1984

Industrial research and development and inventive activity in Australian manufacturing industries

Shantha Liyanage
University of Wollongong

Industrial Research and Development and Inventive Activity in Australian Manufacturing Industries

A thesis submitted in fulfilment of the
requirements for the award
of the degree of

DOCTOR OF PHILOSOPHY

from

THE UNIVERSITY OF WOLLONGONG

by

Shantha Liyanage. B.Sc.

Department of History and
Philosophy of Science. March 1984.

Table of Contents

	Page No.
List of tables	viii
List of figures	xv
Declaration	xvi
Acknowledgements	xvii
Abstract	xxviii

<u>Chapter One</u> **<u>Impact of technological advances and research and development on industrial performance</u>**

1.0	Introduction	1
1.1	Significance of technological advances as a source of productivity growth	8
1.2.0	The contribution of technical advances to productivity growth	13
1.2.1	Transmission of technological advances through new capital formation	14
1.2.2	Technology related growth without new capital investment	18
1.3.0	Concepts of technical change, invention, innovation and research and development	20
1.3.1	Contribution of product and process innovation productivity growth	24
1.3.2	Effects of industrial research and development on productivity growth	26
1.4.0	Influence of economic factors on technological advances	32
1.4.1	Firm size	34
1.4.2	Competition	38
1.4.3	Firm diversification	40
1.4.4	Other factors	42
1.5	Technological advances in Australian manufacturing industry	43
1.6	Aims of the study	45

Reference Chapter One 49

Chapter Two **Technological development and diffusion in Australian manufacturing industry, 1900-1968.**

2.1.0 Introduction 61

2.1.1 The definition of manufacturing industry 65

2.1.2 The concepts of industrial research and development and technical innovation 67

2.2.0 The economic and technological factors in the development of Australian manufacturing industry 71

2.2.1 General features of early development of Australian industry 72

2.2.2 Emergence of modern industrial structure 79

2.2.3 Explanations for the decline in manufacturing growth 84

2.3.0 Government assistance to the growth of manufacturing industry 87

2.3.1 Industrial protection to manufacturing industry 88

2.3.2 Incentives and industrial assistance 89

2.3.3 Development of industrial R&D and technical structure 91

2.4.0 Resources devoted to industrial R&D by private manufacturing industries during the post war period 98

2.4.1 Surveys of scientific activities during the post war period 98

2.4.2 Estimates of expenditures and personnel on R&D 100

2.4.3 Higher education research effort on industrial research 106

2.5 Technological advances and scientific output 108

2.6 Conclusion 110

Reference Chapter Two 114

Chapter Three The level of scientific and technological research in manufacturing industries in Australia, 1968/69 to 1979/80

3.0	Introduction	124
3.1.0	Recent surveys of resources devoted to R&D in manufacturing industry	135
3.1.1	Limitations of measurement and interpretation of R&D input statistics	136
3.1.2	National surveys of input indicators-R&D expenditures and personnel in the business enterprise sector	137
3.1.3	R&D personnel effort in business enterprise sector	142
3.1.4	Type of R&D cost in the business enterprise sector	146
3.1.5	Ownership and R&D level in business enterprises	147
3.2.0	Industrial research in public and higher education institutions on manufacturing industry problems	149
3.2.1	Resources devoted to industrial R&D by government sources between 1973/74 and 1978/79	150
3.2.2	Type of industrial research activities in Australian manufacturing industry	154
3.2.3	Sources of finances for IR&D in the manufacturing sector	156
3.3.0	Trends and relationship of private investment in R&D in manufacturing industries	158
3.3.1	Growth trends of R&D expenditure in different industry classes	159
3.3.2	Growth trends of R&D expenditure in constant 1979/80 prices	162
3.3.3	R&D expenditure and purchase of knowhow in the private business enterprise sector	165

3.3.4	Growth of payments for knowhow in manufacturing industry	168
3.4.0	Research intensity and the relation between industrial R&D expenditure and economic variables	170
3.4.1	Relationship between knowhow purchase and economic indicators	174
3.5.0	R&D intensity in manufacturing industry	176
3.5.1	Intensities of industrial research in different industry classes	181
3.5.2	R&D expenditure as a ratio of manpower	184
3.6.0	Behaviour patterns of R&D expenditure with firm size	190
3.7	Conclusions	191
	Reference Chapter Three	195

Chapter Four **Strategy and direction of inventive effort in private manufacturing industry**

4.0	Introduction	200
4.1	Strategies of firms for inventive activity	202
4.2	Inventive patterns of manufacturing industry	206
4.3.0	Level of resource allocation to inventive activity in industry	208
4.3.1	Level of resource allocation to R&D over time	209
4.3.2	Inventive intensity in manufacturing industry	213
4.3.3	Factors influencing inventive activity	217
4.4	Product and process inventive activity	220
4.5	Connection between R&D input and firm output	225

4.6 Effect of firm size on inventive activity 234

4.7 Conclusion 244

Reference Chapter Four 256

Chapter Five **Project formulation and Management: Directing industrial R&D in manufacturing industry.**

5.0 Introduction 261

5.1 Previous studies concerning R&D project selection, evaluation and budgetary allocation 265

5.2.0 Characteristics of R&D projects selected in Australian Industries 269

5.2.1 Distribution of R&D projects by industry classes 270

5.3.0 Relationship between cost, project length and personnel in R&D projects 272

5.3.1 Financial resources devoted to R&D projects 273

5.3.2 Distribution of project length by industry classes 275

5.3.3 R&D personnel effort on R&D projects 278

5.3.4 The relationships between project cost, length and R&D personnel 281

5.3.5 Influence of project length on size of projects 285

5.4 The composition of R&D project spending 286

5.4.1 Types of project costs involved in industrial R&D projects 287

5.4.2 Process and product development strategies in R&D projects 290

5.4.3 Types of R&D activity in manufacturing research projects 296

5.5.0 Firm objectives in R&D projects 299

5.6.0 The effect of institutional variation on R&D projects 304

5.6.1 Research capabilities of firms conducting R&D projects 304

5.6.2 The effects of firm size on project selection 306

5.6.3 The influence of firm size on type of project costs 310

5.6.4 The influence of ownership on project selection 311

5.6.5 The influence of firm size and ownership on product and process development in R&D projects 315

5.7 Conclusions 319

Reference Chapter Five 325

Chapter Six **Effectiveness of Private Industrial R&D Effort**

6.0 Introduction 330

6.1 State of the R&D projects undertaken in firms 333

6.2 Estimates of cost and time in industrial R&D projects 340

6.3 Effect of institutional factors and the composition of R&D on cost and time overrun 342

6.4 Factors affecting cost and time overruns 345

6.5 Reasons for delay in project progress 348

6.6 Conclusions 350

References Chapter Six 353

Chapter Seven **Summary and Conclusions**355

List of Tables

Table 1.1	Source of productivity growth in the United States during 1929-1969 and 1948-1969.
Table 2.1	The average gross capital formation in Australian industry from 1861 to 1939.
Table 2.2	The value of production of different manufacturing industries from 1913 to 1939 (selected years).
Table 2.3	Contribution of manufacturing industries to gross domestic product (GDP) at factor cost, selected years 1901-1968/69.
Table 2.4	A comparison of the share of percentage distribution of GDP (at factor cost) by manufacturing and agriculture sectors.
Table 2.5	Labour force by industry, Australian census 1901 to 1976 ('000 persons).
Table 2.6	The average annual growth rate of manufacturing industry from 1962/63 to 1975/76 (at constant 1974/75 prices).
Table 2.7	Annual average percentage of total imports of capital equipment for private and public enterprises.
Table 2.9	Research expenditure on selected field by commonwealth government institution, selected years.
Table 2.10	Private estimates of industrial research from 1959-1968.
Table 2.11	The average R&D growth at current and constant 1967/68 prices from 1959 to 1968.
Table 2.12	The estimate of manpower devoted to R&D in industry.
Table 2.13	Patent application submitted by Australian and teritory between 1931 and 1967.
Table 3.1	New fixed capital expenditure (less disposal) in manufacturing industry at current and constant 1979/80 prices.
Table 3.2	The expenditure of research and experimental development in manufacturing industries at current prices by industry division from 1968/69 to 1978/79 (million dollars)

Table 3.3	Research manpower employed in manufacturing industries during 1968/69 to 1978/79.
Table 3.4	The composition of professional research employment by industry classes, 1971/72 to 1978/79.
Table 3.5	Distribution of type of costs in business enterprises.
Table 3.6	Number of private manufacturing enterprises undertaking R&D by ownership.
Table 3.7	R&D expenditure by ownership in selected periods.
Table 3.8	Distribution of payments for technical knowhow among local and foreign suppliers.
Table 3.9	IR&D effort in Commonwealth and State government, higher education and private non-profit sectors, 1973/74 to 1978/79.
Table 3.10	Gross industrial R&D effort in the manufacturing, 1973/74 to 1978/79.
Table 3.11	Gross industrial R&D expenditure at constant 1979/80 prices.
Table 3.12	Expenditure on IR&D in manufacturing by type of activity in private industry between 1976/77 and 1978/79.
Table 3.13	R&D expenditure in manufacturing sector by type of research activity and by performer between 1976/77 and 1978/79.
Table 3.14	IR&D expenditure by source of fund in private enterprises in 1976/77 and 1978/79.
Table 3.15	IR&D expenditure by source of funds in 1976/77.
Table 3.16	Correlation coefficient for the growth of R&D expenditure between 1968/69 and 1978/79.
Table 3.17	Composition of the industrial research expenditure in government and private enterprises during 1976/77.
Table 3.18	A series of deflators for the conversion of R&D expenditure based on domestic product at 1979/80 prices.
Table 3.19	R&D expenditure by private manufacturing industry at constant 1979/80 prices.
Table 3.20	Expenditure on R&D and technical knowhow during 1968/69-1978/79 at constant 1979/80 prices.

Table 3.21 Average percentage growth rate of expenditure on purchase of technical knowledge and R&D expenditure at constant 1979/80 prices.

Table 3.22 Agregated expenditure on R&D and knowhow by industry classes during 1968/69-1978/79 at constant 1979/80 prices.

Table 3.23 Growth of payments of knowhow by industry classes between 1968/69 and 1978/79 at current prices.

Table 3.24 Pearson correlation coefficient between R&D expenditure and sales. turnover and value added.

Table 3.25 Pearson correlation coefficient between R&D employment and sales. turnover. and value added.

Table 3.26 The average professional R&D manpower as a percentage of total R&D employment in manufacturing industry.

Table 3.27 Pearson correlation coefficient between R&D professional employment and sales. turnover. value added.

Table 3.28 R&D expenditure as a percentage of sales. turnover. and value added by industry classes that performed R&D from 1968/69 to 1978/79.

Table 3.29 The distribution of R&D expenditure and manpower in the research intensive and non-intensive industry groups at constant 1979/80 prices.

Table 3.30 The share of R&D and technical knowhow among research intensive industry division at constant 1979/80 prices.

Table 3.31 Import and export performance according to research intensity.

Table 3.32 R&D intensity of the chemical industry division.

Table 3.33 R&D intensity of the other machinery and equipment industry division.

Table 3.34 R&D intensity of the other machinery and equipment industry division.

Table 3.35 R&D expenditure per R&D person-year by industry class at constant 1979/80 prices.

Table 3.36 Per capita R&D expenditure in research intensive and other industry groups at constant 1979/80 prices.

Table 3.37 Per capita R&D expenditure on capital and salary at constant 1979/80 prices.

Table 3.38 Per capita R&D expenditure on capital and salary at constant 1979/80 prices.

Table 3.39 Relationship of capital and labour cost with total R&D. turnover. and value added of industry-1976/77 to 1978/79.

Table 4.1 R&D expenditure and personnel effort by industry classes(constant 1979/80 prices).

Table 4.2 Distribution of percentage of expenditure to turnover (E1) and personnel to employment (M1) allocation in 1979/80.

Table 4.3 Frequency distribution of industries according to ratio of turnover and employment allocation on R&D-1979/80.

Table 4.4 R&D expenditure allocated to product and process development from 1976/77 to 1979/80.

Table 4.5 R&D employment on product and process development from 1976/77 to 1978/79.

Table 4.6 Per capita R&D expenditure on product and process development from 1976/77 to 1979/80.

Table 4.7 Relationship between inventive input and economic output-1976/77 to 1979/80.

Table 4.8 Correlation coefficient between turnover and R&D expenditure and employment an R&D personnel in product and process development-1976/77 to 1979/80

Table 4.9 Regression analysis of R&D inputs with turnvoer and employment.

Table 4.10 Average ratio of R&D expenditure to turnover for process and product development by industry classes-1979/80.

Table 4.11 Average ratio of R&D personnel to employment for process and product development by industry classes-1979/80.

Table 4.12 Percentage of annual rate of growth of R&D expenditure for product and process development by industry classes(at constant 1979/80 prices).

Table 4.13 Total R&D expenditure by firm size.

Table 4.14 Total R&D manpower by firm size.

Table 4.15 Research intensity (R&D expenditure/turnover) by industry classes according to firm size-1979/80.

Table 4.16 Research intensity (R&D personnel/employment) by industry classes according to firm size. 1979/80.

Table 4.17 Average R&D expenditure per industry product and process development by firm size.

Table 4.18 Average R&D personnel per industry in product and process development by firm size.

Table 4.19 Average R&D expenditure per research person on product and process development by firm size.

Table 4.20 Average ratio of R&D expenditure to turnover for product and process development by firm size.

Table 5.1 The distribution of R&D projects by industry classes-1979/80.

Table 5.2 The distribution of R&D projects(10 or more) by insutry sub-divisions-1979/80.

Table 5.3 The distribution of R&D project costs by industry classes.

Table 5.4 The distribution of R&D project length by industry classes.

Table 5.5 The distribution of mean project length in industry classes.

Table 5.6 The average R&D personnel effort per project and project cost per person-year by insutry classes($'000).

Table 5.7	Professional and non-professional personnel effort by industry classes (in person-years).
Table 5.8	Multiple regression of project cost with project length and R&D employment in projects.
Table 5.9	Regression analysis of project cost with length and personnel allocation of R&D projects by different industry classes.
Table 5.10	The mean average project cost at different intervals of project length.
Table 5.11	The mean average project cost per person-year at different intervals of project length ($'000 per year).
Table 5.12	Average percentage allocation of different project costs by industry class.
Table 5.13	The distribution of project cost on product and process development by insutry classes($'000).
Table 5.14	The average project cost of product and process development by insutry classes.
Table 5.15	Product and process development effort of projects in research intensive industries($'000).
Table 5.16	Distribution of project cost according to different types of R&D activity($'000).
Table 5.17	Influence of type of R&D activity on product and process development.
Table 5.18	Project cost according to intended technological advances in projects($'000).
Table 5.19	Distribution of project cost by domestic market size($'000).
Table 5.20	Distribution of project cost by export market sizes($'000).
Table 5.21	Distribution of project cost by R&D rating of firm($'000).
Table 5.22	Project expenditure according to firm size by industry classes($million).
Table 5.23	Average R&D employment in projects by firm sizes(person-years).
Table 5.24	Distribution of project cost according to firm size($million).

Table 5.25	Project expenditure by firm size and ownership ($million).
Table 5.26	Percentage distribution of project cost by ownership by industry classes.
Table 5.27	Project expenditure on product and process by firm size ($million).
Table 5.28	Product development activity by firm size and ownership($million).
Table 5.29	Process development activity by firm size and ownership($million).
Table 5.30	Distribution of Project cost by R&D rating and by firm size($million).
Table 6.1	Mean average cost($'000), length(months) and personnel (person-years) input effort by state of project.
Table 6.2	Frequency distribution of projects according to cost and time overruns for completed R&D projects.
Table 6.3	The variation in cost and time factors and level of R&D in completed projects of small, medium and large firms.
Table 6.4	The variation in time factor and R&D level of completed projects by type of development activity.
Table 6.5	The variation in time factor and R&D level of completed projects by advanced technology strategies.

List of Figures

Figure 1 Value of plant and machinery in manufacturing from 1900 to 1970.

Figure 2 R&D expenditure and payments for knowhow at constant 1979/80 prices from 1968/69 to 1981/82.

Acknowledgements

My profuse thanks to Professor Ron Johnston who supervised this thesis: his help, encouragement and guidance was much appreciated. I would like to thank the University of Wollongong for providing the post-graduate scholarship during the writing of this thesis.

Abstract

This thesis provides an analysis of technology development activities in the Australian manufacturing industry. This study has been undertaken in the light of growing concern over the lack of technological competitiveness in Australian industry. It is intended as a contribution towards improving understanding of the structure, effectiveness and limitations of inventive activity in Australian industry.

Investment in research and development and technical innovation is an important area of decision making for both R&D managers and government policy makers. The cost of such investment has to be weighed against the potential benefits, and the likelihood of achieving them, as well as against other investment alternatives available to a firm. However, both theoretical and empirical studies have emphasised the important role of technological innovation in industrial growth.

Science policy makers have emphasised the important role of government in encouraging and assisting industrial innovation in industry. Active participation of government is frequently required to provide adequate facilities for the growth of new technology enterprises. However, these policies will be successful only if private firms recognize a need for developing technologies.

Existing theory on the generation of industrial innovations is quite immature. Many different results have been found, and different industrial systems respond differently under various circumstances. Some general similarities, however, have emerged. One major limitation of most previous studies of industrial innovation has been there reliance

on case studies, or data drawn from a small number of firms. Nor has there been much attempt to understand the determinants of industrial innovation at the level of the firm and individual project.

This study aims to remedy these deficiencies by studying a wide range of determinants of the structure and operation of the R&D structure in Australian manufacturing industries. A sample of 273 private firms undertaking R&D, 585 proposed or current R&D projects, and 80 completed or on-going R&D projects were studied in detail.

This thesis begins with an assessment of theories and hypotheses pertaining to technological innovation and industrial development. In Chapter Two, the growth of the manufacturing sector in Australia and the influence of science and technology on its development has been examined for the period 1900 to 1968. The emergence of modern industrial research activity and its strength have been examined in order to provide a basis for assessing the present state and direction of industrial inventive activity.

R&D resource allocation examined only at the national level often provides a very limited picture of the real situation of the infrastructure of industrial R&D and inventive effort. Chapter Three attempts to trace the development in national industrial research and development (IR&D) effort from 1968/69 to 1981/82. In particular, the rate of public and private sector expenditure on R&D and technical knowhow purchase was examined. However, this study went far beyond aggregated national levels to analyse IR&D activity at disaggregated firm and project levels. This allowed a detailed identification of the external and internal factors affecting a firm's technological activity.

The behaviour of different industry classes in R&D investment, the institutional differences in undertaking R&D activity, the influence of different compositions of R&D activity on industrial performance, management attitudes and strategies towards selecting R&D activity and problems and constraints in developing R&D and technological innovations in industry can be studied by examining individual firm activities. A sample have been assessed by projects were surveyed

Major findings of this thesis point to various deficiencies and strengths in the Australian R&D structure. Most industrial activity is based on a narrow concept of technological development and on short-term market strategies. Many companies have achieved a relatively stable and secure industrial position by such strategies but have neither sought nor been able to penetrate international markets and achieve the level of competitiveness which is needed for the long-term viable existence of a manufacturing sector in Australia.

From its inception, industrial research was moulded by short-term objectives and the constraints of a colonial economy and mentality. This conservatism with respect to technology was deeply rooted in most industrial firms, which were quite unwilling to adopt business strategies in which technological development had a place. The past twenty years has shown the development of a somewhat greater awareness of the role of technology in industrial development. However, resource allocation in most firms remained quite low and those who did invest in R&D, tended to allocate less than 1% of their resources to R&D. However, some small firms have allocated a larger proportion of their resources to R&D. Because of their size, however, these firms have a limited potential to reach the forefront in technology development often possessed only limited R&D facilities. Large firms nevertheless dominate R&D activity in industry.

Some industry classes such as chemicals, other machinery and equipment and transport equipment showed a much higher research intensity than others. However, no industry sector has shown a very strong orientation towards high technology development strategies or a high research intensity.

The composition of R&D activity in this sample suggests that different inventive activity played a significant role in different industries. New product development is the dominant innovative activity of most firms. The variations are related to different business strategies, but are all driven more by market needs than technological needs. A very high level of accuracy in the estimation of project costs and duration has been discovered, much higher than in other countries. However, this is attributed more to the modesty of the technology development strategies, rather than management brilliance.

Some of the findings of this study raise important implications for innovation theory and government policy formulation. The concentration of R&D activity in new product development and the variation of research orientation and capability with firm size suggests new perspectives on appropriate roles for government in support and promotion of technology development.

Chapter One

Impact of Technological Advances and Research and Development on Industrial Performance

1.0 Introduction

Manufacturing industry in the Australian economy contributes a significant share to the national income and employs a considerable percentage of the nation's workforce. The average contribution of Australian manufacturing industry to gross domestic product (GDP) at factor cost was 23.7 per cent from the financial years 1970-71 to 1973-74, but declined to 21.1 per cent from 1974-75 to 1977-78, and 19.7 per cent during 1980-81. The workforce fell from 27 per cent in 1966 to 23 per cent in 1971 and averaged 20 per cent from 1976 to 1980. However, manufacturing remains the highest contributor to GDP by industry[1] (ABS, 1982). These statistics, while signifying the importance of the manufacturing sector, indicate a considerable decline.

1 GDP is reported by 12 distinct industry divisions in the Australian national accounts. These divisions are a) agriculture, forestry, fishing and hunting, b) mining, c) manufacturing, d) electricity, gas and water, e) construction, f) wholesale and retail trade, g) transport, storage and communication, h) finance, etc., business services, i) public administration and defence, j) community services, k) entertainment, etc., personal services, and l) ownership of dewellings.

Development[2] of the manufacturing sector is governed by a number of factors which can be argued to be related to science and technology. The most important of these are the accumulation of physical capital and human resources, labour productivity changes, technological progress and diffusion, increased education of the workforce, improvement in management techniques, and investment in research and development activity. The influence of these factors on the economic performance of the manufacturing sector varies in intensity. One of the objectives of this study is to identify the influence of science and technology factors on the efficient performance of different classes of industry.

Scientific and technological advances which affect the rate of growth of industry originate from and are regulated by activities of the following three major sectors:

a) the higher education sector which is responsible for the education and training of the workforce and is one of the important sources of advances in scientific and technological knowledge;

b) the government sector which supports high risk scientific and technological investment and formulates policies for industrial growth and protection;

c) the private enterprise sector which controls the dynamism of adoption and creation of new technology in most areas and engages in a wide range of activities directed towards the development of technology.

Among these sectors, the process of interaction between technological advances and the growth of industry is a complex one. Technological

2 In the economic literature, the concept of development is treated as the increase in the per capita volume of exchangeable goods and services. The convenient measure of such increase is the growth rate of per capita real national income. A discussion on some of the conceptual difficulties in these measurements is found in Sundrum (1977).

changes as well as the rate at which it occurs is now widely recognized as having an influence on the growth of the economic system (Spaey, 1971).

Two distinct sets of theories concerning the role of technology in industrial growth have emerged. In the first, technical change is regarded as exogenous to the economic system. This view has been taken by a number of neoclassical economic growth theorists, who consider technology disturbs the equilibrium position and leads to new equilibria, and also by those who consider scientific and technological growth to be autonomous. Social, cultural and epistemological factors affecting the growth of scientific and technological advances are discussed in Rubenstein (1957), Kuhn and Kaplan (1959), Freedman (1960), Kaplan (1960), Merton (1961), Baker *et al.* (1967), Ravetz (1971) and others. These explanations, however, leave out the effect of general economic, institutional, organizational, and managerial factors on technological advances in industry.

The second viewpoint emphasises the endogenous nature of the process of technical change to the economic system. Binswanger and Ruttan (1978) have argued that changes in technology are endogenous rather than exogenous to the economic system.[3] They have considered that the production of the new knowledge which leads to technical change and the embodiment of this new knowledge in new processes and new products are themselves the result of institutional innovations and development. Strong arguments have been advanced for considering technical change

3 A similar view is expressed by Schmookler (1966) and he argued that technical inventions are strongly influenced by economic variables.

as either exogenous or endogenous. However, the important issue from the standpoint of this thesis is that the productivity growth of industry can not be considered in isolation from advances of technology *per se*, which themselves must be placed in a more general context of economic, institutional and social factors.

Technological progress provides industrialists with a number of options, such as to reduce the unit cost of production by increasing the efficiency of production or to allow extension of company activity into new product areas. However, all technological advances in a firm do not necessarily increase its profits all the time. Some technological advances are more useful for the growth of a firm than others. Nelson and Winter (1982) have argued that industry may be most benefited by technological change if the new technology can not be imitated quickly and easily by competitors. Hence, industry attempts to develop technology need to be carefully directed in accord with economic and market factors. To the extent that R&D is involved in the development of the technology the direction of investment in R&D also needs to be shaped by these factors.

Technical change can exert a variety of effects on different groups of industry. Some advances of technology may be beneficial to a wide range of firms, whereas other advances may assist only a few and disadvantage a large number of firms. New technological advances that create employment in one sector may cause redundancy in other areas. Those technological advances that help in capital formation in some industries may result in making capital goods in other industries less competitive and obsolete. In particular, those industries that are less progressive in adopting technological advances, capital and educational resources may become vulnerable to such situations (Nelson, 1981). Hence, advances in technology need to be viewed as heterogenous in effect on productivity growth in industry as a whole. These diversified effects can be expected to become critical for the survival of industries as the rate of introduction of technical advances increases.

Modern manufacturing industry employs a wide range of technologies. Changes in these technologies take place by either replacement of existing capital and labour inputs by new capital equipment or improvement of the efficiency of existing capital. It has been commonly argued that productivity increase in industry depends upon employment of more self-acting machines, which will eventually replace a large part of labour (Kuznets, 1930,p.31). However this need not necessarily be so for all technological advances. Schmookler (1966) has pointed out, every industry has two kinds of technologies;

a) product technology and

b) production or process technology.

New product technology does not usually involve labour replacement in the same industry. Hence , technological advances as a source of growth in productivity should not be regarded merely as a process of augmentation of machinery and equipment.

