>0.11 n.s.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.08)</td>
<td>(0.14)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 0.14 1.80&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.08)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 0.05 n.s.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.12)</td>
<td></td>
</tr>
<tr>
<td><strong>First Decile Drought</strong></td>
<td></td>
<td>n.s.</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.28)</td>
</tr>
<tr>
<td><strong>Second Decile Drought</strong></td>
<td></td>
<td>n.s.</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.14)</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
R^2 & = 0.98 & 0.96 \\
\text{d} & = 1.74 & 2.00
\end{align*}

<sup>a</sup> Adjusted for changes in total area of rural holdings.

<sup>b</sup> Sum of significant lag coefficients.

<sup>c</sup> Research Variable = release of myxomatosis virus in 1950-51.
The gross returns for the myxomatosis research variable have also been calculated for this area, using the equation estimated on the SP series. The same assumptions were used as for the previous area. From 1957-58 onwards, gross benefits yielded were $156,400 (deflated) per annum. For the period 1951-52 to 1967-68 total benefits amounted to $2.2 million. The difference between the two Riverina areas in the benefits estimated was largely due to the difference in the price elasticity coefficients. There was no attempt made to calculate a rate of return to rabbit control research as the benefits from myxomatosis were not confined to the Riverina, but were spread over most of southern Australia.

6.1.4 Western Australia (Wheat/Sheep Zone)

The area of concern here is that area comprised of the Northern, Central, and Southern Agricultural Divisions of W.A. This area approximates the part of W.A. between the 10 inch and 30 inch rainfall isohyets - the wheat/sheep zone of W.A. The C.S.I.R.O. began pasture research in W.A. in 1938-39, concentrating on the 15-30 inch rainfall zone. But it was not until 1952-53, when the number of scientists working in that State was increased to seven, that the Division committed itself heavily to research in the area. The biggest expansion in improved pastures in W.A. has taken place in the wheat/sheep zone, where there has been considerable emphasis on pushing the
limits of improved pastures out into the drier areas. The C.S.I.R.O. has also done pasture research in the South West Division, on dairy pastures and high-rainfall, sandy soils. However, this area is not considered in this study.

The areas under established pastures for the period 1929-30 to 1968-69, and the amounts of superphosphate used for the period 1935-36 to 1968-69, in the Northern, Central, and Southern Agricultural Divisions, are graphed in Figures 6.4, 6.5, and 6.6 respectively. In Figure 6.7 the annual totals of these two series for the three Divisions are shown. In the year 1968-69 the area of established pastures represented 21.4 per cent, 31.2 per cent, and 43.5 per cent of the total area of rural holdings in the Northern, Central, and Southern Agricultural Divisions respectively.

The pasture research effort of the Division of Plant Industry has been closely linked with that of the W.A. Department of Agriculture and the W.A. University's Institute of Agriculture (also established in 1938-39). Much of the research work which has been done has been co-operative or complementary, and it is difficult to ascribe particular findings to individual organizations. For this reason all research findings which may have been important to pasture improvement in this wheat/sheep zone have been tested in the model. The model was estimated on the SP and SU series for each of the three Agricultural Divisions, as well as for the totals of these series. The
Figure 6.4  Area of sown pastures and superphosphate use, Northern Agricultural Division, W.A.

Source: Commonwealth Bureau of Census and Statistics, Perth, Statistical Register of W.A.
Figure 6.5 Area of sown pastures and superphosphate use, Central Agricultural Division, W.A.

Source: Commonwealth Bureau of Census and Statistics, Perth, Statistical Register of W.A.
Figure 6.6 Area of sown pastures and superphosphate use, Southern Agricultural Division, W.A.

Source: Commonwealth Bureau of Census and Statistics, Perth, Statistical Register of W.A.
Figure 6.7 Area of sown pastures and superphosphate use, Wheat/sheep zone, W.A.

Source: Commonwealth Bureau of Census and Statistics, Perth, Statistical Register of W.A.
purpose of this exercise was to see if the estimated coefficients varied between Divisions. It was felt that this comparison would provide a test of the model, especially if a priori it could be expected that some research findings would be more important in one or other of the Divisions.

The following research findings were selected for testing in the model:

(i) Recommendation for the improvement of the so-called "light lands" (12-22 inches annual rainfall) by means of Dwalganup subterranean clover, heavy dressings of superphosphate plus the minor elements zinc and copper, and weed control techniques, 1946-47. These findings were the results of 10 years' research at the Department of Agriculture's Wongan Hills Research Station [32].

(ii) Use of a clover-ley system of farming for "light lands", (a) 1950-51 (end of first rotation at Wongan Hills), (b) 1954-55 (end of second rotation at Wongan Hills). This was the result of a co-operative project at Wongan Hills Research Station between the W.A. Department of Agriculture and the Institute of Agriculture. At the Research Station, use of the clover-ley system boosted wheat yields from 14 bushels to 22 bushels per acre and doubled sheep stocking rates and wool yields.
(iii) The lime-pelleting of legume seeds at sowing, 1956-57. After publication of these results by workers at the Division of Plant Industry at Canberra [24], there was apparently much interest shown by farmers in W.A. [31].

(iv) Release of Woogenellup subterranean clover (a "medium-rainfall" strain), 1958-59.

(v) (a) Stocking rate trials showing that commonly-used levels were only half of potential levels [12].
(b) Release of Geraldton strain of subterranean clover (for "low-rainfall" areas), 1959-60.

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8 Smith and Goss [31] had apparently developed a method of lime-pelleting legume seeds in 1948 to enable W.A. farmers to sow into dry soil.

9 Subterranean clover, the basis of pasture improvement in W.A., was introduced from South Australia in 1902 [32]. By 1914 it was recognized as a useful pasture species, and by 1923 the benefits to be gained from superphosphate topdressing of subterranean clover had also been recognized. Sowing of the S.A. Mt. Barker subterranean clover strain was restricted to areas with annual rainfall greater than 25 to 30 inches. In 1927 the first of the earlier-maturing strains, Dwalganup, was discovered. This strain characteristic made it possible for subterranean clover to be sown in areas receiving less than 25 inches of rainfall annually. Discovery and plant breeding has led to other early-maturing strains being made commercially available.

10 Since 1949, Millington of the Institute of Agriculture has been breeding subterranean clover strains for the drier parts of the wheat belt. Geraldton was one of the results of this programme.
(vi) Commercial release of Cyprus strain of
Barrel medic in 1961. 11

(vii) Molybdenum deficiency found on "light lands",
1965-66 [16].

Because of the large number of research findings
to be tested and the number of these which seemed to have
been important, and because of the computer programming
restrictions on the number of lagged variables which could
be included in the estimated equations (four only), the
interpretation of the results was somewhat confounded. After
testing all of these research findings in the model, singly,
in pairs, and in threes, a number were found to be
consistently insignificant. These were (ii)(b), (iv), and
(v) above. It was decided to put all of the research
findings into one equation and estimate it without lags,
i.e., to assume instant adjustment to a change in pasture
technology. As can be seen from Table 6.4 the results of
the instant adjustment model in no way contradict the
results from the lagged model. Research variables (ii)
(b), (iv), and (v) were always insignificant for all
Divisions. It is of interest to compare the results in
Table 6.4 with some of the results from the lagged model
to see if the two models are consistent. Table 6.5 presents,
for the three divisions, estimated equations which included

11 This plant was introduced by the C.S.I.R.O. and tested by
the Institute of Agriculture [2]. It was first released
to farmers by the Institute in 1959, and seed was first
sold commercially in 1961.
research variables (i) and (vi). Table 6.6 presents results for equations which included research variables (i) and (vii). Research variable (i) was included in both sets of estimations because it was the most important influence, and in the lagged model seemed to dominate research variable (ii) (a). A comparison of the results in the three tables shows that the same orderings and the same orders of magnitude are approximately maintained within and across the three division for research variables (vi) and (vii).

In the two sets of results, both research findings were more important in the Northern Agricultural Division (N.A.D.) than in the Central Agricultural Division (C.A.D.), and were more important in the C.A.D. than in the Southern Agricultural Division (S.A.D.). Except for the N.A.D., research variable (vii) was more important than research variable (vi) within any division.

These results are also consistent with agricultural data. A priori, both research findings would appear to be relatively more important in the N.A.D. than in the two other divisions. Cyprus Barrel medic has attained widespread use since its release. In 1965 this strain comprised 96 per cent of the 300,000 acres of Barrel medic sown [29]. It is recommended to be grown on alkaline soils. This would appear to favour the N.A.D. and the C.A.D. over the S.A.D. [26, Map 2].

The first experiments by Doyle et al., [16] on molybdenum response in wheat-growing areas were conducted
in the N.A.D., beginning in 1960.\textsuperscript{12} In 1964 experiments were conducted in parts of the C.A.D. and S.A.D. The addition of molybdenum increased wheat yields in the experiments by up to 3½ bushels per acre. The researchers' recommendations were for the use of molybdenum on wheat and pastures "... on sandy and gravelly soils typical of extensive areas of the high level scrub plain in the central, eastern and north-eastern parts of the wheat belt". The relevant area, which they mapped, lies predominantly in the N.A.D. and C.A.D. Farmer response to this finding, as estimated in the lagged model, was large and swift.

According to data on fertilizer use, the consumption of molybdenum trioxide in W.A. increased by 550 per cent between 1965 and 1967 [23, p.A18].

The lack of contradiction between the results from the models and the other corroborating data gives increased confidence in the performance of the model. Because all research variables could not be included in the lagged model at any one time, the estimated coefficients in these equations are considered to be overestimates. The results in Table 6.4 were therefore accepted as a reasonable approximation to the actual behaviour. In equations (1) to (4) of Table 6.4, i.e., where the SP series is the

\textsuperscript{12} Teakle [33], in 1944, carried out the only other experiments on molybdenum deficiency in the wheat-growing areas of W.A. He found only one responsive site out of 32, at Yericoin in the N.A.D. Teakle concluded that: "The spectacular results reported from the Eastern States cannot be expected in Western Australia".
dependent variable, the Durbin-Watson statistic indicates substantial serial correlation. Of those estimations on the SU series, only equations (6) and (7) show some serial correlation. Consequently, equations (5) to (8) were considered useful for calculating the returns from research. However, rates of return have been calculated only for the whole wheat/sheep zone, i.e., using the results from equation (8).

The results in Table 6.4 suggest that fertilizer demand is very inelastic to price changes. In none of the equations, however, is the coefficient on the price variable significant. In equation (8) the elasticity coefficient is -0.22. This estimate is reasonably close to being significant, so that some confidence may be placed in the calculations made from this equation. The same value for the real-price coefficient was obtained in the simple time-trend model, after correction for serial correlation. The gross benefits streams yielded by each of the successful research findings up to 1967-68 are presented in Table 6.7. Various internal rates of return have been calculated as follows.

(i) The benefits streams of research variables (i) and (ii) were combined, on the basis that both these findings came from research at the W.A. Department of Agriculture's Wongan Hills Research Station. Research costs were estimated at 2 scientists per
Table 6.4
Estimated Equations: Demand for a Stock of Improved Pastures (Instant Adjustment Model)
Wheat/Sheep Zone, Western Australia

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Intercept</th>
<th>ln(Pt/Pp)t - 1</th>
<th>RV(i)</th>
<th>RV(ii)</th>
<th>RV(iii)</th>
<th>RV(vi)</th>
<th>RV(vii)</th>
<th>FDD</th>
<th>R²</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) ln (SP) N.A.D.</td>
<td>-2.27</td>
<td>-0.13 n.s.</td>
<td>2.90</td>
<td>0.67 n.s.</td>
<td>0.45 n.s.</td>
<td>0.37 n.s.</td>
<td>0.51 n.s.</td>
<td>0.88</td>
<td>0.93</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td>(0.41)</td>
<td>(0.42)</td>
<td>(0.41)</td>
<td>(0.51)</td>
<td>(0.57)</td>
<td>(0.49)</td>
<td>(0.58)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) ln (SP) C.A.D.</td>
<td>-1.36</td>
<td>-0.07 n.s.</td>
<td>3.10</td>
<td>0.56 n.s.</td>
<td>0.43 n.s.</td>
<td>0.24 n.s.</td>
<td>0.33 n.s.</td>
<td>0.48 n.s.</td>
<td>0.94</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>(0.42)</td>
<td>(0.40)</td>
<td>(0.40)</td>
<td>(0.43)</td>
<td>(0.49)</td>
<td>(0.41)</td>
<td>(0.45)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) ln (SP) S.A.D.</td>
<td>1.34</td>
<td>-0.42</td>
<td>1.50</td>
<td>0.14 n.s.</td>
<td>0.59</td>
<td>0.06 n.s.</td>
<td>0.27 n.s.</td>
<td>0.44 n.s.</td>
<td>0.93</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>(0.21)</td>
<td>(0.22)</td>
<td>(0.24)</td>
<td>(0.26)</td>
<td>(0.31)</td>
<td>(0.25)</td>
<td>(0.27)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>(4) ln (SP) Total</td>
<td>-0.02</td>
<td>-0.41 n.s.</td>
<td>1.89</td>
<td>0.43 n.s.</td>
<td>0.74</td>
<td>0.07 n.s.</td>
<td>0.40 n.s.</td>
<td>0.51 n.s.</td>
<td>0.95</td>
<td>0.58</td>
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<tr>
<td></td>
<td>(0.25)</td>
<td>(0.27)</td>
<td>(0.27)</td>
<td>(0.32)</td>
<td>(0.39)</td>
<td>(0.33)</td>
<td>(0.32)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5) ln (SU) N.A.D.</td>
<td>4.28</td>
<td>-0.15 n.s.</td>
<td>0.85</td>
<td>0.51</td>
<td>0.40</td>
<td>0.42</td>
<td>0.80</td>
<td>0.27</td>
<td>0.98</td>
<td>2.10</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(0.16)</td>
<td>(0.13)</td>
<td>(0.16)</td>
<td>(0.18)</td>
<td>(0.15)</td>
<td>(0.18)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(6) ln (SU) C.A.D.</td>
<td>5.40</td>
<td>-0.30 n.s.</td>
<td>0.70</td>
<td>0.48</td>
<td>0.34 n.s.</td>
<td>0.23 n.s.</td>
<td>0.48</td>
<td>0.09 n.s.</td>
<td>0.96</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>(0.22)</td>
<td>(0.20)</td>
<td>(0.20)</td>
<td>(0.17)</td>
<td>(0.19)</td>
<td>(0.16)</td>
<td>(0.18)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(7) ln (SU) S.A.D.</td>
<td>5.67</td>
<td>-0.08 n.s.</td>
<td>0.90</td>
<td>0.31</td>
<td>0.29</td>
<td>0.20 n.s.</td>
<td>0.32</td>
<td>0.06 n.s.</td>
<td>0.97</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>(0.11)</td>
<td>(0.14)</td>
<td>(0.12)</td>
<td>(0.13)</td>
<td>(0.15)</td>
<td>(0.12)</td>
<td>(0.13)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(8) ln (SU) Total</td>
<td>6.39</td>
<td>-0.22 n.s.</td>
<td>0.77</td>
<td>0.44</td>
<td>0.45</td>
<td>0.22 n.s.</td>
<td>0.52</td>
<td>0.22 n.s.</td>
<td>0.97</td>
<td>1.67</td>
</tr>
<tr>
<td></td>
<td>(0.13)</td>
<td>(0.15)</td>
<td>(0.13)</td>
<td>(0.14)</td>
<td>(0.17)</td>
<td>(0.14)</td>
<td>(0.14)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

N.A.D. = Northern Agricultural Division.
C.A.D. = Central Agricultural Division.
S.A.D. = Southern Agricultural Division.
RV(i) = "Light lands" improvement recommendations, 1946–47.
RV(iii) = Lime pelleting legume seeds, 1956–57.
**Table 6.5**

Estimated Equations: Demand for a Stock of Improved Pastures (Lagged Model) - Wheat/Sheep Zone, W.A.

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Dependent Variable - ln(SU)</th>
<th>N.A.D.</th>
<th>C.A.D.</th>
<th>S.A.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intercept</strong></td>
<td></td>
<td>4.24</td>
<td>5.19</td>
<td>5.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.19)</td>
<td>(0.11)</td>
<td>(0.14)</td>
</tr>
<tr>
<td><strong>ln(Pi/Pp) t-1</strong></td>
<td></td>
<td>0.34 n.s.</td>
<td>0.19 n.s.</td>
<td>0.23 n.s.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.19)</td>
<td>(0.12)</td>
<td>(0.14)</td>
</tr>
<tr>
<td><strong>RV(i) t-i</strong></td>
<td>i=1</td>
<td>0.27</td>
<td>0.22</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.08)</td>
<td>(0.07)</td>
<td>(0.05)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.39</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.07)</td>
<td>(0.04)</td>
<td>(0.05)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.38</td>
<td>0.37</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.07)</td>
<td>(0.07)</td>
<td>(0.05)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.29</td>
<td>0.30</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.08)</td>
<td>(0.07)</td>
<td>(0.06)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.15 1.47(^a)</td>
<td>0.18 1.42(^a)</td>
<td>0.07 1.19(^a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.07)</td>
<td>(0.06)</td>
<td>(0.04)</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.03 n.s.</td>
<td>0.07 n.s.</td>
<td>0.02 n.s.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.05)</td>
<td>(0.08)</td>
<td>(0.04)</td>
</tr>
<tr>
<td><strong>RV(vi) t-i</strong></td>
<td>i-1</td>
<td>0.50</td>
<td>0.40</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.14)</td>
<td>(0.09)</td>
<td>(0.09)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.37</td>
<td>0.21 0.61(^a)</td>
<td>0.17 0.43(^a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.07)</td>
<td>(0.07)</td>
<td>(0.04)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.20</td>
<td>0.09 n.s.</td>
<td>0.05 n.s.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.13)</td>
<td>(0.08)</td>
<td>(0.08)</td>
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<tr>
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<td>4</td>
<td>0.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.13)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.26 1.55(^a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>-0.22 n.s.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.28)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Sum of significant lag coefficients

Research Variable \((i)\) = "Light lands" improvement recommendations, 1946-47.

## Table 6.6

Estimated Equations: Demand for a Stock of Improved Pastures (Lagged Model) - Wheat/Sheep Zone, W.A.