Technological progress in manufacturing industry can lead to a range of new and improved products and processes. One of the consequence of technical progress is a growing level of product and process differentiation, which itself can lead to increased competition among manufacturing firms. Hence technical progress can increase competition and in return competition requires technical progress. Industrial firms are required to keep up with the pace of new technological developments if they are to maintain their profit levels in the long run in competitive market conditions.[4] Industrial firms are compelled either to undertake more inventive activities or to purchase knowhow in the form of new capital equipment, intermediate goods and patents.

For these reasons, the manufacturing industry sector in any country cannot afford to ignore the importance of technical changes. The evidence to be presented suggests that Australian manufacturing industry has done just that. The Bureau of Industry Economics (1979) has pointed out that after a comfortable period of growth in the 1950s and 1960s, manufacturing industry has undergone a steady decline in its growth rate.

The factors affecting the growth of manufacturing industry may differ from country to country depending on national industrial policies. Australian manufacturing industry is confronted with a range of specific problems in addition to those encountered by manufacturing industry in other industrialized countries. First, a significant portion of manufacturing industry in Australia is controlled by foreign multinational companies which operate alongside Australian owned monopolies and small competitive industrial enterprises. Crough *et al.,* (1980, pp.125-126) have shown that foreign control of manufacturing industry increased from

4 Some monopolies may continue to operate without substantial changes in technology or technological advances under certain protective trade policies. However, even for those firms, which are actively involved in new technological advances, can not afford to ignore the needs to maintain continuous inventive activity. Krugman (1979) has pointed out monopoly in new technology is continually eroded by technological burrowing and must be maintained by constant innovative activity.

37 per cent in 1963 to 59 per cent in 1976. Some of the key sectors of manufacturing industry show very high levels of foreign control with motor vehicles having 100 per cent control, oil refining 91 per cent, basic chemicals 78 per cent and transport equipment 55 per cent. Secondly, the output of Australian manufacturing industry is largely geared to a relatively small domestic market; hence substantial growth of the sector depends on penetrating export markets. Thirdly, competition from overseas industry is a significant factor, which is increasingly having an influence on the rate of growth of manufacturing industry in Australia. Technological progress and diffusion in Australian manufacturing industry is considered as slow and inadequate, intensifying the dependence on overseas sources for technology and skilled manpower supplies.

The declining competitive edge of Australian manufacturing industry in terms of both technology and productivity has led to an appreciable increase in the awareness of some government departments of the importance of developing industrial research and development and upgrading technological advances in this sector.[5] However there has been only a limited response from industry.

A more detailed examination of factors responsible for the state of Australian manufacturing industry, including the following, is warranted:

5 Australian government policy provides for a variety of industry assistance to industrial R&D including government grants, taxation incentives and assistance through government research laboratories. These mechanisms are discussed in Johnston (1982).

a) international factors affecting manufacturing industries and factors special to Australia;

b) the level of technological development in industry and sources of technological development;

c) awareness of the importance of different sources of industrial growth by industry and government.

This study is mainly concerned with the problems related to the development, adoption and utilization of scientific and technological knowledge in manufacturing industry with special reference to policy formation aspects, criteria for resource allocation, the effectiveness of the present R&D system, and intensity of the introduction of technical innovations.

1.1 Significance of Technological Advances as a Source of Productivity Growth

The ability to shift the rate of growth of industrial output by technological and scientific advances has been investigated extensively by various scholars. Classical economists such as James Steuart (1767), Adam Smith (1776), Thomas Malthus (1815 and 1820), David Ricardo (1815 and 1817), Karl Márx (1867), and Joseph Schumpeter (1934 and 1939) have studied the production function and its relation to improvement of machinery and technological processes. The production function is an analytical tool which describes the maximum output that can be obtained from a given set of inputs assuming a fixed state of technical knowledge. Neoclassical growth theory has concentrated on quantifying technical change and identifying it as a source of growth by considering firms as profit seeking and competitive elements in an equilibrium process of economic growth in which technological knowledge was regarded as a public good.

It is only in recent years that literature on economic growth theory has given a prominence to the study of technological change as a source of growth. It began with a series of studies conducted on the measurement of total factor productivity indexes for the United States economy. Schmookler (1952), Mills (1952), Schultz (1953), Abramovitz (1956), Fabricant (1959), and Kendrick (1961) studied the growth of output in the economy and were able to establish that the conventionally measured weighted growth of capital and labour inputs did not explain a large portion of the growth of output.

Consequently, the shift of production function due to factors other than weighted growth of capital and labour was identified as "residual", which was taken as largely a consequence of technological advance.

One of the most important developments in the study of technical change and total factor productivity resulted from Robert M Solow's work in which he measured the rate of growth of total factor productivity and quantified technological change. Solow (1957) studied the rise of output per man hour of work in the United State non-farm sector between 1909 and 1949. He defined technical change other than simply capital and labour inputs. His study revealed that 87.5 per cent of the increase in gross output per man-hour was attributable to improvement in production practices and equipment generally identified as technical change. Fabricant (1954) estimated that over the period of 1871 to 1951 about 90 per cent of the increase in output per capita was attributable to technical progress.

The measurement of technical change by identifying non-technological inputs in the residual such as improvement in the education of the workforce, advances in management techniques, changes in organisational structure, and improved resource allocation was developed in studies by Denison (1962, 1967 and 1974), Jorgenson and Griliches (1967) and Kendrick (1973). These studies have indicated that the importance of advances in knowledge to productivity growth, while the percentage of contribution of such advances differs according to the period and industry examined. Denison's 1974 study of the growth of output in United States economy disaggregated labour and capital inputs and treated the process of growth of output as arising from either an increase in capital and labour resources (contribution of total factor input) or an increase in the output obtained from the same quantity of resources (contribution of total output per unit of input). His findings showed capital and advance in knowledge were the primary sources of increase in growth of potential output during 1929 and 1969. Denison (1974,p.130) pointed out that the sources of long-term growth of output in the United States, after allowing for economies of scale, originated entirely from six types of changes. The percentage distribution of growth of total output by source of growth was as shown in Table 1.1.

In terms of growth of output per person employed, advance in knowledge was responsible for more than half of the growth rate of potential output per worker after allocating economies of scale. Denison indicated that both long run and short run economic growth, advance in knowledge was an important source of growth.

Table 1.1 Source of Productivity Growth in the United States During 1929-1969 and 1948-1969

	%age Growth 1929-1969	%age Growth 1948-1969
a)Advances in knowledge and n.e.c.	31.1	34.1
b)Labour input except education	28.7	23.9
c)Capital	15.8	21.6
d)Increased education per worker	14.1	11.9
e)Improved resource allocation	10.0	9.0
f)Dewellings occupancy ratio and irregular factors	0.3	-0.5

Note n.e.c. denotes not elsewhere classified. Growth rate refers to per cent of growth with economies of scale allocated.
Source Denison (1974).

The methods of measuring the contribution of technical change to a production function were based on a number of assumptions and had some limitations. Some studies assumed a unitary elasticity of substitution between capital and labour, constant return to scale, neutral technical change, linearity of aggregate production function, the public good aspect of technological knowledge and growth as an equilibrium process. The validity of measured technical change depended on the model used relaxing each of these assumptions to conform with real situations.[6] The quantification of technological change is also subjected to limitations of data availability, construction of accurate capital indices and problems of aggregating capital inputs.

6 It is worth noting that economic growth theory was unable to come to terms with empirical realities due to complexity of the connection between technological advances and economic factors. For a critical comment on this aspect see Nelson and Winter (1982,p.4).

Solow's study in 1957 assumed constant returns to scale, that capital and labour are paid their marginal product, the aggregated production function was strictly linear, and technological change is neutral. His later study (1962) was based on the assumption that all technological changes must be embodied in new capital if they were to increase output. The difficulties in measuring and constructing an index of capital and giving a precise meaning to the quantity of capital were discussed in Robinson (1954), Kaldor and Mirrlees (1962), Harcourt (1969) and Rymes (1971). The problems of aggregation of capital have been discussed in Nerlove (1965) and Solow (1970 and 1971). Both Denison (1962) and Griliches (1963) have attempted to reduce or eliminate errors in the measurement of weighted contribution of capital and labour and adjusted for economy of scale. Jorgenson and Griliches (1967) have shown that there were some errors in the measurement in labour services in Denison's 1962 study. These difficulties have been acknowledged and in some cases surmounted in later studies. One such important improvement in labour and capital substitution was achieved through the development of a constant elasticity of substitution (CES) production function by Arrow *et al.*, (1961). The CES production function accounts for the difference in elasticity of substitution between capital and labour in different industries. Surveys of the earlier work of the measurement of production function and technological change are found in Hahn and Matthews (1964), Nadiri (1970), Kamien and Schwartz (1975), Heertje (1977), Denison (1979a) and Kendrick and Grossman (1980).

1.2.0 The Contribution of Technical Advances to Productivity Growth

In general all the models developed hitherto for the measurement of the contribution of technical change to productivity growth provide evidence that technical change to productivity growth provide evidence that technical progress is an important cog in the engine of economic growth. The existence of the relation between production and technological progress is thus well documented. However, the exact coupling process between technological advances and productivity growth is not very well explained by these macro-economic models.[7]

The process of incorporating advance in technology into productivity growth can be analysed in two different contexts. First, in terms of the target areas of productivity to which technical advances are addressed. Second, in the manner in which technological advances are incorporated in the productivity growth. Kuznets (1974, pp.187-196) has explained the first through his argument that technological change is a cost reducing and demand creating activity. Technological advances are necessary to reduce the cost of production of existing consumer products or services and to improve the quality of existing products to make the industry competitive. In addition, technological advances are also necessary to produce demand-creating and market expanding new products, processes and services.

The manner in which technical advances enter into the production process is associated with capital and labour inputs. The magnitude of capital

7 An alternative model based on evolutionary theory has been put forward to resolve some of the drawbacks of the previous models. See Nelson and Winter (1982).

and labour contributions are categorized according to capital-saving, labour-saving or neutral technical change as discussed in details by Hicks (1932) and Harrod (1937). Technological change is said to be neutral when it raises the marginal productivity of labour and capital in the same proportion. It is considered to be labour-saving or capital-saving according to its capacity to raises the marginal productivity of capital more or less than that of labour. Robinson (1938) pointed out that labour-saving means that it saves labour in the sense of an increase output per unit of capital or in other words the new techniques increase the productivity of labour. Capital investment has increasingly become the major vehicle of transmitting technological advances to productivity growth.

1.2.1 Transmission of Technological Advances Trough New Capital Formation

One of the obvious ways of incorporating advances of knowledge into productivity is through capital goods such as new plants, machinery and equipment. Denison (1962,p.253) assumed that half of the application of new technical knowledge to production is governed by age of capital stock. Solow (1957, p.316) held a view that many, perhaps nearly all, innovations must be embodied in new plant and equipment to be realised at all. Solow (1962,p.76) has emphasised that embodied technological progress is more important than the disembodied kind and he assumed that all technical progress needs to be embodied in newly produced capital goods before they can have any effect on output.

An important function of technological change seems to be increasing the rate of new capital formation and the efficiency of old capital. In other words, technical advances can reduce the capital and labour inputs, while maintaining the output of productivity unchanged. In such a context, advances in technology are more favourable in increasing new capital formation. Almost all progress oriented technological advances are designed to increase the efficiency of capital thus decreasing the number of man-hours required to accomplish the same task. The new capital thus formed takes the place of routine or menial tasks handled by labour and allows labour to be engaged in more productive activities. For example, Kaldor (1957) has suggested that,

> The use of more capital per worker... inevitably entails the introduction of superior techniques which require 'inventiveness' of some kind.
> (Kaldor, 1957,p.595)

Kaldor also argues that increase in labour productivity through technical innovations requires the use of more capital per man. Salter (1969,p.36) has pointed out that technical progress in the manufacture of capital goods produces a continuous pressure throughout industry for the substitution of capital equipment for labour. The precision and accuracy which is required in modern manufacturing processes can be achieved to a high degree by self-acting machines. As a result, with the rising cost in labour, investment in new capital equipment has become more attractive than investment in labour.

Although technical progress provides the opportunity to reduce the cost of unit production by increasing the efficiency of capital and labour inputs used in the production process, the economic decision to employ more new capital depends on a series of factors such as organizational goals, scale of production, factor costs of inputs and entrepreneurial decisions. In this sense, the decision to incorporate new capital in the productive process is not determined only by technical advances. Shove (1933,p.471) considering a short run economic model, has advanced the argument that capital goods are produced with labour so that increase in wages result in a proportionate increase in the price of capital goods; therefore substitution of labour by capital goods may not be economical.

Introducing capital and producing capital goods has different effects on labour input. Hicks (1965 and 1969) has pointed out that making a new machine frequently requires more labour than is needed for the replacement of the old one, while the introduction of the machine leads to considerable savings of labour. However, in a capital dominated production process making a new machine will also be ultimately performed with less labour in efficient manufacturing industry. It is usual for an industry with declining labour productivity and increasing wage bills to look for alternatives to increase production efficiency and to replace labour with machinery. The augmentation of capital by technological advances are ultimately expected to cause a decline in the potential of advancing production technology in industry. For example, Kuznets (1930) and Salter (1969) advanced the thesis that technological progress which resulted in capital augmentation will ultimately cause a diminution of the inventive potential of production technology. Abernathy (1978,p.4) argues that, in general, to achieve gains in productivity, there must be attendant losses in innovative capability and this would mean that the conditions needed for rapid innovative changes may be different from those that support high level of production efficiency.

Technical advances and the production of capital are closely integrated. Therefore, it is logical to assume that a portion of capital reflects the captured portion of advances in knowledge. In other words, a part of the contribution of measured capital in factor productivity is actually a contribution of advance in knowledge. Rymes (1972,p.79) has argued that there is a theoretical fault in long run total factor productivity as measured by Hicks, Solow, Denison, and others, due to a conceptual difference between technical change and capital accumulation. He argues that technical advance is a long-period or dynamic phenomenon, so that measures used in counting identical capital goods as the same amount of capital input are not suitable because capital is an intermediate input produced by the economic system and the ever-increasing ability of the economic system to produce capital goods must be taken into account. Technical advances increase the productivity in the production of capital goods, hence allowing the production of more capital goods with the same input. When the additional capital is formed, it enters the production process. In Denison's and Solow's studies, the contribution made by this extra capital is counted as a contribution of capital and not as a contribution of technical advances. Fellner (1970) has objected to the concept of capital embodied technological progress and argued that,

> All progress is necessarily disembodied in the sense that new ideas must always be put into effect with reliance on the initially given resources.
> (Fellner, 1970,p.13)

The difficulty in Fellner's argument is that he tended to include the cumulative effect of technical advances and industrial research inputs, which logically also should be disaggregated. That capital formation in an industry can be steered by technical progress suggests that changes in relative prices of capital goods, increasing wages, declining labour productivity, and other factors associated with increase in the costs of labour input can induce an industry to invest in more inventive activities in order to employ more capital investment in place of labour. Although technological advances are apparently incorporated into production system more via capital goods, human resources are also play a significant role. In particular, Pavitt (1980) points out the importance of highly trained engineers and scientists in the R&D and productivity improvement activity.

1.2.2. Technology Related Growth Without New Capital Investment

Technology related factors originate from organized R&D activity as well as in the process of conducting routine production work. As previously noted, technological advances are not always related to augmentation of capital equipment and specific innovations. Labour input is also a significant vehicle for inducing technical change which can increase productivity growth in industry. Lundberg (1961) reported such a case in Horndall Iron Works in Sweden, where productivity, measured as output per man-hour, increased at a rate of about 2 per cent per year without any new investment for 15 years. Lundberg advanced the hypothesis that technical change is in general ascribed to experience, that is the very activity of production, which gives rise to problems for which favourable responses are selected over time.

A similar argument has also been made by Fellner (1969) who described technical change as a "learning by doing" phenomenon. Arrow (1962a and 1969) also emphasised the steadily increasing performance which can only be imputed to learning from experience. In the case of certain industry growth, learning-by-doing had stronger effects than formal R&D activity. A study by Wilson *et al.* (1980) pointed out that as experience accumulates the learning curve becomes increasingly steep in the semi-conductors industries, reflecting the reduction in unit production cost.

R&D and learning-by-doing are complementary to the economic growth of an industry. Hollander (1965) and Dahlman (1979) have noted an intricate connection between these two in the productivity growth studies of DuPont's rayon plants and Brazilian steel plant, respectively. The importance of utilising production workers in R&D activity was reported by Sagal (1978), indicating the advantage of incorporating learning-by-doing with R&D. He reported that the high success rate of R&D activity in Western Electric's Engineering Research Centre in Princeton, was mainly due to a rotational program which brought manufacturing engineers to the Centre, and in return sends Centre engineers and scientists on temporary assignments to manufacturing locations. The usefulness of feedback from users to R&D activity in the innovations of certain products were reported by Von Hippel (1976) and Rosenberg (1980). The reason for success in such programmes was mainly the inter-relation between R&D activity and learning-by-doing.

These studies infer that R&D scientists and engineers need to learn about industry problems by involvement in production themselves; they cannot depend only on learning from other people's experience. Nelson

(1981,p.1047) has identified learning-by-doing as in part a substitute and in part a complement to learning through R&D. Evidence suggests that learning by doing is as a significant mechanism of generating productivity growth as the formation of new capital. In particular, the generation of new ideas for the development of new products can be substantially influenced by the experience of workers. The combined effort of R&D and learning-by-doing is likely to affect the growth of productivity more than any one of these activities on their own. The most relevant issue is to identify the combination that produces optimum productivity growth.

1.3.0 Concepts of Technical Change, Invention, Innovation and Research and Development

The production of knowledge, its application in the process of invention and the use of inventions to produce technical innovations, which are ultimately used in productive processes, are regarded as separate but closely related and integrated activities. In most cases, it is difficult to clearly distinguish boundaries between each of these activities. The entire process of producing knowledge up to its final use in a commercial purpose may be identified as technical change. However, the term technical change may be extended to entail changes in quality of workforce as well as change in capital equipment.

Schumpeter (1939,pp 85-108) recognised the coherence of the different activities involved in a technological change. He argued that technological change occurs from a sequence of activities known as invention, innovation, and imitation or diffusion. According to his definitions, invention involves generating an idea of a new product or process and solving a purely technical problem associated with its application. Innovation was defined as the entrepreneurial functions required to convert a technical possibility into an economic reality by identifying markets, the opening of new markets and raising capital. The process of imitation or diffusion was seen as the stage at which a new product or process comes into widespread use through the acquisition of the innovation by other producers. Basically, Schumpeter separated invention, which occurs independent of practical need, from innovation which was conditioned by "objective needs". However, Schumpeter's description does not account for industrial research and development undertaken to generate innovations in an industry; he treated the source of innovations as exogenous to the economic system.

Solo (1951,p.441) argued that innovation is more realistically analysed as an ordinary business practice rather than the extraordinary efforts of new men as described in Schumpeter's thesis. According to this approach technological change, including the change in the knowledge available, may be termed as invention and change in the actual technological arrangements when existing knowledge is applied may be termed innovation.

A somewhat different viewpoint was expressed in Ruttan (1959,p.605), who argued that the term invention is more appropriate in a descriptive sense when confined to its institutional context and used to refer only to that subset of technical innovations which are patentable. A recent definition of invention and innovation given by Freeman (1974) suggests that,

> An invention is an idea, a sketch or a model for a new or improved device, product, process or system. Such inventions may oten (not always) be patented but they do not necessarily lead to technical innovations. ...An innovation in the economic sense is accomplished only with the first commercial transaction involving the new product, process, system or device, although the word is used also to describe the whole process.
> (Freeman, 1974,p.22)

Scherer (1970,p.350) argued that it is more useful to explain innovative process in terms of four essential functions.

a) invention,

b) entrepreneurship,

c) investment and

d) development.

Such a schema would help to link research activities with the productive process Abernathy (1978,p.78) has described formal R&D in industry as a predominant stimulus for innovation. In order to encompass varied perspectives of the process of innovations, Utterback (1979,p.41) defined innovation as a process involving the creation, development, use and diffusion of a new product or process. These definitions suggest that the separation of technological change into different activities is largely a matter of convenience to identify a series of activities that are elements of a single process. R&D activities in this process can play prominent role and are responsible for generating knowledge up to a stage where process or product development reaches a prototype or pilotplant scale. The utilization of such a result from there onwards depends on entrepreneurial decisions, commercial factors, market structures and investment opportunities at a given time. It should be noted that R&D activities do not always yield positive results and bring about new innovations. The advance in knowledge that has resulted from R&D also influence quality changes in products and knowledge advances in the workforce, which help industry to increase its productivity.

The diffusion of technological knowledge may be a slow process. The art of production is often closely guarded, as long as possible, in order that the producer can enjoy the maximum benefits. The slower the technological knowledge diffuses, the more profits the industrialist may make. Fellner (1951,p.576) argued that when knowhow is new, it begins to spread gradually and never becomes completely diffused.

Larger total sales volume or market share is considered as a factor for placing greater reliance on formal R&D activities in innovation (Richardson, 1975). The profit rate of an industry is also a strong driving force which partly determines the intensity of R&D activity. For example, Hamberg pointed out that,

> If the profit rate is not necessarily in danger of falling, we do not need innovations to maintain it.
> (Hamberg, 1959, p.244)

In actual practice falling profit rates are often accompanied by decreased investment in innovations (Twiss *et al.,* 1980,p.35). However, the innovations are often required to maintain the dynamism of profit rate. An industry, which maintains R&D activity at least hopes to sustain its efficiency and prevent its profits falling below a certain level. It is necessary to maintain a sufficient amount of inventive activity in order to preserve technological competitiveness of industries. The pure profit motivation of industry may result in subsequent slowing down in research activity, particularly once it overcomes threats of technological inferiority.

Lack of enthusiasm in channelling a considerable amount of profits for R&D investment may be caused by factors such as absence of technical rivalry or an existence of a monopoly market condition which is substantially backed by government protection policies. In spite of such policies, industries may be required to keep-up with technical innovations to maintain their profits levels in the long-run.

1.3.1 Contribution of Product and Process Innovation to Productivity Growth

One of the critical problems of measuring the growth of output is the difficulty in accounting for quality changes in products. Denison (1962,p.3) referred to economic growth as the increase in the national product, measured in constant prices. The increase in marketable goods and services is measured by economic growth. Technical advances which cause quantitative and qualitative changes in products and processes must be accounted for in economic growth. Scherer (1970,p. 347) noted that the studies of Denison, Solow and others on total factor productivity measure only the changes that have resulted from process innovations. The quality changes due to product innovations were disregarded. The improvements in products therefore became a "non economic" or unmeasured" quality change. One reason has been the lack of a satisfactory method to measure the change in quality of products. The difficulties in developing indexes for the measurement of quality changes are discussed by Lancaster (1978). He pointed out that major complication of adopting such indexes are due to non-separability, taste changes, and relative price changes among goods not being indexed for quality change.

The advance in knowledge that permit business to supply final goods different from those previously available were excluded in Denison's (1974,p.79) productivity measurement studies. This was due to the fact that measurement of national products do not capture the quality changes in products. Denison (1962) explains that,

> The introduction of new or better final products, and of cheaper final products if they differ in physical characteristics from the old, does not, in general, increase the measured national product.
> (Denison, 1962,p.155)

This would mean that a large amount of resources devoted to product innovations are not reflected in total factor productivity measurements. Adelman and Griliches (1961) have pointed out the importance of quality measurements in economic growth accounting. They have argued that a large part of the increase in price indices may be attributable to quality changes; hence disregarding quality changes would lead to a gross understatement of the growth of output. As a consequence, a considerable effort has been made to account for quality changes (Griliches, 1971 and Lancaster, 1978).

In addition, technical advances achieved in terms of product development will also be undervalued. This is obviously a major omission. As Abramovitz (1962,p. 781) has stated,

> The bulk of R&D - perhaps, 4/5 of private and virtually all government expenditure - is devoted to product improvement, which does not register in measured national product, but which we want.
> (Ambramovitz, 1962,p.781.)

Product and process innovations constitute the major inventive efforts of a firm undertaking R&D activities. The improvements in both process and product can contribute to the growth of an industry. Minasian (1969), Griliches (1973), Denison (1979a), and others have included advances in knowledge or technical change that reduce the unit cost of final products already in existence in their productivity measures. However, R&D activities are also concerned with the development of new products and improving existing products. Some of the implications of disregarding the importance of R&D on new products are discussed in Gustafsson (1962). He argued that,

> One industry's (or firm's) new product is frequently another industry's (or firm's) cost-reducing improvement. ..research and development expenditure would show no correlation with productivity change in small, but would have a substantial impact on the economy as a whole.
> (Gustafsson, 1962,p.184).

It must of course be recognised that R&D is only a part of expenditure which is needed for technological innovations. Mansfield (1982) has shown that out of the total cost of product innovation, the average R&D cost accounted for 45 per cent while the remainder was for tooling, design and construction (40%) and manufacturing and marketing start-up (15%).

1.3.2 Effects of Industrial Research and Development on Productivity Growth

As explained in the previous sections, the role of R&D in innovative activity is complex. The relation between R&D and productivity growth occurs through a series of coupling activities. R&D effort operates primarily through the advancement or application of knowledge, whereas productivity changes require such knowledge, whereas productivity changes require such knowledge be successfully used in the productive system. Price and Lawrence (1966) wrote,

> The dialogue between science and technology plays an important, but usually nonlinear, role in innovation. (Price and Lawrence, 1966,p.802).

The utilization of knowledge is determined by market structure, entrepreneurial activity, industry profit level, competition and other economic factors. R&D activities which result in successful inventions will be used to produce new capital goods in industry. The new capital goods in return will improve the productivity in industry. Productivity growth in an industry may also be achieved by purchase of new capital and intermediate products from another industry which is engaged in R&D (Terleckyj, 1980a,p.376).

Innovations translate the effects of R&D into productivity growth. R&D effort, measured as expenditure or manpower on R&D, has frequently been used as a proxy for technological change in productivity measurements. This assumes the measures of R&D inputs are sufficient and satisfactory proxies for the output of R&D. The difficulties in quantifying output measures and the relative abundance in R&D input statistics are primary reasons for making this assumption.[8]

Minasian (1962), Comanor (1965), Mansfield (1968), and Comanor and Scherer (1969) found that there exists a close relation between the rate of

---

8 The relationship between R&D input and output measures have been examined in number of studies. In a recent study by McLean and Round (1978) have discussed some of these attempts; for a critical review of available see Chapter Four of this thesis.

R&D inputs and the innovative output when the firm size was held constant. Pavitt and Wald (1971) found a high correlation between R&D funding and rate of technical innovation in 13 industries in the United States. In a number of studies on productivity and technical change, R&D expenditures have been taken as an index of technical change. Minasian (1962) argued that,[9]

> The research and development program of a firm reflects the effort or costs of the firm in the direction of obtaining efficiency. Logically, therefore, one would expect that a change in the productivity of the firm would be somehow related to its research and development activities.
> (Minasian, 1962,p.100)

Griliches (1979 and 1980a&b) has made comprehensive studies on research expenditures and the role of research in productivity growth. Some of the difficulties in using R&D in productivity studies are discussed in Griliches (1973).

Assumptions have been made that R&D will always bring positive results. In reality, there is a great deal of uncertainty in research activities and frequently a long time elapses before returns to research are achieved. The uncertainty is greater in basic research and research undertaken in the public sector than in industrial research. Griliches (1973) pointed out that,

> For public and primarily basic research, the average lag appears to be of the order of five to eight years. For the bulk of industrial research (applied or development) the lag is much shorter, of the order of two to three years, but still significant.
> (Griliches, 1973,p.61).

---

9 Recent studies show that a large part of the change in productivity is not so much dependant on R&D; however, expansion of R&D is considered to be a promising way of promoting productivity growth in industry. See Denison (1979b,p.7) for a detailed discussion.

Terleckyj (1980b) has also confirmed that commercial R&D undertaken with a definite business objective is found to show a clearer and more direct relationship with productivity growth than for government financed R&D.

The expenditures and manpower utilized in R&D are often used as statistics to measure R&D effort. These statistics, however, do not truly represent the actual research effort. As Denison (1962, p.239) has argued, statistics on research expenditures and manpower do not provide even in principle an index of advances in knowledge themselves, but only of the resources utilized in the pursuit of such advances.

Denison (1979b, p.7) has emphasised that the productivity slowdown in U.S. economy in 1970s is not attributable to R&D spending. He explained that research and development expenditure financed from private industries, measured at constant prices, did not decline, so that there was no assurance that R&D spending contributed anything to the decline in productivity growth. However, one of the important drawbacks in this interpretation is, as noted earlier, measurements of growth mainly accounts for the cost-reducing process research. Griliches (1973) estimated that only about half of total R&D is likely to affect measured productivity and that only about half of the remainder represents a net addition to the stock of knowledge.

Another significant factor in R&D is that not all types of research will be reflected in productivity improvements. Johnson (1965), for example, points out that some R&D advances will have purely social returns and will not be useful in the improvements in products and services immediately. Certain types of research such as basic research will have a different impact to that of applied research in the productivity have a different impact to that of applied research in the productivity improvements in industry. Price and Lawrence (1966) have argued that basic research is an essential part of the innovative process. The National Science Board (1979) has also pointed out that,

> Benefits of basic research often do not accrue primarily to the sponsor, and their nature and incidence are unpredictable ...the results of basic research are usually public goods as loss production cannot be supported by the private market.
> (National Science Board, 1979,p.15)

It is generally regarded that the effort of basic research in industrial research is meagre. In 1979, basic research expenditure was 3% of total industrial expenditure in the United States (National Science Board, 1979,p.87). However, Mansfield (1980a) found a significant and direct relationship between basic research and the rate of increase of total factor productivity, when expenditure on applied research was held constant. Wilson *et al.*, (1980,p.74) in a study of semi-conductor industry have concluded that basic research appears to be important in the birth and childhood of an industry and as the industry mature firms do relatively little basic research can provide major innovations. Various models have been developed to explain the dynamic process of innovation in industry (Abernathy and Utterback, 1978 and Utterback, 1979).

A number of important studies including those of Minasian (1962 and 1969), Terleckyj (1974), Griliches (1980a), and Mansfield (1968, 1980a and 1980b) provide evidence that there exists a strong connection between R&D expenditure and productivity growth. For example, Mansfield (1964,p.319) studied ten chemical and petroleum firms and concluded that among petroleum firms, regardless of whether technical change was capital embodied or organizational, the marginal rate of returns averaged about

40 to 60 per cent. Among the chemical firms, they averaged about 30 per cent if technical change was capital embodied, but only 7 per cent if it was organizational. Minasian (1969,p.84) in a study of 17 chemical industries during 1948-57, found that the gross return on investment in R&D was 54 per cent a compared with 9 per cent for capital. Griliches (1973) in a study based on regressions of productivity growth on R&D investment ratios for aggregated inter-industry data for 85 manufacturing industry estimated 32 per cent in 1966 and 40 per cent in 1970 for the rate of return to R&D, based on R&D data for 1958. A similar study by Terleckyj (1974) on twenty manufacturing industries, again based on 1958 R&D data, estimated a rate of return of 37 per cent to company financed R&D and almost zero to Federally financed R&D. Griliches (1980b) in a recent study on the chemical and petroleum, metal and machinery, electrical equipment, motor vehicle, aircrafts and missile and other manufacturing industries for the period between 1957 and 1965 arrived at similar results to the two previous studies by Griliches and Terleckyj. The estimated rate of private return to total R&D was on the order of 30 to 40 per cent, except for electrical equipment and aircraft and missiles industries for which the lowest estimate of average 19 per cent was obtained.

Griliches (1973,p.61) and Schmookler (1962) have recognised investment in R&D as capital investment which is subject to depreciation as any other investment and eventually becomes obsolete. Most of the available empirical studies indicate that the relation between research input and inventive output is remarkably close. The ability of research input and inventive output to effect the changes in productivity in industry suggests that factors affecting the changes in research input and inventive output contribute to the productivity growth in industry.

1.4 Influence of Economic Factors on Technological Advances

All technological advances may not be successfully incorporated into the productivity process. The utilization of new knowledge is not simply a matter of creating and adopting new capital equipment. The successful utilization of new knowledge in a commercial venture is determined by a number of institutional, economic, social and market factors. The intensity of these factors controls the production, diffusion and adoption of new technology. Advances in technology in turn interact with these factors. In other words, technical advances in industry are not necessarily governed by merely scientific and technological goals and objectives. Comprehensive reviews of the literature on the effect of market, institutional and economic factors on technological innovations and vice-versa are found in Scherer (1970), Kamien and Schwartz (1975) and Nelson (1981). Only the literature on some of the most important concepts pertaining to advancement in technology is considered in this study.

Some of the sources for technological advance in industry have been examined in previous sections. The effectiveness of these sources, which may be either R&D or learning-by-doing, are also related to institutional, economic, social and market factors. These factors play an indirect role in the growth of productivity. As pointed out in the beginning of this chapter, the complexity of the factors affecting technological progress and their coupling procedure with economic growth has resulted in technological change being treated as an exogenous variable in many neo-classical growth models. Schmookler (1966 and 1972) and Binswanger (1978), on the other hand, have argued that the endogenous nature of technical change is more pronounced than the exogenous nature.

The importance of economic, institutional, and market factors in technical change and productivity growth are too large to be ignored. Among these the most important ones are

a) firm size,

b) competition or rivalry,

c) diversification activities of firms,

d) economies of scale, factor endowment and others.

The influence of these factors on R&D can vary according to sources of finance and location or environment in which research is conducted. Leonard (1971), Terleckyj (1974) and Griliches (1980b) have provided some evidence to suggest that government financed R&D has a much lower impact than privately financed R&D. This is primarily due to institutional objectives in R&D investment. Government financed R&D may attempt high risk R&D areas whereas privately financed R&D is cautious of such investment. Identification of determinants of R&D input and inventive output in an industry would be very useful in obtaining the optimum benefits of research investment. Most of the factors affecting R&D investment also affect the inventive output; hence the factors discussed below are addressed commonly to R&D input and inventive output.

1.4.1 Firm Size

The size of a firm has been considered to be an important factor in determining the inventive output and R&D investment in an industry. There is a general belief that large oligopolistic firms conduct more research, generate more research products, and capture more benefits from research than small firms. Schumpeter (1942) was the first to suggest that the large scale establishment was to be preferred to small competitive firms in this respect. Clemency and Doody (1966) commenting on Schumpeter's argument write,

> In a world of large-scale enterprises, innovations may be practicable only if some measures are taken to protect the firm's advantage over an interval during which reward may be collected.
> (Clemency and Doody, 1966,p.62)

Galbraith (1956,p.86) argued that innovations are becoming increasingly costly and therefore can only be afforded by large firms. Schmookler (1959) commented that big oligopolistic firms can afford big projects; their greater diversity facilitates the use of the results of research, their greater life expectancy permits a longer pay-off, and having a large share in the market they can recapture a large portion of the aggregate economic and social gains from research.

Technical innovations are often a costly exercise, which involve a high risk because of the uncertain outcome of R&D and of launching a new product. The stability of big companies and their capacity to absorb such risks are cited as important determinants of research budgets. Villard (1958) commented that more private research will be undertaken under a regime of large oligopolistic firms than under a more competitive regime of small firms. Markham (1965,p.332) advocates a similar view that large corporations and some degree of market power appear to be concomitant with organized innovative effort. If the company is too small, it will not be able to maintain a research laboratory, which will need expensive equipment and entail high operating costs. Scherer (1970,p.353) has argued that a firm needs to consider economies of scale in the operating of R&D laboratory; below a certain level it will be ineffective and uneconomical. However, Mansfield (1963,p.575) has shown that it is not possible to generalise the proportion of inventive output in large firms in the case of all industry classes. The industry studies by both Mansfield (1968,p.43) and Scherer (1970,p. 361) concluded that with the exception of the chemical industry, large firms do not invest more in R&D relative to their size than somewhat smaller firms.

Although a large firm can have a greater advantage over a small firm in investing in R&D, there is evidence to suggest that the use of research results in large firms is less effective than in small firms. The ability of large firms to conduct more R&D automatically ensures neither a greater ability to obtain maximum benefits on each dollar invested, nor greater productivity in achieving results compared with small firms. In an attempt to determine the relationship between firm size and rate of return to R&D, Jewkes *et al.* (1958) in a study of patents found that the research activities of small firms had higher returns than the big firms. A similar conclusion was drawn in studies by Hamberg (1963) and Cooper (1964). These studies imply that under utilization of research resources and research output are relatively greater in large firms than in small firms. In particular, industries investing in research on a large scale seem to suffer from inefficiency in decision-making and responsibility-taking on products of R&D. Rubenstein (1958) and Roberts (1968) have discussed some of the problems encountered by managers of large firms in making decisions on innovation. Schmookler (1962) and Sanders (1964) in studies based on patent statistics, have shown that "small" firms use a substantially higher proportion of the patents they own than do "large" firms. Mansfield (1964) studied a sample of chemical, petroleum, and steel industries and found that holding R&D outlay constant, the number of significant inventions made by large firms declined as the size of firm increased. Schmookler (1972) emphasised that,

> Evidently, as the size of firm increases, there is a decrease per dollar of R&D in a) the number of patented inventions b) the percentage of patented inventions used commercially, and c) the number of significant inventions.
> (Schmookler, 1972,p.39)

These view were confirmed by the results of a recent study by the National Science Foundation for the United States Senate Select Committee on Small Business (1978,p.432) which concluded that during the period 1953-1973, firms with less than 1000 employees were responsible for half of the 'most significant new industrial products and processes'. Firms with 100 or fewer employees produced 24 per cent of such innovations in spite of the fact that they accounted for only 3 per cent of the total dollar value of R&D. In effect small firms produced twenty four times more major innovations per research dollars expended than large firms. However, small firms encounter disadvantages because as technology matures more effort is needed to make further improvements and often such effort becomes costly (Abernathy, 1978).

According to Fisher and Temin (1973) very little can be said with certainty about the relationship between firm size and R&D input on the basis of empirical evidence available. Although large firms are placed in an advantageous position to undertake more R&D, it is found that after a certain limit, marginal returns to such investment becomes lower than that of small firms. For example, Griliches (1980b) has concluded that,

> We find no evidence for, and some evidence against, the notion that large firms either have a higher propensity to invest in R and D or are more effective in deriving benefits from it.
> (Griliches, 1980b,p.446)

However, Links (1980,p.771) in a study of a sample of firms from the chemical and allied product industries (SIC 20) found that size is still a prerequisite for successful innovative activity. The estimated rates of return to R&D for the smaller firms was 30 per cent, while for the larger firm it was 78 per cent. His results suggest that for chemical and allied industries there exist a close relation between firm size, R&D investment and rate of return to R&D investment. These results also suggest that the relationship between R&D investment and productivity growth varies with industry differentiation. Therefore, technical advances in different industries influence the rate of growth differently. These studies, however, do not provide definite conclusions on the relationship between firm size and rate of returns to R&D investment. Nevertheless, the importance of firm size to the relation between inventive output and investment in R&D has been demonstrated.

1.4.2 Competition

A firm investing in research and development is naturally concerned with the similar activities conducted by its rivals because there can be distinct advantage in being the first to invent and introduce an innovation into the market. There is uncertainty in the outcome of research and development activities, as well as when a product should be introduced into the market. Dasgupta and Stiglitz (1980) have demonstrated that such uncertainties, contrary to common belief, provide a good reason for a firm to be engaged in R&D. If there was no uncertainty it would be likely that only the single largest firm would engage in R&D, whereas with uncertainty more firms perceive a chance of success.

Schumpter's (1939) analysis has placed more emphasis on the monopoly situation whereby large firms are needed to capture the benefits of innovations. Scherer (1967) has attempted to explore the relation between intensity of competition and the rate of inducing invention. His general conclusions suggest that rivalry stimulates the development of new products. Arrows (1962,p.619) argued that the incentives to invent are less under monopolistic than under competitive conditions.

The stimulating effects of rivalry on R&D activity were examined in a study of eight chemical firms for the period from 1947 to 1966 by Grabowski and Baxter (1973). Their findings supported the concept that a firm's R&D expenditure respond positively to a rival's R&D investment. Freeman (1973,p.241) has also emphasised that the presence of competitive pressure may be important in stimulating attempts to innovate.

The important feature of rivalry from a national point of view is the conditions under which it is best suited to inventive activities. In order to obtain the maximum benefits of innovative activities, the optimum condition of competition needs to be determined. Either a purely competitive market or a purely monopolistic market seems to have adverse effects on inventive output. Kamien and Schwartz (1976) have concluded that an intermediate intensity of technical rivalry is most stimulating for inventive activity. A somewhat similar conclusion was drawn by Loury (1979), who suggested that more competition is not socially desirable, although the competition induces the competing industry to invest more in R&D than otherwise would be optimal in any market structure. He further suggested that with continuously diminishing returns to R&D investments, atomistic competition would be the best market structure for optimal innovative activity. The presence of competition leads all firms to be conscious of research activities of other firms and their potential effect on profit levels.

These studies suggest that competition cause firms to engage in more research activities and increase their effort to innovate earlier. A moderate competition seems to provide the best conditions for optimal innovative activities. 'Early' innovations seem to have less sensitivity to competition and may be controlled by other factors such as spill-over effects of R&D activities from other industries, entrepreneurial activities and firm policy with regard to investment. For example, interesting results were obtained in a recent study by Reinganum (1981) on the relationship between rate of innovations and publication of research results. Her study shows that on the average the firms keeping their research findings private are slower to innovate than if their research findings are publicly known. The study concludes that the public good aspect of knowledge generation may actually result in earlier innovation than would occur if knowledge were a private good.

1.4.3. Firm Diversification

The extent of diversification of a firm has a positive impact on the resource allocation to R&D and inventive output, according to some analysts. A highly diversified firm has to diffuse its R&D effort over a range of activities. However, such a firm may be able to capture the results of R&D, which may lead to progress in different directions, more easily and effectively. Nelson (1959) has pointed out that highly diversified firms have a greater advantage in utilizing results of research, particularly basic research. The ability of a firm to capture technical progress oriented in a wide range of directions has been pointed out by Rosenberg (1972). He argued that if progress in science slows down or changes its direction leading to fewer opportunities, technological progress in the market is slowed down. Therefore the ability of a firm to maintain a diversified market for its product will enable it to utilize any technological development with greater chance of success.

However, other analysts have argued that diversification has a negative effect on R&D output. Comanor (1965) studied 57 pharmaceutical firms in U.S. during the period between 1955 and 1980 and found that R&D productivity measured as total new drug product sales during the first two calendar years following introduction, was inversely correlated with diversification. He considered that diversification deals only with the division of output among the various pharmaceutical markets and not with the divisions between non-pharmaceutical and pharmaceutical markets. He emphasised that parameters suggest that for given research and development, higher rates of technical change will be achieved if attention is concentrated towards a few product areas. However, Comanor believed the major good of R&D is in the development of new, differentiated products that afford a protected market position. He further emphasised that research effort would be greater in industry where the prospects for successful product differentiation are better. Scherer (1965) studied electrical equipment, chemical and drug companies and found that partial correlations between R&D employment or patenting and diversification did not appear to be a stimulus to greater research effort. Johannisson and Lindstrom (1971) in a study of patent application in Swedish industry found that diversification did not seem to explain variation in inventive output, except as it reflected diversification from a low patenting industry into an industry that is more technically progressive. Kelly (1970) studied 18 multi-national firms and concluded that diversified firm are likely to invest in a higher proportion of research but the advantage of diversification for research for technically related products is the same for industry groups classified at the two digit Standard Industrial Classification (SIC) level.

Grabowski (1968) found that, quite contrary to Comanor's results mentioned earlier, R&D spending as a percentage of sales rose with diversification (as measured by the number of SIC five-digit product lines in which the firms operated) after taking into account variables reflecting research productivity and cash flow in an earlier period.

These studies suggest diversification provides a more favourable condition for a firm to adopt research result; however, the effect of diversification on the efficiency of use of research is as yet unclear.

1.4.4 Other Factors

Economies of scale and factor endowment are also regarded as important determinants of productivity change and technological progress. The abundance of relative factors inputs influences the rate and direction of technical progress. Hicks (1932) concluded that innovators are sensitive to the relative supply of factors of production in their local economy and he further suggested that a change in the relative price of factors could influence the nature of invention and innovation. Salter (1969,pp 43-44), however, denied that a change in the relative price of factors could exert an influence on the nature of technical invention. Fellner (1969) argued that an anticipation of a rise in the relative price of a factor might influence the nature of invention and that an actual rise would not do so. Ahamad (1966,p.349) argued that innovation in response to a relatively higher price of a factor would use less of that factor, hence a rise in the price of labour would lead to an innovation which is labour saving, if the invention possibility is technologically unbiased. The latter is of course a very strongly determining factor.

Inventive activity in different countries appears to be influenced by national and international market factors. Fellner (1961) pointed out the existence of market forces which direct the factor-saving impact of inventive activity. Habbakuk (1962) suggested that the direction of innovations in different countries is influence by the relative scarcity of factors of production in those countries. International variation in relative factor costs level as a determinant of the technological evolution of basic industries in different countries has been examined by Rosenberg (1969). In a recent paper, Davidson (1979) argues that innovative activity will be concentrated in industries which intensively use a nations' relatively costly inputs of production and he proposed that innovations are responsive to relative factor costs.

These studies illustrate that the rate and direction of inventive activity is influenced to a great extent by factor price, abundance of resources, comparative advantage of certain factors and economy of scale. Therefore, depending on the condition of a country, the research effort will be oriented to minimise the cost of scarce factor by replacing it with either an abundant factor or a relatively low cost production process.

1.5 Technological Advances in Australian Manufacturing Industry

In the light of the theoretical background described above, the impact of industrial research and development on the growth of manufacturing industry in Australia can be evaluated. Manufacturing industry in

Australia is under severe pressure to increase its productivity and technological competitiveness in order to retain its economic viability. There is a growing concern of government policy to encourage new technology-based industries.

Studies carried out on the performance of Australian manufacturing industry have revealed that the future of industry is bleak in terms of growth of productivity (Giesecke, 1980) and its competitive edge in technology is continually being eroded compared with most other industrialized countries. Among the measures suggested to remedy this situation are structural modifications (Crawford Committee Report, 1979), an increase support to R&D effort (Vernon Committee Report, 1965; Jackson Committee Report, 1975; OECD Report, 1975; Birch Committee Report, 1977; ASTEC Report, 1978; Crawford Committee Report, 1979), inducing technological changes (Myers Committee Report, 1980), and changes in government incentive (Industries Assistance Commission Report, 1982).

The influence of technical change on productivity growth in manufacturing industry has been empirically examined in a few studies. Edwards and Drane (1963,p.269) have reported that technical progress was an important factor for productivity increase, especially during the post Second World War period. Neville (1964, p.277), however, has expressed a different view point and maintained that the investment has been more important than the technical progress in increasing output per capita in Australian economy. Lydall (1968) also has studied the production function for the period from 1949/50 to 1959/60 and reported that there was a fairly close positive relationship between technical progress and change in productivity. Sampson (1969) has reached a similar conclusion. According to the estimates of Robertson (1978) and Kasper (1980), the contribution of technical advances to the Australian economic growth has varied from 33 to 40 per cent during the period between 1950 and 1979. Kaspura and Ho-Trien (1980, p.1) have argued that the low productivity in certain manufacturing industry between 1968/69 and 1977/78 was largely due to inadequate technological changes during the 1970s.

The existing knowledge of the process of generating innovations in Australian industry is limited. There exist very little empirical studies on industry's inventive effort. Most studies mentioned above have mainly concentrated on structure of government policies and their effects on industrial R&D effort. It has been repeatedly argued that the level of technological innovations and R&D in private industries is inadequate and the government policies have not been industry and technology specific (Tisdell, 1983). A few empirical studies such as Stubbs (1967), Encel (1970), Clark (1977) and the Senate Standing Committee on Science and Environment (1979) have attempted to analyse some aspects of R&D and inventive effort of industry. However, a comprehensive study of maufacturing industry to find out the factors and conditions which are vital in generating successful innovations and developing industrial R&D capabilities is not available.

1.6 Aims of the Study

The main objective of this study is to identify the structure and performance of industrial research and development and inventive activity related to the development of Australian manufacturing industry. It is also intended to identify some of the key factors influencing the generation of successful innovations in industry.

One of the important constraints in ascertaining the level of industrial research and technological inventive effort, already reported in Stubbs (1968) and Jackson Committee Report (1975), is the inadequacy and inconsistency of national data available on research investment and inventive activity in manufacturing sector.

The pattern of industrial innovations and R&D investment in industry can be examined from input and/or output perspectives. In this study, input effort is examined in detail and wherever statistics permit output analysis is carried out. Chapter Two and Three present an analysis of the development of industrial research and development activity in the Australian manufacturing sector.

Chapter Two describes the state of industrial research and inventive effort in a historical perspective with reference to public and private initiatives to develop R&D and economic efficiency of the manufacturing industry. The level of R&D inputs and various attempts to estimate industrial research effort are examined.

Chapter Three attempts to trace the recent development in public and private support for industrial R&D and analyses the trends of resources committed to inventive activity. The industrial R&D effort since 1968/69 is considered in detail to examine the relationship of the intensity of input resources to research and development and technological advances. The relationship between resources allocation and economic performance in different industry classes is examined and the R&D intensity of different industry groups is evaluated in this chapter.

The expenditure and manpower devoted to R&D at an aggregated industry level is neither sufficient nor adequate to determine the structure and character of inventive effort of individual industries in order to isolate the specific features of Australian R&D structure in relation to organisational. technological and industry's environmental differences.

Chapter Four to Six report and examine the findings of industry surveys which were carried out on a large sample of manufacturing firms and their projects in this study. Chapter Four is focussed on R&D and technological investment, its direction, special features and constraints on developing innovations at industry level. The product and process inventive intensities in different firms, the influence of organisational variations such as firm size on R&D investment and managerial role in R&D activity are discussed in detail.

Chapter Five examines a sample of R&D projects formulated by manufacturing firms to find out the direction of inventive activity and resource commitment, nature of projects selected. management decision making, process of project formulation, and the effect of firm size and ownership on type of projects undertaken in industries. The industry research capability and technological advances in relation to nature of projects proposed are briefly discussed.

projects. The rate of success or failure and overrun in estimated project cost and time and reasons for failure and success are examined.

Finally, the findings are summarized in Chapter Seven.

Reference-Chapter One

Abernathy, W.J. (1978) The Productivity Dilemma: Roadblock to Innovation in the Automobile Industry. Baltimore: Johns Hopkins Uni. Press.

Abernathy, W.J. and Utterback, J.M. (1978) 'Patterns of industrial innovation', Technology Review, Vol. 80, June/July, pp.2-9.

Abramovitz, M. (1956) 'Resources and output trends in the United States since 1870', American Economic Review, Papers and Proceedings, Vol.XLVI(2), May, pp.5-23.

Abramovitz, M. (1962) 'Economic growth in the United States. A review article, American Economic Review, Vol. LII(4), pp.762-782.

Adelman, I. and Griliches, Z. (1961) 'On an index of quality change', Journal of American Statistics Association, Vol. 56(295), Sept., pp.535-548.

Ahamad, S. (1966) 'On the theory of induced invention', Economic Journal, Vol. 76(32), June, pp.344-357.

Arrow, K., Chenery, H., Minhas, B. and Solow, R. (1961) 'Capital-labour substitution and economic efficiency', Review of Economics and Statistics, Vol. 43, Aug., pp.255-250.

Arrow, K. (1962a) 'The economic implication of learning by doing', Review of Economics and Statistics, Vol. XXIX(3),pp.155-73.

Arrow, K. (1962b) 'Economic welfare and the allocation of resources for innovation', in NBER, The Rate and Direction of Inventive Activity, Economic and Social Factors, Princeton: Princeton University Press.

Arrow, K.(1969) 'Classification notes on the production and transmission of technological knowledge', American Economic Review, Vol. LIX(2), May, pp.29-35.

Australian Bureau of Statistics(ABS), (1982) Australian National Accounts, 1980-81: Preliminary Statement, No. 3, Cat. No. 5203.0, Canberra: ABS.