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Dependent Variable - ln(SU)</th>
<th>N.A.D.</th>
<th>C.A.D.</th>
<th>S.A.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td></td>
<td>4.55</td>
<td>5.47</td>
<td>5.97</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.29)</td>
<td>(0.14)</td>
<td>(0.17)</td>
</tr>
<tr>
<td>( \ln(P_i/P_p)_{t-1} )</td>
<td></td>
<td>-0.03 n.s.</td>
<td>-0.12 n.s.</td>
<td>-0.08 n.s.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.29)</td>
<td>(0.15)</td>
<td>(0.16)</td>
</tr>
<tr>
<td>RV(i)_{t-i}</td>
<td>i=1</td>
<td>0.22</td>
<td>0.17</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.13)</td>
<td>(0.07)</td>
<td>(0.07)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.30</td>
<td>0.28</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.11)</td>
<td>(0.06)</td>
<td>(0.07)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.29</td>
<td>0.30</td>
<td>0.20 0.68&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.11)</td>
<td>(0.06)</td>
<td>(0.07)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.20 1.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.25</td>
<td>0.11 n.s.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.13)</td>
<td>(0.07)</td>
<td>(0.07)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.10 n.s.</td>
<td>0.14 1.15&lt;sup&gt;a&lt;/sup&gt;</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(0.11)</td>
<td>(0.06)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td></td>
<td>0.03 n.s.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.05)</td>
<td></td>
</tr>
<tr>
<td>RV(vii)_{t-i}</td>
<td>i=1</td>
<td>0.77</td>
<td>0.45</td>
<td>0.30</td>
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<tr>
<td></td>
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<td>(0.21)</td>
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<td>(0.11)</td>
</tr>
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<td></td>
<td>2</td>
<td>0.66 1.43&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.30 0.75&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.19 0.50&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
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<td>(0.19)</td>
<td>(0.07)</td>
<td>(0.07)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.13 n.s.</td>
<td>0.03 n.s.</td>
<td>0.01 n.s.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.28)</td>
<td>(0.13)</td>
<td>(0.14)</td>
</tr>
</tbody>
</table>

\( R^2 \) \( d \)

0.92 1.06

1.06 1.05

1.06 1.06

<sup>a</sup> Sum of significant lag coefficients

**Research Variable (i)** = "Light lands" improvement recommendations, 1946-47.

Table 6.7

Gross Benefits Estimated for Successful Pasture Research in W.A. (wheat/sheep zone)

<table>
<thead>
<tr>
<th>Research Variable</th>
<th>Annual Gross Benefits ($</th>
<th>- from</th>
<th>- to</th>
<th>Total Gross Benefits to 1967-68 ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i)</td>
<td>634,890</td>
<td>1947-48</td>
<td>1967-68</td>
<td>13,332,690</td>
</tr>
<tr>
<td>(ii)</td>
<td>380,073</td>
<td>1951-52</td>
<td>1967-68</td>
<td>6,461,241</td>
</tr>
<tr>
<td>(iii)</td>
<td>357,487</td>
<td>1957-58</td>
<td>1967-68</td>
<td>3,932,137</td>
</tr>
<tr>
<td>(iv)</td>
<td>134,548</td>
<td>1962-63</td>
<td>1967-68</td>
<td>807,288</td>
</tr>
<tr>
<td>(v)</td>
<td>330,434</td>
<td>1966-67</td>
<td>1967-68</td>
<td>660,868</td>
</tr>
<tr>
<td>Total</td>
<td>25,194,200</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Research Variables (i) - Improvement recommendations for "light-lands", 1946-47.


(iii) - Lime-pelleting of legume seeds, 1956-57.

(iv) - Release of Cyprus Barrel medic, 1962-63.

(v) - Molybdenum deficiency of "light lands", 1965-66.
year from 1935-36 to 1945-46, and 3 scientists per year from 1946-47 to 1955-56. These costs were assumed to include some expenditure by the W.A. Institute of Agriculture which co-operated on the clover-ley studies. The internal rate of return on this cost stream was approximately 53 per cent.

(ii) The W.A. Department of Agriculture was solely involved in the molybdenum studies - research variable (vii). Research costs on this project were estimated at 2 scientists per year for the period 1960-61 to 1967-68. The internal rate of return calculated for this project alone was 86 per cent.

(iii) An effort was made to estimate the internal rate of return on all pasture research in this wheat/sheep zone since 1935-36. The estimated research cost stream included research expenditure at Wongan Hills from 1935-36, plus research expenditure by the Division of Plant Industry and the Institute of Agriculture from 1938-39. The costs were based on the number of scientist-years each organization contributed to research in this area. The gross benefit streams estimated for all successful research findings were added together, and the internal rate of
return for total pasture research was calculated at approximately 48 per cent.

The costs used for assessing expenditure by the three organizations were those calculated for the Division of Plant Industry and presented in Chapter 5. It should be pointed out that the estimates of costs are rough approximations, with the main emphasis on showing the differences between regions in the rates of return from individual projects and from pasture research as a whole. It should also be noted that errors in the estimated annual costs would not have nearly as much effect on the internal rate of return as would errors in the date on which the research project was commenced.

6.2 Northern Australia

In the five northern Australian areas of interest, all in Queensland, beef and dairy products are the principal output of pastoral enterprises. In two of the areas studied, Townsville Statistical Division and Maryborough (Wallum), beef production has always been much more important than dairying. In the remaining areas, Rockhampton (Southern Spear Grass), Rockhampton (Brigalow), and Maryborough (Dairy Pastures), dairying was important in the past, and large areas of improved pastures were utilized for dairying; however, in these areas also, beef production is now the main type of pastoral activity.
In the main, the C.S.I.R.O.'s pasture research effort in northern Australia has been a post-1945 activity, and has been based on the potential for utilization of new pasture technology in beef enterprises. The recently developed pasture technology is different from that used in dairying last century and earlier in this century. Unlike the new technology, the old pasture technology was not based on the use of superphosphate and other inorganic fertilizers. Therefore, in an area where superphosphate and other fertilizers are now important components of pasture technology, the SU and PF data series should reflect current changes in the fortunes of the dairy and beef industries more accurately than the SP series. Because of the irreversible nature of investment in improved pastures, in those areas where dairying has been important previously, but has been displaced to an extent by beef production, the SP data series is the resultant of the long-term decline in old dairy pastures and the current investment in new pasture technology by beef and dairy producers.

To try to take account of the fact that both beef and dairy enterprises may have adopted the new technology and that other fertilizers besides superphosphate may be important, a number of different combinations of input price and product price series were used for the real price variable in the two Maryborough and two Rockhampton areas. In those regressions where the dependent variable was either the SP or PF series, the following were used as
alternative measures of the real price variable: (i) superphosphate price index/export beef price index (SI/BI); (ii) superphosphate price index/weighted beef and dairy export products price index (SI/WBDI); (iii) all-fertilizers price index/export beef price index (FI/BI); and (iv) all-fertilizers price index/weighted beef and dairy export products price index (FI/WBDI). Other fertilizers, particularly nitrogen compounds, may be just as important as superphosphate in the total quantity of fertilizers spread in any year. In some areas, therefore, the SU series was likely to be an inappropriate index of fertilizer use. For this reason, despite the possible limitations discussed previously, the PF series was also used as a measure of the the stock of improved pastures. Finally, where the dependent variable in the regressions was the SU series, the real price variable used was either (SI/BI) or (SI/WBDI).

13 The export beef and dairy products price indices were weighted by the numbers of beef and dairy cattle, respectively, in the area at 31st March each year. The product price indices and the all-fertilizer price index used were those published in the Quarterly Review of Agricultural Economics. Over 40 per cent of beef produced in Queensland is currently exported. In the past the percentage was even larger. It was decided to use the export beef price on the grounds that if exports do not largely influence the average price received, they at least serve to put a floor under beef prices. The export dairy products price index was used as Queensland dairy production goes mostly into manufactured products, and again, a large proportion of this is exported.
6.2.1 Townsville, Qld. (Northern Spear Grass)

The history of pasture improvement in this area, as in many of the drier, beef-producing areas north of Maryborough, is the history of Townsville Stylo \( (\text{Stylosanthes humilis}) \). This plant was discovered in the vicinity of Townsville very early in this century. Townsville is a port which previously had some trade with Central and South America, where this species is a native. The feeding value of Townsville Stylo, and its value as a legume addition to pastures was recognized by the then Queensland Department of Agriculture and Stock as early as 1914 [18].

The Queensland Department of Primary Industries carried out species evaluation experiments with Townsville Stylo at several sites in coastal, central, and southern Queensland in the early 1930's [18, p.4], and the legume was apparently very successful in the Rockhampton and Mackay districts. In its early plant introduction work in Queensland during the 1930's, the C.S.I.R.O. concentrated on members of the \( \text{Stylosanthes} \) spp. in an attempt to provide a broad-spectrum legume for northern Australia. Many believe that this has been accomplished with Townsville Stylo.

In 1964-65 the C.S.I.R.O. Division of Tropical Pastures established a laboratory and research station at Townsville. From this centre, pasture investigations are carried out on spear grass areas extending from Rockhampton
to north of Cooktown, and on the northern brigalow areas as well as the wet-coastal, tableland, and Gulf Ti-tree areas.

The Townsville Division was chosen for this study as representative of the dry, northern spear grass areas. Moreover, this is where Townsville Stylo has become naturalized. The area is also of interest because the Division of Plant Industry became involved in irrigated pastures at Ayr as early as 1947-48.

Data series have been collected for the Queensland areas for the period 1949-50 to 1969-70, and the model has been estimated over the 20-year period to 1968-69. In most areas, very little superphosphate or any other purchased fertilizers were being used on pastures in 1949-50. The SP and PF series for the Townsville Division are graphed in Figure 6.8. With the total area of rural holdings in this Division being 21 million acres, in percentage terms the area of improved pastures in 1969-70 was insignificant at 0.5 per cent. The SU series was not used as a dependent variable in this area as there was no superphosphate applied until 1953-54.

Two research findings were tested for the Townsville Division.

(i) Publication of the results of grazing trials on Townsville Stylo and superphosphate at
Rodd's Bay, 1959-60 [30].

(ii) First year's results from grazing trial at Landsdown Research Station, Townsville, 1964-65 [14, pp.53-4].

There was no support from the regression results for these findings being important in explaining changes in the SP and PF series.

The best results were obtained from a model which assumed instant adjustment in the price variables. In the first two equations presented in Table 6.8, both the real and relative price variables have been retained. The simple correlation coefficient between these two variables is 0.75; which is not as high as for other areas. In equation (1) the estimated coefficients on the price variables are not significant. In equation (3) the regression was estimated without the relative price variable. The real price coefficient is now highly significant and its value is about equal to the sum of the two coefficients in equation (1); however, the degree of serial correlation is increased.

In equation (2) the two price variables are significant in explaining changes in the PF series. This

---

14 In [13, p.3] it was stated that the improvement of pasture by oversowing of Townsville Stylo "... can now be safely recommended". Humphreys [18] argued that the very recent increases in northern Australia in sowings of Townsville Stylo and superphosphate use were due to the demonstration by Shaw at Rodd's Bay of the response in pastures and livestock to superphosphate.
Figure 6.8 Area of sown pastures and area of pastures fertilized, Townsville Statistical Division, Qld.

Source: Commonwealth Bureau of Census and Statistics, Brisbane, *Statistical Register of Queensland*. 
### Table 6.8

Estimated Equations: Demand for a Stock of Improved Pastures - Townsville Division, Qld.

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Dependent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ln(SP)</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>Intercept</td>
<td>-3.68</td>
</tr>
<tr>
<td></td>
<td>(0.59)</td>
</tr>
<tr>
<td>( \ln(P_1/P_p) )</td>
<td>-1.57</td>
</tr>
<tr>
<td></td>
<td>(1.02)</td>
</tr>
<tr>
<td>( \ln(P_i/P_j) )</td>
<td>-1.00</td>
</tr>
<tr>
<td></td>
<td>(0.62)</td>
</tr>
</tbody>
</table>

\[ R^2 \]

0.63  0.90  0.56

d  
1.40  1.59  1.19

\(^a_{(P_1/P_p)} = \text{Fertilizer Price Index/Export Beef Price Index.}\)

\(^b_{(P_i/P_j)} = \text{Fertilizer Price Index/Land Values Index.}\)
is probably due to the fact that the problem of multicollinearity is less here than in other areas. However, the standard errors will be biased downwards somewhat, given the existence of some positive serial correlation. The $R^2$ has been increased to 0.90. With a value of -4.57, the price elasticity of demand for the input is very high - much more elastic than for the southern areas. Briefly, the recent experience of the area has been a four-fold increase in the area of pastures fertilized in the five-year period 1964-65 to 1968-69 (the area of pastures fertilized remains small in absolute terms). The estimated equations predict this upswing reasonably well. An examination of the price indices forming the real price variable (which is a more important influence than the relative price variable) shows that in this recent period there has been a much faster increase in the export beef price index than in the all-fertilizer price index. The conclusion is drawn that the new pasture technology was unprofitable until the recent large fall in the real price of fertilizers. There is also some indication that with changes in relative factor prices there has been substitution of improved pastures for land.

6.2.2 Rockhampton, Qld. (Brigalow)

The Rockhampton Statistical Division was split into those shires in which development of the brigalow areas has taken place, and the remaining shires which were
considered to be representative of the southern spear grass region. The shires included in the brigalow area are: Banana, Broadsound, and Duaringa. In Figure 6.9 the SP, SU, and PF series for the three shires in the brigalow area are graphed for the period 1949-50 to 1969-70. Of the total area of rural holdings (10.8 million acres), 10.8 per cent was under sown pastures in 1969-70.

The three shires chosen here cover what is known as the northern brigalow region. This particular area was the first brigalow area to be opened up by the Queensland Government for land settlement under The Brigalow and Other Lands Development Act of 1962 [9]. A peculiar characteristic of the brigalow belt is the heavy density of the acacia tree (Acacia harpophylla) and its persistency through regrowth by prolific suckering and seedlings. No large-scale clearing was carried out until following World War II, when with the availability of large machinery, contract rates for land clearing dropped sharply. Along with this development has gone improvements in the techniques of clearing. Once cleared, the area has to be sown to introduced pastures, or sprayed with chemicals to allow regrowth of native pastures without competition from brigalow regrowth. It must be expected, therefore, that closer settlement of the area would be accompanied by substantial increases in the level of sown pastures. Since 1961-62, the area of sown pastures has increased from 603,173 acres (5.3 per cent of total holdings) to 1.2 million acres (11.1 per cent) in 1968-69. However, the primary concern here is with the factors which
influenced the rate at which this growth took place.

The Division of Plant Industry began field work in the brigalow areas of Queensland in 1955-56, and the Division of Tropical Pastures has carried on this interest. However, no research findings have been tested here because there seemed to be no particular results which could have influenced farmers' decisions about improved pastures.

The equations estimated included two 0-1 dummy variables. The first, with values of unity dating from 1962-63, was included to measure the effect of the brigalow closer settlement scheme. The other, with values of unity dating from 1966-67, was designed to register the impact of the Queensland Government's Dairy Pasture Subsidy Scheme. Here again, the model which assumed instant adjustment in the price variables yielded preferred results to the lagged model. Some of these results are presented in Table 6.9.

Considering that the amount of superphosphate used and the area of pastures fertilized remain very small compared with the acreage of sown pastures (see Figure 6.9), it is perhaps surprising that the all-fertilizer price index

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15 This scheme was introduced in September 1966. The establishment of improved pastures on dairy farms is subsidised by $14.00 per acre up to a maximum of 20 acres in any year, and 100 acres per farm.

16 One of the reasons for this is that the nitrogen status of cleared brigalow is initially high. The most likely reason for the use of superphosphate being so low is that so far a suitable legume has not been found for widespread use in brigalow areas, see Coadrlake [10, p.134].
Figure 6.9  
Area of sown pastures, superphosphate use and area of pastures fertilized 
Rockhampton (Brigalow).

Source: Commonwealth Bureau of Census and Statistics, Brisbane, Statistical Register of Queensland.
is so significant in equations (1) and (2). In fact, the other real price variables used in the regressions on the SP variable, (SI/BI), (SI/WBDI), (FI/WBDI), gave results almost as good. As fertilizers are unimportant and clearing costs so critical to pasture development programmes, a machinery price index was tried instead of the all-fertilizer price index. The results from this construction of the real price variable, while still significant, had a lower predictive power.

The problem of multicollinearity between the real and relative price variables shows up in equations (1), (3) and (6). For the SP series, the real price variable on its own, equation (2), gives far better results than does the relative price variable. However, in the remaining equations, the real price variable on its own, while it is still significant, has poorer predictive power than the relative price variable, and the Durbin-Watson statistic indicates a higher level of positive, first-order autocorrelation. Comparisons between equations (4) and (7), and (5) and (8) show that the coefficients on the price variables are very close, which indicates that both series provide a similar description of fertilizer use. That is, the quantity of fertilizer applied per acre has not changed in response to price changes.

17 There is, in fact, a high level of collinearity between all post-war indices of prices paid by farmers.
The closer settlement dummy (BLAD) is significant only in equation (2) (but nearly so in equation (1)). This result was probably to be expected, in view of the lack of importance of fertilizers in the brigalow development programmes. The coefficient on the Dairy Pastures Subsidy Scheme dummy (DPSSD) is highly significant in all equations, but much smaller in size in equations (1) and (2). The explanation for this is that in the dairying areas of this region, fertilizer use is now an important part of the establishment of improved pastures. So a large part of the significant increase in fertilizer use since 1965-66 is explained by the dairy pastures subsidy. There has been an absolutely larger increase in the area of sown pastures in this period, but only a small part of this increase is on dairy farms and therefore the coefficient on the subsidy dummy is smaller. The remainder, which largely took place in 1967-68 is explained by changes in the real price variable. The significance of the dairy pastures subsidy dummy in the model is confirmed by data on the scheme's performance. In the two months after the introduction of the scheme, over the whole State 816 farmers applied for

18 With the increase in the export beef price index, especially in the years 1966-67 and 1967-68, there was a rapid shift in the relative price ratio between beef and dairy products. The consequences of this can be seen in the shift from dairying to beef production in all dairying areas of Queensland. In this area, dairy cattle numbers halved in the four years to 1968-69, while total cattle numbers increased by almost 100,000. In 1968-69 the proportion of dairy cattle was 3.9 per cent out of a total of 655,010 head, whereas in 1956-57 they reached a peak of 16 per cent of total cattle numbers.
Table 6.9

Estimated Equations: Demand for a Stock of Improved Pastures − Rockhampton, Qld. (Brigalow)

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Intercept</th>
<th>( \ln(\frac{P_i}{P_j})_{t-1} )</th>
<th>( \ln(\frac{P_i}{P_j})_{t-1} )</th>
<th>( \ln(\frac{P_i}{P_j})_{t-1} )</th>
<th>BLAD</th>
<th>DPSSD</th>
<th>FDD</th>
<th>TDD</th>
<th>( R^2 )</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) ( \ln ) (SP)</td>
<td>0.67</td>
<td>-0.94(^a)</td>
<td>-0.21(^b) n.s.</td>
<td>0.22 n.s.</td>
<td>0.31</td>
<td>0.28</td>
<td>0.04 n.s.</td>
<td>0.08</td>
<td>0.96</td>
<td>1.76</td>
</tr>
<tr>
<td></td>
<td>(0.07)</td>
<td>(0.24)</td>
<td>(0.13)</td>
<td>(0.13)</td>
<td>(0.11)</td>
<td>(0.13)</td>
<td>(0.08)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) ( \ln ) (SP)</td>
<td>0.63</td>
<td>-1.22(^a)</td>
<td>0.25</td>
<td>0.68 n.s.</td>
<td>3.32</td>
<td>1.17 n.s.</td>
<td>0.72 n.s.</td>
<td>0.67</td>
<td>0.96</td>
<td>1.72</td>
</tr>
<tr>
<td></td>
<td>(0.07)</td>
<td>(0.17)</td>
<td>(0.13)</td>
<td>(0.12)</td>
<td>(0.97)</td>
<td>(1.10)</td>
<td>(0.67)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) ( \ln ) (PF)</td>
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<td>-2.99(^b)</td>
<td>-0.27 n.s.</td>
<td>3.19</td>
<td>1.90 n.s.</td>
<td>0.50 n.s.</td>
<td>0.80</td>
<td>0.73</td>
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<tr>
<td></td>
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<td>(1.13)</td>
<td>(1.28)</td>
<td>(1.16)</td>
<td>(1.27)</td>
<td>(0.80)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>(4) ( \ln ) (PF)</td>
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<td>-3.73(^a)</td>
<td>-2.88(^b)</td>
<td>-0.74 n.s.</td>
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<td>1.24 n.s.</td>
<td>0.69 n.s.</td>
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<td>0.82</td>
<td>1.45</td>
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<td>(1.70)</td>
<td>(0.75)</td>
<td>(0.97)</td>
<td>(0.93)</td>
<td>(0.95)</td>
<td>(0.62)</td>
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</tr>
<tr>
<td>(5) ( \ln ) (PF)</td>
<td>2.26</td>
<td>0.58(^c) n.s.</td>
<td>-3.25(^d)</td>
<td>-1.84 n.s.</td>
<td>5.25</td>
<td>0.10 n.s.</td>
<td>1.88</td>
<td>0.84</td>
<td>1.42</td>
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<td></td>
<td>(0.42)</td>
<td>(2.23)</td>
<td>(1.25)</td>
<td>(1.13)</td>
<td>(1.07)</td>
<td>(1.26)</td>
<td>(0.73)</td>
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<tr>
<td>(6) ( \ln ) (SU)</td>
<td>1.71</td>
<td>-3.69(^e)</td>
<td>0.58(^c) n.s.</td>
<td>-1.30 n.s.</td>
<td>5.14</td>
<td>0.95 n.s.</td>
<td>1.68</td>
<td>0.76</td>
<td>1.30</td>
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</tr>
<tr>
<td></td>
<td>(0.62)</td>
<td>(1.79)</td>
<td>(2.23)</td>
<td>(1.33)</td>
<td>(1.27)</td>
<td>(1.45)</td>
<td>(0.86)</td>
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</tr>
<tr>
<td>(7) ( \ln ) (SU)</td>
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<td>-3.01(^d)</td>
<td>-1.93 n.s.</td>
<td>-1.30 n.s.</td>
<td>5.23</td>
<td>0.27 n.s.</td>
<td>1.83</td>
<td>0.84</td>
<td>1.38</td>
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</tr>
<tr>
<td></td>
<td>(0.68)</td>
<td>(1.79)</td>
<td>(1.04)</td>
<td>(1.03)</td>
<td>(1.06)</td>
<td>(0.69)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( a(\frac{P_i}{P_j}) = \) Fertilizer Price Index/Beef Export Price Index.