Australian Science and Technology Council(ASTEC), (1978) Science and Technology in Australia 1977-1978, Canberra: AGPS.

Baker, N.R., Siegman, J. and Rubenstein, A.H. (1967) 'The effects of perceived needs and means on thegeneration of ideas for industrial research and development projects' IEEE Transactions of Engineering Management, Vol. EM-14(4), Dec., pp.156-163.

Binswanger, H.P. and Ruttan, V.W.eds. (1978) Induced Innovations, Technology, Institutions and Development, Baltimore: The Johns Hopkins University Press.

Binswanger, H.P. (1978) 'Induced technical change: Evolution of thought', in Binswanger, H.P. and Ruttan, V.W.eds. (1978) op.cit. pp.13-43.

Birch Committee Report (1977) Independent Inquiry into the Commonwealth Scientific and Industrial Research Organisation, Parliamentary Paper, 283/77, Canberra, AGPS.

Bureau of Industry Economics, (1979) Australian Industrial Development- Some Aspects of Structural Changes, Research Report No.2, Canberra, AGPS.

Clark, R.J. (1972) High Technology Industries in Australia; The Prospects for Innovation by Small Firms, M.Sc. Thesis, University of Monash, Melbourne.

Clemency, R.V. and Doody, F.S. (1966) The Schumpeterian System, New York; Augustus M Kelly Publishers.

Comanor, W.S. (1965) 'Research and technical change in the pharmaceutical industry', Review of Economics and Statistics, Vol. 47(2), May, pp.182-90.

Comanor, W.S. and Scherer, F.M. (1969) 'Patent statistics as a measure of technical change', Journal of Political Economy, Vol. 77(3), May/June, pp.392-98.

Cooper, A. (1964) 'R&D is more efficient in small companies',Harvard Business Review, Vol. 51, pp.127-35.

Crawford Committee Report, (1979) Study Group on Structural Adjustment, Vol. I&II, Canberra, AGPS.

Crough, G., Wheelwright, T. and Wilshire, T. (1980) Australia and World of Capitalism, Melbourne; Harmondsworth.

Dahlman, C.J. (1979) A Macroeconomic Approach to Technical Change; The Evolution of the Usiminas Steel Firm in Brazil, Doctoral Dissertation (Unpublished), Yale University.

Dasgupta, P. and Stiglitz, J. (1980) 'Uncertainty, industrial structure and the speed of R&D', Bell Journal of Economics, Vol. 11(1), pp.1-28.

Davidson, W.H. (1979) 'Factor endowment, innovation and international trade', Kyklos, Vol. 32(4), pp.764-774.

Denison, E.F. (1967) Why Growth Rates Differ; Post War Experience in Nine Western Countries, Washington, D.C.; Brooking Institution.

Denison, E.F. (1974) Accounting for United States Economic Growth 1929-1969, Washington D.C.; Brooking Institution.

Denison, E.F. (1979a) Accounting for Slower Economic Growth: The United States in the 1970s, Washington D.C.: Brooking Institution.

Denison, E.F. (1979b) 'Explanation of declining productivity growth'. Survey of Current Business, Vol. 39(8:2), pp.1-23.

Edwards, H.R. and Drane, N.T. (1963) 'The Australian economy July 1963', The Economic Record, Vol. 39(87), Sept. pp. 259-281.

Encel, S.(1970) 'Science, discovery and innovation: An Australian case study', International Social Science Journal, Vol. 22(1), pp.42-53.

Fabricant, S. (1954) Economic Progress and Economic Change, 34th, Annual Report of NBER, New York; NBER.

Fabricant, S. (1959) 'Basic facts on productivity change'. Occasional paper, No. 63, New York, also published in American Economic Review, 1956, Vol. 46(2), May, pp.5-23.

Fellner, W. (1951) 'The Influence of market structure on technical progress', The Quarterly Journal of Economics, Vol. LXV, pp.556-557.

Fellner, W. (1969) 'Specific interpretation of learning by doing', Journal of Economic Theory, Vol. 1(2), August, pp.119-40.

Fellner, W.(1970)'Trends in the activities generating technological progress', American Economic Review, Vol. LX(1), March, pp.1-29.

Fisher, F.M. (1969) 'The existence of aggregate production functions', Econometrica, Vol. 37, Oct., pp.553-57.

Fisher, F.M. and Temin, P. (1973) 'Returns to scale in research and development. What does Schumpeterian hypothesis imply?,' Journal of Political Economy, Vol. 81(1), Jan/Feb., pp.56-70.

Freedman, P. (1960) The Principle of Scientific Research. London: Pergamon Press.

Freeman, C. (1973) 'A study of success and failure in industrial innovation', in Williams, B.R.ed. Science and Technology in Economic Growth, New York, Wiley Pub. Co. pp. 227-45.

Galbraith, J.K. (1956) American Capitalism, Revised edition, Boston: Houghton, Miffin.

Giesecke, T. (1980) Is there a productivity Slowdown in Australia?, Working Paper, No. 12, Research Branch, Canberra; Dept. of Productivity.

Grabowski, H.G. (1968) 'The determinants of industrial research and development. A study of the chemical drug and petroleum industry', Journal of Political Economy, Vol. 76(2), March/April, pp.292-306.

Grabowski, H.G. and Baxter, N.D. (1973) 'Rivalry in industrial research and development', Journal of Industrial Economics, Vol. 21(2), pp. 209-35.

Griliches, Z. (1963) 'The sources of measured productivity growth. United States agriculture, 1940-1960.',Journal of Political Economy, Vol. LXXI(4), August, pp. 331-346.

Griliches, Z. (1971) Price Indexes and Quality Changes: Studies in New Methods of Measurement, Cambridge, Mass.:Harvard University Press.

Griliches, Z. (1973) 'Research expenditure and growth accounting', , in Williams, B.R.ed. Science and Technology in Economic Growth, New York, Wiley Pub. Co. pp. 59-83.

Griliches, Z. (1979) 'Issues in assessing the contribution of research and development to productivity growth', Bell Journal of Economics, Vol. 10(1), pp.92-116.

Griliches, Z. (1980a) 'R&D and the productivity slowdown', American Economic Review, Vol. 70(2), May, pp.343-348.

Griliches, Z. (1980b) 'Returns to research and development expenditure in the private sector', in Kendrick. J.W. and Vaccara, B.eds. New Development in Productivity Measurements and Analysis, Chicago, London; University of Chicago Press.

Gustafsson, E. (1962) 'Research and development, new products, and productivity change', American Economic Review, Vol. LII(2), May, pp.117-185.

Habbakuk, H.J. (1962) American and British Technology in the 19th Century, Cambridge; Cambridge University Press.

Hahn, F.H. and Matthews, R.C.O. (1964) 'The theory of economic growth: a survey', The Economic Journal, Vol. LXVII(296), Dec., pp.779-902.

Hamberg, D. (1959) 'Production functions, innovations and economic growth', Journal of Political Economy, Vol. LXXVII(3), June, pp.238-245.

Hamberg, D. (1963) 'Innovation in the industrial laboratory', Journal of Political Economy, Vol. LXXI(2), April, pp.95-115.

Harcourt, G. (1969) 'Some Cambridge controversies in the theory of capital', Journal of Economic Literature, Vol. 7(2), June, pp.369-405.

Harrod, R.F. (1937) 'Essays in theory of employment', Economic Journal, Vol. XLVII, pp.326-330.

Heertje, A. (1977) Economic and Technical Change, English Translation, London; Weidenfeld&Nicolson.(First edition, 1973, Stenfert Kroese B.V.)

Hicks, J.R. (1932) The Theory of Wages, London; Macmillan, 1st edition.

Hicks, J.R. (1965) Capital and Growth, Oxford; Oxford Uni. Press.

Hicks, J.R. (1969) A Theory of Economic History, London; Macmillan.

Hollander, S.(1965)The Source of Increased Efficiency: A Case Study of Dupont's Rayon Plants, Cambridge; Mass.,MIT Press.

Industrial Assistance Commission, (1982) Certain Budgetary Assistance to Industry, Report No. 303, Canberra;AGPS.

Jackson Committee Report, (1975) Policies for Development of Manufacturing Industry, Vol. I&II, Canberra; AGPS.

Jewkes, J., Sawers, D. and Stillerman, R. (1958) The Sources of Invention, New York; St. Martin's Press.

Johannisson, B. and Lindstrom, C. (1971) 'Firm size and inventive activity', Swedish Journal of Economics, Vol. 73(4), Dec., pp.427-42.

Johansen, L. (1972) Production Function, Amsterdam; North Holland Publishing Co.

Johnson, H.G. (1965) 'Federal support of basic research: some economic issues', in National Academy of Science, (1965) Basic Research and National Goals, Washington; Government Printing Office.

Johnston, R. (1982) 'Australian science policy-Now we can steer, where do we want to go?', Current Affairs Bulletin, Vol. 59(3), pp.20-30.

Jorgenson, D.W. and Griliches, Z. (1967) 'The explanation of productivity change', Review of Economic Studies, Vol. 34, July, pp.249-83.

Kaldor, N. (1957) 'A model of economic growth', Economic Journal, Vol. LXVII, Dec. pp. 601-624.

Kaldor, N. and Mirrlees, J. (1962) 'A new model of economic growth', Review of Economic Studies, Vol. 29(3),pp.174-92.

Kamien, M.I. and Schwartz, N.L. (1975) 'Market structure and innovation: A survey', Journal of Economic Literature, Vol. 13(1), pp.1-37.

Kamien, M.I. and Schwartz, N.L. (1976) 'On the degree of rivalry for maximum innovative activity', The Quarterly Journal of Economics, Vol. XC(1), Feb., pp.245-60.

Kasper, W. (1980) 'Technological change and economic growth', in Myers Committee Report, Vol. 4, op.cit.,

Kaspura, A. and Ho-Trien, L. (1980) Productivity and Technical Change in Australian 3-digit Manufacturing Industries, 1968/69-1977/78., Working Paper, No. 10, Research Branch, Canberra; Department of Productivity.

Katz, J.M. (1969) Production Functions, Foreign Investment and Growth, Amsterdam; North Holland Publishing Co.

Kelly, T.M. (1970) The Influence of Firm Size and Market Structure on the Research Effort of Large Multiple Product Firms, PhD Dissertation, Oklahoma State University.

Kendrick, J. and Grossman, E. (1980) Productivity in the United States; Trends and Cycles, Baltimore; John Hopkins Press.

Krugman, P.C. (1979) 'A model of innovation, technology transfer and the world distribution of income', The Journal of Political Economy, Vol. 87, pp.253-66.

Kuhn, T.S. and Kaplan, N. (1959) 'Environmental conditions affecting creativity', in Taylor, C.N. ed. The Third (1959) University Utah Research Conference on the Identification of Creative Scientific Talent, Salt Lake City, Utah; University of Utah press. pp. 313-316.

Kuznets, S. (1930) Secular Movements in Production and Prices, Boston; Houghton Miffin Co.

Kuznets, S. (1974) Population, Capital, and Growth,London; Heinmann Education Books, First published by W.W.Norton &Co(1973).

Lancaster, K. (1978) 'The measurement of change in quality', Review of Income and Wealth Series, No.23,pp.157-172.

Leonard, W. (1971) 'Research and development in economic growth', Journal of Political Economy, Vol. 79, pp. 232-56.

Links, A. (1980) 'Firm size, and efficient entrepreneurial activity. A reformation of Schumpeterian hypothesis', Journal of Political Economy, Vol. 88(4), Aug. pp.771-788.

Loury, G. (1979) 'Market structure and innovation', The Quarterly Journal of Economics, Vol. XCIII(3), August, pp. 395-409.

Lundberg, E. (1961) Producktivitet och rantabilitet, Stockholm; P.A. Norstedt and Soner.

Lydall, H.F. (1968) 'Technical Progress in Australian manufacturing', The Economic Journal, Vol. LXXVII, pp. 807-826.

Malthus, T.R. (1815) An Inquiry Into The Nature And Progress Of Rent And The Principle By Which It Is Regulated, London.

Malthus, T.R. (1820) Principle Of Political Economy Considered With A View To Their Practical Application, 1st edition, London; New edition (1951) New York: Augustus M. Kelly.

Mansfield, E. (1963) 'Size of firm, market structure and innovation', Journal of Political Economy, Vol. LXXI(6), Dec., pp.556-576.

Mansfield, E. (1964) 'Industrial research and development expenditure: Determinants, prospects, and relation to size of firm and inventive output', Journal of Political Economy, Vol. LXXII(4), Aug., pp.319-340.

Mansfield, E. (1968) Industrial Research and Technological Innovation, New York; Norton W.W. and Co.

Mansfield, E. (1980a) 'Basic research and productivity increase in manufacturing industry' American Economic Review, Vol. 70(5), Dec., pp.863-873.

Mansfield, E. (1980b) 'Returns to research and development expenditure in the private sector. A comment', in Kendrick and Vaccara eds. op.cit.

Mansfield, E. (1982) 'How economists see R&D', Research Management, July, pp. 25-29.

Markham, J.W. (1965) 'Market structure, business conduct and innovation', American Economic Review, Vol. LV(2), May, pp. 323-332.

Marx, M. (1867) Das Kapital-Capital a Critique of Political Economy, Abridge version of edition first published in Hamberg, Late edition see Capital-A Critical Analysis of Capitalist Production, ed. Engels, F., London; Lawrence and Wishart, 1974. Vol. 1.

McLean, I.W. and Round, D.K. (1978) 'Research and product innovation in Australian manufacturing industry', Journal of Industrial Economics, Vol. XXVII(1), Sept, pp.1-12.

Merton, R.K. (1961) 'The role of genius in scientific advance', New Scientists, Vol. 12(259), Nov. pp. 306-308.

Mills, F.C. (1952) Productivity and Economic Progress, Occassional Paper, No. 38, New York, NBER.

Minasian, J.R. (1962) 'The economics of research and development', in NBER The Rate and Direction of Inventive Activity, Princeton: Princeton Uni. Press, pp. 93-142.

Minasian, J.R. (1969) 'Research and development, production function and rate of return', American Economic Review, Vol. LIX(2), pp.80-85.

Myers Committee Report (1980) Technological Change in Australia,, Vol. I-IV, Canberra; AGPS.

Nadiri, M.I. (1970) 'Some approaches to the theory and measurement of total factor productivity: A survey', Journal of Economic Literature, Vol. 85(4), Dec., pp.1137-77.

National Science Board, (1979) Science Indicators, 1978, Washington, D.C., U.S. Government Printing Office.

Nelson, R.R. (1959) 'The simple economics of basic scientific research', Journal of Political Economy, Vol. LXVII(3), June, pp.297-306.

Nelson, R.R. (1981) 'Research on productivity growth and productivity differences: dead ends and new departures', Journal of Economic Literature, Vol. XIX(3), Sept., pp.1029-1064.

Nelson, R.R. and Winer, S. (1982) An Evolutionary Theory of Economic Capabilities and Behaviour, Cambridge, Mass; Harvard University Press.

Nerlove, M. (1965) Embodiment and All That: A Note, Mimeo, University of Chicago.

Neville, J.W. (1964) 'Technical change in Australian manufacturing', The Economic Record, Vol. 40(90), June, pp.271-298.

OECD, (1975) The Industrial Policy of Australia, Paris;OECD.

Pavitt, K. (1980) Technical Innovation and British Economic Performance , London; Macmillan.

Pavitt, K. and Wald, S. (1971) The Conditions for Success in Technological Innovation, Paris:OECD.

Price, W.J. and Lawrence, W.B. (1966) 'Scientific research and innovative process', Science, Vol. 169, May, pp.802-806.

Ravetz, J.R. (1971) Scientific Knowledge and its Social Problems, New York; Oxford University Press.

Reinganum, J. (1981) 'Dynamic games of innovation',Journal of Economic Theory, Vol. 25(1), Aug.,pp.21-41.

Ricardo, D. (1815) An Essay on the Influence of a Low Price of Corn on the Profits of Stock, London.

Ricardo, D. (1817) On the Principles of Political Economy and Taxation. London.

Richardson, P.R. (1975) The Acquisition of New Process Technology by Firms in the Canadian Mineral Industries. Ph.D. dissertation, University of Western Ontario.

Roberts, E.B. (1968) 'Entrepreneurship and technology', Research Management, July, pp.249-266.

Robertson, D.H. (1978) 'Australia's growth performance: An assessment', in Kasper, W. and Parry, T.G. eds. Growth, Trade and Structural Change in an Open Australian Economy, Centre for Applied Economic Research, Sydney; University of New South Wales.

Robinson, J. (1938) 'The classification of invention', Review of Economic Studies, Vol. 20, pp.139-142.

Robinson, J. (1954) 'The production function and the theory of capital', Review of Economic Studies, Vol. 21(2:55), pp.81-106.

Rosenberg, N. (1969) 'The direction of technological change: Inducement mechanisms and focusing devices', Economic Development and Cultural Change, Vol. 18(1), pp. 1-24.

Rosenberg, N. (1976) Perspective of Technology, Cambridge: Cambridge University Press.

Rosenberg, N. (1980) 'Learning by using', Mimeographed, Uni. of Stanford.

Rubenstein. A.H. (1957) 'Setting criteria for R&D', Harvard Business Review, Vol.35(1), pp.95-104.

Rubenstein, A.H. (1958) Problems of Financing New Research Based Enterprises in New England, Boston; Federal Reserve Bank Report.

Ruttan, V.W. (1959) 'Ushers and Schumpeter on invention, innovation, and technical change', The Quarterly Journal of Economics, Vol. LXXIII(4), Nov., pp. 596-606.

Rymes, T.K. (1971) On Concepts of Capital and Technical Change, Cambridge University Press.

Rymes, T.K. (1972) 'The measurement of capital and total factor productivity in the context of the Cambridge theory of capital', Review of Income and Wealth, No. 1, March, pp.73-108.

Sagal, M.W. (1978) 'Effective technology transfer from laboratory to production line', Mechanical Engineering, April, pp.32-35.

Salter, W.G. (1969) Productivity and Technological Change, Cambridge; Cambridge University Press.

Sampson, G.P. (1969) Productivity Change in Australian Manufacturing Industry, Unpublished PhD thesis, Monash University.

Sanders, B. (1964) 'Patterns of commercial exploitation of patented inventions by large and small companies', Patent Copyright and Trademark Journal, Spring.

Scherer, F.M. (1965) 'Firm size, market structure, opportunity and the output of patented inventions', American Economic Review, Vol. 55(5), Dec.,pp.1099-1125.

Scherer, F.M. (1967) 'Research and development resources allocation under rivalry', The Quarterly Journal of Economics, Vol. LXXXI(3), August, pp.359-394.

Scherer, F.M. (1970) Industrial Market Structure and Economic Performance, Chicago, Rand McNally.

Schmookler, J. (1952) 'The changing efficiency of the American economy, 1869-1938.', Review of Economic and Statistics, Vol. 34(3),pp.214-231.

Schmookler, J. (1959) 'Bigness, fewness, and research',Journal of Political Economy, Vol. LXVII(6), Dec.,pp.628-632.

Schmookler, J. (1962) 'Change in industry and in the state of knowledge as determinant of industrial invention', in NBER, op.cit., pp.195-251.

Schmookler, J. and Brownlee, O. (1962) 'Determinants of inventive activity', American Economic Review Vol. LII(2),pp. 165-176.

Schmookler, J. (1966) Inventions and Economic Growth, Cambridge, Mass; Harvard University Press.

Schmookler, J. (1972) Patents Inventions and Economic Change, Cambridge, Mass; Harvard University Press.

Schultz, T.W. (1953) The Economic Organization of Agriculture, New York; McGraw Hill.

Schumpeter, J.A. (1934) The Theory of Economic Development, Translated by Redvers Opie, Cambridge, Mass; Harvard University Press.

Schumpeter, J.A. (1939) Business Cycle, Vol. 1, London and New York; McGraw Hill.

Schumpeter, J.A. (1942) Capitalism Socialism and Democracy, New York; Haper and Bros.

Senate Standing Committee on Science and Environment, (1979) Industrial Research and Development in Australia, A report presented to the Commonwealth Parliament, Canberra: AGPS.

Shove, G.F. (1933) 'Imperfection of the market: A further note, Economic Journal, Vol. XLIII, pp. 113-125.

Smith, A. (1776) An Inquiry into the Nature and Causes of the Wealth of Nations, 1st edition, Vol. 1 & II, London, New edition (1976) Campbell, R.H.,Skinner, A.S. and Todd, W.B.(eds.), Oxford: Clarendon Press.

Solo, C.S. (1951) 'Innovation in the capitalists process. A critique of the Schumpeterian theory', The Quarterly Journal of Economics, Vol. LXV, pp.556-557.

Solow, R.M. (1957) 'Technological change and the aggregate production function', Review of Economics and Statistics, Vol. 39. Aug. pp.312-320.

Solow, R.M. (1962) 'Technical progress, capital formation and economic growth', American Economic Review, Vol. LII, pp.76-86.

Solow, R.M. (1970) Growth Theory: An Exposition, Oxford: Clarendon Press.

Solow, R.M. (1971) Capital Theory and the Rate of Return, Amsterdam: North Holland Publishing Company.

Spaey, J. (1971) Science for Development: An Essay on the Origin and Organisation of National Science Policies, Paris: OECD.

Steuart, J. (1767) An Inquiry into the Principles of Political Economy:, Being an Essay on the Science of Domestic Policy in Free Nations, 1st edition, London.

Stubbs, P. (1968) Innovation and Research-A Study in Australian Industry, Applied Economic Research Unit, Melbourne: Uni. of Melbourne.

Sundrum, R.M. (1977) 'The limits of economics for the study of development' Occasional Paper, Research School of Pacific Studies, Canberra: ANU.

Terleckyj, N. (1974) Effects of R&D on the Productivity Growth of Industries-An Exploratory Study, Washington: National Planning Association.

Terleckyj, N. (1980a) 'Direct and indirect effects of industrial research and development on the productivity growth of industries', in Kendrick and Vaccara eds. op. cit., pp.359-386.

Terleckyj, N. (1980b) 'What do R&D numbers tell us about technological change?', American Economic Review, Vol. 70(2),pp. 55-61.

Tisdell, C. (1983) 'The international real politik of science and technology policy',Prometheus, Vol. 1(1),pp. 127-143.

Twiss, B.C. (1980) Managing Technological Innovation, 2nd edition, London, Longman.

United States Senate Committee on Small Business, (1978) Joint Hearing Before the Committee on Small Business, House of Representative, 95th Congress, 2nd session, Washington; Govt. Printing Office.

Utterback, J.M. (1979) 'The dynamics of product and process innovation in industry', in Hill, C.T. and Utterback, J.M.eds. Technological Innovation for a Dynamic Economy, New York;Pergamon Press.

Villard, H. (1958) 'Competition, oligopoly, and research', Journal of Political Economy, Vol. LXVI, Dec., pp.483-97.

Vernon Committee Report, (1965) Report of the Committee of Economic Inquiry, Vol. I&II, Canberra; AGPS.

Von Hippel, E. (1976) 'The dominant role of users in the scientific instruments innovation process', Research Policy, Vol. 5, July, pp. 212-39.

Wilson, R.A., Ashton, P.K. and Egan, T.P. (1980) Innovation, Competition, and Government Policy in the Semi-Conductor Industry, Lexington, Mass; Lexington Books.

Chapter Two

Technological Development and Diffusion in Australian Manufacturing Industry, 1900-1968.

2.1.0 Introduction

As noted in the previous chapter, technological advance and industrial growth can often be achieved by systematic and intensive efforts, which are generally known as research and experimental development activities. Increasing investment in R&D activities reflects the ambition of an industry to increase its profit rates through technological efficiency. Following the decision to invest in R&D an industry has the option of either performing research activities in its premises and/or contracting research institutions to carry out research related to the industry.

The quantification of R&D effort and its rate of return have some different problems. There are no direct and accurate methods to determine either the total R&D input effort or output because of the intangible properties of R&D activity. However, a number of proxies have been developed to account for quantitative and qualitative measures of R&D effort. These are generally known as science (or science and technology) indicators (Johnston and Liyanage, 1980, 1983). Science indicators can be useful in demonstrating trends of resource allocation to R&D and determining rate of returns to R&D. Input indicators are designed to measure the resources devoted to scientific activity: output

The level of research and technology development in an industry is measured by a number of variables. Among these, the most useful input variables are:

a) the funds and human resources available for R&D and inventive activity;

b) the incentives, rewards and stimuli to produce innovations;

c) availability of capital equipment, instruments and material for scientific and technological activity.

The expenditure and manpower resources devoted to R&D activities have most commonly been used as quantitative input indicators. Guidelines and methodology for measuring input indicators and the problems associated with such measurements have been discussed in OECD (1962, 1970 and 1976), Freeman and Young (1965), UNESCO (1969), National Science Foundation (1967 and 1972a), and Freeman (1974). One of the major problems in measurement is defining the boundaries between different activities. Some of the basic concepts used and definitions adopted are discussed by Falk (1974), Brown (1972), Rothschilds (1972), Abernathy and Utterback (1978), and Utterback (1979).

Scientific output is often quantified using products of R&D such as patents, inventions, royalties, trademarks, new products, new processes and technical publications. The general methods available to quantify scientific output are discussed in UNESCO (1970) and Kochen (1978). The prospects and limitations in quantifying patent statistics as an output indicator are discussed in Sanders (1962) and Schmookler (1966). The application of publication counts has been studied by many including Price (1963), Wilson (1964), Shilling and Bernard (1964), Caplow and McGee

(1965), Bayer and Folger (1966), Box and Cotgrove (1968), Frame and Narin (1976), Narin (1976), McAllister (1980), and McAllister and Wagner (1981).

Expenditure and manpower variables, however, capture only a part of research effort. The quality of input, particularly the manpower inputs are often unaccounted by these variables. The quality of scientific output is even more difficult to evaluate. Attempts have been made using indicators such as citation counts and honourific awards and peer reviews. These include the works of Cole and Cole (1967 and 1968), Cole *et al.,* (1977), Crane (1965), Kaplan (1965), Zuckermann (1967), Bayer and Folger (1966), Anderson *et al.,* (1978) and Carpenter (1979).