\( b(\frac{P_i}{P_j}) = \) Fertilizer Price Index/Land Values Index.

\( c(\frac{P_i}{P_j}) = \) Superphosphate Price Index/Beef Export Price Index.

\( d(\frac{P_i}{P_j}) = \) Superphosphate Price Index/Land Values Index.

BLAD = Brigalow Lands Act Dummy.

DPSSD = Dairy Pastures Subsidy Scheme Dummy.

FDD = First Decile Drought.

TDD = Third Decile Drought.
the subsidy [28]. At 20 acres per farmer this would mean 16,320 acres of newly-established pastures. In the first full year of the scheme, 1967-68, the sowing of 62,000 acres was approved [7, p.105]. If approvals in the period October 1966 to March 1967 continued at the same rate as for the October-November period above, and these same farmers continued their programme in the second year, this would mean that there would only be 652 new applicants in the full year 1967-68. At this rate it is difficult to see the scheme leading to one million acres of new improved dairy pastures, as envisaged by the Minister in his statement [28].

If, as seems to be the case, the PF and SU series have been more strongly influenced by what is happening in the older dairying areas than by the brigalow development, the fact that a different rainfall level is significant in equations (1) and (2) from that in equations (6) to (8) is not unreasonable. The coefficients on the rainfall variables are positive. This suggests that following a year (December to December) in which, according to the Gibbs and Maher classification, rainfall is "below average", there is a compensatory effort by farmers to increase the area of sown pastures or amount of superphosphate used in the following December to March period (i.e., the growing period in northern Australia).
6.2.3 Rockhampton, Qld. (Southern Spear Grass)

The shires included in this area are Calliope, Fitzroy, Livingstone, Miriam Vale, Monto, Mount Morgan, and Taroom. For these shires the aggregates of the SP, PF, and SU series are graphed in Figure 6.10. The total area of rural holdings in 1969-70 was 10.7 million acres, of which 7.7 per cent was under sown pastures.

The spear grass area, as represented by these shires, includes a slightly larger proportion of long-established dairying areas than does the brigalow area examined above. In 1956-57, dairy cattle numbers in the area were at their peak, making up 18.4 per cent of total cattle numbers. In 1968-69 dairy cattle numbers had fallen to 7.2 per cent of the total. The recent rate of decline in dairy cattle numbers has been much less than in the brigalow part of the Rockhampton Division - reducing by half over a ten-year period. Also, by comparison with the brigalow area, the proportion of pastures improved is less. But the use of fertilizers is a more important aspect of pasture improvement. Although, as can be seen from Figure 6.10, the more widespread use of fertilizer is a very recent phenomenon. In 1966-67 the area of pastures fertilized and the quantity of superphosphate used increased threefold. Superphosphate is by far the main type of fertilizer used.

This southern part of the spear grass zone is of particular interest as the C.S.I.R.O. has several research
facilities in the area: at Rodd's Bay near Gladstone (since 1945-46); at Westwood near Rockhampton; at "Brian Pastures", near Gayndah (a co-operative venture with the Queensland Department of Primary Industries, established early in the 1950's); and "Narayen" Research Station (established 1966-67). "Narayen", west of Gayndah, is involved with pasture investigations in both spear grass and brigalow areas. There has been an emphasis on Townsville Stylo at Rodd's Bay since work was begun there. By 1947-48 plot experiments at Rodd's Bay had shown Townsville Stylo to be easily established by surface seeding, and that it gave marked responses to superphosphate [11]. Grazing experiments, commenced in 1955, have since shown that there is a response in carrying capacity and beef production per acre to both Townsville Stylo and superphosphate [30].

Two research findings have been tested in the model: (i) Results from the grazing trial at Rodd's Bay, 1959-60; and (ii) recommendation for planting of the legume, Siratro, 1961-62. The results of the earlier plot experiments at Rodd's Bay were not tested, as the data series

---

19 Townsville Stylo had been sown by Mr. W.J.D. Shaw, grazier, at Rodd's Bay in 1936 and 1940. These sowings were inspected by Division of Plant Industry personnel in 1944 [30].

20 The legume Siratro (Phaseolus atropurpureus) was bred by Hutton [19] of the Division of Tropical Pastures. It is recommended for tropical and subtropical areas in the 25-70 inch rainfall zone. It is not recommended for the brigalow. The impact of this recommendation has also been tested in the two Maryborough areas.
Figure 6.10 Area of sown pastures, superphosphate use and area of pastures fertilized Rockhampton (Spear Grass).

did not extend back to this point in time. However, until 1953-54 there was negligible use of superphosphate. The results from the estimated equations suggest that only the first of these research results has been important in this area. However, the first research finding was significant only where the SP series was the dependent variable (see equation (4), Table 6.10). This result is not unreasonable as Townsville Stylo is a plant which grows satisfactorily under poor soil conditions [18]. Further, as will be seen, the two fertilizer-use series are influenced largely by what dairy farmers are doing, and Townsville Stylo is not a recommended plant for dairy pastures. Obviously, there have been a lot of pastures sown without fertilizers.

Within the lagged model the real price variable was unstable, suggesting multicollinearity with the research variable. The instant adjustment model was also estimated, and the best results from these regressions are shown as equations (1) to (3) in Table 6.10. The real price variable coefficients are highly significant, and point to very elastic demand for fertilizer use. Although superphosphate is the main fertilizer used (93 per cent in 1968-69), the real price variable which included the all-fertilizer price index gave slightly better results.

The importance of the dairy pastures subsidy dummy in explaining the two fertilizer-use series indicates that fertilizer use is important for dairy pastures. The non-significance of this dummy variable in the equations
estimated on the SP series points to the relative unimportance of dairy enterprises in the total sowings of improved pastures in this area. In the PF and SU series the first decile drought variable is positive and significant. For the PF series, at least, the evidence is that following "below average" rainfall farmers tend to fertilize less than the average number of acres.

Equation (4) was used as the basis for calculating the economic benefits generated by the Rodd's Bay grazing trial. As the price elasticity coefficient in this equation was likely to be an underestimate, the value of -1.34 from equation (1) was also used as an upper limit. If what has been measured is an increase in sowings of Townsville Stylo, it is obvious that farmers are not following recommended practice and applying up to 10 cwt. of superphosphate per acre in the first ten years. However, they will still be incurring machinery costs, seed costs, and perhaps some clearing costs. The converted annual cost of pasture improvement was, therefore, assumed to be equivalent to the cost of one-half cwt. of superphosphate per acre. The two streams of gross benefits calculated were thus: for a price elasticity of -0.53, total benefits generated to 1967-68 were $294,000; given a price elasticity of -1.34, the total benefits yielded to 1967-68 were $108,000. The research costs for the grazing trial project were assumed to be three-quarters of a scientist per year from 1954-55 to 1961-62. The two benefit streams estimated above yielded internal
<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Intercept</th>
<th>ln(P_t/P_p)_t-i</th>
<th>RV(i)_t-i</th>
<th>DPSSD</th>
<th>FDD</th>
<th>TDD</th>
<th>R^2</th>
<th>d^</th>
<th></th>
</tr>
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<tr>
<td>(1) ln (SP)</td>
<td>0.44</td>
<td>-1.34^a</td>
<td></td>
<td>0.20 n.s.</td>
<td>0.28 n.s.</td>
<td>0.02 n.s.</td>
<td>0.91</td>
<td>1.93</td>
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<td></td>
<td>(0.08)</td>
<td>(0.16)</td>
<td></td>
<td>(0.14)</td>
<td>(0.16)</td>
<td>(0.10)</td>
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</tr>
<tr>
<td>(2) ln (PF)</td>
<td>3.66</td>
<td>-4.52^a</td>
<td></td>
<td>2.38</td>
<td>1.82</td>
<td>-0.50</td>
<td>0.96</td>
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<td></td>
<td>(0.20)</td>
<td>(0.40)</td>
<td></td>
<td>(0.35)</td>
<td>(0.40)</td>
<td>(0.25)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>(3) ln (SU)</td>
<td>3.60</td>
<td>-4.67^b</td>
<td></td>
<td>2.84</td>
<td>1.83</td>
<td>-0.39 n.s.</td>
<td>0.88</td>
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<tr>
<td></td>
<td>(0.38)</td>
<td>(0.75)</td>
<td></td>
<td>(0.67)</td>
<td>(0.80)</td>
<td>(0.49)</td>
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<tr>
<td>(4) ln (SP)</td>
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<td>-0.06 n.s.</td>
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<td>0.09</td>
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<td></td>
<td>(0.11)</td>
<td>(0.09)</td>
<td></td>
<td>(0.06)</td>
<td>(0.04)</td>
<td>(0.02)</td>
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<tr>
<td></td>
<td>i = 1</td>
<td>0.04 n.s.</td>
<td></td>
<td>0.25</td>
<td></td>
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<td></td>
<td>i = 2</td>
<td>-0.08 n.s.</td>
<td></td>
<td>0.09 n.s.</td>
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<td>(0.12)</td>
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<td>(0.05)</td>
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<td>i = 3</td>
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<tr>
<td></td>
<td>i = 4</td>
<td>-0.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.05)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

^a Fertilizer Price Index/Wtd. Beef and Dairy Export Price Index.
^b Superphosphate Price Index/Export Beef Price Index.
Research Variable (i) = Results from Rodd's Bay grazing trial, 1959–60.

DPSSD = Dairy Pasture Subsidy Scheme Dummy.
FDD = First Decile Drought.
TDD = Third Decile Drought.
rates of return of 51 per cent and 32 per cent on this research investment. The rate of return was also estimated on an assumed total pasture research and extension expenditure in the area by the C.S.I.R.O. and the Queensland Department of Primary Industries. Total costs were assumed to be the equivalent of one scientist per year from 1954-55 to 1957-58, and of two scientists per year from 1958-59 to 1962-63. On these costs the internal rates of return calculated were 44 per cent and 24 per cent.

6.2.4 Maryborough, Qld. (Wallum)

The Wallum zone is an infertile, sandy strip of coastal lowlands in south-east Queensland and northern New South Wales. In the past the Wallum has been undeveloped apart from the planting of pine forests and extensive cattle grazing. Despite its low fertility, it was considered that with its high rainfall and proximity to markets the area offered possibilities for research into pasture improvement. The Division of Plant Industry began pasture research on the Wallum at Beerwah in 1952-53. The emphasis in the research programme was on testing of species, and evaluation of soil nutrition requirements (with emphasis on nodulation aspects of legumes). By 1954-55 results were forthcoming

21 As well as the experiments carried out at Beerwah, the Division of Tropical Pastures has also carried out pasture investigations in the northern half of the Wallum zone at Howard and North Isis. The Queensland Department of Primary Industries has a Wallum research station at Coolum in the southern part of the zone.
which showed that good pastures of white clover and paspalum could be grown with a comprehensive fertilizer programme which overcame deficiencies of plant nutrients and legume rhizobium [4, 8]. In the ensuing period, research has isolated a number of grasses and legumes which are adapted to the Wallum environment [7, p.107]. In this section it is attempted to test the importance which this research has had for development of improved pastures in the Queensland part of the Wallum zone.

Seven shires from the Maryborough Statistical Division and three shires from the Moreton Statistical Division encompass the Queensland portion of the Wallum. These shires are:—Burrum, Gooburrum, Isis, Noosa, Tiaro, Widgee, and Woongarra from the Maryborough Division; and Landsborough, Maroochy, and Caboolture from the Moreton Division. The total area of rural holdings in these shires in 1969-70 was 2 million acres. The area of sown pastures in that year (as shown in Figure 6.11) accounted for 14.1 per cent of the total. As can be seen from Figure 6.11, the area of sown pastures has been declining since 1950-51, when it accounted for 22.3 per cent of total rural holdings. It is believed that this decline is a phenomenon of the deteriorating economic conditions in the dairying industry. Improved pastures were at a peak in Queensland dairying areas early in the century, but as economic conditions have worsened, so, according to our model, the demand for improved pastures in dairying has fallen and existing improved pastures have been allowed to deteriorate. For
instance, in the Burrum Shire, the acreage of paspalum, the principal component of the old dairy pasture technology, has fallen from 7,000 acres in 1959-60 to 5,000 acres in 1969-70. However, the SP series is very sluggish in a downwards direction. For so long as a pasture can be considered to be mainly paspalum, or whatever, it is likely to be recorded as being "improved".

The area of the Wallum zone which is within the boundaries of the above ten shires is that area of coastal lowlands in south-east Queensland from the Caboolture River, 30 miles north of Brisbane, to Winfield, 170 miles north of Brisbane. There are approximately two million acres of Wallum land in this coastal strip [25, p.140]. Out of the two million acres, more than 830,000 acres are controlled by the Queensland Department of Forestry. Another 8.6 per cent is devoted to public purposes; while over 300,000 acres is classified as vacant Crown land. Some 86 per cent of the Crown land is in the northern part of the Wallum (Burrum, Gooburrum, Isis, and Woongarra Shires). This area has a soil salinity problem which may make pasture development more difficult [17]. Within the 10 shires chosen for this study, the total area of rural holdings is approximately two million acres. So, less than half of these holdings are Wallum, and some of this has a salinity problem. The remaining area is what is termed by the C.S.I.R.O. Division of Tropical Pastures - "South Queensland Dairy Pastures".
Figure 6.11 Area of sown pastures, superphosphate use and area of pastures fertilized Maryborough (Wallum).

Source: Commonwealth Bureau of Census and Statistics, Brisbane, *Statistical Register of Queensland*.
Thus, in estimating the demand function for improved pastures in the Wallum zone, a number of difficulties arose. First, there was the problem that the Wallum area cannot be represented in a satisfactory manner by shire boundaries. Second, the area of sown pastures has in fact declined since 1949-50. This is the net result of the gradual decline in pastures previously improved under dairying, and of the fact that there has been comparatively little investment in improved pastures in recent years by either beef or dairy farmers. Dairying has never been important in the Wallum zone, therefore the changes in dairy pastures refer only to the non-Wallum part of the 10 shires under consideration. Consequently, the SP series was not considered here.

As mentioned previously, the old diary pasture technology was not dependent on artificial fertilizers. Therefore, the two fertilizer-use series should reflect only interest in the new pasture technology. Thus, the SU and PF were used as the dependent variables in the regressions. However, by now it is obvious that with the dairy pasture subsidy scheme, recent fertilizer use changes have been very much influenced by dairy-farmer activity.

Three research findings from the work by the C.S.I.R.O. have been tested in the model. These are:

---

22 According to a Bureau of Agricultural Economics survey, approximately 1.7 per cent of the Wallum strip described above was used for dairying in 1967 [25, Table 3].
(i) Recommendation of the legume *Desmodium Uncinatum*, 1957-58 [5]; (ii) Recommendation of the legume *Lotononis bainesii*, 1960-61 [6]; and (iii) Recommendation of the bred legume Siratro, 1961-62 [19]. Unfortunately, it was not possible to test the early results from research on plant nutrient and rhizobium problems, see [4, 8]. The data on fertilizer use shows that there has been a steady increase since 1949-50, whereas this is not true for other areas. However, the area involved is not large in total.

As well as the dairy pastures subsidy dummy variable, a 0-1 dummy variable was included in the input-demand equation to pick up the influence of the closer settlement scheme which has been operating in the Wallum since 1963-64. Between February 1964 and December 1967 the Queensland Department of Lands made available 67,375 acres in 18 blocks under special development lease provisions [25]. However, as can be seen from the results presented in Table 6.11, this form of government activity has not been estimated as having any impact on the demand for fertilizers. The coefficient on this dummy variable was unimportant and insignificant in all equations.

Only one of the three research variables generated a lag with significant coefficients (see equation 3, Table 6.11), and then only with the SU series as the dependent variable. This variable was representing the commercial release of the legume Siratro. The period of the lag is only four years, of which two coefficients are significant.
However, the Durbin-Watson statistic indicates negative serial correlation. For the evidence to be consistent this research variable should also have been significant when the PF series was the dependent variable. In this case a positive lag was generated but none of the coefficients was significant. It was decided to accept the results as showing this research finding to have had some impact on the demand for improved pastures.

Regressions were also run on the PF and SU series after omitting the research variables and assuming instant adjustment in the price variables. The best results from this model are given in equations (1) and (2) of Table 6.11. In the absence of the research variable and the relative price variable, the coefficients on the real price variable increased in size. The relative price variable was omitted because of multicollinearity problems. The (FI/BI) construction of the real price variable was slightly better than (SI/BI) in explaining changes in the PF series, and much better than the (FI/WBDI) construction. This could be interpreted as follows. Other fertilizers besides superphosphate are important, which they are in the Wallum, and the changes in fertilizer use are determined more by economic conditions in the beef industry than in the dairy industry.

The dairy pasture subsidy scheme dummy is significant in equations (1) and (2). The coefficient on this variable was of the correct sign and of a similar
### Table 6.11

Estimated Equations: Demand for a Stock of Improved Pastures - Wallum Area

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>ln(PF)</th>
<th>ln(SU)</th>
<th>ln(SU)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Intercept</td>
<td>7.48</td>
<td>7.86</td>
<td>8.72</td>
</tr>
<tr>
<td></td>
<td>(0.19)</td>
<td>(0.21)</td>
<td>(0.12)</td>
</tr>
<tr>
<td>ln(PI/PP) t-i i=1</td>
<td>-3.05a</td>
<td>-3.19b</td>
<td>-0.87b</td>
</tr>
<tr>
<td></td>
<td>(0.47)</td>
<td>(0.58)</td>
<td>(0.20)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-0.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-0.25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>-0.32</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>-0.32</td>
<td>-2.10c</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.12)</td>
</tr>
<tr>
<td>RV(iii) t-i i=1</td>
<td>-0.04</td>
<td>n.s.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.18)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.17</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.42</td>
<td>0.81c</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.04</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.15)</td>
<td>(0.89)</td>
</tr>
<tr>
<td>DPSSD</td>
<td>0.99</td>
<td>1.16</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>(0.37)</td>
<td>(0.47)</td>
<td>(0.94)</td>
</tr>
<tr>
<td>WLAD</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>FDD</td>
<td>0.56</td>
<td>0.82</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>(0.35)</td>
<td>(0.45)</td>
<td>(0.14)</td>
</tr>
<tr>
<td>TDD</td>
<td>-0.53</td>
<td>-0.91</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td>(0.50)</td>
<td>(0.62)</td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.93</td>
<td>0.92</td>
<td>0.99</td>
</tr>
<tr>
<td>d</td>
<td>1.76</td>
<td>1.84</td>
<td>2.85</td>
</tr>
</tbody>
</table>

- Fertilizer Price Index/Export Beef Price Index
- Superphosphate Price Index/Export Beef Price Index
- Sum of significant lag coefficients
- RV(iii) = legume Siratro, 1961-62.
- DPSSD = Dairy Pastures Subsidy Dummy
- WLAD = Wallum Lands Act Dummy
- FDD = First Decile Drought
- TDD = Third Decile Drought
magnitude in equation (3), but the standard error is large. This may be a result of multicollinearity with the lagged variables. The size of the coefficient on this dummy is smaller than in the Rockhampton areas, which accords with the fact that dairying is important only in the non-Wallum part of this area. In equations (1) and (2), the coefficients on the first decile drought variable are positive and almost significant, while the coefficients on the third decile drought variable are negative and almost significant. These results are in line with those obtained in the previous section. That is, the evidence suggests that following the worst drought years farmers compensate by increasing the stock of improved pastures above the equilibrium level; and following "below average" rainfall years they decrease the stock level below the equilibrium.

The gross benefits on the research finding shown to be significant in equation (3) amount to only $640 per annum. If it is assumed that research and extension costs for this research project alone were the equivalent of one-half scientist per year from 1957-58 to 1965-66, the net benefits stream is always negative.

6.2.5 Maryborough, Qld. (South Queensland Dairy Pastures)

In this section, the shires remaining in the Maryborough Statistical Division (after excluding those in the Wallum area above) have been aggregated and an input-
demand function for improved pastures estimated. This analysis was carried out mainly for purposes of comparison with the results from the Wallum area. Apart from the coastal strip of Wallum land, the land types in all the Maryborough shires are similar. It was hoped by this comparison to indicate how well the functions estimated in Table 6.11 reflected pasture improvement activity in the Wallum zone itself.

The total area of rural holdings within the remaining Maryborough shires was 6.8 million acres in 1969-70, of which 312,768 acres were sown to introduced pastures (4.6 per cent). In Figure 6.12 the SP, PF, and SU series for this area have been graphed for the period 1949-50 to 1969-70. In these shires too, the area of introduced pastures has been declining steadily, though not as fast as in the group of shires in section 6.2.4. Here again, the confounding of the offsetting effects of dairy and beef farmers involvement in pasture improvement meant that the SP series had to be discarded. Artificial fertilizers have been in use on pastures in this area since 1949-50, but even so, with over 300,000 acres of improved pastures, only 15,000 acres were fertilized in 1967-68. There are large differences between the two Maryborough areas in the use of fertilizer, which is considered to be a reflection of the critical importance of fertilizer use for establishing pastures in the Wallum.
Equations (2) and (3) in Table 6.12 show that the real price variable is highly significant in the explanation of changes in the PF and SU series. The fact that the input-demand equations explain changes in fertilizer use in both areas is encouraging. It is also encouraging that the (FI/BI) construction of the real price variable gives better results in explaining changes in the Wallum PF series than the (SI/BI) construction, whereas the reverse is true in the present area. The use of other fertilizers as well as superphosphate is essential for the development of improved pastures in the Wallum.

Pasture research has been carried out within this area by the Divisions of Plant Industry and Tropical Pastures from a number of centres – Lawes, Samford, Beaudesert, Nanago, and Conondale, to name some. It was at Lawes that the Division of Plant Industry began pasture research in Queensland, when in 1930-31 it set up the first plant introduction centre in Australia.

Two research findings were tested for this area: (i) recommendation for sowing of Lotononis bainesii, 1960-61; and (ii) recommendation for sowing of Siratro, 1961-62. Neither of these were significant in the estimation of the lagged model. It should be pointed out that the $R^2$ in equations (2) and (3) of Table 6.12 are much lower than for equations (1) and (2) in Table 6.11. It can be concluded that some important influence has been omitted. As well as the so-called south Queensland dairy
Figure 6.12 Area of sown pastures, superphosphate use and area of pastures fertilized Maryborough (Dairy Pastures).

Source: Commonwealth Bureau of Census and Statistics, Brisbane, Statistical Register of Queensland.
pastures, the Maryborough Division also contains a significant proportion of the southern spear grass zone. It may be that some of the Rodd's Bay research results were important in this area. However, they were not tested. In the results in Table 6.12 the (SI/BI) construction of the real price variable gives better results than the (SI/WBDI) construction, and the coefficient on the dairy pastures subsidy scheme dummy is small by comparison with the Rockhampton areas, and barely significant. This evidence points to the following conclusions. First, the beef industry appears to be the main source of increases in fertilizer use. Second, a lot of research in the South Queensland Dairy Pastures area has had little effect on either the beef or dairy industries, if the results are measured in terms of increases in the use of fertilizers.

In the three equations in Table 6.12 the drought variables are not significant. However, in respect of the signs of the coefficients it can be noted that a similar pattern holds as in previous Queensland areas.

One general point should be made about the Queensland results. Humphreys [18] has argued that the very recent increases in sowings of Townsville Stylo and superphosphate use were due to the demonstration by Shaw at Rodd's Bay of the response in pastures and livestock to superphosphate fertilizer. In the lagged model, this particular research finding did affect the demand for improved pastures in the Rockhampton (Southern Spear Grass)
Table 6.12

Estimated Equations: Demand for a Stock of Improved Pastures - South Queensland Dairy Pastures

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>ln(PF) (1)</th>
<th>ln(PF) (2)</th>
<th>ln(SU) (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>5.68</td>
<td>5.56</td>
<td>5.51</td>
</tr>
<tr>
<td></td>
<td>(0.36)</td>
<td>(0.29)</td>
<td>(0.29)</td>
</tr>
<tr>
<td>$\ln(P_I/P_P)_{t-1}$</td>
<td>-2.44 n.s.</td>
<td>-3.26</td>
<td>-3.20</td>
</tr>
<tr>
<td></td>
<td>(1.51)</td>
<td>(0.61)</td>
<td>(0.62)</td>
</tr>
<tr>
<td>$\ln(P_I/P_J)_{t-1}$</td>
<td>-1.05 n.s.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.77)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DPSSD</td>
<td>1.11</td>
<td>0.96</td>
<td>1.22</td>
</tr>
<tr>
<td></td>
<td>(0.60)</td>
<td>(0.53)</td>
<td>(0.54)</td>
</tr>
<tr>
<td>FDD</td>
<td>0.94 n.s.</td>
<td>1.03 n.s.</td>
<td>1.07 n.s.</td>
</tr>
<tr>
<td></td>
<td>(0.64)</td>
<td>(0.61)</td>
<td>(0.62)</td>
</tr>
<tr>
<td>SDD</td>
<td>-0.79 n.s.</td>
<td>-0.86 n.s.</td>
<td>-0.61 n.s.</td>
</tr>
<tr>
<td></td>
<td>(0.78)</td>
<td>(0.76)</td>
<td>(0.76)</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.82</td>
<td>0.82</td>
<td>0.83</td>
</tr>
<tr>
<td>d</td>
<td>1.67</td>
<td>1.54</td>
<td>1.94</td>
</tr>
</tbody>
</table>

*a Superphosphate Price Index/Export Beef Price Index.

*b Superphosphate Price Index/Land Values Index.

DPSSD = Dairy Pastures Subsidy Scheme Dummy.
FDD = First Decile Drought.
SDD = Second Decile Drought.
area, and, while it was not tested, it may have been important in the Maryborough (Dairy Pastures) area. However, this research finding was tested in the Townsville (Northern Spear Grass) area and was found to have not affected the demand for improved pastures. But, more importantly, most of the recent increase in superphosphate use in all areas was explained by changes in the real price variable and, except in the Townsville area, the dairy pastures subsidy dummy. Moreover, the recent upsurge in investment in improved pastures can be observed in areas where Townsville Stylo is not planted, and in fertilizers other than superphosphate.

In addition, Humphreys also argued that these results by Shaw (and similar results from Katherine Research Station in the Northern Territory) had stimulated an increase in pasture research in northern Australia by the C.S.I.R.O. and the Queensland Department of Primary Industries. In terms of the normative research allocation model outlined earlier, Humphreys is essentially saying that the work by these people has had an effect on predictions about the size of K, the percentage shift of the supply curve (or, in terms of the alternative model, the shift of the marginal revenue curve). But it should be noted that with prospects of continuing high and rising beef prices, the expected gain from any given increase in productivity is increased. So it would be rational for this latter reason alone to increase the amount of research into improved pastures for beef production.
6.3 References


In this chapter it is proposed to discuss the foregoing results of the analysis of research findings from two angles. First, the results will be compared with findings of other related studies. These other studies include investigations of the returns on agricultural research, the lags between research and adoption, and the lags in the adoption process itself. Second, it is clear from the nature of the Division's work and indeed from that of other agricultural research organizations as well, that pasture research can be subdivided into a number of distinct areas of research, e.g., plant introduction, plant breeding, plant nutrition, pasture management, etc. It is proposed to review briefly the Division's pasture research, and then to see from which areas of research the major contributions have been made.

7.1 The Significance of the Results in Relation to Other Findings

In this section the results obtained from the empirical analysis will be reviewed and discussed within the context of findings from related studies. In the first part the discussion centres around the estimated regional
coefficients on the real price variable. Next there is some comment on the length of the research lags, before turning to an extended discussion of the adoption lags. Following this, the rates of return estimated on the various research projects are discussed. Finally, some conclusions are drawn about the results obtained from inclusion of the rainfall variables in the model.

7.1.1 The elasticity of demand for improved pastures

The preferred real price coefficients estimated on the different data series for each region have been brought together in Table 7.1. Where the coefficient was estimated with a lag, these are shown. Otherwise, it is assumed that adjustment takes place within one year. In those cases where an alternative estimate was obtained by what was described as the simple alternative model, these are also shown.

Two features of the results stand out. First, within any region the coefficients on the fertilizer-use series (PF or SU) are larger than those for the SP series. Second, the coefficients for the Queensland areas are much larger than in the southern areas. It can be seen by inspection of any of the data series presented in the previous chapter that the PF or SU series are more volatile than the SP series. It was argued in Chapter 5 that the SP series takes no account of farmers' efforts to change the equilibrium level of the stock of improved pastures through
### Table 7.1

Regional Long-Run Real Price Elasticities for Improved Pastures

<table>
<thead>
<tr>
<th>Region</th>
<th>Dependent Variable</th>
<th>ln(SP)</th>
<th>ln(SU)</th>
<th>ln(PF)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>New South Wales</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern Tablelands</td>
<td></td>
<td>-0.71</td>
<td>-0.32</td>
<td>-1.03 to -0.56&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Southern Tablelands</td>
<td></td>
<td>-0.36 to -0.55&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riverina (Irrigation)</td>
<td></td>
<td>-0.50</td>
<td>-0.17</td>
<td>-0.68</td>
</tr>
<tr>
<td>Riverina (Dryland)</td>
<td></td>
<td>-0.46</td>
<td>-0.35</td>
<td>-0.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.69</td>
<td>-0.57</td>
<td>-0.28</td>
</tr>
<tr>
<td><strong>Western Australia</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total W.A. Wheat/sheep zone</td>
<td></td>
<td>-0.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Queensland</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Townsville</td>
<td></td>
<td>-2.88</td>
<td></td>
<td>-4.57</td>
</tr>
<tr>
<td>Rockhampton (Brigalow)</td>
<td></td>
<td>-1.22</td>
<td>-3.69</td>
<td>-3.73</td>
</tr>
<tr>
<td>Rockhampton (Spear Grass)</td>
<td></td>
<td>-1.34</td>
<td>-4.67</td>
<td>-4.52</td>
</tr>
<tr>
<td>Maryborough (Wallum)</td>
<td></td>
<td>-3.19</td>
<td></td>
<td>-3.05</td>
</tr>
<tr>
<td>Maryborough (Dairy Pastures)</td>
<td></td>
<td>-3.20</td>
<td></td>
<td>-3.26</td>
</tr>
</tbody>
</table>

<sup>a</sup> estimated coefficients from the "simple alternative model".
the application or withholding of fertilizers. The difference between the coefficients is a reflection of this fact. It also helps to explain why the real price variables used were often unsatisfactory in estimations on the SP series. The point should be made that while the superphosphate or fertilizer price index may not be the best measure of the price of improved pastures, the area of sown pastures is not a good measure of the stock of improved pastures. Indeed the downwards sluggishness of the SP series in the two Maryborough regions made the series quite useless.

It was mentioned in Chapter 5 that the elasticity of demand for an input may change over time. By estimating the input-demand function in double-log form, the detection of any such changes is foregone; the assumption is that the coefficient is constant through time. In their linear estimations, Metcalf and Cowling [26] found that the elasticity of demand for fertilizers in the United Kingdom fell from -1.2 in 1948 to -0.6 in 1965. Stigler [33, p.191] has suggested the weak proposition that the elasticity of demand for an input will be smaller the lower the proportion of total cost spent on this input, given the possibility of substituting other inputs. It has been calculated from data presented in Cowling et al., [5, p.205] that in the U.K. over the period 1954-55 to 1966-67 expenditure on fertilizers as a proportion of total farm costs increased from 2.3 per cent to 3.7 per cent. In a study of regional differences in fertilizer demand in the U.S., Griliches [18] suggested the hypothesis that the demand for
fertilizer is more price elastic in regions with low levels of fertilizer use. If this holds, then within a region, as fertilizer use increases, demand will become less price elastic. The results from the U.K. are in conformity with this hypothesis. Griliches' hypothesis was advanced on the basis that there is a "ceiling" to fertilizer response on crops or whatever (probably approached at a diminishing rate). It is also assumed that regions with low levels of fertilizer use are further away from their potential ceilings, and hence the same price change will result in larger percentage changes in fertilizer use than in high-use areas. On the basis of broad comparison between the Queensland areas and southern areas the hypothesis certainly cannot be rejected. However, while the large differences in levels of fertilizer use between these two broad groups appear to outweigh other considerations, it would be rash to justify all the difference in the price elasticity between any two areas in terms of the difference in levels of fertilizer use. This would assume that the production function in the two areas was the same.

A second hypothesis advanced by Griliches was that the more experience farmers have had with fertilizers, the faster they will adjust to price changes. The model which Griliches used was the one he had used in earlier work [16], and the same as that used by Metcalf and Cowling [26] - the Koyck-Nerlove partial adjustment model in the real price of fertilizers. As explained in Chapter 5, for
the "simple, alternative model" used in the present study it was preferred to estimate the adjustment to price changes directly by means of the polynomial distributed lag. For equations in which the lagged dependent variable is an explanatory variable, the Durbin-Watson statistic is no longer a valid test of the presence of serial correlation [34]. In the absence of such a test, however, it is not known whether the results estimated by Griliches are biased due to the presence of serial correlation. In such a case, the adjustment coefficient will be underestimated, and farmers will be estimated to adjust more slowly than they actually do. In his regional estimates, Griliches found that it took three to five years for the first three-quarters of an adjustment to a price change to take place.

From the results in this study there is no clear-cut conclusion about the nature of adjustment to price changes, except that adjustment is generally much faster than Griliches found. There was no indication of lagged adjustment in the Queensland data. Lags were estimated on the real price variable for some southern regions. These results are the reverse of what would be expected from Griliches' second hypothesis.

It has been demonstrated here that the adoption of pasture improvement practices can be explained by an input-demand model which takes account of the diffusion of advances in pasture technology. It has been seen that some advances may not be utilized until there has been a change in real or

1 However, Durbin [13] has recently developed a test for serial correlation in such circumstances.
relative prices, while other advances may be utilized immediately. It is acknowledged that the technology utilized when a price change occurs may be a mixture of the various techniques developed over time. This is the question of the blurring of the effects of technological change, raised by Salter [30, Ch. 4] and Brown [3, p. 74]. That is, when a price change induces a change in the stock of improved pastures, does the new stock incorporate best practice techniques? The model probably copes with this problem better than previous models which have analysed technological change, as it attempts to distinguish the diffusion pattern of each new technique. However, where there has been little or no adoption of any pasture improvement techniques (even though the region may have had a lengthy period of pasture research) and there occurs substantial adoption following a change in the price variables, there is no way of saying from the results what practices have been adopted. This problem will be discussed further in section 7.1.3.

Owing to the high degree of collinearity between the real and the relative price variables it was generally impossible to separate the effects of the two. Therefore, no firm conclusions can be drawn about the role which factor substitution between land and improved pastures has played in the demand for improved pastures. It should also be remembered that because the effects of these two variables could not be separated, the coefficients estimated on the
real price variable are probably overstated.

In the Townsville data, the level of collinearity between the real and the relative price variables was not as high as in other areas and significant coefficients were obtained on both variables in regressions on the PF series. In the Rockhampton (Brigalow) area, unlike other areas, the relative price variable dominated the real price variable, and by itself had better predictive power. It can be tentatively concluded that provided beef prices remain at their present level or continue to rise, and provided property values continue to rise and perhaps lead to some decrease in property size, more attention will be given to improved pastures in Queensland.

Finally, the regional elasticity coefficients estimated in the model have some value for policy considerations, as, for instance, in considering the effects of a change in the bounty on superphosphate. Also, the model provides a more realistic basis for making predictions about the effect of the growth in improved pastures on the growth in wool production than, say, an assumption that the rate of growth in improved pastures in the future will be the same as in some past period. The model can certainly help to provide a more realistic prediction of the demand for fertilizers than one based, say, on the area of Australia which has potential for pasture improvement.  

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2 See, for example, Scobie [32].