Although the quality of R&D effort is not totally reflected in expenditures and manpower counts, these are used to account for R&D activity at a given period, simply because there is no alternative method to account for absolute R&D effort. Aggregated data on R&D expenditures and scientific and technical manpower have been used as partial indicators of industrial R&D eort in this study.

This chapter commences with a discussion on the definitions of manufactures, industrial research and development and technical innovations. The importance and growth of the manufacturing sector in the Australian economy is then briefly examined. It is followed by an account of government support for the growth of the manufacturing sector since the beginning of the 20th century and an examination of the development of industrial research in public and private enterprise sectors.

It was mainly the post Second World War industrial expansion which provided a strong impetus to the development of research capabilities in private sector. R&D statistics, even in the simplest form, became available only after this expansion. The first attempt to collect R&D statistics was undertaken in 1952. Since then, there have been sporadic attempts by various groups to collect R&D expenditure and manpower statistics for industry. The official regular collection of R&D statistics was commenced in early 1970s for the period 1968/69.

Examination of the resources devoted to R&D activities and the sources of technological advances in the manufacturing sector have been divided into two periods: prior to and after 1968/69. The reasons for selecting 1968/69 as a base year are as follows:

a) There was a conceptual change in the classification of manufacturing industries in surveys by the Australian Bureau of Statistics (ABS) (the then Commonwealth Bureau of Census and Statistics) in 1968/69. Therefore, the statistics collected prior to 1968/69 cannot be directly compared with more recent statistics;

b) The official surveys of R&D have only been regularly conducted since 1968/69;

c) The rate of growth of manufacturing output began to decline towards the end of 1960s so around the 1968/69 period can be considered as a turning point in the development of manufacturing industry.

For these reasons industrial R&D investment and advances in technological knowledge are more appropriately considered on separate time scales. In this chapter, the resources devoted to science and technology in Australian manufacturing industry prior to 1968/69 are examined. The role of government in developing technological activities and private industry attempts to develop research and technology are also studied together with the growth and performance of manufacturing industry since the beginning of the twentieth century. Scientific and technological development since 1968/69 is examined in the following chapter.

2.1.1 The Definition of Manufacturing Industry

The definition of manufacturing activities and the categorization of the manufacturing sector into various industry groups in this study has followed the concepts used by the Australian Bureau of Statistics in its census. A major conceptual change relating to classification of manufacturing activities took place during the 1968/69 survey year with respect to the central census unit.

Prior to 1968/69, the ABS adopted the industrial "establishment" (also referred to as a factory) as the central census unit; it was defined as a unit engaged in manufacturing activity and employing four or more persons or using power (other than manual labour) in any manufacturing process. Any part of the business which met this definition was treated as a manufacturing establishment, though activities which involved selling and delivery to the location were excluded from manufacturing activity (Commonwealth Bureau of Census and Statistics, 1970, p. 1043).

In order to conduct an integrated economic census in 1968/69, the ABS revised the concept of the central census unit to "enterprise", which is broadly defined as an operating legal entity. This was the first time that the economic censuses were collected on the basis of a common framework of reporting units, data concepts and in accordance with an Australian Standard Industrial Classification (ASIC). According to the new concept, a manufacturing establishment is one predominantly engaged in manufacturing, but data supplied for it also covers all activities, including selling and delivery at the location. On the other hand, the statistics of factory establishments, which were involved in manufacturing activity as minor activity of predominantly retail establishments, were excluded.

The change in the concept of census unit also led manufacturing establishment, which were servicing units of a particular manufacturing establishment, formerly classified as independent, to become an ancillary unit of that establishment. The introduction of an ASIC classification in the 1968/69 also resulted in changes in the scope of the manufacturing census. Establishment which were concerned with electricity and gas, were separated from manufacturing surveys and treated as a separate industry group. A large number of establishments, which were previously included under manufacturing, were shifted to services. Among those were motor vehicle repair, repair and servicing of agricultural machinery, dry cleaning, laundry and clothes dyeing services, watch, clock and jewellery repairing, boot and shoe repairing, and tyre rethreading and repairing. The establishments engaged in slaughtering, milk treatment, and publishing, which were previously excluded from manufacturing activities, were included in the 1968/69 survey (Commonwealth Bureau of Census and Statistics, 1971,p.714). Those changes resulted in a reduction in the number of enterprises defined as manufacturing institutions.

The definition of Australian manufacturing activities in the modern context usually follows concepts similar to those adopted by ABS since the 1968/69 survey. The following industry divisions are identified as two digit level manufacturing industries (Commonwealth Bureau of Census and Statistics, 1969 and ABS, 1981).

ASIC code	Industry Class
20	Manufacturing undefined
21	Food, beverages and tobacco
23	Textile
24	Clothing and footwear
25	Wood, wood products, printing and publishing
26	Paper, paper products, printing and publishing
27	Chemicals, petroleum and coal products
28	Non-metallic mineral products
29	Basic metal products
31	Fabricated metal products
32	Transport equipment
33	Other machinery and equipment
34	Miscellaneous manufacturing and manufacturing not elsewhere classified.

2.1.2 The Concepts of Industrial Research and Development and Technical Innovation

The research and development effort of a firm, which can be measured in terms of investment of financial and human resources, is one of the sources of advancement of scientific knowledge and technical innovations. There are, however, other means by which advancement of technical knowledge occurs. These include learning by doing, individual research efforts, education of the workforce, technological spill-over effects, and inter-industry and intra-industry transfer of knowledge in terms of technical information, capital goods and intermediate products. All these activities commonly contribute towards advancing technological knowledge in industry. As pointed out in Chapter One, among all these activities organized R&D has generally been accepted as the most influential and effective source of the development of technology.

The concept of R&D is interpreted in many ways. The generally accepted definition, which follows the international standard for measuring R&D by OECD (1976), defines research as original investigations undertaken towards discovery of new scientific knowledge. Research activities are separated into basic and applied research depending on the objectives and aims of conducting research. In basic research, new knowledge is sought without a specific application in mind and in applied research, knowledge is pursued with a specific application or use in view. Experimental development is defined as technical activities concerned with non-routine problems encountered in translating research findings into products and processes (Mansfield, 1968,p.7). The definitions of R&D adopted in the surveys of the National Science Foundation include:

> Basic and applied research in sciences (including medicine) and in engineering, and design and development of prototypes and processes. It does not include non-technological activities and technical services, such as quality control routine product testing, market research, sales promotion, sales services, geological and geophysical exploration, or research in the social science or psychology.
> (Keezer, 1960,p.355)

The activities included in R&D deviate not only in broad definitions but also at the level of unit of performers of R&D. The type of research conducted in different economic sectors places the emphasis on different types of R&D activity. The industrial sector characteristically is more concerned with experimental development and applied research than with basic research. The objective of undertaking different types of R&D differ significantly, so that, the nature and methodology of R&D may also vary. For example, Daniel (1976,p.3) argued that industrial research often differs from pure or basic research. He writes,

> Because of the shortage of available technicians, because of the entire lack of any theory for more properties, because of the multiplicity of factors that may influence a product and because of the multiplicity of factors to which it must be insensitive, industrial research often differs widely from pure or basic research. In particular, more factors must be studied, and so it is often said, and rightly, that more data must be taken in industrial research problems than in pure research ones.
> (Daniel, 1976,p.3)

If industrial R&D needs more empirical data than R&D carried out in other sectors in the economy, it may be that R&D depends significantly on the environment which is carried out. Hence the concept of R&D is complex not only because of problems in definitions but also because of the actual practice of R&D undertaken according to different institutional goals and objectives. In general, private industrial R&D investment is directed to specific objectives with the intent of achieving a maximum rate of return. New ideas are generated not only by experienced scientists but also by ordinary workers, who handle day-to-day production. Hence a dynamic industry must also devote efforts to capturing ideas generated outside the R&D laboratories and in particular those generated among experienced production workforce in the factory.

There is a considerable confusion among Australian private enterprises over the definitions of industrial R&D. The national R&D surveys conducted by the Department of Science and Australian Bureau of Statistics adopted the definitions laid down by OECD (1976). In actual practice, financial reporting and budgetary accounting for R&D in firms are largely influenced by the definitions of R&D adopted by the Australian Industrial Research Development Incentives Board (AIRDIB). Further variations occur between industries. The Industrial Research and Development Incentives Act 1976 (Commonwealth Aust., 1976) defined industrial R&D as,

> Systematic experimentation or analysis in a field of science or technology carried on by the company, or procured by it to be carried out, in Australia with the object of-
> a) acquiring knowledge that may be of use for the purpose of devising or developing new or substantially improved material products or new or substantially improved processes for or in connexion with the production or use of material products (including processes for disposing of, or rendering harmless, waste products or emissions resulting from the production or use of material products):
> b) applying knowledge for the purpose referred to in paragraph (a).
> (Commonwealth Aust. Act No. 85, 1976,p.5.)

The basic difference of AIRDIB definitions and OECD concepts established for the purpose of collecting R&D statistics are that AIRDIB concepts focused mainly on products and processes new to enterprise and research on applied and experimental development activity. Basic research in industry is not covered by these definitions and R&D carried out overseas on behalf of the company is also excluded. According to OECD concepts all types of research including social science and humanities research conducted by industry also should be included. Moreover, the OECD definitions are more universal and mainly refer to R&D activity that has not been already undertaken elsewhere in the world. These ambiguities influence the R&D financial and manpower reporting in industry at aggregate levels.

The expenditure incurred and manpower used in R&D activities partly reflect the quality of effort directed towards the growth of scientific knowledge and inducing technical innovations. The quality of manpower employed and sophistication of equipment used in experimentation must also be considered in accounting for the total input to R&D.

Investment in R&D activities and inducing technical innovations is largely a function of industrial performance. In a mature industry investment in R&D is significantly controlled by profit rates, previous levels of R&D expenditures and entrepreneurial activities. The strategies of an R&D program available to a firm can be considered as lowering the cost of production, improving the efficiency of existing products and processes, and producing new and improved products to broaden existing markets. The allocation of resource to R&D will depend on the firms strategy toward productivity improvement.

The decision to invest more on R&D at the expense of the expansion of production, advertising and marketing is determined by judgement of the risks of the different types of investment. As a strategy of technological advance, a firm may decide to increase its purchase of licenses and equipment as against increasing expenditures on R&D. Therefore, the interplay between managerial decisions on R&D investment and other options influence the size of R&D budget.

2.2.0 The Economic and Technological Factors in the Development of Australian Manufacturing Industry

The development pattern of technology based manufacturing industry in Australia appears to show a selectivity depending on prevailing conditions and comparative advantages of available resources. In an attempt to describe the growth of the manufacturing sector relative to technological change as a source of growth, it may be best to consider the development of the sector in three successive periods. These are the period prior to Federation: between 1901-1939 and the period after the Second World War to the present time.

2.2.1 General Features of Early Development of Australian Industry

The late 19th century is regarded as an important gestation period for the development of the manufacturing sector in a pastoral dominated Australian economy. Butlin (1958,p.13) pointed out that manufacturing share in net national product rose from less than 5 per cent in 1861 to a level of 12.5-15.0 per cent in 1881. He argued that during the thirty years 1861-1891, Australian economic growth was sustained, stable, and rapid and much of the credit for it could be attributed to the rapidly rising population and stock of capital equipment. He pointed out that during 1870s investment on new domestic capital formation was in the order of 20 per cent of the net national product new capital formation. McCarty (1964,p.18) emphasised the importance of technical change rather than capital investment. He argued that the economic growth during 1860-1900 can be attributed to the adoption of new technologies in principal rural industries such as wool-growing, agriculture, mining and transport. Both Hall (1963) and McCarty (1964) pointed out that as innovations and investments reduced costs and increased output, there emerged a large number of import replacing manufacturing industries.

The development of the manufacturing sector took a secondary position in the economy. Butlin (1959,p.409) pointed out that the growth of productive assets in the 19th century, however, concentrated on pastoral equipment, with a substantial but very much smaller proportion of resources devoted to industrial and commercial structures and equipment. A relative decline of pastoral capital formation and the rise of industrial and commercial investment occurred in the early twentieth century. The growth of commercial and industrial capital comprise about one third of the private total in the first decade of the century and it was boosted to 40 per cent before the First World War and after the war averaged between 33 and 50 per cent (Butlin,1959,p.412). It has been noted (Butlin,1970,p.311) that during the late nineteenth century, manufacturing was characterised by a

a) largely local processing building material industry,

b) consumer goods supply industry of food and drinks, and

c) metal and machinery industry.

These largely constituted the manufacturing industry until the First World War. Manufacturing was restricted to the production of goods for domestic requirement using basic local and imported material. The small scale of these industries and the local political environment caused most of the country's requirements to be met by imports from Britain (Boehm, 1979). There was no significant development in the manufacturing industry sector during this period apart from the development of food, beverages, clothing steel and some light engineering manufacturers. Other minor industries included textile, iron and steel making, a wide range of engineering industries, ship building and chemicals.

One of the promising industries commenced operations in the 19th century was the iron and steel industry. The first blast furnace was erected in Mittagong (New South Wales) in 1848 for the smelting of ores for the production of pig iron. It was found by successive iron masters that it was impossible to compete with overseas products and as a result the works were closed down in 1886. In 1875, a blast furnace was erected at the Eskbank Ironworks in Lithgow (NSW) for the production of pig iron and struggled for existence until 1882 (Commonwealth Australia, 1927,p.6). The absence of an auxiliary industrial structure to utilize products of the basic steel industry made its operation difficult before Federation. Innovations in power and energy were needed and these sectors showed a significant growth only during the second decade of the twentieth century (Butlin, 1959, p.413 and Maizels, 1957,p.166).

During the period 1901 to 1939, there was a substantial expansion of manufacturing industry. An increase in tariff protection for manufacturing and incentives to build a scientific institutional infrastructure were provided by the Commonwealth Government. Haig (1975,p.143) has shown that manufacturing product output doubled with an annual growth rate of 2.7 per cent between 1910 and 1938/39. The rapidly growing industries were chemicals, non-metallic mineral products and textiles, whereas leather and wood industries reported the slowest growth. Boehm (1979,p.164) has pointed out that a large scale production of steel and iron, machinery, food, beverages, textile fabrics and clothing provided nearly two thirds of the value of production and employment. The first steel making furnace with a capacity of 4 tons per cast was commissioned at Lithgow in April 1900. The Commonwealth and State governments assisted the steel-making endeavour by assuring a contract for railway supplies over a number of years. In spite of this it was still compelled to abandon operations after few years mainly due to cost of production. The metals industry took off only after 1915 with New South Wales government assistance in the form of the Newcastle Iron and Steel-Works Act in 1911 (BHP,1979).

The chemical industry also had a similar difficult start. The major chemical operation at the beginning of the century was the distillation of zinc metal. Sulphide Corporation Limited maintained a small zinc distillation plant at Cockle Creek, New South Wales between 1902 and 1908. In 1915, Broken Hill Associated Smelters Proprietary Ltd. engaged in zinc distillation until 1921, when Risdon Electrolytic Works began. Thereafter, the development of sulphide acid plant and superphosphate production to local agricultural use began, placing the chemical industry on a path to stable development (Electrolytic Zinc Company of A'asia Ltd., 1963). Ford (1963) has discussed the problems underlying the development of chemical industry research in Australia.

The most striking feature of this period was the trend toward transition from an agrarian economy to an industrial economy. Butlin (1959,p.412) has argued that the period 1896-1914 was important for this transition from a pastoral to an industrialised economy. The development of the manufacturing sector was more or less determined by the needs of the large farming and mining community. Manufacturers mainly catered for a domestic market and were not geared for a competitive export market. The development of manufacturing industry was hampered by constraints such as a wide-spread and small domestic market, geographical isolation from industrial markets, and heavy dependence on imported goods which completed with local produced goods. A major factor stimulating the growth of manufacturing industry was the scarcity of essential supplies created during the two world wars as pointed out by Forster (1953) and Mellor (1958).

Maizels (1957) has argued that in the long term, during the period from the beginning of the century up to the Second World War, only about one third of the total growth in manufacturing output can be attributed to the increase in physical output per employee; about two thirds was due to the expansion in the labour force. He argues that this type of industrial expansion, which is largely labour intensive, was characteristic of most Australian industry in this period. However, the average gross capital formation in industry increased significantly during the 2nd and 3rd decades of the twentieth century. Table 2.1 indicates the average gross capital formation in Australian industry from 1861 to 1939.

Table 2.1 The Average Gross Capital Formation in Australian Industry From 1861 to 1939($'000)

Period	Capital Investment
1861-1870	2420
1871-1880	4662
1881-1890	6290
1891-1900	2908
1901-1910	10408
1911-1920	24576
1921-1930	42640
1931-1939	34168

Note Since 1901, years referred to correspond financial years beginning from June. 1 U.K pound is taken as approximately equivalent to 2 Australian dollars.

Source Butlin (1959,pp 397-399).

These statistics indicate that capital formation was remarkably high after 1911. The approximate value of plant and machinery used in manufacturing industry also increased considerably during the 1920s as

These statistics indicate that capital formation was remarkably high after 1911. The approximate value of plant and machinery used in manufacturing industry also increased considerably during the 1920s as illustrated in Graph 1. The increase in capital investment in terms of equipment and plant may have had a substantial effect on technical advances in Australian industry.

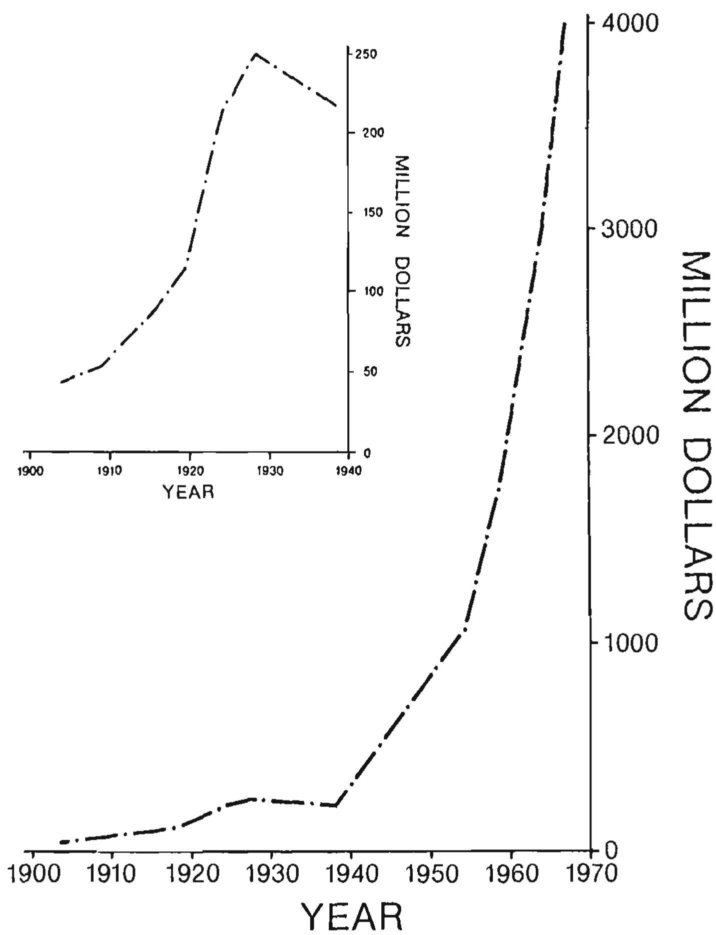

Figure 1. Value of Plant and Machinery in Manufacturing from 1900 to 1970

Boehm (1979) argues that when the Second World War began in 1939, Australian manufacturing industry was considerably diversified and developed. Manufacturing industries included iron and steel, non-ferrous metals, machinery and engineering, electrical equipment, motor vehicle assembly and parts, chemicals and fertilizers, food processing, textiles and clothing, wood products and printing and publishing. The relative importance of the different industry sectors is presented in Table 2.2.

Table 2.2 The Value of Production of Different Manufacturing Industries From 1913 to 1939, Selected Years(million dollars)

Period Industry Sector	1913	1920-21	1928-29	1938-39
Metal works & machinery	30.1(25%)	44.7(22%)	71.3(23%)	124.8(33%)
Food & Beverages	29.0(24%)	45.3(22%)	47.8(23%)	83.3(22%)
Textile & clothing	16.7(14%)	33.9(16%)	32.4(16%)	33.0(9%)
Paper, printing & Pub.	10.0(8%)	16.6(8%)	16.4(8%)	21.9(6%)
Wood & wood work	9.8(9%)	17.3(8%)	17.3(6%)	25.0(7%)
Other	25.3(20%)	50.1(24%)	79.4(25%)	96.0(25%)

Source Boehm (1979,pp 157-158).

A large proportion of the manufacturing activity was centred around metal works, food, and beverage industries. It is interesting to note that industry composition as a percentage of value of production remained relatively static indicating a very little change in industry growth. Haig (1975,p.143) has pointed out that the largest percentage increase in Australian manufacturing products occurred during World War II. The period between 1938/39 and 1948/49 marked with an annual rate of growth of 4.7 per cent with chemical industries and metal industries exhibiting high growth rates.

2.2.2 Emergence of Modern Industrial Structure

In the third phase of development after the war, growth of manufacturing was unprecedented. Maizels (1957,p.166) has pointed out that total manufacturing production expanded substantially and the production during the 1953/54 and 1954/55 period was more than double that of the immediate pre-war average, and over 5 times greater than that prior to the First World War. During the 1950s, expansion occurred in the energy, chemical and engineering industries. The lowest expansion was in areas of textiles, leather, clothing and the processing of food and beverages.

Morse (1964) has pointed out that by 1959 factory products and primary production were equal in value and by 1964 factory production was more than double primary production. Nevertheless primary production dominated the export market, accounting for 75 per cent of total exports. The growth of manufacturing continued well into the 1960s. Butlin (1970, p.322) asserted that the outstanding feature of post-war development until the early sixties was accelerating labour productivity and a rapid increase in output of manufacturing industry. Relaxation of foreign exchange constraints at the beginning of the 1950s helped manufacturing industry to incorporate technological changes. how

Middleton (1970) has pointed out that in the years 1963-1968 factory output rose by an annual average growth rate of 9.7 per cent. Thus, by 1968 over 73 per cent of the combined value of production of primary industry and secondary industry came from the manufacturing industries. Also manufacturing contributed more than 32 per cent of the value of exports in 1967/68. The reasons for the sudden growth of the sector, apart from tariff protection and increasing demand in the local market, was Australia's ability to capture the export market in former British colonies east of Suez (Commonwealth Bureau of Census and Statistics, 1965,p.144). During the post war industrial expansion, industries such as iron and steel, transport equipment, plant and machinery, engineering, electrical equipment and metals were prominent, each group reporting high growth rates. Waterman (1972,p.153) has pointed out that the manufacturing and services sector between 1950 and 1958 absorbed 85 per cent of the increase in the workforce. The relative importance of manufacturing industry and diminishing role of primary industry was reflected in gross domestic product.

Table 2.3 Contribution of Manufacturing Industries to Gross Domestic Product(GDP) at Factor Cost, Selected Years, 1901-1968/69

Sector Period	Manufacturing (percentage)	Primary Producer (percentage)	GDP ($million)
1900/01	12.1	19.3	382
1913/14	13.4	23.5	830
1919/20	13.5	23.5	1161
1928/29	16.7	21.2	1607
1938/39	18.5	19.5	1697
1948/49	26.2	21.3	4031
1950/51	23.7	29.0	6583
1955/56	28.0	15.9	9483
1962/63	26.8	12.6	14446
1968/69	26.1	9.6	24327

Source Boehm (1979, 2nd edition,pp.10-11).

The contribution of manufacturing industry to the gross domestic product has been greater than the combined effort of the traditional primary industries and mining industry during the last few decades. In 1901, the manufacturing sector contributed nearly 12 per cent (OECD, 1975,p.8). The growth of manufacturing industries from 1901 to 1968/69 in selected periods is presented in Table 2.3.

The growth of the manufacturing sector has begun to slow down since 1970/71. Although there was a considerable increase of GDP at factor cost by manufacturing industry from $8141 million in 1971/72 to double prices that amount, $16267 million in 1977/78, the percentage contribution to GDP has gradually declined as shown in Table 2.4.

Table 2.4 A Comparison of the Share of Percentage Distribution of GDP (at factor cost) by Manufacturing and Agriculture Sectors

Year	1970/71	71/72	72/73	73/74	74/75	75/76	76/77	77/78	78/79
Agri.	6.7	6.9	8.0	9.1	6.6	5.8	5.7	5.0	7.3
Manu.	25.2	24.0	23.3	22.8	22.0	21.3	20.9	20.4	19.4

Note Agriculture sector includes agriculture, forestry, fisheries and hunting.

Source ABS (1980). Australian National Accounts - National Income and Expenditure, 1979/80,. Cat. No. 5204.0, and ABS (1981), Australian National Accounts Preliminary Study, No. 3, Cat. NO. 5203.0, Canberra.

The manufacturing sector also began to grow as an employer in the postwar period. Prior to the war employment in industry grew at a slow rate. The second progress report of the Royal Commission of National Insurance (Commonwealth Aust., 1927, p.1421) reported that the main problem in connexion with unemployment was said to be in Australian secondary industries. It was stated that at the 1891 census 13.2 per cent of the population was employed in the industrial sector and at the 1921 census the percentage was practically the same, 13.3 per cent.

Manufacturing industry became an important source of employment with industrial expansion. However, with the decline in share of GDP, there occurred a comparable decline in employment in terms of both real absolute numbers and as a percentage of total employed in the work force. Table

2.5 illustrates the diminishing employment prospects in manufacturing industry.

Table 2.5 A Comparison of the Share of Percentage Distribution of GDP (at factor cost) by Manufacturing and Agriculture Sectors

Sector	Primary Industry	Manufacturing	Total Employment
1901	412(26%)	272(17%)	1615
1911	492(25%)	394(20%)	1990
1921	533(23%)	494(21%)	2329
1933	596(22%)	519(19%)	2744
1947	505(16%)	882(28%)	3196
1954	501(14%)	1038(28%)	3702
1961	469(11%)	1164(27%)	4225
1966	457(09%)	1312(27%)	4856
1971	386(07%)	1216(23%)	5240
1976	405(07%)	1139(20%)	5788

Note The manufacturing industry between 1901 and 1966 includes electricity and gas industries. Primary sector includes agriculture, forestry, hunting and fishing. The employment includes only those of age 15 years and over.