3 See, for example, Hutton [20], and Davies and Eyles [9]. "We have calculated an ultimate improved pasture acreage of 370 million for the whole of Australia (110 in the south, 260 in the north). If we assume that half this goal is achieved by the end of this century, and that the average annual requirement at that stage is 1 cwt. per acre, then the annual superphosphate requirement for pastures alone will be over 9 million tons" [9, p.90]. In 1965 total (cont'd.)
7.1.2 The research lag

Table 7.2 contains a summary of a number of characteristics of those research results found to have influenced the demand for improved pastures. The so-called research lag is discussed in this section. The research lag has been taken to be the lag between the commencement of a research project and the announcement of the research results, which marks the beginning of the adoption or diffusion lag. It was found that making a decision on the commencement date for the various research projects was often an arbitrary matter. It is frequently the case that the results of one project lead on to another project, and so on. At any stage in a chain of projects there may be information available which has practical application. The Rodd's Bay investigations in the Rockhampton (Spear Grass) region provide an example of the problem. Research was begun there in 1945-46. By 1947-48, results were available from experimental plots. These results could have had some impact on the demand for improved pastures from 1948 onwards (due to data limitations it was not possible to test this proposition in the model). Experimentally, research continued, as the plot results were then tested under grazing. In Table 7.2 the grazing experiment has been considered as a separate project.

3 (cont'd.)
production of superphosphate was 2.5 million tons. The only mention of demand considerations in Davies and Eyles' discussion was the following: "... with world population expected to double to 6,000 million by the year 2,000 A.D., and over half of the present population underfed (especially in terms of essential animal proteins) and ill-clothed, there is no doubt of the need for a great increase in animal products" [9, p.91].
In estimating the total contribution by agricultural research in the U.S., Evenson [14] fitted a function which included a distributed lag on research and extension expenditure. The lag estimated was considered to be the lag between expenditure on research and its effect on production. The highest $R^2$ was obtained with lags of from 6 to 7½ years. The research lags in Table 7.2 are, on the average, very close to Evenson's findings. There is not enough variation in the size of the lags to draw any inferences about the relationship between the size of the lags and the type of research involved.

7.1.3 The adoption lag

Numerous sociological studies have examined the so-called adoption lag - the numbers of farmers adopting new practices over time, see Jones [22]. The usual picture which emerges from these studies is one of a high proportion of farmers in a specified area adopting a practice over a long period of time. Griliches [15], in an analysis of the adoption of hybrid corn in the corn-growing area of the U.S., formed adoption curves in terms of the percentage of total corn acreage planted with hybrid corn. These data showed some regions moving to almost 100 per cent adoption within eight to ten years, while other regions took in excess of 20 years to reach somewhat lower ceilings. These differences in the rate of adoption Griliches related to the differences in profitability of hybrid corn.
## Table 7.2

### Characteristics of Successful Research Findings

<table>
<thead>
<tr>
<th>Regions</th>
<th>Research Finding</th>
<th>Type of Research</th>
<th>Rate of Return</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Research Total</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Project (%)</td>
</tr>
<tr>
<td>Northern Tablelands, N.S.W.</td>
<td>(i) Response to Superphosphate Use</td>
<td>Plant Nutrition</td>
<td>65-80</td>
</tr>
<tr>
<td></td>
<td>(ii) Success with sheep breeding</td>
<td>Pasture management</td>
<td></td>
</tr>
<tr>
<td>Southern Tablelands, N.S.W.</td>
<td>(i) Use of molybdenum and lime</td>
<td>Plant nutrition</td>
<td>53-67</td>
</tr>
<tr>
<td></td>
<td>(ii) Lime pelleting clover seeds</td>
<td>Plant nutrition</td>
<td></td>
</tr>
<tr>
<td>Riverina, N.S.W. (Irrigation)</td>
<td>Myxomatosis virus</td>
<td>Plant protection</td>
<td></td>
</tr>
<tr>
<td>Riverina, N.S.W. (Dryland)</td>
<td>Myxomatosis virus</td>
<td>Plant protection</td>
<td></td>
</tr>
<tr>
<td>Wheat/sheep zone W.A.</td>
<td>(i) Improvement of &quot;light lands&quot;</td>
<td>Plant nutrition &amp; management</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>(ii) Cyprus barrel medic</td>
<td>Plant introduction &amp; selection</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>(iii) Molybdenum deficiency on &quot;light lands&quot;</td>
<td>Plant nutrition</td>
<td>86</td>
</tr>
<tr>
<td>Rockhampton, Qld (Spear Grass)</td>
<td>Rodd's Bay grazing trial results</td>
<td>Plant nutrition &amp; species testing</td>
<td>32-51</td>
</tr>
<tr>
<td>Maryborough, Qld (Wallum)</td>
<td>Release of Siratro</td>
<td>Plant breeding</td>
<td>negative</td>
</tr>
</tbody>
</table>
One feature of the results in Table 7.2 is the comparative shortness of the adoption lag; measured in this study as the adjustment in the stock of improved pastures to a change in pasture technology. The purpose here has been to differentiate between those changes in demand for improved pasture which are a function of changes in price, i.e., movements along a production function, and those changes in demand which are a function of shifts of the production function itself. The former is captured by the price variable, the latter by the research variables. In the context of this model, adoption measured in terms of the total number of farmers adopting over time is a meaningless concept. In Chapter 5 it was argued that when an improvement in technology is made available, it should be expected that there would not be instant adjustment by those who found it profitable to do so at ruling prices. There would be a lag because diffusion of the knowledge would take time, and uncertainty about the new technology would be reduced over time. From the results in Table 7.2 it is apparent that this adoption or adjustment lag is quite short. Evidently, the remainder who adopt the new technology (which would appear to be the "long tail" measured in sociological studies) do so as part of the technology package they incorporate into investment in pasture improvement; investment which is induced by changes in input and product prices. Because the profit-maximizing model performs as well as it does here in explaining changes in the demand for improved practices, it has to be accepted that those who do not adopt an
innovation believe the new technology to be unprofitable. These results negate the conclusion which has been drawn from the sociological-type studies - that farmers react slowly to changes in technology.

Donald has argued that the reasons for the lack of adoption of pasture improvement practices in Australia prior to the post-war period, besides the lack of scientific knowledge in some areas, were:

"... the lack of knowledge of the practice among landholders, the unavailability of capital in a period of low prices, and sociological barriers."

He concluded that:

"... the delayed adoption of pasture improvement was due to the inadequacy of our extension services - and we must recognize the heavy cost of such inadequacy" [12, p.81].

The results obtained here imply that knowledge of new practices is in fact transmitted very quickly within a farming community. Much longer lags were tested for in the expectation of slow knowledge diffusion. Because the profit-maximizing model explains changes in demand as well as it does, the sociological arguments must also be discounted. It is admitted that with any increase in expenditure on extension, the education level of farmers is increased and any given technique will become more profitable; however, the benefits from such an increase in government expenditure must generate a suitable rate of return. There is no evidence here that a greater extension effort would be able to reduce the adoption lag significantly.
The capital availability argument has been dealt with previously. It implies irrationality on the part of both farmers and non-farmers. The hypothesis which is implied in the model tested here is that the profitability of adopting a given practice will increase with an increase in the price of the product, *ceteris paribus*. This implies that it was not unavailability of capital in a period of low prices, but unprofitability of capital investment. However, it has also been shown that the post-war upswing was not a case of "old" technology becoming profitable in a period of high prices, but rather a large payoff to improved technology.

Donald has also argued that the rate of adoption of agricultural practices

". . . depends not only on the capital outlay involved or the potential profit, but also on the simplicity of the change and even its appeal in aesthetic terms. . . . The most rapid adoption has been of those innovations which are cheap, simple and clearly profitable. A notable example is the use of trace elements on pastures. . . . On the other hand, some of the most valuable innovations, in particular those influencing land use, have been accepted all too slowly. Many wheat growers have been slow to adopt proven methods of ley farming, even though neighbours may have shown spectacular increases in production" [12, p.60].

The evidence from the Western Australian results is that the clover-ley system of farming, recommended in 1950-51, was adopted immediately, and that the adoption lag was the same

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4 Mansfield [25] found no relationship between a firm's financial health, as measured by its profitability, liquidity and growth rate, and the time it waits before introducing a new technique.
as the average observed. Indeed, there was no significant response to the second rotation results from the research station. In the Riverina areas, the clover-ley system had been recommended much earlier; at the time, it was recommended mainly as a control measure for skeleton weed. The conclusion which is drawn from the results obtained for these areas is that wheatgrowers did not diversify into a grazing/cropping system until the high post-war wool prices made the rotation system a more attractive alternative.

This study has examined only one form of investment, pasture improvement; thus no conclusions can be reached about the effect on adoption of the size of investment involved. The results support Donald's contention that technological advances in the form of trace elements have had rapid adoption. But it should be noted that most of the results which have been found to be important are in the area of plant nutrition. Therefore, the broader conclusion should be drawn, that after these pieces of knowledge were supplied the use of improved pastures became more generally profitable.

7.1.4 Rate of return on research

In the main, the few retrospective evaluations of agricultural research which have been made have related aggregated research inputs to aggregate supply and demand for agricultural products. The approach involved, typified by the studies of Griliches [19] and Evenson [14], has been
to include research (and perhaps extension) as an input in an aggregate production function. If the production function is in the form of a Cobb-Douglas function, the coefficient on the research variable can be interpreted as a production elasticity and the marginal product of research obtained (\( MP = \text{geometric mean of value added/geometric mean of research expenditure} \times \text{elasticity coefficient} \)). In this way Griliches [19, p.968] obtained a marginal product of $13 for each public dollar spent on agricultural research and extension in the U.S. After making allowances for private research expenditure and government support of agriculture, Griliches estimated an internal rate of return on total research and extension of between 35 and 170 per cent. Evenson [14, p.1423] obtained a marginal product for production-oriented research and extension in U.S. agriculture of $10. He did not attempt to convert this to a rate of return on investment.

Using the production function approach, Peterson [29, p.667] obtained a marginal return of $18.52 for each dollar spent by U.S. state experiment stations on poultry research. After allowing for private and federal research and extension, Peterson calculated that the marginal product of total research and extension in the poultry industry was $6.00. He converted this to an internal rate of return of 33 per cent by assuming that the average lag between research and adoption was 10 years. By an alternative approach, which measured the increase in
consumers and producers surplus resulting from productivity-
increasing poultry research, Peterson [29, p.665] estimated
that the internal rate of return on total poultry research
and extension was approximately 20 per cent. Peterson made
two points in comparing the results obtained from the
different approaches. First, the production function
approach does not take into account the costs of past
research involved in producing current results, though it
includes the benefits of past research in facilitating
current research. Second, the production function approach
yields a marginal rate of return whereas the other approach
yields an average rate of return. Poultry research began
in 1915, but net benefits from research were not positive
until the mid-1930's. One would expect, therefore, that
the marginal rate of return would be higher than the
average rate.

As mentioned previously, Griliches [17] developed
the approach of measuring the value of research to society
in terms of the increase in consumers and producers surplus
resulting from a shift in the supply curve. By this means
he calculated the benefits to the U.S. from research into
hybrid corn. The internal rate of return he estimated was
between 35 and 40 per cent.

In the present study, the main purpose of which
was to test the importance of particular research findings,
it has been found that some individual findings have
yielded very high rates of return. Because of this, the
average rate of return on total pasture research and extension in particular regions was also very high. While there are significant differences between regions, the rates of return on total pasture research were within the range of rates yielded by agricultural research in the U.S.

In respect of the rates of return calculated on total pasture research, however, a number of points should be made. No allowance has been made for the costs of basic research which has been carried out as part of the pasture research input in Australia. The benefits from research have been calculated within the often rather artificial boundaries of statistical divisions. Only in one instance, that of lime-pelleting of clover seed in W.A., was a research finding made in one area tested in another area. The results obtained in this instance illustrate how far and how quickly new information can travel. It may be that the research effect measured in the two Riverina areas included a spill-over of results from other areas, as well as the impact due to rabbit control by myxomatosis virus. Likewise, it was not attempted to measure the impact of the release of myxomatosis virus in other areas.

Because the average return on pasture research has been very high in the post-war period, it can also be

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5 Latimer and Paarlberg [23] have examined the spill-over of research results from one state to another in the U.S., and found that a single state could curtail its expenditure on research and extension without much change in farm income.
inferred that the marginal return on research has been high. The implication can be drawn that there has been under-investment in agricultural research, especially if these rates are compared with the yields on water conservation projects, see Davidson [7]. With regard to the future, given the present wool prices, and prospects for wool in the future, the expected benefits from a given increase in productivity in woolgrowing areas must be considerably reduced. However, this is not the only consideration. The expected benefits from pasture research will also be affected by the likelihood of breakthroughs in the different fields of science which are involved in pasture research and the possibilities for application of these new ideas in the different regions of Australia. As Samuelson suggests, the generation of new techniques may not be an altogether random process.

"Any scientist can tell you, after some breakthrough has been made, that there is likely to be 'pay-dirt' in pursuing a certain line of invention rather than another. Indeed, the whole art of decision-making in creative science is to discern such promising developments" [31, p.353].

7.1.5 The effect of rainfall

A summary of the results obtained from the inclusion of three dummy variables to represent levels of below-average rainfall is given in Table 7.3. Some of these estimates were not quite significant. Though significant estimates were not obtained for all regions and for all forms of the dependent variable, those obtained are
consistent enough not to be regarded as random. The response pattern suggested by these results is that following the severest drought years (FDD), there is a compensatory effort by farmers to increase the equilibrium level of the stock of improved pastures. In the years following less severe drought, there is either less of an offsetting increase in the stock level (Riverina), or, in areas where the absolute quantity of annual rainfall is larger (Queensland areas), the nature of the trade-off is to reduce the equilibrium stock level. There was also evidence from the Rockhampton (Brigalow) area that the form of land use affects the levels of rainfall at which these trade-offs take place.

These results suggest that there is a form of trade-off between rainfall and the demand for improved pastures, and that perhaps the range over which it takes place differs according to the size of the annual rainfall. Further work needs to be done to confirm this, perhaps by way of the examination of other decile ranges.

7.2 The Contributions made by Different Fields of Pasture Research

In regard to pasture improvement research, the research decision essentially comprises four sub-decisions: selection of the industry; selection of the geographical area; selection of the problem or topic for research; and selection of the field of research to undertake the project. In this section the results in Table 7.2 are
Table 7.3

Regional Estimated Coefficients on Drought Variables

<table>
<thead>
<tr>
<th>Region</th>
<th>Dependent Variable</th>
<th>Severity of Drought</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>FDD</td>
</tr>
<tr>
<td>Riverina (Dryland)</td>
<td>ln(SU)</td>
<td>0.91</td>
</tr>
<tr>
<td>Nthn Agric. Div. (W.A.)</td>
<td>ln(SP)</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>ln(SU)</td>
<td>0.27</td>
</tr>
<tr>
<td>Cent. Agric. Div. (W.A.)</td>
<td>ln(SP)</td>
<td>0.48*</td>
</tr>
<tr>
<td>Sthn Agric. Div. (W.A.)</td>
<td>ln(SP)</td>
<td>0.44*</td>
</tr>
<tr>
<td>Rockhampton (Brigalow)</td>
<td>ln(SP)</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>ln(SU)</td>
<td></td>
</tr>
<tr>
<td>Rockhampton (Spear Grass)</td>
<td>ln(PF)</td>
<td>1.82</td>
</tr>
<tr>
<td></td>
<td>ln(SU)</td>
<td>1.83</td>
</tr>
<tr>
<td>Maryborough (Wallum)</td>
<td>ln(SU)</td>
<td>0.82*</td>
</tr>
<tr>
<td>Maryborough (Dairy Pastures)</td>
<td>ln(PF)</td>
<td>1.03*</td>
</tr>
<tr>
<td></td>
<td>ln(SU)</td>
<td>1.07*</td>
</tr>
</tbody>
</table>

* = not significant

FDD = First Decile Drought
SDD = Second Decile Drought
TDD = Third Decile Drought
discussed in relation to the various fields of research to which the Division of Plant Industry has committed itself in its pasture investigations. The Division has given different degrees of emphasis to various fields of pasture research at different times, and it is proposed to see how effective its decisions were in this respect.

The importance which a research organization attaches to a particular field of research would appear to be related to the contribution which is expected from work in that field. It seems important, therefore, that research within the Division should be examined not only from the viewpoint of the benefits generated, but also with regard to the fields of research which have made those benefits possible.6 In its earliest years the Division of Plant Industry recognized the possibilities for increasing pasture productivity (by means of improved yields and/or quality) through plant breeding (intensive selection and breeding), improvement in plant nutrition (with the emphasis on superphosphate), and plant introduction and testing, see Dickson [11, p.6]. Later, the possibilities for improvement through pasture management studies, delineation of all major and minor plant nutrient deficiencies, and the

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6 In a research management context, it seems that a research organization will have a degree of inflexibility in that its technology is mostly embodied in its scientific personnel. Thus it may not be able to shift quickly to new areas of research. In this respect, the policy of having a significant proportion of the staff as fixed, short-term appointments, initiated by the late Dr. J.E. Falk, seems an eminently desirable one.
microbiological aspects of legumes were also recognized. In the first decade of the Division it appears that most importance in pasture research was attached to plant breeding and selection, and plant introduction. W. Davies [10], in his report to the C.S.I.R. in 1933, said that the four main areas of grassland improvement were species, strain, soil fertility, and pasture management. But he gave priority to the selection of strains of grasses and legumes suitable for the different regions of Australia. Davies did encourage the investigation of plant nutrition aspects other than the response to phosphorus. More importantly, he urged that the inoculation of clover and lucerne seed with rhizobium bacteria be investigated in areas where these legume species did not thrive. Interestingly, this area of research did not receive much notice in the Division for the next decade. The breakthroughs in legume microbiology were still to come at the time Davies was writing.

At the Eleventh International Grassland Congress held in Australia in April 1970, three prominent Australian agricultural scientists presented review papers on the contributions to the development of Australian pastures from research in plant introduction and breeding, plant nutrition, and legume bacteriology. These papers by Hutton [21], Loneragan [24], and Norris [28], provide a useful background against which to set the results of the present study. Research in the area of pasture management is also discussed.
7.2.1 **Plant introduction and plant breeding**

(i) **Plant introduction and testing**

Most of the exotic species of grasses and legumes now in widespread use in northern and southern Australia were introduced by chance before the C.S.I.R.O. organised the activity of plant introduction in 1931. To the present, about 50,000 introductions have been made into Australia; of these about 61 per cent are pasture and forage species [21, p.A3]. The early emphasis in the pasture plant introductions by the Division was on legumes for the monsoonal areas, i.e., northern Australia, and plants for the semi-arid areas; particularly for those areas of the wheat belt where erosion was a problem.

Hutton [21] provides a list of the important Australian pasture species and cultivars. Of the existing cultivars, 44 legumes and 23 grasses are suitable for temperate conditions and 23 legumes and 40 grasses are suitable for the tropics and sub-tropics. Hutton says that over half of all cultivars have resulted from introduction and improvement work since 1954. Of the legume cultivars suitable for southern Australia, 14 are subterranean clover cultivars. The selection within this species for earlier-maturing strains has been mentioned previously. Because of the adverse effect of the oestrogenic activity of subterranean clovers on lambing performance, there has been considerable attention given to the selection or development of cultivars with low oestrogenic activity.
Following introduction and testing, a number of cultivars have been registered by workers in the Divisions of Plant Industry and Tropical Pastures. However, only three of these were tested in the model. The others were not tested either because they were registered very recently (e.g., Oxley Fine-Stem stylo and Samford Rhodes grass in northern Australia), or because they were not recommended in the regions examined (e.g., Beenong and Yamina Cupped clover, and Olympus Rose clover in southern Australia). Woogenellup and Geraldton, two subterranean clover cultivars discovered in W.A., were tested; however, the conclusion was that they did not have an impact on the demand for improved pastures in the W.A. wheat/sheep zone. Miles lotononis was tested in the two Maryborough areas, but was found to have made no impact. It should be pointed out that those bred cultivars derived from introductions are included in the following sub-section.

The manner in which the stock of improved pastures has been measured in the empirical analysis gives most weight to changes in the area improved; although the use of the superphosphate data series is an attempt to take into account changes in the level of services per acre. It cannot be claimed, therefore, that changes in the capital stock of improved pastures which involve the substitution of one introduced species for another have been properly considered, e.g., the substitution of a subterranean clover cultivar low in oestrogenic activity for one high in
oestrogenic activity, or the substitution of a newly-recommended medic for a poorly-performing subterranean clover. To this extent the method of analysis used here is biased against research in plant introduction and plant breeding. However, if such innovations are adopted they must also have the effect of increasing the area under improved pastures, and in this sense should have made an impact which could be estimated in the model.

(ii) Plant breeding and intensive selection

Farrer's success in controlling disease and obtaining higher yields through wheat breeding seemed to figure very large in the Division's early stress on the possibilities for plant breeding in increasing pasture productivity [11, p.6]. The Division's efforts in this regard began in northern Australia at Lawes in 1935 and in southern Australia at Canberra and Moss Vale in 1936. The primary interest expressed was in the improvement of pastures in the marginal and summer rainfall areas. The work at Canberra was concentrated upon breeding an improved type of the native grass, Danthonia. The particular concern was the need for a drought-resistant pasture plant to rehabilitate wheat lands suffering from erosion. No positive results have come from this project. The work at Moss Vale, which was to breed plants for the higher rainfall, temperate zone, was closed down in 1941-42 without any progress being made. Genetics research in the Division lapsed during the
war years, but was re-established in 1950-51 with the formation of a Section of Plant Genetics. At this time there seemed to be a general feeling that genetics research would solve many of the pressing problems in agriculture. Again the emphasis at Canberra was on improved grasses for the south-eastern area of the wheat belt of N.S.W. In Queensland, with the expansion of pasture investigations there in 1953-54, the pasture plant breeding programme was broadened to cover specific regions such as the brigalow, spear grass, and coastal lowlands areas.

A number of cultivars have been registered by scientists in the C.S.I.R.O. following plant breeding or intensive selection, namely Howard subterranean clover, Cancreep lucerne, and two Phalaris cultivars, Siro Seedmaster and Sirocco, all of which are suitable for temperate Australia; and Siratro and three Townsville Stylo cultivars, which are suitable for various regions in northern Australia [21]. Of these, only Siratro was tested in the model. The release of this species did affect the demand for improved pastures in the Maryborough (Wallum) area, but the benefits generated in that area did not cover the costs of research. Cyprus barrel medic, introduced by the C.S.I.R.O. and developed by the W.A. Institute of Agriculture, was also evaluated in the model and the results confirmed Hutton's conclusion that this legume is "... now particularly valuable in the drier parts of the wheat belt of southern Australia" [21, p.A5].
In summarizing the admittedly incomplete evidence (both negative and positive) which has been generated in this study, it must be concluded that research in plant introduction and plant breeding has made few important contributions to pasture technology. Certainly not the sort of contribution which would be expected if Davies' [10] prognostications were correct. It must be acknowledged that the breakthroughs in legume bacteriology and the role of soil elements other than phosphate did not occur until the mid-1930's. It may be significant in this context that over half of all cultivars have been registered in the last 15 years, i.e., since the problems of plant nutrition and legume bacteriology have been largely understood. However, this pattern of cultivar registrations must be partly a function of the probably large lag between research initiation and results in the fields of plant introduction and breeding. It seems that the early emphasis on plant introduction and plant breeding may, at least, have been a case of putting the cart before the horse.

7.2.2 Plant nutrition and legume bacteriology

(i) Plant nutrition

Loneragan says that the growth in the use of artificial fertilizers (mainly superphosphate) on pastures since 1920 has been "... largely as a result of research findings, which led to the development of new concepts of the value of fertilizers to pasture production" [24, p.A13].
These four concepts are: (i) nitrogen and phosphorus deficiencies limit pasture production on almost all virgin soils during periods when water is adequate; (ii) trace element deficiencies also limit plant and animal growth on some soils; (iii) the symbiotic system of utilizing atmospheric nitrogen is sensitive to adverse soil conditions; and (iv) multiple soil deficiencies exist on many soils and these can be resolved by studying responses to, and interactions between, soil additives.

The deficiency of phosphorus for increased pasture production on most Australian soils, and the importance of correcting this for the stimulation of the nitrogen-fixing role of legumes was recognized by the early 1920's. However, in a number of well-watered regions, improved pastures did not result from the addition of superphosphate and the introduction of legumes. As a result of overseas research, and the discovery by Samuel and Piper that manganese deficiency caused the grey speck disease of oats in South Australia, it was realized that some of these problem soils were deficient in minute quantities of elements other than phosphorus and nitrogen (mainly molybdenum, copper, cobalt, and zinc). Three of the areas deficient in trace elements are included in the present

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7 The early breakthroughs in knowledge about the importance of elements other than phosphorus and nitrogen were mainly due to scientists working under A.E.V. Richardson at the Waite Agricultural Research Institute, Adelaide, see Davies [8, p.60].
study, viz., Southern Tablelands, N.S.W., parts of W.A. wheat/sheep zone, and the Wallum area in Queensland.

In setting up the Division of Economic Botany in 1927, the C.S.I.R. saw the improvement of pastures in higher rainfall areas by top-dressing, sowing, or other means, as one of its main areas of interest. However, it was a long time before the Division did any work on soil fertility (or indeed any agrostological research in higher rainfall areas, especially in southern Australia). The C.S.I.R. Annual Report of 1938-39 provides the first account of soil fertility investigations. These were conducted at its headquarters in Canberra. The reason which was repeatedly advanced for not undertaking this work sooner was the world-wide shortage of trained agrostologists. However, the impression has been gained that another constraint was the efforts by the state government institutions to prevent "unnecessary duplication" of research by the federal body. The only areas in the high-winter-rainfall zones where the Division has carried on a substantial research programme are Northern and Southern Tablelands in N.S.W., and south-western W.A. The remainder of the Division's pasture research has been in the semi-arid and summer-rainfall zones.

8 The Standing Committee on Agriculture was formed initially to oversee the research programme of the new Council; in particular, to see that the Council did not undertake research which the States considered to be their prerogative. The fact that two research organizations may be working on the same problem is not of itself an inefficient use of public funds; it may well be just the opposite, especially if the problem is an important one, see Nelson [27].
The importance of molybdenum for pasture production was discovered in 1942 in South Australia [1]. Loneragan says that:

"In many situations survival and growth of rhizobium in soils has proved so much more sensitive to soil conditions that it has dominated the response of pastures to nutrients. . . . inhibition of the reactions of nitrogen fixation by molybdenum deficiency has had a profound influence on the growth of pastures in all states" [24, p.A16].

The results of the analysis of data relating to pasture improvement on the Southern Tablelands, N.S.W. showed that the Division's investigations of the interactions between molybdenum, calcium, and the nitrogen-fixing capabilities of legumes made an important contribution in that area.9 There was also a very important response in the demand for improved pastures in W.A. to the knowledge that some soils were deficient in molybdenum. The Wallum area in Queensland has been shown to be deficient in a number of elements besides superphosphate. However, it was not possible to examine the significance of this finding. It was noted that the application of these results as measured in terms of fertilizer use has, as yet, not been very widespread.

9 The general impression gained is that in the early 1930's the subterranean clover/grass pastures on the Southern Tablelands were not performing as well as expected. Divisional research directed towards this problem had concentrated on plant breeding, to improve the species, and on plant introduction aimed at introducing better species. As it eventuated, the problems were mainly nutritional and, basically, microbiological. The time lag in prosecuting these latter lines of work delayed the solution to these problems until the late 1940's.
The light-land, wheat/sheep zone of W.A. was also shown to be deficient in the minor elements zinc and copper [4]. The efficacy of the copper-zinc-superphosphate/Dwalganup subterranean clover recommendations for the "light lands" was demonstrated in Chapter 6.

(ii) Research in legume bacteriology

Because pasture improvement in Australia has relied so heavily on introduced legume species, research in legume bacteriology is believed to have played an important role in pasture development [28]. As in the case of plant nutrition, the elucidation of principles of legume bacteriology in the earlier-developed, temperate zone led to fairly rapid progress of rhizobium research in tropical Australia. Besides those investigations into the relationships between plant nutrition and the nitrogen-fixing performance of legumes (described in the previous sub-section), legume bacteriological research has involved the following: (i) identification of rhizobium strains; (ii) assessment of the effectiveness of native and introduced rhizobium strains for the survival and performance of legumes; (iii) investigation of competition between rhizobium strains in the soil; and (iv) seed-pelleting procedures, production processes for inoculants, and improvements in the handling and application of inoculants. Improvements in pasture technology resulting from these investigations must lead to increased productivity of improved pastures.
However, some improvements would apply to the technology of manufacturing inoculants, and the gains from these would accrue in terms of decreases in the price of inoculants. As the construction of a price index for legume inoculants was not attempted, the measurement of such price effects was put aside.

One of the research findings which relates to the application procedures for use of inoculants by farmers is that of lime-pelleting of legume seeds. It was shown by scientists in the Division at Canberra that lime-pelleting overcame the adverse effect of excess soil acidity on the survival of rhizobia. Also, it enabled seeds coated with inoculant to be mixed and spread with superphosphate. This finding was tested for both the Southern Tablelands, N.S.W., and the W.A. wheat/sheep zone. Though the research itself was relatively unimportant, it had a substantial impact on the demand for improved pastures in both regions. The benefits most probably lie in the reduction in costs in not having to spread lime, and in that seed and fertilizer can be broadcast or drilled together.\(^{10}\)

Other research by the Division showed that heavy inoculation methods improved the establishment of legumes in areas where the seed may have to lie on the ground for some time waiting on germinating rains. This finding was

\(^{10}\) Apparently, so widespread has the use of the technique become, that an effort is being made to stop farmers from using it in tropical areas [28, p.A29].
tested in the irrigated part of the Riverina Division, but was found to be unimportant.

In summary, the payoff to research into plant nutrition for pastures appears to have been very high. Research by the Division has made a significant contribution in this field. However, the Division's actions are puzzling in two respects. First, that it delayed in moving into this field; and second, that it has done work in so few of the high-winter-rainfall areas in southern Australia. A number of reasons are advanced to explain these actions. The organization said at the time that agrostologists were unavailable. The evidence suggests that perhaps the Division was more preoccupied with work in the fields of plant introduction and plant breeding. Both of these reasons could be regarded as symptomatic of the lack of flexibility of a research organization in responding to changes in research direction. It is also suggested that the Division was constrained from doing research in the high-winter-rainfall areas because the state agricultural research bodies regarded this as their prerogative. As a result the Division was forced to concentrate research in the semi-arid and summer-rainfall areas where perhaps the expected payoffs from research have never been high.

7.2.3 Research into pasture management

The first time that pasture management research was mentioned in the Council's annual reports was in 1936-37.
Speaking generally about the Division's investigations into pasture problems, the Annual Report [6, p.7] stated:

"Broadly there are three major phases of investigation, viz., pasture management, introduction of suitable plants, and the improvement of pasture plants".

The implication of the statement is that improvements in productivity may be possible first, through changes in management; second, by the introduction of new pasture species; and third, by means of plant breeding. Work in the field of pasture management had not begun at that time. In 1938-39, however, the Wool Board made available a grant of $4,000 specifically for research into the management of pastures. The Division's commitment to this type of research increased from that time. The following were some of the pasture management studies undertaken subsequently:

- at Canberra a grazing experiment on improved pastures comparing rotational and continuous grazing, 1938-39;
- at "Gilruth Plains" Station, Queensland, a grazing experiment on native pastures to study different rates and times of stocking, 1940-41;
- at Canberra, an experiment on deferred grazing of improved pastures, 1944-45;
- at Trangie, N.S.W., a grazing experiment on native pastures to examine rates of stocking and deferment, 1945-46;
- at Armidale, an experiment on native pastures to compare continuous and rotational grazing, 1945-46;
- at "Gilruth Plains" the use of conservative stocking and pasture spelling to regenerate perennial native grasses, 1947-48; and
- at Deniliquin, N.S.W., an ecological study of the influence of grazing intensity on native pastures, 1949-50.
There can be two different rationales to justify research into pasture management. Either, that current farming practices are causing a decline in the productivity of the pastures, or, that current farm practice in terms of stocking rate and thus, pasture productivity, is sub-optimal.

With respect to most of the grazing trials on native pastures mentioned above, the first rationale was used to justify the Division's investigations. Concern was often expressed about the overgrazing of native pastures in low-rainfall areas and the subsequent degeneration of perennial native grasses. It is suggested here that the premises on which these investigations were undertaken were false, or at least, unproven.

The second rationale is perhaps more applicable to the grazing studies of improved pastures mentioned above. It is not suggested here that these investigations were misdirected; however, apparently few worthwhile results flowed from them. The following comments apply only to pasture management research on native pastures, and particularly to those studies in the so-called, semi-arid zone.

Pastures in the semi-arid zone have been under grazing since early in the 1830's. To assume that researchers could improve on existing farm practice by testing practices such as deferment of grazing, which had
been common knowledge for many years, was to ignore something which, according to Arrow and others, has played a considerable part in technical progress. Arrow called it "learning by doing" [2]. It has also been suggested that landholders in the pastoral zone have been exploitative of the pastures, causing their permanent degeneration. This assumes that either the landholders follow some short-run profit maximization strategy, or that the landholder is irrational. The first of these assumptions does not seem applicable to a situation where climatic considerations would appear to dictate that a long-term view be taken of farm income.

The questioning of the assumptions underlying the Division's early investigations of pasture management in low-rainfall areas is the subject of an empirical study reported fully in Appendix I. The study examines these assumptions within the context of a model which estimates the rate of technological progress in the semi-arid zone of N.S.W. The results of the study also have implications for current discussions about the need for research and legislation to prevent "exploitation" of the pastoral zones of Australia.

The results of the empirical analysis reported in Appendix I are briefly as follows:

(i) The estimated rate of technological advance in the period 1892 to 1968 was about one per cent; three-quarters of which was due
to factors affecting the numbers of sheep carried. The estimated rate of technological progress in the period since 1944 was greater than two per cent.

(ii) The carrying capacity of the rangelands has probably fallen during periods of low rainfall, but this decline does not seem to have been permanent, as during periods of higher-than-average rainfall, carrying capacity recovered. The results highlighted the lack of attention given by ecologists to long-term patterns in rainfall.

These results certainly contradict the assumption that there has been a continual decline in the carrying capacity of the area. The higher rate of technological advance for the period since 1944 suggests that landholders have been prepared to adopt improved husbandry practices made available to them in this period. Accusations of exploitation do not appear to be generally valid under such circumstances. An attempt was also made to test the hypothesis put forward above about the effect of learning by doing on productivity; however, the data available do not go back sufficiently far to allow a test of this hypothesis.

If the premises upon which pasture management research in low-rainfall areas have been based are invalid, it is reasonable to assume that there has been a poor
return on research of this nature. If there has not been a decline in productivity as claimed, it is also reasonable to suggest that in the absence of new technology which would raise pasture productivity in the area, returns from pasture management research will remain low. Until such new technology is provided, it seems that a basic research approach to the pasture/animal system in the pastoral zone would be more appropriate.

7.3 Summary

Because of multicollinearity between the real and the relative price variables, the effects of these could not be separated. However, changes in the three data series used as proxies for the stock of improved pastures were, in most cases, able to be predicted by the real price variable, certain research findings, and rainfall variables. There were marked differences in the size of the price elasticity between the northern and the southern areas. Broadly, this difference could be attributed to the more recent interest in, and hence, lower levels of use of pasture improvement techniques in the northern areas. Another feature of the estimated price elasticities was that the two fertilizer-use series were more elastic than the sown pastures series. This was a reflection of the general insensitiveness of the SP series. A sufficiently consistent pattern was obtained in the coefficients estimated on the rainfall variables to conclude that farmers do make trade-offs between rainfall and the level of
improved pastures. It seemed that the pattern of trade-offs could be influenced by both the absolute size of the annual rainfall and the type of land use.

The conclusion drawn from the short adoption lags estimated was that farmers quickly become aware of, and evaluate, new technology. Therefore, the inferences made about farmers' decision-making processes from the kinds of adoption lags constructed by sociologists should be questioned. A number of arguments which have been advanced for the lack of adoption of pasture improvement in the pre-war period were rejected. These included, lack of knowledge of new technology, sociological barriers such as "graziers refused to be farmers", and unavailability of capital in a period of low wool prices.

The rates of return estimated on the various research findings were compared with the results of a number of U.S. studies. It was suggested that in the post-war period the average and marginal return on pasture research in Australia has been high; and there has most probably been under-investment in agricultural research. Given the present prospects for wool prices, there is a reduced scope for such high returns in the future. However, the returns to research also depend upon the prospects for breakthroughs in the various fields of pasture research, i.e., for the returns on research to be as high in the future, the productivity breakthroughs must be so much more substantial.
It seems that plant introduction and plant breeding research in the Division have made a small contribution by comparison with that made by research into plant nutrition. It was pointed out, however, that the method of analysis used is biassed against this type of research. The delay of the Division in moving into plant nutrition research was queried. This may have been partly due to inflexibility, and partly due to a preoccupation with plant introduction and breeding. It was also suggested that the constraints by the states on the activities of the Division could have acted largely to restrict the Division to research into the lower-rainfall and northern areas.

An empirical analysis, fully reported in Appendix I, was made of the premises upon which early work on pasture management in low-rainfall areas was based. It was suggested that if these premises were incorrect, as was shown to be the case, then the payoff to such research was most likely very low.

7.4 References


"An overall summary of the discussion might picture the economic analysts and scientists as reservedly pessimistic about the future of quantitative economic evaluation methods for research and extension. One discussant contended that scientists should stress to decision makers that adequate tools have not been developed at present, that there is a role for such quantitative methods in their decision processes, that some progress is being made in the refinement of the methods and procedures, and that such developmental efforts are worth their support and encouragement."

14th International Conference of Agricultural Economists, Minsk, 1970

8.1 Summary of the Study and its Findings

The main aim of the study was to assess the economic gains to society from pasture research in the Division of Plant Industry. A secondary aim was to further understanding of the economic factors which influence the size of returns from research leading to new and improved processes. Interest in the research decision-making process has increased tremendously in recent years, and an attempt was made to delineate the role which economics should play in that process. It was argued that for decision-making in research, explicit benefit/cost analysis is not so critical for
efficient resource allocation as in other areas of public expenditure. This does not gainsay the fact that an improved understanding of the influence of economic factors on the benefits from research will result in more effective decision making.

In a review of literature relating to the importance of research and other factors in economic growth, it was seen that the role of research was far from fully understood. Efforts to measure the gains from research have concentrated either on very successful projects or on aggregate research expenditure. Prior to this study, there has been no attempt made to estimate the gains from all research findings generated by one organization in a given field of endeavour over a long period of time. A suggestion has been made that in order to improve our knowledge about the role of research in the economic process, we should attempt to increase our understanding of the nature of the transmission of new information. The single-equation regression model which was the basis for the empirical analysis in the study was formulated so as to be able to test the impact on improved pasture productivity of a number of research findings. Polynomial distributed lags were fitted to each of the research variables to provide information about the adoption process.