Source ABS, Census of Population and Housing, Various issues; Boehm (1979, 2nd edition,pp.74-75).

The performance of manufacturing industry during the last decade has considerably deteriorated. The annual growth rate of the sector at 1974/75 constant prices has dropped considerably. The Bureau of Industrial Economics (1979) has reported that the growth rates for the 1962/63 and 1968/69 period were reduced by nearly 50 per cent in 1968/69 and 1975/76 periods, respectively. Table 2.6 shows the fluctuation of growth rates at constant prices.

There has been slow growth in capital investment in Australian industry. However, the statistics available on the nature of the investment and the amount of capital required for a speedy growth of manufacturing industry is limited. Gilbert (1959, p.132) has pointed out that since the late 1930s, the value of capital equipment and unfinished goods essential for the processing industries was about 80 per cent of total imports.

Table 2.6 The Average Annual Growth Rate of Manufacturing Industry from 1962/63 to 1975/76 (at constant 1974/75 prices)

Period	1962/63 to 68/69	1968/69 to 72/73	1972/73 to 75/76	1968/69 to 75/76	1975/76 to 78/79
Growth Rate	5.6	4.5	1.3	3.1	2.4

Note Growth rates from 1975/76 to 1978/79 were calculated using ABS (1981).

Source ABS(1981), Australian National Accounts Gross Domestic Product by Industry at Current and Constant Prices, Cat. No. 5211.0, Canberra; Bureau of Industry Economics (1979), Australian Industrial Development-Some Aspects of Structural Changes, Report No. 2, Canberra, AGPS.

Link

Table 2.7 indicates the annual average percentages of total imports and share of essential processing capital equipment among those imports. The value of capital goods imported for processing in industry may be taken as an indicator of technical change. Therefore, the period between 1913 and late 1950s may reflect a slow accumulation of technical change measured in terms of imports of processing capital equipment.

Table 2.7 Annual Average Percentage of Total Imports of Capital Equipment for Private and Public Enterprises

Category Year	Processing equip.	All capital equipment and unfinished goods used
1913	11%	68%
1919/20	8%	71%
1920/21	8%	74%
1928/30	8%	76%
1935/40	10%	80%
1946/49	9%	82%
1957/58	16%	81%

Source Gilbert (1959, p.132)

2.2.3 Explanations for the Decline in Manufacturing Growth

The reasons for the slowdown in the growth of the manufacturing sector can be separated into economic and non-economic ones. Some earlier studies suggested the following reasons were most responsible for the sluggish growth of manufacturing industry (Commonwealth Aust.. 1927b. p.1421):

a) Unprecedented volume of goods flowing into the country;

b) Opportunities to produce some of these goods were not taken and efficient plants were under utilized;

c) Prejudices against Australian made goods and preference for imports;

d) Lack of appreciation for extensive fostering of manufacturing industry;

e) Inability of Australian manufacturing to compete with low-wage countries;

f) Inadequacy of tariff protection and inability to further strengthen controls owing to adverse effects on other industry sectors;

g) Rate of wage increases and increased costs of production;

h) Difficulties due to the domestic transportation system.

Some of the recent explanations for the decline in the growth of manufacturing industry, which in many ways are remarkably similar, include: (Kasper and Parry, 1978,p. 12)

a) a low level of research and experimental development activities in manufacturing industries;

b) an inappropriate structure of manufacturing industries;

c) a slow rate of technical change;

d) a low level of capabilities, organisation, protection from import competition and provision for other regulatory controls;

e) an inability to increase labour productivity due to the increase in wage costs and the fragmented trade union structure;

f) the low input of government R&D programs and other assistance to industrial innovations.

The insufficient level of R&D expenditures and level of technical change are cited as significant drawbacks in the development of the manufacturing sector in a number of studies including Scott (1957) and Hunter (1963). However, these claims are often difficult to evaluate due to lack of sufficient information on the historical development of technology and general scarcity of science and technology statistics in Australia.

The available studies on the R&D system and technical development in Australia provide only limited information on the level of technical progress in Australian manufacturing industry.

The Vernon report (1965,p.418) highlighted the importance of R&D for productivity growth, but failed to make a substantial contribution to understanding the structure of the R&D system and its effects on productivity growth[10] Stubbs' (1968) study aimed at identifying R&D structure in Australian industry until 1964 and the capacity to generate innovations. He pointed out the high level of dependence on imported technology and the limited resources available for local R&D activity. He concluded that Australian R&D has played only a minor role in the growth and profitability of industry compared with market factors and managerial inputs. The OECD report (1975,p.21) outlined the importance of industrial research in the manufacturing industry sector with particular reference to the R&D survey results of 1971/72. The Jackson report (1975,p.69), which was designed to develop policies for manufacturing industry, devoted a little effort to analyse the structure of R&D and the capacity to generate innovation industry. The OECD report on national science policy (OECD, 1977,p.123) briefly discussed the industrial R&D structure and emphasised the importance of strengthening research in industry. The ASTEC report (1978) provide an analysis of the role of scientific organizations in developing research in industry and of research activities in different sectors of industry. The Crawford report (1979,pp 7-19), which examined the need for structural adjustment in manufacturing sector discussed in some detail the state of industrial technology and innovations. The Senate Standing Committee report (1979) on industrial R&D provided a comprehensive analysis of industrial research policies, the adequacy of government support for the development of research in manufacturing sector.

more effort needed to justify point

The information available on the purchase of technical knowhow and local technical output are equally weak. Encel and Inglis (1966) have

10 For a critique of the Vernon report see Hogan, 1966.

studied the patents and inventions in Australian industries since the beginning of the century and they have noticed an increase in patenting activity in Australian industry. However, they have also pointed out the heavy dependence on imported technology.

The above mentioned studies by and large have reported the level of industrial research and have attempted to quantify the IR&D effort. Some of those studies have made reference to the availability and adequacy of the data base in determining the effectiveness of the industrial research structure. However, no comprehensive analysis of resources devoted to R&D by manufacturing industry prior to 1968/69 has been made. The effectiveness of the R&D structure in industry and the level of technical advances needed in manufacturing industry has not been fully investigated.

2.3.0 Government Assistance to the Growth of Manufacturing Industry

There have been a number of Commonwealth and State Governments initiatives to develop the manufacturing industries from the beginning of the twentieth century. These initiatives basically comprised the legal provision for industrial protection, encouragement of private and public sector research activities and financial incentives to manufacturing industry. Under the Commonwealth Government assistance scheme manufacturing industry enjoyed the benefit of protective tariffs, import restrictions, local content schemes, government purchasing policies, dumping and countervailing duties, research incentives, export incentives, tax concessions and more. The Jackson report (1975,p. 56) discussed some of these forms of assistance.

These various forms of assistance can be reduced to three general types:

a) protection policy,

b) incentive and industrial assistance, and

c) development of industrial R&D and technological advances.

2.3.1. Industrial Protection to Manufacturing Activity

One of the more effective forms of protective measure was the tariff policy introduced in 1908 by the Commonwealth Government to safeguard manufacturing industry. A wide range of goods and a large number of industries were supported by this protective system which became the principal strategy of manufacturing industry. The main objective of the tariff has been to ensure adequate protection to certain industries from imports. The system has also been used as an instrument of safeguard to some industries. For example, in 1966 many chemicals were granted minimum import prices to protect local producers from very low-priced imports and in 1965 manufacturers of passenger motor vehicle components were supported through a local content plan (Jackson Report, 1975, p.33). The structure and effectiveness of the tariff system is discussed in many Australian studies including Corden (1966 and 1971), Gruen and Evans (1971) an Evans (1972). From the onset the tariff system has been revised a number of times and in 1921 a Tariff Board was created in order to strengthen it. In 1973, the Industrial Assistance Commission succeeded the Tariff Board.

Another important protective measure was the payment of bounties to certain industries by the Commonwealth Government. The Manufacturing Encouragement Act (Commonwealth, Aust. 1909) was introduced in 1908 and bounties were paid to industries such as pig iron, steel, galvanized sheet, plate iron or steel, wire netting, wire, and iron or steel tube making. Payments of bounties were later extended to various other industries.

The Patent Act of 1903 was enacted to protect industrial inventions (Commonwealth Aust., 1903). The protection of industrial property was strengthen in 1954 when the Patent Act of 1952 was revised to provide inventors with rewards and other encouragements. The Patent Act of 1952-1973 (Commonwealth, Aust., 1975) has made further provisions for the inventor with exclusive rights to sell or assign the patents. It also provides rights to the patent outright or to grant licenses exclusively to one person or non-exclusively to several enabling the inventor to receive royalty payments. Lamberton (1970,p.10) has pointed out that the Patent Act 1952-2969 provided the inventor with exclusive control over the use of his invention for sixteen years, in exchange for his making the invention public knowledge.

2.3.2 Incentives and Industrial Assistance

Hardly any development of private technological capability occurred in manufacturing industry in the early part of the century. Manufacturers relied heavily on purchase and lease of machinery and equipment embodying technology from overseas. The overseas supplier often dictated the terms of using technology in Australia. Under certain circumstances the Federal government was led to introduce special legislation to protect local producers from the terms of overseas technology suppliers. The Australian Industries Preservation Act introduced in 1906 had the effect of safeguarding local industrialists from unfair technological exchanges (commonwealth, Aust.,1906a). The statutory declarations made to the parliament by certain manufacturers reveal that the problems faced by local industrialists owing to technological dependency were a significant constraint to local production (eg. Commonwealth, Aust. 1906b, p.253).

Responsibility for the development of a local technological capability fell largely to government. The first attempt was made in 1916, when the Governor General appointed an Advisory Council of Science and Industry to consider and initiate scientific research in connexion with, or for the promotion of, primary and secondary industries in the Commonwealth. The report of the Executive Committee of the Council suggested branches of industrial and scientific research in which investigations would be of immediate practical use to producers an manufacturers (Commonwealth, Aust., 1919,p.829). The Council was responsible for the initiation and preparation of groundwork for a proposed Institute of Science and Industry.

The government's initial attempts to support technological endeavour was channelled through the organising and financing of R&D activities to service various sectors of industry. Apart from that, major taxation provisions on R&D were introduced in the Income Tax Assessment Act 1936-1968. These provided exemptions from income tax for a variety of expenditures for a business. Those include expenditure of a capital nature on scientific research related to that business, payments to an approved research institute for scientific research related to that business belonged. The tax exemption provisions also applied to expenditures incurred in producing industrial properties such as patents besides R&D. Taxation incentives are discussed in Lamberton (1970,p.53) and Edwards (1979,pp 17-39).

2.3.3 Development of Industrial R&D and Technical Structure

Federal and State Government interest in scientific research have provided a prime driving force for industrial R&D in Australia. In 1920, the Institute of Science and Industry Act was legislated by the Federal Government (Commonwealth, Aust.,1920). The act provided legal status for the creation of a Commonwealth Institute of Science and Industry Research and to establish a Bureau of Agriculture and a Bureau of Industry therein. The Institute was empowered to conduct all aspects of agricultural and industrial research which were relevant for the development of agriculture and industry.

In 1926, the Institute of Science and Industry Act was amended to broaden the activities of the Institute which was transformed to a Council by the revised Act of Science and Industry Research (Commonwealth, Aust..1926a). The Science and Industry Endowment Act of 1926 established a fund of

$200,000. the income from which was to be used for research (Commonwealth. Aust.,1926b). A major portion of the activities of the Institute/Council of Scientific and Industrial Research was directed towards the problems of primary industry while the manufacturing industry needs were relatively neglected.

There are no detailed statistics to illustrate the private industry involvement in research in the early part of the century. Expenditure on research seems to have been made exclusively by the Commonwealth Government. The expenditure items allocated for research in the Government estimates begins to appear from 1915. After the formation of the Commonwealth Institute of Science and Industry Research in 1920, considerable sums were allocated in the Government estimates to research expenditures. The departments involved in research activity included Agriculture, Home and Territories, Postmaster General's, Health, Defence and Prime Minister's departments. However, some of the expenditure items classified under R&D appears to be more properly labelled related scientific activity. The budget of the Commonwealth Institute and Department of Defence dominated R&D expenditure until the late 1920s when the Department of Health and Postmaster General's Department spent a considerable sum on research. In the early part of the century research in agriculture, forestry and fisheries dominated while research into the physical sciences and industry was virtually non-existence. Table 2.8 provides some idea of the level of R&D expenditure incurred by the Commonwealth Departments for selected years.

Table 2.8 Expenditure of Commonwealth Government in R&D Activity from 1920/21 to 1939/40, Selected Years ($'000)

Year Field	1921/22	24/25	27/28	30/31	33/34	37/38	39/40
Agriculture	25	41	153	220	216	537	553
Mining and Metallurgy.	-	-	2	1	2	11	8
Physical Science	-	-	1	9	16	18	50
Medical research	-	13	29	20	97	60	20
Defence research	18	17	25	30	-	-	-
IIry Industry	-	-	-	-	-	4	10
Res. Grants*	-	-	-	-	-	60	60
Related Sc. Activity	8	15	12	11	22	44	95
Total	51	85	222	291	353	734	796

Note * refers to research grants for physical and social sciences. Related scientific activity includes research services, miscellaneous investigation, subscriptions to research organizations, contribution to conferences, routine testing, geological investigations, library, publication and scholarship expenditures. Physical sciences includes fuel, chemicals, radio, aeronautics, tribophysics, building and nuclear energy research.

Source Commonwealth Australia, Estimates of Receipts and Expenditure, Budget Papers, Various Issues.

Agricultural research constituted a major part of the Commonwealth research effort and it increased substantially over the period from 1921 to 1940. These data indicate that expenditure on industrial research problems was quite low while research into the physical sciences grew substantially since 1930/31. Wade (1965) has examined the organisation of agricultural research in Australia and has found that until 1939 the CSIR was concerned almost entirely with research related to primary industry.[11] The low priority of industrial research was brought to the Government's attention in the late 1930s. In 1937, the Commonwealth Government appointed a Parliamentary Committee to report on Secondary Industries Testing and Research in order to expand the activities of the

11 Research expenditure of CSIRO on manufacturing industry problems was averaging about one fifths of total CSIRO research expenditure during 1950-1981. See Macdonald(1983).

CSIR (Commonwealth, Aust. 1937). The report of the committee revealed the weaknesses of CSIR efforts directed towards industry's problems and the general inadequacy of industrial research in the country.

The report of the Committee on Secondary Industry Testing and Research provided a great deal of information on the state of industrial research and technological dependency of various industry sectors. It was reported by the committee that,

> The Council of Science and Industry covers research for all sections of industry, whether primary or secondary. the activities of the council hitherto have been confined almost exclusively to primary industry research. ...and at present there exists in Australia no comprehensive and adequate means of providing services for making scientific testing and research as well as up-to-date technical knowledge readily available to industry.
> (Commonwealth Aust., 1937,p.947)

The committee conducted a comprehensive survey of Australian secondary industries in order to find out industry's research need. Those sectors included in the survey were ferrous and non-ferrous metal production and metal fabricating, aircraft and motor vehicles. electrical engineering, marine engineering and ship-building, cement, building, ceramics, drugs and chemicals, paints, varnish and lacquers, rubber, leather, textiles, and food industries.

The results of the survey revealed a large number of problems in geological, metallurgical, chemical, physical and engineering investigations in industry. It was found that one of the major concerns of most industrialists was the heavy reliance on overseas sources for the supply of material and products. For example, in the machinery and electrical industries all tool and steel fabricated and used in

Australia was imported, and the electrical industry was dependent upon overseas supplies of raw materials and semi-fabricated products (Commonwealth Aust..1937,p.959). The report commented that the level of research in factories was quite low and research into new processes and material was insignificant. The low level of research was attributed to the small size and weak financial status of companies. A majority of private enterprises were unaware of the technical possibilities of efficient production and were reluctant to engage in high risk capital investments to create new industries. The companies also were skeptical about the financial returns from research investment. The Committee, therefore, urged the government to strengthen research activities in the CSIR in the areas of chemistry, physics, metallurgy, and engineering as a support to private enterprise efforts in research. Although provisions were made to strengthen the IR&D in the CSIR, the actual level of research effort in the manufacturing sector remained static for a long period. Table 2.9 indicates the Commonwealth Government effort on research in various fields between 1940 and 1955. It indicates that research into agricultural problems grew considerably during the period and physical sciences were lagging behind compared with the agricultural sector. Moreover, a major proportion of research in the physical sciences was not directly applicable to industry problems.

Table 2.9 Research Expenditure on Selected Fields by Commonwealth Government Institutions, Selected Years ($'000)

Year Field	1940/41	1945/46	1949/50	1955/56
Agriculture	518.5	864.1	2384.6	6583.4
Physical Science	78.9	858.6	1343.9	2733.4
Mining and metallurgy	11.4	10.2	32.7	73.8
Medical research	40.0	80.0	136.1	300.0
Related sc. activity	174.4	362.8	648.6	1660.6
CSIRO research	62.6	166.1	339.9	568.3
Total	888.3	2359.6	4885.9	12456.8

Note Related scientific activity includes research services, miscellaneous investigation, subscriptions to research organizations, contribution to conferences, routine testing, geological investigations, library, publication and scholarship expenditures. Physical sciences includes fuel, chemicals, radio, aeronautics, tribophysics, building and nuclear energy research.

Source Commonwealth Australia. Estimates of Receipts and Expenditure, Budget Papers, Various Issues.

The Commonwealth Government revised the Science and Industry Act in 1949 to restructure the CSIR into the Commonwealth Scientific and Industrial Organization (CSIRO) providing more facilities for research into primary and secondary industries. The CSIRO has achieved a big research reputation and is noted for its innovations in many fields ranging from automation of cheese manufacturing to techniques for atomic absorption spectrophotometry. In 1966, it was stated that

> Although its resources are limited, it can be said without argument that the CSIRO as a government sponsored body is probably creating more new inventions or new applications for Australian industry than any other body in the country. (Goode, 1966,p.13)

In addition to the CSIRO effort in industrial research, R&D activities were supplemented by a number of research programs conducted in several government institutions. Prior to 1939, research effort was mainly concentrated in biological sciences and defence research. The

Department of Supply had been responsible for conducting research on defence and Antarctic research expedition activities since the early part of the century. The research laboratory of the Postmaster General's Department was involved in radio and communication research long before the Second World War and continued afterwards. The Department of Agriculture was also involved in various research activities including farm mechanization research. The Atomic Energy Commission, which was established in 1953, was also primarily a research organisation.

All told, over thirty Commonwealth Government agencies were involved in a wide range of research projects on primary and secondary industry, health, education, social work, communication and transport, atomic energy and defence (Commonwealth Bureau of Census and Statistics, Year Book, 1971,p.670). Sutherland (1967) reported that the Federal and State agencies involved in R&D were mainly involved in primary industry problems and Government funds were received by only three laboratories - the Bread Research Institute, the Australian Coal Industry Research Laboratory and the Wine Research Institute. The research projects carried out in some of these organizations had a direct impact on technological development in manufacturing industry. For example, the research activities of the Department of Supply led to patenting of methods such as electro-photographic reproduction in colour, the formulation of new high temperature alloys for high performance jet engines and special purpose cameras (Goode, 1966,p.13).

The level of IR&D in Australia began to improve gradually with the post Second World War industrial expansion, particularly in the 1950s and 1960s. As a result private investment in R&D grew considerably during this period. The development in technical efficiency in private industries were officially recognized as critical in the expansion of manufacturing industry by the Commonwealth Government during the late 1960s, when a series of steps were taken including the passage of the Industrial Research and Development Incentive Act in 1967 and the provision of assistance for private inventors in 1969.

2.4.0 Resources Devoted to Industrial R&D by Private Manufacturing Industries During the Post War Period

A systematic collection of data on performance of R&D in manufacturing industry has only begun relatively recently, since 1952. Since then a number of individual inquiries and sample surveys have been conducted to estimate industrial R&D effort. The official statistical collection of resources devoted to R&D was not begun until 1970s. Hence the statistics available prior to 1968/69 must be regarded with some caution.

2.4.1 Surveys of Scientific Activities During the Post War Period

The first comprehensive attempt to collect R&D statistics on private industry was undertaken by the Research Committee of the Australian Institute of Engineers in 1955, following a preliminary survey carried out by the Institute in 1952 (Inst. of Engineers, Aust. 1956,p.28). The survey included industries such as chemicals, machinery (including electrical machines and equipment), motor vehicles, aircrafts, basic and fabricated metals, and ship building. All firms with more than 1000 employees and a random sample of 1 to 4 of those employing 50-999 persons were included in the sample. The total number of firms approached was 238. Of those 104 firms (44 per cent) responded. The definition of R&D adopted in the survey was somewhat broader than would be used currently. All activities directed to the improvement of existing products and processing methods and the development of new ones, but excluding market research and quality control, were regarded as R&D.

The major findings of the survey were that the estimated annual expenditure on R&D in private enterprises, which had industrial production in excess of $1000 million per annum was about $3.4 million which represents an average of 0.3 per cent of turnover. It was also noted that the most research oriented classes of industry were chemicals, electrical machinery, communication, and transport and motor vehicles. The primary metals and metal fabrication industries lagged well behind and the ship-building industries included in the sample were not engaged in R&D activities at all (Inst. of Engineers Aust., 1956,p.283).

There was an increase in the number of qualified research staff by 63 per cent between 1950 and 1955. The average ratio of total research staff to qualified research staff was 4 : 1. The survey revealed that research employment by firms as a percentage of total employment was 0.54 per cent. Out of 833 person employed as research personnel in all firms, 75 per cent were employed by large firms with more than 1000 employees. However, large firms represent only a 36 per cent of the total number of firms being surveyed. It was concluded in the survey that

> Large firms have a less intensive research effort than smaller firms. Taken as a whole largest concerns have less than half as many researchers per 1000 employees as have firms employing between 200 to 1000, (except in the electrical machinery and communication group).
> (Inst. of Eng. Aust., 1956,p. 283)

Another important finding of the survey was that about 64 per cent of firms depend on their own or local resources for research. Less than 30 per cent of resources or in some cases no resources at all were spent on research conducted overseas.

However, it should be noted that this survey had a number of limitations. The definitions adopted of R&D activities, the sample of industries selected, the coverage of industries and the response rate were limited. The survey also excluded a number of important manufacturing industries such as textiles, leather, clothing, food, saw-milling and furniture. Nevertheless, the survey was the first large scale attempt to quantify the R&D effort and thereby set a precedent for the collection of R&D statistics in industry.

2.4.2 Estimates of Expenditures and Personnel on R&D

There have been a number of attempts to estimate the R&D level in industries. These estimates were based on the Institute of Engineers survey, costing qualified researchers employed, and revising figures by analysing research expenditure of large firms. For example, Encel's (1961) estimation was based on a revision of the figures by analysing the research expenditure of two major concerns, the Broken Hill Propriety Company (BHP) and Colonial Sugar Refining Company (CSR). He estimated that industrial research expenditure during 1958/59 was in the range of A$6-10 million and he pointed out almost all this expenditure was spent on development rather than research. Encel emphasised the general inadequacy of industrial R&D and identified the steel industry as the largest performer of research in 1958/59. The other industries in which research establishments existed were chemicals, sugar, pharmaceuticals, paper and pulp, food processing, electronics, gas production, non-ferrous metal and textiles. It was noted that the work done by CSIRO that was of direct or indirect benefit to manufacturing industry was still more important than industry's own research effort (Encel, 1961, p.265).

A study conducted by the Stanford Research Institute in Menlo Park, considered the incomplete responses to a survey in 1955 and subsequent salary increases and growth of industry and calculated the IR&D component as A$30 million for 1959/60 (Stanford Res. Inst., 1961). Williams (1962,p. 10) estimated the industrial research component using Department of Labour statistics and cost per qualified researcher and arrived at a figure $16-20 million for 1959.

The estimates made by others were basically modifications of previous estimates described above. Weickhardt (1962,p.28) arrived at a figure of A$10-14 million for 1958/59 assuming that there were a small number of large companies and the minimum cost of an R&D department was about $200,000. An estimate for 1962/63 by Stebbins (1963,p.259) adopted William's highest estimate of $20 million as an average figure. He pointed out that a component of the payments for overseas research resulting as patents, royalties and copyright also should be added to this figure. These payments amounted to $6-8 million in 1958/59, $32 million in 1959/60,

$26 million in 1960/61 and $30 million in 1961/62. The mineral industry research component was estimated by Nixon (1965) in 1963 as $5.1 million. Clark (1966,p.N-64) calculated IR&D for 1964/65 as $25 million, using the Nixon's figure and extending William's estimates. Stubbs (1968, p.98) estimated IR&D expenditure for 1964 using a sample of 45 firms and calculated the research expenditure using cost per qualified researcher which amounted to $17,000 and using Nixon's estimate he concluded that the amount of expenditure for 1964 was $28 million and for 1966 it was $32 million.

A survey conducted by the Australian Industrial Research Group (AIRG) on 112 companies reported R&D expenditure at $31.4 million and estimated that actual R&D was around $35 million (Whitton, 1969,p.153). Bastow in 1964 conducted a personnel survey of 75 firms of varying sizes and technical sophistication and reported that,

> Only 8 firms had the will and capacity to think out, develop and produce something really new.
> (Bastow, 1964,p. N-38.)

Table 2.10 summarizes the attempts to estimate IR&D effort and their relation to gross national product at factor cost. Gross private industry expenditure on research was less than 1 per cent of gross national product by manufacturing. Disregarding the Stanford Research Institute estimate, which is rather high for 1959 compared with the other estimates, the average of R&D expenditure per year for the period between 1959 and 1968 was approximately $26 million at current prices and the average R&D expenditure as a percentage of GNP was 0.5 with a annual growth rate of 0.9 per cent.