The role of agriculture and agricultural research in the Australian economy was discussed. It was noted that agricultural research has been used as a selective policy
instrument in attempts to correct balance of payments problems and to increase incomes in regions where there was considered to be an imbalance in income distribution. It was shown that under certain circumstances, agricultural research will be an inappropriate and ineffective means of pursuing such ends. The use of productivity-increasing research as a means of improving or maintaining the distribution of income could have a differential impact on marginal and infra-marginal units of production. An examination was made of the changes in returns to producers from such differential effects under different demand elasticities. It can be concluded that as the demand curve becomes more inelastic, in order to maximize economic benefits the emphasis in productivity-increasing research should be placed more and more on infra-marginal units of production. If agricultural research is intentionally directed towards ends other than the maximization of real income per head, it is inappropriate to judge its results solely in these terms.

An examination was made of the economic decision criteria which the Division of Plant Industry had employed in the past. It was found that during the 1920's and 1930's the organization had been quite explicit in its use of economic criteria. Decisions about research were made on the basis of the size of the expected reduction in unit costs and the size of the industry. If these are the important parameters, the effectiveness of research decision making depends on the effectiveness of the predictions
relating to the impact of research on the production costs of the region or industry, and to the future demand for the product. It was seen that for some decisions, especially about agricultural development in northern Australia and in the drier areas of Australia, the predictions made were unsoundly based. But it was in respect of these decisions that it seems most likely the direction of agricultural research was reflecting social aims other than pure economic growth.

In a situation of Paretian optimality, no spillover of research results to other industries, and foreign demand for the country's exports is infinitely elastic, the value to society of an increase in productivity can be measured as the increase in consumers and producers surplus resulting from a shift of the supply curve. In an examination of the sensitivity of the increase in consumers and producers surplus to changes in various parameters, it was pointed out that where this analysis is used as a criterion for ordering research projects it is more important to estimate correctly the expected decrease in unit costs than the elasticities of supply and demand for the product. In this respect, the decision criterion as used by the Division was a reasonably good approximation to the prescriptive model. It was pointed out that some qualifications should be recognized. If, as a result of protection, market distortions occur, the criterion is no longer a valid basis for comparisons of research projects relating to different industries. Also, in those industries where foreign demand
for Australian production is less than perfectly elastic, part of the increase in consumers surplus will accrue to overseas consumers.

The decision criterion used by the Division appeared to be static in nature. It was suggested that in this, together with other aspects of decision-making behaviour, the Division appears to avoid uncertainty by behaving in a like manner to that hypothesized for large firms.

Since the 1930's the Division has become much less explicit about the economic considerations underlying its decisions. A number of circumstances which have developed may explain this. First, there has been increased government intervention in agricultural markets. Second, the Division has undertaken proportionately more basic research over time. (Because the economic benefits of basic research are much harder to estimate, and because the likelihood of non-material benefits from research is much greater in basic research, allocation of resources to basic research is likely to be less amenable to economic analysis than applied research.) Third, the projects with which applied research in the Division has been concerned in recent times have been unsuited to the employment of the above criterion. During the 1920's and 1930's research was mainly concerned with diseases and pests of plants. In respect of these projects, the expected reduction in unit costs from research are directly calculable. The main
emphasis in the Division's applied research programme since
that time has been in the area of pasture improvement.
Improved pasture is only one of a number of intermediate
inputs in a production process. The results of a
productivity increase in an input are usually not directly
observable in output response. A method of analysis was
suggested for calculating the benefits from research which
leads to increases in the productivity of an input, and it
was applied in a retrospective evaluation of the Division's
pasture research.

Demand for the stock of the input, improved
pastures, was estimated as a function of real and relative
prices, rainfall variables, and changes in the state of
technology. Changes in the state of pasture technology were
related directly to research findings of the Division of
Plant Industry and other agricultural research organizations.
A formula was derived for estimating the value to society
of the shift of the input-demand curve. The model was
estimated for a number of regions wherein the Division has
carried out pasture research, and all research findings
which it was felt may have been important were tested in the
model. Internal rates of return were calculated for those
research findings found to have had an impact on the demand
for improved pastures. Rates of return were calculated
both for individual research projects and for total pasture
research and extension within the region.
Generally, the model performed well. It was acknowledged that the results on the tests of the research findings could be ambiguous, especially if a number of research findings are made about the same time. In a number of cases where other data could be used as a test of the results of the model, the results were heartening. While the results on the research variables may be ambiguous in the sense that it is not possible to differentiate between findings occurring simultaneously, the model tested a number of findings from which there has been no significant response. In this negative sense the model can give more explicit results.

Very high rates of return were calculated for most of the important research findings, and, as a consequence, average rates of return on pasture research in the post-war period were also high. Most of the important research findings were in the field of plant nutrition research. It was suggested that the Division had been slow to move into this field of research and that this was partly due to its preoccupation with research into plant introduction and plant breeding. In view of the high pay-offs to pasture research in the winter-rainfall areas and the negligible returns from similar research in the low-rainfall and summer-rainfall areas, the emphasis by the Division on these latter areas is puzzling. It was suggested that inter-institutional jealousies could have been a factor in determining this emphasis. While the
returns from pasture research in Queensland have been unimportant to date, maintenance of beef prices at their present or a higher level, will mean a greater pay-off to any future improvement in pasture technology. However, the justification for continuing pasture research there at its present high level rests heavily on the likelihood of important breakthroughs in pasture technology.

The results show that the adoption lag for new technology is on the average about four to five years; much shorter than sociological studies have shown it to be. Therefore, the image of farmers as slow to react to new ideas is not borne out, at least for an important proportion of Australian farmers.

8.2 Implications of the Study for Research Decision Making

A number of ways in which this study has contributed to an improved understanding of the economics of agricultural research have been mentioned above. In a more direct sense, the input-demand elasticities estimated for improved pastures in the various regions should be useful information for the allocation of resources to pasture research. This information, together with estimates of the expected increases in the marginal productivity of pastures, provide a reasonably sound basis upon which to choose between pasture research projects in various regions. Generally, for a given increase in the productivity of improved pastures, higher levels of use of the input and
less elastic input demand lead to a greater pay-off from research. The level of input use and the degree of elasticity in input demand may be related. It may also be the case that with greater levels of input use, there is less likelihood of an important discovery in pasture technology.

It has to be remembered that use of the input-demand function analysis is demanding in terms of historical data requirements. Estimation of the benefits from pasture research in an area where improved pastures have never been sown, will require use of other techniques such as budgeting [2], linear programming [1], or perhaps systems analysis.

8.3 Scope for Further Work

A number of refinements can be made to the econometric analysis carried out here which should provide the research decision maker with additional (and perhaps improved) information. It was suggested that specific aspects of pasture improvement technology connected with particular types of research could be subjected to the same sort of analysis. The input price series used could be improved by constructing indices which reflected all relevant pasture improvement costs in each region. Perhaps improved indices of the stock of improved pastures could be constructed, for example, to correct for bias against new technology such as new pasture species.
It was suggested that in the future there will be more research into new and improved products, which poses the problem of allocating research resources between improvements in processes and improvements in products. Economic analysis has not ventured into this area as yet. A possible approach to this problem was described, based on a recent development in consumer theory.

8.4 References


Appendix I

TECHNOLOGICAL CHANGE IN THE ARID ZONE OF NEW SOUTH WALES*

1. Introduction

This study examines the almost mechanistic interpretation of the changes in sheep numbers in the semi-arid and arid areas of Australia which is characteristically put forward as the basis of discussions relating to research, conservation, and tenure in these areas. It has come to be a statement of fact that these areas when settled for grazing suffered serious and permanent reduction in carrying capacity from overstocking. It is further claimed that this man-made depletion is being continued, especially during periods of economic stress (as in the current period of low wool prices and drought), and that any stability in production which these areas may have appeared to have gained has been due to the ability of graziers to carry this exploitation over a larger area by means of additional watering points and fencing for the stock. It is claimed

*A paper based on the work in this section has been accepted for publication, see R.C. Duncan, "Technological Change in the Arid Zone of New South Wales", Aust. J. Agric. Econ., (forthcoming).

1 For a recent example see Whalley [15].
that landholders have not been able or willing to develop and use management practices which prevent long-term exploitation of the rangelands and that such management standards must be provided by research and implemented either by means of extension or legislation.

In an investigation of these claims one is interested in the relationships between the results of past research and the possibilities for future research, technological progress or otherwise in the grazing industry, the scope for and the effect of capital intensification, and the development of improved farming practices by graziers. A method of analysis which lends itself to an examination of these matters is the estimation of the rate of technological change and elasticity of factor substitution in the framework of the constant elasticity of substitution (C.E.S.) production function, as developed by Arrow et al. [3].

The analysis is concerned solely with the arid zone of N.S.W. Data have been collected for the Western Statistical Division, and these are listed fully in Appendix II. A definition of the arid zone in N.S.W. as the area covered by the Western Division is more restrictive than that used by the Bureau of Agricultural Economics or by Perry [10]. The eastern boundary of the Western Division lies some distance to the west of the boundaries set by the B.A.E. and Perry, which means that the incidence of cropping and beef cattle activities and improved pastures can be more easily ignored.

2 For example, see Waring [14].
In 1868-69 the total area occupied for agricultural purposes in the Western Division was 76.7 million acres. The Division carried 11.7 per cent of the State's sheep and cut 13.3 per cent of the State's total wool production.

Settlement of the area began in the 1830's. The fastest rate of land occupation occurred in the 1870's and 1880's, due, according to Barnard [4], to the stimulus of higher wool prices. The peak of sheep numbers (14.1 millions) was reached in the early 1890's. Total sheep numbers fell to a low of 3.6 millions in 1902. Since that year sheep numbers have fluctuated within a range of 3.8 millions (1919-20) and 9.6 millions (1963-64). Accurate statistics for sheep numbers are not available prior to 1893. Data on wool production in the Division are not available before 1906. Wool production was 46.2 million lb. in 1906 and has since fluctuated within a range of 35.3 million lb. (1945-46) and 108.3 million lb. (1963-64). Wool production data for the four years 1926-27 to 1929-30 are not available.

The generally accepted interpretation of the events in the arid zone, which underlie the above changes in sheep numbers and wool production, proceeds in the following vein. The rate of stocking achieved in the early 1890's was far in excess of the natural carrying capacity with the inevitable consequences during the extended period of dry years from 1895 to 1902. These years of overstocking before and during the long drought period led to a permanent decrease in the carrying capacity of the zone because of the loss of plant species. For example, Perry writes:
"the grazing industries have been exploitative - they have been steadily mining the vegetation and land resources on which they depend for their future viability. This has not been documented by vegetation measurement but can be implied from areas in poor condition and from the trends in stock numbers. For all areas investigated stock numbers show a rapid rise following settlement, followed by a spectacular sudden crash (generally associated with a drought period) and then a recovery to a fairly steady level at about a third of peak figures. Relative stability is maintained only with continuing improvements, particularly extra watering points, which in effect bring more land within reach of stock."3

Further to his last point, Perry says:

"Maintaining stock numbers by increasing the area of land grazed is obviously a short-term pattern of development which will soon come to a halt. Production may appear static now but in reality it is unstable with further decline inevitable unless management based on conservation principles is adopted."4

It is argued that this continual decline in the productivity of the area will only be halted by somehow putting into practice improved management techniques developed by research.

"In Australia we are fortunate that although almost all our arid and semi-arid pastures now have a lower carrying capacity than they had originally, a relatively small proportion of the area has been badly degraded. This is more likely due to the relatively short period of occupation than to conservative management practices."5

"...there is a challenge for research to develop management standards which maximise for long-term ecosystem stability rather than for short-term animal productivity."6

3 Perry [11, p.258].
4 Perry [10, p.71].
5 Perry [10, p.11].
6 See Preface to Slatyer and Perry [12, p.viii].
These arguments pose a number of economic questions about the behaviour of graziers operating in the arid zone. First, the short-term exploitative behaviour attributed to them does not fit well in a situation where climatic considerations dictate that a long-term view be taken of farm income. Secondly, the arguments appear to deny any "learning by doing" effect; or if there is any such effect that landholders are prepared to take advantage of it. If tenure or other considerations make landholders unwilling to improve their management practices, this affects the adoption of new practices generated from both internal and external forces. So, thirdly, what effects have new farming practices coming from research had on productivity? Fourthly, has there in fact been a shift towards more capital intensive production as implied by the argument relating to the increase in watering points?

2. Assumptions and Model

As stated previously, for statistical reasons the arid zone of N.S.W. is defined here as the Western Statistical Division. This restrictive definition, while not affecting the application of any results coming from this exercise, makes it easier to assume that woolgrowing is the only pastoral enterprise and that wool is the only
product of the area. To examine closely the nature of any technological change and the sources of any such change it has been assumed that total sheep numbers is a measure of output which excludes only the change in wool production per sheep. By this means, the estimates of the rate of technological change can be split into changes in wool per sheep and changes in ability to carry sheep. Of course, this assumption ignores the way in which sheep numbers measure the scope for income derived from selling sheep.

Because the size of and changes in the elasticity of substitution between capital and labour is of interest, the Cobb-Douglas specification of the input-output relationship, which assumes this elasticity to be equal to unity, will not be used. It will be assumed, following the C.E.S. specification developed by Arrow et al., that production in the grazing industry of the arid zone can be characterised by the class of linear homogeneous functions written,

\[ Y = A_0 e^{\lambda t} \left( \delta L^\rho + (1-\delta) K^{-\rho} \right)^{-\frac{1}{\rho}}. \]

Output \((Y)\) is a function of labour \((L)\), capital \((K)\) and changes in the level of productivity; where \(0 < \delta < 1\) and

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7 According to the Bureau of Agricultural Economics, *The Australian Sheep Industry Survey 1960-61 to 1962-63*, Canberra, May 1965, for the 3-year period of the survey wool returns were approximately 80 per cent of sheep enterprise returns, which in turn were 91 per cent of average total returns per property for properties in the pastoral zone of N.S.W.
\( \rho > -1 \) are constants, \( \rho \) being the substitution parameter related to the elasticity of substitution \( \sigma \) through the formula \( \sigma = \frac{1}{1 + \rho} \). In order to avoid the problems in non-linear estimation associated with estimation of the function in this form the side relation for output per man is derived and estimated. Under the postulates of perfect competition, the labour factor equilibrium condition derived from (1) can be written,

\[
\ln(Y/L) = \ln A^* + \sigma \ln(W/P) + \lambda(1-\sigma)t,
\]

where \( A^* = (1-\sigma) \ln A^0 - \sigma \ln \delta \), \( W/P \) is the real wage, and \( t \) is time. The rate of Hick's-neutral technological advance, \( \lambda \), and the real wage coefficient or elasticity of substitution parameter, \( \sigma \), are estimated from (2). With a valid model similar estimates for \( \sigma \) and \( \lambda \) should also be obtained from estimating a function for the output/capital ratio. These two means of estimation were not compared as the data for capital were by far the least satisfactory of all series available.

Rainfall variability must be considered a most important influence in the arid zone. Consequently, it was attempted to construct a fairly sensitive series for rainfall data to be included as shift variables in the estimating equation. Gibbs and Maher [7] and Maher [9] have compiled a series of maps of Australia showing, for the years 1885 to 1968, annual rainfall variability in terms of decile ranges. The maps illustrate annual rainfall in seven categories:
(i) very much above "average" (decile range 10)
(ii) much above "average" (decile range 9)
(iii) above "average" (decile range 8)
(iv) "average" (decile ranges 4 - 7)
(v) below "average" (decile range 3)
(vi) much below "average" (decile range 2)
(vii) very much below "average" (decile range 1).

For the present purposes these have been given the values 3, 2, 1, 0, -1, -2, -3, respectively. The value assigned in each year was made by appraisal of the overall situation in the Division.

The time of the year at which the various statistics have been collected varies over time for some series and also varies between series. In general, however, it was attempted to obtain the following relationship between the various series in the estimated equation (3),

\[(3) \ln(Y/L) = \ln(1 + \sigma) + \alpha t + a_1 R + a_2 R_{-1} + a_3 R_{-2} + u\]

where \(L\) is the number of persons permanently employed in the pastoral industry at the time the annual agricultural statistics are collected (since 1931-32, at 31st March); 9

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8 The values 4, 2, 1, 0, -1, -2, -4 were also tried but the \(R^2\) was not altered.

9 All persons permanently employed (including owners and managers) on agricultural holdings in the Western Division are available from 1892-93 to 1968-69. Persons permanently employed on pastoral holdings are available from 1892-93 to 1941-42. To use the latter series in the analysis it was augmented by subtracting the number (or an estimate where not available) of agricultural holdings in the Division below 2,000 acres from the total number of persons employed. This was done on the...cont'd.
\( Y_w \) is the quantity of wool produced in the full year preceding the data collection date; \( Y_s \) is the number of sheep on rural holdings at each data collection date; \( W \) is the wage rate ruling at the time the agricultural statistics are collected; \( P \) is the N.S.W. average greasy wool price for that year ending 30th June preceding the date the farm statistics are collected; \( R \) (lagged two periods) is the rainfall for that year ending 31st December which coincided most closely with the full year for which wool production was recorded; and \( u \) is the disturbance term.

3. Results

The equation estimated by ordinary least squares for wool production \((Y_w)\) per man for the 58 years over the period 1906 to 1967 was,

\[
\ln(Y_w/L) = 8.38 + 0.13 \ln(W/P) + 0.013t + 0.027R + 0.041R_{-1} + 0.01R_{-2}
\]

\[
(4) \quad (0.60) (0.09) (0.002) (0.016) (0.016) (0.02)
\]

\( (\text{standard errors of coefficients in brackets}) \quad R^2 = 0.67 \)

\( \text{Durbin-Watson statistic (d) = 0.69} \)

9 \( \text{(cont'd.)} \)

assumption that these holdings would not be engaged in wool production and would not be employing more than one person, i.e., the operator. Casual labour was not included as this would be primarily for shearing; moreover, the numbers included in different categories are not identifiable. The labour series was not adjusted to a standard hours per week as there has been no statutory provision for hours worked in the pastoral industry until very recently.

10 Data are available in the N.S.W. Statistical Register for the average yearly earnings for a stockman up to 1917. After that date the minimum award wage for a stockhand was used.
Given the above estimate of the elasticity of substitution, 0.13, the annual rate of technological advance is 1.49 per cent (calculated as \((0.013/1 - 0.13)\times 100\)). However, given the degree of positive serial correlation present in the disturbance term with the equation estimated in this form the estimated parameters are not necessarily fully efficient. One possible cause of serial correlation in the disturbance term is misspecification due to excluded variables. A possibility which suggested itself was that the farm labour market is not in instantaneous equilibrium. To investigate this hypothesis a distributed lag model of the Koyck-Nerlove type was estimated. This is equivalent to including the lagged dependent variable as an explanatory variable. The resulting estimated equation was,

\[
\begin{align*}
\ln\left(\frac{Y_w}{L}\right) &= 2.84 + 0.018\ln\left(\frac{W}{P}\right) + 0.0042t + 0.041R + 0.022R_{-1} - 0.017R_{-2} \\
&\quad + 0.68\ln\left(\frac{Y_w}{L}\right)_{-1}
\end{align*}
\]

\(a_1 = 0.128\) \hspace{1cm} \(\sigma = 0.056\) \hspace{1cm} \(R^2 = 0.81\)

\(a_2 = 0.069\) \hspace{1cm} \(\lambda = 0.0131\) \hspace{1cm} \(d = 2.01\)

The result of this exercise was that the fit of the equation has been substantially improved. However, while the coefficient on the lagged dependent variable is

\[\text{For a full discussion of this partial adjustment model see Wallis [13]. Other distributed lag models were also tried, without success, such as a simple moving average and the quadratic form of the Koyck-Nerlove model.}\]
highly significant, it is not possible to say whether or not
the partial adjustment hypothesis of the labour market is
substantiated as the estimated value for $\sigma$ is near to zero.
With these results, together with the fact that the Durbin-
Watson statistic is now almost exactly 2.0, one can claim
to have corrected for the serial correlation bias rather
than to have substantiated the partial adjustment
hypothesis. Therefore, the coefficients estimated in (5)
are preferred to those in (4); which means that the
elasticity of substitution was approximately zero for this
period while the average annual rate of technological
progress was 1.31 per cent. The picture emerges of the
farm-firm operating along a fixed capital/labour path with
current rainfall playing the major part in changes in output
from year to year.