Table 2.10 Private Estimates of Industrial Research From 1959 To 1968

Source	Year	IR&D Exp. current prices	IR&D as a %age of GNP*
Encel	1958/59	6-10	0.25
Weickhardt	1958/59	10-14	0.38
Williams	1959	16-20	0.57
Stanford Inst.	1959/60	30	0.84
Stebbins	1962/63	20	0.49
Clark	1964/65	25	0.50
Stubbs	1964	28	0.61
Stubbs	1966	32	0.60
AIRG	1968	35	0.56

Note * denotes GNP by manufacturing industry at factor cost.

Table 2.11 illustrates the growth of R&D in industry during this period at average constant and current prices.

Table 2.11 The Average R&D Growth at Current and Constant 1967/68 Prices From 1959 To 1968 (in million dollars)

Year*	Current Price	Constant Prices	Index No.(Cons. Prices)
1959	13	24	100
1960	30	52	217
1963	20	30	125
1964	28	38	158
1965	25	31	129
1966	32	38	158
1968	35	35	146

Note * denotes year refers to financial year in some cases as shown in Table 2.10.

These estimates indicate that industrial research was primarily supported by private industries and government involvement in industrial research problems was relatively low. In the absence of an official national survey of R&D activities, it is not possible to draw definite conclusions on the level of R&D of various performers in the country. Available evidence suggests that the growth of industrial research was rather slow.

Estimates of manpower employed in R&D was not treated as being of equal importance in the above mentioned studies. Some detailed statistics are found in Stubbs and the AIRG studies. The Institute of Engineers survey of 1955 reported the research employment in industry for 1950 and 1955. There were 520 qualified research persons in 1950 and it increased to 851 persons in 1955, an increase of 64 per cent. The ratio of qualified research worker to 1000 employees was 5.4 in 1955. A large percentage (44 per cent) of research personnel was employed by the chemical, paints and rubber industry group. The percentage of the total research employed by the other industries was as follow: electrical machinery and communication equipment - 20 per cent; transport vehicles including aircrafts - 13 per cent; basic metals - 6 per cent; and fabricated metals - 2 per cent and the rest by other miscellaneous industry (Inst.Eng. Aust., 1956,p.282)

Williams, using labour statistics for 1959, estimated that the number of qualified research workers in industrial research departments was 1900 (Williams, 1962, p.8). Morse (1963,p.254) assumed that the percentage increase of research personnel for 1955-1961 was the same as for the period between 1951 and 1955 as calculated in the survey of the Institute of Engineers and hence calculated the number of qualified research workers for 1961 as 1200 persons. However, allowing for the crudeness of such an assumption, he suggested that the real value lay somewhere between 800-1600 i.e. a standard deviation of 50 per cent.

Stubbs (1968, p.76) estimated the research employment in industry for 1964 as 3030 persons, out of which 758 (about 25 per cent) were qualified. The ratio of qualified research workers to 1000 employees in industry was 3.65, in comparison to the Institute of Engineers figure of 5.4 in 1955. Chemicals, pharmaceuticals and petroleum industries employed 23 per cent of qualified research staff, transport equipment 35 per cent, machinery and electrical 15 per cent and metals 11 per cent. AIRG estimated a total staff of 4659 in R&D in 1968 and 1999 persons (about 42 per cent) as qualified.

Table 2.12 indicates the manpower resources estimated for research and development activities in industries during 1950 and 1968 by the various sources.

Table 2.12 The Estimate of Manpower Devoted to R&D in Industry

Source	Qualified Researcher	Total Res. Employment	Qualified Res. per 1000 Researcher
Inst. Eng.(1950)	520	n.a.	n.a.
Inst. Eng.(1955)	851	n.a.	n.a.
Williams(1959)	1900	n.a.	n.a.
Stubbs(1964)	1484	3030	3.7
AIRG(1968)	1999	4659	n.a.

The qualified researchers available per 1000 employees has been suggested as a measure of industry's research consciousness (Stubbs, 1968).

These estimates indicate that the research effort was mainly concentrated in a few industry groups such as chemicals, transport equipment and electrical equipment. Although a number of these studies have indicated that one of the major spenders of R&D effort was the steel monopoly BHP, manpower estimates show that the R&D effort was fairly low in the metal industry.

Stubb's (1968,pp48-68) study indicates that the chemical and pharmaceutical industry group were the major introducers of product innovations. Transport equipment, other machinery and electrical equipment, plastic and glass industries were moderately involved in product development activities and research activities. These estimates provide only a scanty picture of the IR&D effort in industry during 1950 to 1968. Resources reported as R&D have varied substantially depending on individual approaches. The reliability of these estimates is low.[12] However, they provide some indication of the allocation of effort and to some extent the adequacy of resources devoted to industrial research. The IR&D effort in private enterprises during 1950s was also reported to be low in the report of the Murray Committee of Higher Education(1957,p.27), which commented that only a few companies were genuinely interested in their own research or to promote the establishment of research to conduct research on their behalf.

2.4.3 Higher Education Research Effort on Industrial Research

The government sector was the major performer of national R&D activity although its emphasis was directed more towards primary production and defence. Stubbs (1968,p.24) has pointed out that in the 1964/65 period 72 per cent of R&D was funded and conducted in government institutions, 15 per cent in higher education institutions and 13 per cent in private industry. Most of the funds for research originated from government sources and the higher education sector was almost entirely dependent

12 Even in recent national R&D surveys, a number of problems of measurement are encountered; for a discussion of these problems see annex 1.

on government funds. Middleton (1970,p.170) also pointed out that more than 70 per cent of funds for R&D originated from government sources and industry was responsible for less than 25 per cent.

University research also remained at a very low level prior to 1950. Limited government support and meagre grants for developing Australian universities were highlighted by Coplan (1949). Gani (1973,p.75) reported that the Commonwealth Government made minor research grants to the universities and in 1936 a five-year programme was drawn up by which $60,000 per annum was spent in the physical and biological science. By 1950, this amount had reached $200,000. Research in universities was substantially strengthened only after the establishment of the Australian National University Act of 1946 (Commonwealth Aust.,1946). It provided for the setting-up of research schools in the University and provided 325,000 pounds per annum. Florey (1950) noted that,

> It is unfortunate that Australian Universities good as they are and great records behind them, have apparently not yet succeeded in sufficiently (Howard Florey, 1950, p.728)

Encel (1961) estimated the total research expenditure in universities in 1958/59 at $8 million of which $6 million was the calculated salary portion due to research activity and the rest was direct research expenditure. Clark (1966) estimated that the universities were spending about $30 million, which was more than industry expenditure on research. Lonergan (1975) pointed out that as late as 1969, universities spent somewhat less than $3 million on industrial R&D objectives, out of a research total of $66 million. The corresponding expenditure on R&D by industry was $95 million. Kolm and Baklien (1979) pointed out that 91 per cent of industry research was financed by industry itself.

There has been a general lack of collaboration between industry and universities. The problem of industry and university co-operation is discussed in the Jackson Report (1975), Swan (1975) and Macmillan (1975). The evidence available suggests that involvement of Australian universities in manufacturing problems has been notably low.

2.5 Technological Advances and Scientific Output

There is no strong evidence to suggest that R&D activity has resulted in technological advances in all industry sectors. Selected cases provide some evidence of strong links between industrial research and development and local technological capabilities. Patent applications submitted by Australian inventors and successful innovations are indications of the outcome of Australian R&D. The Australian Academy of Science (1979) and Lewis (1960) reported a number of important inventions and innovations. These inventions included the Stump-Jump plough in 1894; the flotation process of separating metals in 1901 by C.V. Potter; the centrifugal method of making concrete in 1910 by Humes; the development of Michell's thrust bearing; the automatic totaliser by George Julius; the calculable standard of capacitance in 1955 by Thompson and Lampard; flame ionization in 1957 by Ian McWilliam at ICIANZ company; the liquid development process in xerography in 1953 by Metcalfe and Wright; the development of the atomic absorption spectrometer by Walsh at CSIRO, and the self-twisting spinning machine in 1960 by David Hanshaw.

A majority of patent applications submitted were from overseas. Encel and Inglis (1966,p.582) have pointed out that the number of domestic patent applications submitted by firms in Australia increased from 1.9 per cent in 1910 to 37 per cent in 1949 and 51 per cent in 1954. For overseas applications the corresponding figures were 24 per cent, 73 per cent and 81 per cent. The percentage of patent applications submitted by Australian inventors has decreased from nearly 55 per cent in the 1930s to 26 per cent in 1967 in relative terms. Table 2.13 illustrates the number of patent applications received by the Patent Office by source of origin. Although there was no significant increase in the average of patent applications per annum from Australian inventors, the activity of inventions remained roughly steady. Tisdell (1975) has shown that patenting activity in Australian inventors increased by 15 per cent between 1967 and 1973 and this may be correlated with increasing private and government effort in R&D compared with previous years.

Table 2.13 Patent Applications Submitted by Australia and Territory Between 1931 and 1967

Year	Australia	Overseas	Total
1931	4766(52%)	4457	9223
1932	4912(60%)	3248	8160
1951	3200(45%)	3900	7100
1952	3800(47%)	4250	8050
1953	4400(49%)	4500	8900
1954	3900(43%)	5100	9000
1955	3600(40%)	5400	9000
1956	3800(40%)	5600	9400
1957	4100(41%)	5800	9900
1958	4274(41%)	6237	10511
1960	4026(34%)	7802	11828
1961	4300(33%)	8600	12900
1963	3978(30%)	9470	13448
1964	3972(28%)	10162	14134
1965	4123(27%)	11027	15150
1966	4445(28%)	11562	16007
1967	4058(26%)	11675	15733

Source Lamberton, D.M.(1970) and Encel and Inglis (1966).

Encel and Inglis (1966,p.582) have argued that Australian dependency on the purchase of knowhow increased considerably as a result of post-war industrialization and the most active fields of innovations, the manufacture of electrical equipment and machinery, which has shown an almost unbroken upward trend in the number of patents since the 1920s in terms of comparative and actual figures. The large dependency on material and equipment from overseas sources by the electrical industry was highlighted in the report of the Committee on Secondary Industry and Testing and Research as indicated previously. Detailed evidence of technical inventive output is scanty. The Annual Report from ICI (Aust.) Limited (1976,p.12) reported that since 1956 approximately 800 inventions had been made in the company's laboratories and more than 200 patents had been granted throughout the world.

2.6 Conclusions

The evidence available to suggest that the growth of manufacturing industry in the first half of the century was influenced by R&D activity carried out in public and private industrial laboratories is limited. The development of manufacturing industry in terms of productivity and also in employment, however, was considerable during this period and much of it is attributed to increased investment in physical capital and the expansion of the workforce. The increased imports of capital goods combined with the experience of the workforce were the most significant sources of technological change in manufacturing industries during this period.

R&D in Australia developed with almost exclusive support from Commonwealth Government sources. The Government effort was largely confined to primary industry and defence sectors until 1939. The spill-over effects of technological development in these two sectors had some impact on technological progress in related industry such as chemicals used in agricultural products. Private industry involvement in industry research was evidently insignificant until the post Second World War period. The rapid growth of manufacturing since the war provided a considerable incentive for industry to invest its' profits in R&D. Only a few large companies took advantage of such an opportunity and brought industrial technological competence up to date. A few industry groups such as chemical, petroleum and coal products, other machinery and equipment and food beverages and tobacco products readily captured a large share of the market and returns on R&D investment.

Most industry relied on the CSIRO to undertake research. However, the deep seated tradition in primary research activity in CSIRO did not allow it to shift its concentration effectively to service a wide range of industry problems. Private industries increasingly began to involve themselves in R&D after this time. A few industries were responsible for undertaking a bulk of R&D activity. Some of these were the well established oligopolist companies such as BHP, CSR and ICIANZ. Their research effort essentially had the character of adopting foreign technology with minor modification to suit local conditions. A large part of the activity of research staff constituted routine scientific investigations such as quality control, testing and standardizing. Although sub-standard industry research in private and public institution prevailed, some areas made significant breakthroughs via R&D and inventive activity. The major areas of research developed prior to 1968 were in electrical, metals and food and beverages.

The need to build up R&D capabilities was realized by the public and private institutions towards the end of the 1960s. This was mainly in response to the apparent decline in productivity and technological competitiveness in manufacturing industry. This realization led to a series of Government inquiries followed by an increase in Government incentives and increased research expenditures by some private industries compared with previous levels.

In spite of these incentives and Government involvement in research, private industry was unable to reduce its dependence on foreign technology significantly. This was partly due to slow adoption of R&D activity in Australian manufacturing industry and also in part due to a lack of tradition and motivation towards risky investment in R&D. The high level of protection enjoyed by some industry was a disincentive to develop technological competence. The local innovators, however, achieved sporadic technological innovations in some areas.

The competitive environment and drive to increase the technological advances in industrial efficiency were lacking from the very beginning of the development of manufacturing industry sector. The attempts of private manufacturing industry to establish research capability is of recent origin. More industries have apparently embarked on R&D activity.

The establishment of a scientific infrastructure, the campaign for more secondary industry activity in CSIRO, and the strengthening of university research since 1940 gave an impetus to the revival of industrial research in the 1950s and 1960s. However, the importance of involvements in R&D and technical innovations had a marginal impact in most industry programmes and reluctance to embark on R&D investment is well pronounced in most industries. However, there is a strong trend in certain sectors of industry with a long standing tradition of research and innovations. These industries have overwhelmingly control over a significant proportion of R&D as well as markets.

References - Chapter Two

Abernathy, W.J. and Utterback, J.M. (1978) 'Patterns of industrial innovations', Technology Review, Vol. 80, June/July,pp. 2-9.

Anderson, R.C. and McAllister, P.R. (1978) 'Publication ratings versus peer ratings of universities ', Journal of the American Society for Information Science, Vol. 29, pp. 91-103.

Australian Academy of Science, (1979) From Stump-Jump Plough to Interscan, Report No. 10, Canberra; Australian Academy of Science.

Australian Bureau of Statistics(ABS), (1978) Australian Standard Classification, Vol. 1, Cat. No. 1201.0, Canberra;ABS. June/July,pp. 2-9.

Australian Bureau of Statistics, (1980) Australian National Accounts, National Income and Expenditure, Cat. No. 5204.0, Canberra;ABS.

Australian Science and Technology Council(ASTEC), (1978) Science and Technology in Australia, 1977-1978, Canberra;AGPS.

Bayer, A.E. and Folger, J. (1966) 'Some correlates of a citation measure of productivity in social science', Sociology of Education, Vol.39(4),pp.383-390.

Bastow, S.H. (1964) 'Research in the manufacturing industry in Australia', Journal of Institute of Engineers, Australia(J.I.Eng.Aust.), Vol. 36(6),pp.N37-40.

Boehm, E.A. (1979) Twentieth Century Economic Development in Australia, Melbourne; Longman Cheshire.

Box, S. and Cotgrove, S. (1968) 'The productivity of scientists in industrial research laboratories', Sociology, Vol.11(2),pp.163-172.

Broken Hill Proprietary Limited (BHP)(1979) Fact Sheet, Melbourne; Public Affairs Department, BHP.

Brown, A.E. (1972) 'New definitions for industrial R&D'Research Management, Sept., pp.55-57.

Bureau of Industry Economics, (1979) Australian Industrial Economic Development-Some Aspects of Structural Changes, Report 2, May, Canberra; AGPS.

Butlin, N.G. (1958) 'The shape of the Australian economy 1861-1900', The Economic Record, Vol.34(67), Nov., pp.10-29.

Butlin, N.G. (1959) 'Some structural features of Australian capital formation, 1861 to 1938/39', The Economic Record, Vol.35(72), Dec., pp.389-415.

Butlin, N.G. (1970) 'Some perspectives of Australian economic development,1890-1965' in Foster, C. ed. Australian Economic Development in the Twentieth Century op.cit.

Caplow, T. and McGee, R.J. (1965) The Academic Market Place, 2nd edition, New York: Gorden City, Double Day.

Carpenter, M.P. (1979) International Science Indicators - Development of Indicators of International Scientific Activity Using the Science Citation Index, Final Report under NSF SRS-77-22770, Washington D.C.: National Science Foundation.

Clark, N.F. (1966) 'Expenditure on research and development in Australia' J.I.Eng.Aust., Vol.38(6), June, pp.N63-64.

Cole, S. and Cole, J.R. (1967) 'Scientific output and recognition: A study in the operation of the reward system in science', American Sociological Review, Vol.32, pp. 377-390.

Cole, S. and Cole, J.R. (1968) 'Visibility and the structural bases of awareness of scientific research' American Sociological Review, Vol.33, pp. 392-413.

Cole, S., Rubin, L. and Cole, J.R. (1977) 'Peer review and the support of science' Scientific American, Vol.237, pp. 33-41.

Coombes, L.P. (1965) 'Research and development in manufacturing industry of Australia, A review of existing literature', J.I.Eng.Aust., Vol.6, Feb., pp.N40-44.

Commonwealth Australia, (1906a) 'The Australian industry preservation act, No.9 of 1906' The Act of the Parliament of the Commonwealth of Australia, Vol.5, Victoria: Government Printer.

Commonwealth Australia, (1906b) 'Australian industries preservation bill-declarations quoted in the debate by H. Best, William Marshall and Andrew Hunter' Journals of the Senate, Session 1906, Vol. S-1, pp.253-255, Victoria: Government Printer.

Commonwealth Australia, (1908) 'Patent Act, an act relating to patents and inventions, No. 21', Commonwealth Act, Vol.II, pp.132-155, Victoria: Government Printer.

Commonwealth Australia, (1909) 'An Act for the encouragement of manufacturing in Australia, No.26 of 1908', The Act of the Parliament of the Commonwealth of Australia, Passed in the session of 1908, Vol. VII, Victoria: Government Printer.

Commonwealth Australia, (1919) 'Report of the executive committee of the Commonwealth Advisory Council of Science and Industry, 1916-1917', Papers Presented to the Parliament of the Commonwealth of Australia, Vol.V, Sessions 1917-18-19, Victoria: Government Printer..

Commonwealth Australia, (1920) 'Institute of science and industry act, No. 22 of 1920', _The Act of the Parliament of the Commonwealth of Australia_, Vol.18, Victoria; Government Printer.

Commonwealth Australia, (1926a) 'The science and industry research act 1920-1926', _The Act of the Parliament of the Commonwealth of Australia_, Vol.24, Victoria; Government Printer.

Commonwealth Australia, (1926b) 'Science and industry endowment act (1926)' _The Act of the Parliament of the Commonwealth of Australia_, No 21 of 1926, Victoria: Government Printer.

Commonwealth Australia, (1927a) 'Tariff board, iron and steel industry - application for increased protection', _Papers Presented to the Parliament of the Commonwealth of Australia_, Vol.4(179), pp. 2005-2048, Victoria; Government Printer.

Commonwealth Australia, (1927b) 'The second progress report of the royal commission on national insurance and unemployment', _Papers Presented to the Parliament of the Commonwealth of Australia_, Session 1926-28, Vol. 4(79), pp.1411-54, Victoria; Government Printer.

Commonwealth Australia, (1937) 'Secondary industry testing and research - extension of activities of Council for Scientific and Industrial Research, February, 1937', _Papers Presented to the Parliament of the Commonwealth of Australia_, Session 1937-38-39-40, Vol.4, pp. 941-983, Canberra; Government Printer.

Commonwealth Australia, (1946) 'Australian National University Act-1946', _Commonwealth Acts_, Vol.XLIV, pp. 55-63, Canberra; Government Printer.

Commonwealth Australia, (1965) _Report of the Committee of Economic Inquiry(Vernon Report)_, Vol. I&II, May, Melbourne;Wilke & Co. Ltd.

Commonwealth Australia, (1967) 'Industrial research and development grant act-1967', _Act of the Parliament_, No. 51, Canberra;AGPS.

Commonwealth Australia, (1975) _Report of the Committee to Advise on Policies on the Development of Manufacturing Industry(Jackson Report)_, Vol. I&II, Canberra; AGPS.

Commonwealth Australia, (1975) 'Patent, trade marks, designs and copyright act 1939-1973', _Act of the Parliament_, Vol.9, Canberra;AGPS.

Commonwealth Australia, (1976) 'Industrial research and development incentive act-1976', _Commonwealth Acts_ , No. 85, Canberra;AGPS.

Commonwealth Bureau of Census and Statistics,(1965) _Year Book of Australia_, No. 51, Canberra;CBCS.

Commonwealth Bureau of Census and Statistics,(1966) Year Book of Australia, No. 52, Canberra;CBCS.

Commonwealth Bureau of Census and Statistics,(1969) Australian Standard Industrial Classification, Preliminary edition, Cat. No. 2113, Vol. 1,Canberra;CBCS.

Commonwealth Bureau of Census and Statistics,(1970) Year Book of Australia, No. 56, Canberra;CBCS.

Commonwealth Bureau of Census and Statistics,(1971) Year Book of Australia, No. 57, Canberra;CBCS.

Coplan, D.B.(1949) 'The place of the Australian National University in the academic structure of Australia', Paper Presented to the Parliament, Vol. II, pp.725-727, Canberra, AGPS.

Coombes, L.P.(1965) 'Research and development in the manufacturing industry of Australia - A review of existing literature', J.I.Eng.Aust., Vol. 6, pp.N40-44.

Corden, W.M. (1966) 'The structure of a tariff system and the effective protective rate', Journal of Political Economy, Vol. 74(3), June, pp.221-237.

Corden, W.M. (1971) The Theory of Protection, Oxford: Clarendon press.

Crawford Report, (1979) Study Group on Structural Adjustment, Canberra, AGPS.

CSIRO, (1972) CSIRO and Secondary Industry, Report of the CSIRO Secondary Industry Committee, Canberra; CSIRO.

Crane, D. (1965) 'Scientists at major and minor universities. A study of productivity and recognition', American Sociological Review, Vol. 30, Oct., pp. 699-714.

Daniel, C. (1976) Application of Statistics to Industrial Experimentation, New York; John Wiley & Sons.

Edwards, K.J.(1979)'Australian tax structure and taxation incentives', in Anthoine, R. ed. Tax Incentives for Private Investments in Developing Countries, Netherlands; Kulver Deventer.

Electrolytic Zinc Company of A'asia Ltd. (1963) 'The early Australian chemical industry', Proceedings of Royal Australian Chemical Institute, Vol. 30, May, pp. 197-206.

Encel, S. (1961) 'Financing scientific research in Australia', Science, Vol. 134, pp.260-266.

Encel, S. and Inglis, A. (1966) 'Patents, invention and economic progress', The Economic Record, Vol. 42, March, pp.572-588.

Evans, H.D. (1972) A General Equilibrium Analysis of Protection, The Effect of Protection in Australia, Amsterdam: North Holland Publishing Co.

Falk, C.E. (1974) 'Dynamics and forecasts of R&D funding', Technological Forecasting and Social Change, Vol. 6, pp.171-189.

Florey, H. (1950) 'Medical research, with special reference to the John Curtin school of medical research in the Australian National University', Papers Presented to the Parliament, Session 1951-53, Vol. II, pp.737-731, Canberra, AGPS.

Ford, D.L. (1963) 'Factors influencing the scale of industrial research in Australia', Proceedings of Royal Australian Chemical Institute, Vol. 30(9), Nov. pp. 337-343.

Forster, C. (1953) 'Australian manufacturing and the war of 1914-18', The Economic Record, Vol. 29(2), Nov., pp.211-230.

Forster, C. (1970) 'Economies of scale and Australian manufacturing', in Forster, C. ed. Australian Economic Development in the Twentieth Century, London and Sydney; George Allen & Unwin, pp.123-68.

Frame, J.D. and Narin, F. (1976) 'NIH funding and biomedical publication output', Federation Proceedings, Vol. 35, pp.2529-32.

Freeman, C. and Young, A. (1965) The R&D Effort in Western Europe, North America and the Soviet Union: An Experimental International Comparison of Research Expenditure and Manpower, Paris; OECD.

Freeman, C. (1974) Economics of Industrial Innovations, New York; Penguin Books.

Gani, J. (1963) The Condition of Science in Australian Universities, Oxford; Pergamon Press.

Gilbert, P.S. (1959) 'Structural trends in Australian imports', The Economic Record, Vol. 35(70), April, pp.130-132.

Goode, J.ed. (1966) 'Management and organisation: Is Australian industries doing enough research?', Factory and Plant, Vol. 54(10), Oct., pp.10-15.

Griliches, Z. (1973) 'Research expenditure and growth accounting', in Williams, B.R. ed. Science and Technology in Economic Growth, New York and Toranto; Macmillan, pp. 59-83.

Griliches, Z. (1980) 'Returns to research and development in the private sector', in Kendrick, J.W. and Vaccara, B. eds. New Development in Productivity Measurement and Analysis. Studies in Income and Wealth Series, Vol. 44, New York; NBER.

Greun, F.H. and Evans, H.D. (1971) 'Tariff policies and the tariff board', Australian Economic Review, Second Quarter, pp.37-42.

Haig, B.D. (1975) 'Manufacturing output and productivity, 1910 to 1948/49', Australian Economic History Review, Vol. 15(2), Sept., pp.136-161.

Hall, A.R. (1963) The London Capital Market and Australia, 1870-1914, Canberra; Australian National University press.

Hirst, J. (1974) 'Foreign investment and industrial research and development', Paper Presented to the Forth Conference of Economists, Aug., 1974, Canberra; Australian National University.

Hogan, W.P. (1966) 'Productivity, research and development', The Economic Record, Vol. 42, March, pp.59-66.

Hunter, A. (1963) The Economics of Australian Industry, Melbourne; Melbourne University press.

Institute of Engineers Australia, (1956) 'Australian industrial research, 1955. A report by the research survey committee of the institution', J.I.Eng.Aust., Vol.28(10&11), Oct.-Nov.,pp.282-289.

Institute of Engineers Australia, (1980) Manufacturing in Australia - The Task Force in Manufacturing, Vol. I&II. Canberra; The Institutions of Engineers,Australia.

International Chemical Industries(ICI)Aust. Ltd., (1976) 48th Annual Report and Notice of Meeting, Melbourne; ICI.

Jackson Report, (1975) See under Commonwealth Australia.

Johnston, R. and Liyanage, S. (1980) The Development of Indicators of Academic Research in Australia, STIC/80/17, Paris:OECD.

Johnston, R. and Liyanage, S. (1983) Australian Science and Technology Indicators Feasibility Study - Higher Education, Final Report, Canberra; Dept. of Science and Technology.