---

12 According to recent work by J. Durbin [6], a large-
sample test of bias in the Durbin-Watson statistic when
a lagged dependent variable is included is provided by
the equation

$$h = a \sqrt{\frac{n}{1 - n \hat{V}(b_1)}}$$

where $\hat{V}(b_1)$ is the estimate of variance of the co-
efficient on the lagged dependent variable and $a = 1 - \frac{1}{2} d$; $h$ is tested as a standard normal deviate.

13 For the effects on estimation in ordinary least squares
of autocorrelated errors and lagged dependent variables
see Wallis [13, p.774].

14 See Griliches [8, p34].

15 This is calculated as $(0.0042/0.32)100$ in the context of
the partial adjustment hypothesis, see Wallis [13]. The
rate of technological progress in equations (4) and (5)
is thus the same, if $\sigma$ is assumed equal to zero.
In order to investigate events as far into the past as possible, recourse was made to sheep numbers per man as a measure of production per man, since wool production data are not available prior to 1906. Also, in this way it was hoped to split the rate of technological change into two components - that due to changes in the carrying capacity, and that due to changes in wool production per sheep (the difference between the estimated rates of technological progress for wool production per man and sheep numbers per man). In order to calculate this difference, sheep numbers per man \((Y_s/L)\) was used instead of wool production per man for the period 1906 to 1968. The resulting estimated equation with the lagged dependent variable correction for first-order serial correlation was,¹⁶

\[
\ln(Y_s/L) = 2.41 - 0.013\ln(W/P) + 0.0032t + 0.06R - 0.001R_{-1} - 0.033R_{-2} + 0.68\ln(Y_s/L)_{-1}
\]

\[
(0.79)(0.057) (0.0013)(0.01)(0.011) (0.011)
\]

\[a_1 = 0.187 \quad \lambda = 0.01 \quad R^2 = 0.78\]

\[a_3 = 0.103 \quad d = 1.8 \quad h = 1.3\]

Comparing the results of the estimated equation for sheep numbers per man with that for wool production per man it can be seen that only one quarter of the annual total rate of technological advance is accounted for by factors which change wool production per sheep, while the remainder is due to factors which change the numbers of sheep carried.

¹⁶ The value of h is below 1.96 so the null hypothesis that the Durbin-Watson statistic was not biased could not be rejected.
Current rainfall affects sheep numbers per man more than wool production per man. The reason for this would seem to be the differential effect of rainfall on numbers through lambs, for which the wool yield is well below the average. Rainfall lagged two periods is not significant in regard to wool production per man but has a significant negative co-efficient for sheep numbers per man. It was suspected that this was more likely a statistical phenomenon resulting from the complex lag structure which has been imposed rather than a real influence. 17

Going back as far as the data on sheep numbers allow, i.e., the period 1892 to 1968, the estimated equation for sheep numbers per man is,

\[
\ln(Y/L) = 2.14 + 0.035\ln(W/P) + 0.0025t + 0.072R + 0.0001R_1 - 0.026R_2 - 0.0001R_3 + 0.67\ln(Y/L)_{-1} \]

\[
\begin{align*}
\alpha_1 &= 0.218 \\
\lambda &= 0.0076 \\
R^2 &= 0.78 \\
\alpha_2 &= 0.08 \\
d &= 1.76 \\
h &= 1.53
\end{align*}
\]

17 That this was so was verified by estimating the equations in the form \( \ln(Y/L) = \ln A + \sum (i) \ln(W/P) \)

\[
\begin{align*}
&+ \lambda(1-\sigma)t + \sum a(i)R + u ; \quad \text{that is,} \\
&i=0
\end{align*}
\]

by estimating a separate polynomial distributed lag [1] on the real wage and rainfall variables. According to this model, rainfall lagged once is most important in the period 1906-68, whereas in the longer period current rainfall is most important. All significant lag coefficients on the rainfall variable were positive.
Comparing these results with those for the later period, equation (6), it is seen that the co-efficients measuring the rate of technological change and the effects of rainfall are almost the same. In other words, the period from 1892 to 1905, during which overstocking was supposed to have caused the greatest damage to carrying capacity, has not affected the overall rate of increase in productivity from this source very much at all. If anything, output per man has become slightly less influenced by rainfall. (Any decrease in rainfall influence would be at least partly due to the reduction in stocking rates permitted under governmental lease conditions.) An even more important point revealed in the course of the study was that the rainfall data in Gibbs and Maher show that during the period 1885 to 1891 when the most exploitative grazing period is held to have taken place, the area experienced a series of rainfall levels which have not been approached since. In this seven-year period there were three years of rainfall "very much above average" and two years of rainfall "much above average". The nearest any subsequent period has come to repeating this was during the years 1954 to 1956 when the area had two years of rainfall "very much above average" and one year of rainfall "above average". In 1956-57 sheep numbers rose to 9.1 million.

What would happen to sheep numbers if the rainfall conditions of the years 1885 to 1891 were repeated now, starting from 1969? Using the preferred equation for sheep
numbers per man for the period 1906-69,

\[(8) \ln(Y_s/L) = 2.41 + 0.0032t + 0.06R - 0.033R_{-2} + 0.68\ln(Y_s/L)_{-1}\]

it was calculated that by 1974-75 sheep numbers per man would be 3,428 (government leasing arrangements permitting); higher than at any time for which figures are available. Given the number of persons employed in 1892-93, this would mean a sheep population of 18.8 millions (in the peak year of 1892-93 the sheep population was 14.1 millions). Given the number of persons employed in 1956-57 or 1963-64, the two recent peaks in sheep numbers, the predicted population would be 14.2 millions and 13.0 millions respectively - well above the sheep numbers for those years of 9.1 millions and 9.6 millions.

These calculations, even given the limitations of this sort of exercise, do serve to emphasize further the extent to which rainfall has been neglected by those drawing conclusions from the changes in sheep numbers.

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18 Confidence limits could not be calculated due to the inclusion of the lagged dependent variable.

19 Beadle [5] did run correlations between stocking rate and current rainfall and between stocking rate and rainfall lagged one period but found no correlation between them. He did comment on the high rainfall which Bourke received in 1891, but failed to realise the number of high rainfall years within the period 1885-1892. Instead he was transfixed by the differences in stocking numbers between 1890 and 1902, so much so that he concludes [5, p.91]:

"The lack of a correlation is due mainly to the fact that pasture deterioration has assumed such vast proportions in many districts that stocking values, even in the best seasons, could never approach the high values of last century."
The evidence to this point certainly contradicts the extreme position that there has been an absolute decline in productivity due to exploitation in grazing. A less than extreme position might be taken to the effect that the rate of technological advance has been less than it should have been, due to the mismanagement of range-lands. A number of possibilities exist by which productivity gains may have been made. Productivity gains from external sources may or may not be embodied in new capital. Productivity gains are also possible from internal sources such as improvements in management or through economies of scale in production.

One of the features of this area is that there is little scope for on-farm investment. Moreover, the direct type of capital formation affecting carrying capacity, extra fencing and watering facilities, appears to embody little technological change. It is more likely that less obvious capital items such as road transports, over-land vehicles and aircraft, and external capital formation such as roads could have contributed in this way. However, embodied technological progress will be ignored. Further, attempts to estimate the impact of economies of scale were unsuccessful. This leaves for consideration productivity gains flowing from

(i) improved farm practices brought about by external research (whether having particular relevance to the area or not); and

(ii) "learning by doing" effects.
(i) **External research as a source of productivity gains**

For the arid zone the main productivity advances due to research are believed to have come from advances in knowledge about animal nutrition, animal husbandry and control of rabbits. In particular, the improvements in knowledge which it is believed have been important at the individual property level, relate to nutrition, feeding economics and flock husbandry practices such as blowfly and internal parasite control. The watershed period for these advances has been taken to be the end of World War II. This period also marks the intensification of pasture research in Australia. However, the benefits from this direction are believed to have been negligible. Unlike research in animal nutrition and animal husbandry, pasture research is more geographically specific. There has been a continuing interest by all public research bodies in the arid zone (plant introduction, pasture management, etc.) since the possibilities of pasture improvement were realized, but there has been no concentrated effort in the arid zone until recently with the formation of the C.S.I.R.O. Rangelands Research Unit.

(ii) **The learning by doing hypothesis**

As shown previously, one rationale for agricultural research in this zone is that research is needed to establish the sound rangelands management practices which landholders cannot or are unwilling to develop. This seems to ignore
the implications of the learning by doing principle which Arrow [2] developed. The concept is briefly as follows. By repetition of the same act in a given environment, efficiency is increased - a process of learning. Changes in the environment stimulate new learning situations. New investment is postulated to impose changes on the system and thus present new learning situations. It has been argued, therefore, that to ignore the gains from learning by doing is to undervalue the contribution of capital.

In the arid zone, however, it can be argued that there has been no capital formation which has changed the environment in such a way as to present a new learning situation. But the landholder has been faced with a continually changing climatic environment. Whereas Arrow and others have assumed the contribution from learning by doing to be a function of cumulated output or cumulated investment, it seems reasonable to assume that in the present case it is purely a function of time. In other words, it is to be expected that landholders when unfamiliar with the environment would indeed be prone to miscalculate the carrying capacity of the land but that over time management would improve. The corollary of this line of reasoning is that research into rangeland management can be expected to yield little in the way of improved practices in the absence of a significant breakthrough in basic knowledge. It is felt that it is misleading to approach the problem of arid lands research in the manner in which
it is apparently being done; as though it were an applied research problem.

If, in fact, learning by doing has been a source of productivity gains in the way outlined, it must be shown that the rate of technological advance was comparatively fast in the early years of settlement. It is hypothesized, therefore, that the annual rate of technological change should be expected to exhibit marked curvilinear features in the earliest period of settlement - with first an increasing phase followed by a decreasing phase.

To test the learning by doing hypothesis as formulated here and to see what effect there has been on productivity from the increased research effort since the war the period from 1892 to 1968 has been split into a number of sub-periods. In this way it was hoped to provide a picture of the changes in the rate of technological advance over time. Moreover, the linear estimates of $\lambda$ for each sub-period for both wool production per man and sheep numbers per man were compared with curvilinear estimates obtained by solving for the equation

$$\ln(Y/L) = \ln A^* + \sigma \ln(W/P) + \lambda_1 (1-\sigma)t + \lambda_2 (1-\sigma)t^2 + a_1 R + a_2 R_{-1} + a_3 R_{-2} + u$$

The preferred equations are shown in Table 1.

Given the problem of autocorrelated errors associated with these estimates (equations (v) and (vi) are not free of serial correlation bias) the picture which
### Table 1

**Estimated Equations on Output Per Man for Various Sub-periods**

<table>
<thead>
<tr>
<th></th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
<th>(iv)</th>
<th>(v)</th>
<th>(vi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheep Numbers per Man</td>
<td>1926</td>
<td>Sheep Numbers per Man</td>
<td>1926</td>
<td>Sheep Numbers per Man</td>
<td>1926</td>
<td>Sheep Numbers per Man</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>(X_i)</th>
<th>ln A*</th>
<th>ln (W/P)</th>
<th>(t)</th>
<th>(t^2)</th>
<th>(R)</th>
<th>(R_{-1})</th>
<th>(R_{-2})</th>
<th>ln (Y/L)</th>
<th>(R^2)</th>
<th>(d)</th>
<th>(h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheep Numbers per Man</td>
<td>8.97 (1.08)</td>
<td>-0.19 (0.15)</td>
<td>-0.048 (0.012)</td>
<td>0.0013 (0.0003)</td>
<td>0.136 (0.021)</td>
<td>0.085 (0.021)</td>
<td>0.043 (0.023)</td>
<td>0.35 (0.18)</td>
<td>0.71</td>
<td>1.20</td>
<td></td>
</tr>
<tr>
<td>Sheep Numbers per Man</td>
<td>9.83 (1.63)</td>
<td>-0.36 (0.25)</td>
<td>-0.022 (0.037)</td>
<td>0.0015 (0.0016)</td>
<td>0.105 (0.03)</td>
<td>0.06 (0.023)</td>
<td>0.02 (0.03)</td>
<td>0.44 (0.17)</td>
<td>0.75</td>
<td>1.41</td>
<td></td>
</tr>
<tr>
<td>Sheep Numbers per Man</td>
<td>8.22 (0.91)</td>
<td>0.004 (0.087)</td>
<td>-0.042 (0.021)</td>
<td>0.0006 (0.0003)</td>
<td>0.048 (0.013)</td>
<td>0.036 (0.013)</td>
<td>0.06 (0.03)</td>
<td></td>
<td>0.50</td>
<td>0.82</td>
<td></td>
</tr>
<tr>
<td>Sheep Numbers per Man</td>
<td>10.2 (1.02)</td>
<td>0.06 (0.09)</td>
<td>-0.049 (0.024)</td>
<td>0.0007 (0.0003)</td>
<td>0.037 (0.015)</td>
<td>0.038 (0.015)</td>
<td>0.018 (0.014)</td>
<td></td>
<td>0.53</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>Sheep Numbers per Man</td>
<td>4.86 (1.25)</td>
<td>-0.09 (0.07)</td>
<td>0.0154 (0.004)</td>
<td>0.0006 (0.0003)</td>
<td>0.051 (0.012)</td>
<td>0.018 (0.015)</td>
<td>-0.012 (0.016)</td>
<td></td>
<td>0.80</td>
<td>1.25</td>
<td>2.03</td>
</tr>
<tr>
<td>Sheep Numbers per Man</td>
<td>5.05 (1.52)</td>
<td>-0.04 (0.09)</td>
<td>0.0162 (0.005)</td>
<td>0.0007 (0.0003)</td>
<td>0.048 (0.014)</td>
<td>0.017 (0.016)</td>
<td>-0.003 (0.018)</td>
<td></td>
<td>0.79</td>
<td>1.59</td>
<td></td>
</tr>
</tbody>
</table>

(a) Not able to be calculated because \(n \hat{v}(b_i) > 1\).
emerges is as follows. As suggested by the comparison of
the \( \lambda \) estimates in equations (6) and (7) the period from
1892 to approximately 1910 was indeed a period of declining
productivity. Productivity gains were realized from about
1910 onwards until the 1930's when there was another decline.
The period since 1944 has seen comparatively high
productivity gains of 2.45 per cent annually; 2.37 per cent
being accounted for by factors which have influenced changes
in sheep numbers per man. The implications of these results
for an explanation of the sources of these gains or losses
are interpreted as follows. The learning by doing hypothesis
remains virtually untested as it can be argued that the bulk
of the gains from this source could have been realised in
the 20 years prior to 1892; a period when the area was fully
settled for most of the time. While there has been an
overall increase in productivity, it appears that there
have been fluctuations in productivity, largely associated
with periods of high and low rainfall. The results of
fitting ten-year moving averages to the rainfall data
support this assertion. If this is so, the ability of the
area to recover its productivity must be recognized as another
warning to take account of long-run factors in any
interpretation of events in the arid zone. The comparatively
high rate of productivity gain in recent years appears to
lend support to a pay-off from research but it should be
realised that this period is notable for the absence of very
low rainfall years.
4. **Summary**

The interpretation which has been given of the historical changes in sheep numbers in the arid zone of N.S.W. as being entirely the result of the exploitative activities of landholders is clearly wrong. The exceptional rainfall during the period in which sheep numbers rose to the all-time peak in the early 1890's seems to have been neglected. It may be true that the carrying capacity of these rangelands has declined during periods of low rainfall, but it is just as likely true that the carrying capacity has recovered during periods of high rainfall. The simple predictive exercise described leads to the belief that if the climatic conditions experienced in the late 1880's were repeated now, that sheep numbers could be greater than the peak in the 1890's.

The implied criticism of property management appears to be unjustified. The results herein indicate that landholders have made use of the information which has been made available to them by research since 1943-44. If landholders are prepared to put into practice relevant information received from external sources, there is every reason to believe that they would make use of information coming from internal sources. Certainly there will be exceptions, but discussions at this level do not run in terms of exceptions.

It has been claimed that any increase or stability in productivity has been possible only because of the
intensification of watering points. The evidence here implies that there has been no movement towards capital intensification as this argument would suggest. Because the elasticity of substitution is zero, this implies that any increase in capital formation would be accompanied by an increase in labour. Some evidence is available which bears this out. The Sheep Industry Survey data published by the B.A.E. show that between 1954 and 1957 investment in water supply facilities by properties in the pastoral zone of N.S.W. increased from 5.6 per cent of total capital to 8.1 per cent. In the same period, investment in non-livestock capital stock (water supply, fencing, building, and plant) almost doubled. This was by far the biggest increase in capital stock for these properties since the survey began in 1953. The increase in water supply facilities, absolutely, and as a proportion of total capital stock, was also the largest for the period 1953 to 1967. During the period 1954 to 1957 the number of persons employed in the pastoral industry in the Western Division rose by 16 per cent. These changes suggest a response to an economic stimulus not connected with "exploitative" motives; for example, the "income" effect of a change in relative prices.

Of course, the corollary to the landholders' inability to move to more capital-intensive production is that they are severely limited in the possibilities for coping with changes in the level of real wages.
While the rate of technological advance achieved since 1943-44 has been surprisingly high, at least to the writer, it is surely not comparable with other sectors of the industry or of the economy in general; nor does it seem to be high enough to counter the inevitable squeeze on agriculture.

5. References


### Appendix II

**LISTING OF DATA USED IN APPENDIX I**

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<th>N.S.W. Wage Average Rate&lt;sup&gt;d&lt;/sup&gt;</th>
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<sup>a</sup> Source: Commonwealth Bureau of Census and Statistics, Sydney, Statistical Register of N.S.W.
<sup>b</sup> See method of derivation in footnote 9, Appendix I.
<sup>c</sup> n.a. - not available.
<sup>d</sup> See source of data and method of scale construction in Appendix I.
## Appendix III

### LAND VALUES INDICES\(^{a,b}\) FOR SELECTED AREAS\(^{c}\)

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Base year for index, 1949-50 = 100.

Index = (Unimproved Capital Value/Area of Rural Holdings)\cdot 100.

Source: Commonwealth Bureau of Census and Statistics, Sydney, \textit{Statistical Register of N.S.W.}
Commonwealth Bureau of Census and Statistics, Brisbane, \textit{Statistical Register of Queensland.}