Kasper, W. and Parry, T.G.eds, (1978) Growth, Trade and Structural Changes in an Open Australian Economy, Centre for Applied Economics, Sydney; University of New South Wales.

Kaplan, N. (1965) 'The norms of citation behaviour; prolegomena to footnote', American Documentation, Vol. 15(3), pp.179-184.

Keezer, D.M. (1960) 'The outlook of expenditure on research and development during the next decade', American Economic Review, Vol.L(2), May, pp.355-378.

Kochen, M. (1978) 'Models of scientific output', in Elkana, Y., Lederberg, J., Merton, R.K., Thacktay, A. and Zuckerman, H.eds. Towards a Metric of Science, Toranto; John Willey & Sons.

Kolm, J.E. and Baklien, A. (1979) 'Innovation in Australian industry', Chemical Engineers in Australia, Vol. ChE(1), March,pp.42-47.

Lamberton, D.M. (1970) Science Technology and the Australian Economy, Sydney; Tudor Press.

Lewis, L. (1960) 'Patents and research in CSIRO', Proceedings of Royal Australian Chemical Institute, Vol.27(3), March, pp.77-82.

Llewellyn, H. (1981) 'The use of patents by Australian industry - An empirical analysis', Paper Presented to the 51st Congress of ANZZAS, Brisbane; University of Queensland.

Lonergan, J.P. (1975) 'The industry/tertiary institution interphase; Is therea problem?', Search, Vol. 6(10), Oct.,pp.422-425.

Macmillan, W.P. (1975) 'Interaction between academic and industrial research',Search, Vol. 6(10), Oct. pp. 416-421.

Maizels, A. (1957) 'Trends in production and labour productivity in Australian manufacturing industry', The Economic Record, Vol. 33(64), April, pp. 162-181.

Mansfield, E. (1964) 'Industrial research and development expenditure. Determinants, prospects, and relation to size of firm and inventive output', Journal of Political Economy, Vol. LXXII(4), Aug., pp.319-340.

Mansfield, E. (1968) Industrial Research and Technological Innovation - An Economic Analysis, New York; Norton & Co. Inc.

McAllister, P.R. (1980) Relationship Between R&D Expenditure - Manpower Resources and Publication Output for U.S. Colleges and Universities, Final Report under NSF grant, CHI project 792-R, August, Washington:NSF.

McAllister, P.R. and Wagner, D.A. (1981) 'Relationship between R&D expenditure and publication output for U.S. colleges and universities', Research in Higher Education, Vol. 15(1),pp. 3-30.

McCarty, J.W. (1964) 'The staple approach in Australian economic history', Business Archives and History, Vol. 4(1), Feb., pp.1-22.

Mellor, D.P. (1958) Australia in a War of 1939-45: The Role of Science in Industry, Canberra; Australian War Memorial.

Middleton, B.S. (1970) 'The role of government in the encouragement of research by industry', Proceedings of Royal Australian Chemical Institute, Vol. 37(7), pp.169-179.

Morse, R.N. (1963) 'The state of engineering research in development in Australia', J.I.Eng.Aust., Vol. 35(9), Sept., pp.253-256.

Morse, R.N. (1964) 'Technology for export', J.I.Eng.Aust., Vol.36(6). June, pp.N41-45.

Murray Committee, (1957) The Report of the Committee on Australian Universities, Canberra; AGPS.

Narin, F. (1976) Evaluative Bibliometrics: The Use of Publication and Citation Analysis in the Evaluation of Scientific Activity, Contract NSF C-627, Washington D.C.:NSF.

National Science Foundation. (1967) System for Measuring and Reporting Activities of Colleges and Universities, NSF 67-15, Washington D.C.:NSF.

National Science Foundation, (1972a) Methodology of Statistics on Research and Development, NSF 59-36, Washington D.C.:NSF.

National Science Foundation, (1972b) Science Indicators, Washington D.C.:NSF.

National Science Board, (1979) Science Indicators, NSF 67-15, Washington D.C.:NSF.

Nixon, J.C. (1965) 'Some financial application in research and development in Australian manufacturing industry',Proceedings, 8th Conference of Management , Canberra; Australian National University.

OECD, (1962) The Measurement of Scientific and Technical Activities, Proposed Standard Practice for Surveys of Research and Experimental Development-Frascati Mannual, DAS/PD/62.47, 3rd revision, Paris;OECD.

OECD, (1970) The Measurement of Scientific and Technical Activities. Proposed Standard Practice for Surveys of Research and Experimental Development, DAS/SPR/70.40, Paris;OECD.

OECD, (1975) The Industrial Policy of Australia, Paris;OECD.

OECD, (1976) The Measurement of Scientific and Technical Activities, Frascati Mannual, Paris;OECD.

OECD, (1977) Reviews of National Science Policy, Australia, Paris;OECD.

Price, D. de S. (1962) Little Science and Big Science. New York: Colombia University press.

Rothschilds, L. (1972) 'Forty five varieties of research (and development)', Nature, Vol.239(5372), Oct., pp.373-78.

Sanders, B.S. (1962) 'Some difficulties in measuring inventive activities', in Williams, B.R. ed. The Rate and Direction of Inventive Activity, Princeton; Princeton University press.

Schmookler, J. (1966) Invention and Economic Growth. Cambridge, Mass: Harvard University press.

Schmookler, J. (1972) 'Size of firm and growth of knowledge' in Griliches, Z. and Hurwicz, L. ed. Patents, Inventions, and Economic Change, Cambridge, Mass;Harvard Uni. press.

Scott, W. (1957) Australia and Challenge of Change, Sydney: The Law Book Co. of Australasia Pty, Ltd.

Senate Standing Committee on Science and Environment, (1979) Industrial Research and Development in Australia, A report presented to the Commonwealth Parliament, Canberra: AGPS.

Shelton, J.P. (1965) 'CSIRO patents and research for industry', The Australian Physicist, Vol. 2(1), Jan., pp.3-6.

Shilling, C.W. and Barnard, J. (1964) Informal Communication Among Scientists, Washington D.C.: Technical Report 16A-64.

Stanford Research Institute, (1961) Applied Research on the Development of Australia, A preliminary survey, Monlo Park, California.

Stebbins, H.I. (1963) 'Some economic implications of the present levels of expenditures on industrial research and development in Australia', Proceedings of Royal Australian Chemical Institute, Vol. 30(7), July,pp.257-267.

Stubbs, P. (1968) Innovations and Research. A study in Australian Industry, Institute of Applied Economic Research, University of Melbourne, Melbourne; F.W. Cheshire Pub. Co. Ltd.

Sutherland, K.L. (1967) 'Science policy and the research worker', Proceedings of Royal Australian Chemical Institute, Vol. 34(9), pp. 229-35.

Swan, J.M. (1975) 'Discovery, invention, innovation and development-Is there an industry/university interface?', Search, Vol.6(10), pp. 413-415.

Tisdell, C. (1973) 'The Australian research subsidy to overseas firms and other aspects of distribution of research grants', The Economic Record, Vol.49, pp. 194-214.

Tisdell, C. (1975) 'Science policy and flow of Australian inventions', Search, Vol.6(5), pp. 174-178.

UNESCO, (1969) The Measurement of Scientific and Technological Activities, STS/15, Paris:UNESCO.

UNESCO, (1970) Measurement of Output of Research and Experimental Development, STS/16, Paris;UNESCO.

Utterback, J.M. (1979) 'The dynamics of product and process innovation in industry', in Hill, C.J. and Utterback, J.M. eds. Technological Innovations for a Dynamic Economy, New York; Pergamon press.

Vernon Report, (1965) See under Commonwealth Australia.

Wade, G.C. (1965) 'Development and organisation of agricultural research in Australia', The Journal of the Australian Institute of the Australian Institute of Agricultural Science, Vol. 31(2), June, pp. 127-136.

Walsh, A. (1973) 'Invention and Innovation', Search, Vol. 4(3), March, pp. 69-74. Also appeared in Australian Academy of Science (1977)op.cit..

Ward, R.G. (1975) 'The case of government support of industrial R&D', Search, Vol. 6(10), Oct., pp.407-409.

Waterman, A.M.C. (1972) Economic Fluctuations in Australia, 1948 to 1964, Canberra; Australian National University press.

Weickhardt, L.W. (1962) 'The future of Australian manufacturing industry', Committee for Economic Development of Australia, Study No. 6, Melbourne.

Williams, B.R. (1962) 'Industrial research and economic growth in Australia', The 30th Joseph Fisher Lecture in Commerce, July, The University of Adelaide; The Griffin press.

Wilson, J.C.J (ed) (1962) 'ANZAAS anniversary, Science in Australia', Current Affairs Bulletin, Vol. 30(7), August, pp.99-112.

Wilson, L. (1964) The Academica Man; A Study of in the Sociology of Profession, New York; Octagon press.

Whitton, W.I. (1969) 'Industry and post graduate training', J.I.Eng.Aust., Vol. 36(6), June, pp. 153-158.

Zuckermann, H. (1967)'Nobel laureates in science: Patterns of productivity, collaboration and authorship', American Sociological Review, Vol. 32(3), June, pp. 391-402.

Chapter Three

The Level of Scientific and Technological Research in Manufacturing Industries in Australia, 1968/69 to 1979/80

3.0 Introduction

Science and technology in Australian industry has undergone a considerable development since 1968/69. Features which have been particularly prominent include increased government incentives for industrial research, changing industry spending on R&D, the level of patenting and invention, and the transfer of foreign technology knowhow. The development of science and technology in different manufacturing industry sub-divisions has shown a considerable variation. Some industry groups have invested more resources in R&D and technological innovations than others.

Various aspects of the recent development in R&D in private industry and also government institutions have been investigated in a number of studies. The structure of R&D activities in both the government and private sector between 1968/69 and 1973/74 was examined by Tisdell (1977) who concluded that the relative importance of the Australian Government in generating research declined during this period, whereas in the business enterprises it increased considerably. The position of foreign controlled companies has also been a matter of some interest. Both Parry (1974) and Tisdell (1973) have argued that more than 50 per cent of R&D undertaken in manufacturing industry was conducted in foreign owned firms and their actual share of R&D might really be higher than two thirds. Tisdell claimed that,

> The greater the proportion of R&D expenditure accounted for by foreign controlled firms in Australian manufacturing industries, the greater the research intensities of firms performing R&D.
> (Tisdell, 1977,p.245).

Another feature of R&D structure in Australian industries was the heavy concentration on experimental development activity. Studies by Hunter (1963), Lamberton (1970), McKern (1976 and 1981) and Parry (1974) have shown not only that R&D expenditure were directed towards adopting imported technology but also largely concentrated on development. McKern (1976) argued that there is very little difference in the type and pattern of research expenditure incurred by Australian and foreign owned companies. Tisdell (1977) has pointed out that more than two thirds of expenditure was spent on development activity and the rest was on applied and basic research; expenditure on basic research amounted to only a third of applied research.

A strong commitment towards undertaking experimental development might indicate that manufacturing industry relied heavily on the purchase of foreign know-how rather than developing their own technological capabilities. Brash (1966) and Stubbs (1968) have provided evidence that technology used in Australian manufacturing industry is derived mainly from overseas sources. Morris (1983) also argued that Australia is highly dependent on overseas technology and depends on a few foreign suppliers for technical knowhow.

R&D structure is also influenced by organisational and institutional differences. Large companies are often said to be more likely to invest in technological innovations. McLean and Round (1977) in an investigation of the relationship between R&D and firm size in Australian industry postulated that large firms are likely to undertake more R&D expenditure and R&D effort is likely to increase more than proportionately with size, at least up to some threshold size of firms. Their findings confirmed that absolute R&D expenditure increased with firm size. However, Johns *et al.* (1978) have argued that although small firms appear to participate less in R&D than large firms in the same industry, small firms have a greater relative research intensity, as measured by R&D expenditure as a per cent of sales.

Some of these studies by and large suggest that the R&D structure in Australian manufacturing is only capable of producing minor scientific and technological modifications. However, the effort devoted to the development of indigenous technological innovations has increasingly being made. Particularly in recent years a noticeable development in the science and technology system has been reported compared with the level of R&D in the 1960s. Tisdell (1975) pointed out that there has been an increase of 15 per cent in patent applications originating from Australian inventors between the period from 1967 to 1973. He also noted that there has been a significant increase in payments for imported technology.

Resource allocation to R&D shows a close link with industry economic performance in some cases, and a fixed proportion of industry resources are allocated to R&D by some industries. McLean and Round (1978) examined the research and product innovativeness in manufacturing firms in Australia during 1971/72 and found that in a total sample of 712 firms, the R&D input intensity (defined as the ratio of the firm's expenditure on R&D to its total sales; the proportion of the firm's workforce which consists of R&D employees; and the proportion of the firm's workforce which consists of professional R&D employees) was positively associated with product innovativeness. Parry and Watson (1979) have also shown that R&D investment and industry performance are closely associated. They studied a sample of 196 manufacturing firms in Australia and concluded that there was a significant and positive correlation between weighted R&D expenditure and exports as a percentage of sales.

Many commentators have emphasized the need for developing export oriented industries and concentrating R&D efforts in areas where Australian industry has comparative advantages. Johns (1978) has argued that Australia may have a comparative advantage in developing new technology based industries in selected areas. McKern (1981,p.22) however, has commented that Australia could not hope to compete in the innovation of highly advanced technology, except in a very few areas; Australian firms are successful in operating overseas in products areas where technology is not particularly advanced. Gannicott (1982) has pointed out that Australian industries should opt for selective new technology based industries such as resource industries because of the apparent comparative advantage in innovations in these areas. Such a selective approach to the formulation of science and technology policy is highly debatable and some of these arguments are examined in Tisdell (1983). In addition, Tisdell (1975) has commented that the nation may lose the benefits of social returns of R&D, if it was concentrated only in export oriented industries.

The importance of the industrial R&D system and of technical change has been emphasized partly as a result of the declining rate of growth in the manufacturing sector. It has declined not only in terms of output but also as an employer of the nation's workforce. As described in Table 2.6 in the previous chapter, the rate of growth of manufacturing began to slow down towards the end of the 1960s. The decline in growth rate after 1968/69 occurred in two phases. Between 1968/69 and 1973/74, the rate of growth of most industry sectors was steady, about 5 per cent per annum. Some areas showed an improvement, whereas others suffered a slight decline. For example, industry divisions such as the food, beverages and tobacco, chemicals, petroleum and coal, and basic metal products grew by more than 6 per cent during the 1968/69 to 1973/74 period. However, the clothing, footwear and transport equipment were well below the average growth rate.

The period after 1973/74 was marked by widespread decline in output and employment in almost all industries except the food, beverages and tobacco (Bureau of Industry Economics, 1979 p.26). A general feature has been the steady decline of the textile, clothing and footwear and transport equipment sectors since the 1960s. The major reason for this decline in growth rates is held to be the change in the economic conditions which were enjoyed by industries throughout the 1960s, such as a low rate of increase in domestic prices and wage costs, a tendency for the Australian dollar to be under-valued, tariff protection for secondary industries, and a minimal amount of import competition from Asian countries (Bureau of Economic Research, 1979). Changes in these conditions coupled with a depressed level of domestic demand, failure to capture export markets and a significant increase in import penetration have been cited as major causes for the general slow down in the performance of manufacturing industry. In addition, a deficiency in technological advances and a general technological inferiority in all sectors of manufacturing industry have been suggested as some of the causes. The absence of sufficient competition and a slow rate of growth of capital equipment are considered to decelerate technological advance. Kasper argues that

> The absence of rejuvenating international competition would perpetuate the experience of slow innovation, sluggish productivity growth and frequently substandard quality of output.
> (Kasper,1978,p.109).

The avenues available for advancing technology in industry such as increasing R&D expenditure and investment in new capital equipment need reconsidering. A retardation of the growth of the capital investment in manufacturing industry has been noted and slow rate of introducing technological change is partly attributed to low capital investment. The Department of Industry and Commerce (1977 p.6) has pointed out that new capital investment in plant and equipment grew at an annual average rate of 6 to 7 per cent at constant 1968/69 prices for a period between 1950 and 1965. Furthermore, the ratio of capital expenditure at constant prices to employment in manufacturing industry has increased during this period. For example, between 1952/53 and 1955/56 the ratio of average annual growth rate of capital and employment was 3 : 1 it increased to 6 : 1 during two time periods, i.e. 1958/59 - 1960/61 and 1963/64 - 1965/66. It suggests that the increase in capital investment was higher than the increase in employment. During the period from 1965 to 1977, there has not been a significant growth in investment in new plant and capital equipment. Robertson (1978, p.79) has pointed out that share of private fixed capital expenditure declined from nearly 26 per cent in 1962/63 to 15 per cent in 1975/76. He argued that,

> There was little capital deepening in Australia during 1960s and early 1970s, hence technological advances may have been introduced more slowly in Australia.
> (Robertson, 1978,p.79).

Similarly, the Bureau of Industry Economics (1979,p.33) has pointed out that the ratio of fixed capital expenditure to value added between 1968/69 and 1976/77 fell from 12 to 8 per cent, indicating an increasing age of capital equipment, a slow rate of growth of capital stock and a failure to keep phase with technological development.

The examination of new capital investments in manufacturing industry during the 1968/69 and 1980/81 periods, indicates that the capital expenditure on plant, equipment and vehicles, at current prices, have increased considerably with an annual average growth rate of 10.8 per cent from 684 million dollars in 1968/69 to 2224 million dollars in 1980/81. The percentage allocation of new capital expenditure to equipment, plant and vehicles, has increased from 76 per cent in 1968/69 to 97 per cent in 1980/81. The expenditure on land and building has not increased at a similar rate compared with plant equipment. It indicates a shift of investment patterns towards new plants and equipment (Table 3.1). These results indicate that the Australian manufacturing industries have undergone a 'stagflation' period, during which the proportion of rationalization and replacement investment tend to rise and new capacity investment tend to diminish: more investment will go into machinery and less into new buildings (Freeman *et al.*, 1982). There may have been increasing pressure for 'improvement innovation' and 'product differentiation' in Australian industries between 1968/69 and 1980/81.

Table 3.1 New Fixed Capital Expenditure (less disposals) in Manufacturing Industry at Current and Constant 1979/80 Prices (in million dollars)

Capital Exp. Year	Land,Building& Other structure Current	Constant	Plant,Machinery and Vehicles Current	Constant	PlantEx . Per 1000 Employees Constant
1968/69	219(24%)	548	684(76%)	1710	1.3
1969/70	227(22%)	556	803(78%)	1967	1.5
1971/72	271(21%)	588	1027(79%)	2229	1.7
1972/73	246(20%)	514	999(80%)	2088	1.6
1973/74	291(24%)	544	924(76%)	1728	1.3
1974/75	304(21%)	472	1142(79%)	1770	1.4
1975/76	284(20%)	383	1168(80%)	1517	1.3
1976/77	286(19%)	346	1262(81%)	1527	1.3
1977/78	374(20%)	426	1506(80%)	1717	1.5
1978/79	332(15%)	359	1931(85%)	2085	1.8
1979/80	390(18%)	390	1797(82%)	1797	1.6
1980/81	659(3%)	588	2224(97%)	1979	1.7

Note Since the 1974/75 census, data realted to single establishment with less than 4 employees are excluded.

Source ABS, Census of Manufacturing Establishment, Cat. no. 8202.0, Various issues; Constant 1979/80 prices are calculated using ABS (1981), Australian National Accounts Gross Domestic Product by Industry, 1980/81, Cat. No. 5211.0, Canberra.

However, the investment in new capital expenditure at constant 1979/80 prices hardly shows any growth. The expenditure on plant and machinery remains at an average of 1.5 millions dollars per 1000 employees during this period. There was only a slight fluctuation of this ratio from the mean during different years (Table 3.1).

A slowing down in capital investment also presents a serious problem in incorporating past R&D into industrial production. Griliches (1980) argues that

> It is also possible that much of the effect of past R&D is embodied in new equipment, and a slow down in capital growth may also induce a decline (a postponement) in the effect of R&D on productivity.
> (Griliches, 1980,p.347).

A growth of exports might be considered as an opening for the revival of technological advances. However, the growth of manufacturing exports has been slow in the Australian economy. The export of manufactured goods grew slowly from 1968/69 to 1979/80. The exports as a percentage of turnover grew from 8.6 per cent in 1968/69 to 11.4 per cent in 1975/76 (Bureau of Industry Economics, 1979, p.37). Recent statistics show this percentage has increased to 16.5 per cent in 1979/80 and declined to 16.0 per cent in 1980/81. Among the manufacturing industries, the fast growing exporters were the food, beverages and tobacco industry and basic metal products industries. Exports as a percentage of turnover in food, beverages and tobacco increased its share from 16.6 per cent in 1968/69 to 23.5 per cent in 1973/74 but declined to 22.6 per cent in 1975/76 and increased again to 26.6 per cent in 1979/80. The basic metal products industry showed a steady increase in exports as a percentage of turnover from 15.6 per cent in 1968/69 to 25.3 per cent in 1973/74 to 29.3 in 1975/76 and 35.0 per cent in 1979/80.

As noted previously, industrial development in Australia has been traditionally directed at import replacement. The extent of the dependence on imports is expressed in terms of import penetration, defined as imports as a percentage of domestic sales. Import penetration began to increase towards the beginning of the 1970s. For manufacturing as a whole it increased from 17.6 per cent in 1968/69 to 19.3 per cent in 1973/74, 20.7 per cent in 1975/76, and 23.2 per cent in 1979/80. This increase is particularly marked in industries such as the textiles, 32.8 per cent in 1968/69 and 56 per cent in 1979/80; clothing and footwear, 7.3 per cent in 1968/69 and 20.4 per cent in 1979/80; and other machinery and equipment, 33 per cent in 1968/69 and 73 per cent in 1979/80 (Bureau of Industry Economics 1979,p.37; and ABS, Imports, 1982b; and ABS,Exports, 1982c).

Under the circumstances of slowing down in productivity growth, stagnating exports and increasing competition from imports, the manufacturing industries were compelled to adopt inward looking policies to increase production efficiencies. The options available included increased investment in new capital equipment, undertaking R&D to reduce cost of unit of production by improved process innovations, introducing new products to tap new markets or diversifing manufactures, making structural adjustment, improving education of the workforce and developing better techniques for management and resource allocation.

This chapter and the next intend to evaluate the strength and weakness of industrial research in manufacturing industry and explore its role in industry performance. The selection of areas of industrial research and the evaluation of research structure are of prime importance for R&D managers. The optimum level of resource that should be allocated to different types of research activity and the direction of resource in part determine the efficiency of the R&D system. Moreover the orientation of R&D to product and process innovation strategies of firm is also vital to industry performance.

The main objective of this chapter is to evaluate the trends and directions of the national R&D effort in manufacturing industry research since the 1968/69. The involvement of Commonwealth Government and Private Business Enterprise sector in the development of industrial research in the manufacturing sector in Australia is examined to highlight the structure of resource inputs to industrial innovation. Industrial R&D effort is examined using input indicators such as expenditure and personnel resources allocated to R&D and payments for technical know-how. These statistics are unfortunately available only at aggregated industry levels.

The lack of national statistic on the output of research and inventive activity in industry restricts evaluation of the effectiveness of the R&D structure. The major issues considered in this chapter include industry commitment to technical innovation, inter-industry difference in resource allocation, the relationship between R&D investment patterns and economic output indicators such as sales, turnover, and valueadded, trends in performance of R&D and technical know-how payments, and the direction of R&D and technical inventive activity in industry. The level of R&D funding is presented as a ratio to turnover and valueadded to identify the research intensity of different industries and some characteristics of R&D intensive industries are also examined.

3.1.0 Recent Surveys of Resources Devoted to R&D in Manufacturing Industry

Measurement of scientific activities in Australia has only reached the stages of accounting for inputs of R&D effort. Expenditure and manpower devoted to R&D activity by sector of performance, sources of funds, types of activities and fields of science are measured in the national surveys.

The first national survey for the 1968/69 was initiated by the then Department of Trade and Industry, however, systematic and detailed surveys with a wide industry coverage were available only after the 1973/74 survey which was conducted by the Australian Bureau of Statistics with collaboration of the Department of Science. The national surveys have not attempted to collect related scientific activities and output of R&D effort. A limited information on patents statistics are collected in these surveys.

It should be noted that the quantification of output of research is extremely difficult. The development of methods for the measurement of resources devoted to R&D inputs in different sectors alone has produced a large number of significant problems. It is necessary to identify some of these limitations in order to draw a meaningful interpretation of R&D statistics.

3.1.1 Limitation of Measurement and Interpretation of R&D Input Statistics

The measurement of R&D input raises both general and specific problems which significantly affect the interpretation and comparison of R&D statistics. Common difficulties associated with the measurement of R&D activity are the definitions of R&D, accounting for different types of R&D expenditures, identifying different types of costs, separating R&D expenditure according to sector of performance and field of science, variations in reporting R&D expenditure by different industry and separating personnel allocation to research from routine related scientific activity.

In quantifying R&D input resources, a full count concept is employed. According to this concept, both direct and indirect activity involved in conducting, planning and administering R&D should be included. A survey of a complete population of R&D performers is often necessary as sampling techniques may fail to fully account for actual R&D effort owing to the diversity in patterns of R&D resource allocation in different industries.

Measuring R&D expenditures and personnel effort raises at least three distinct problems;

a) defining and interpreting R&D concepts,

b) accounting and statistical problems in measuring R&D resources, and

c) interpretation of measured R&D effort.

A detailed discussion of the above mentioned problems and related issues is found in Liyanage (1983).

3.1.2 National Surveys of Input Indicators-R&D Expenditure and Personnel in the Business Enterprise Sector

Official surveys of R&D input statistics commenced in the early 1970s, when the then Department of Trade and Industry undertook a survey of IR&D in collaboration with the then Department of Education and Science for the financial year 1968/69 (Dept. of Trade and Industry, 1972). The survey covered all private enterprises believed to be engaged in R&D in the mining and manufacturing sectors. The sample consisted of 5841 companies out of which 70 per cent responded. The definitions adopted in the survey were in accordance with those used by the OECD (1962). The number of manufacturing firms reporting R&D amounted to 1265 out of which 75 per cent were fully Australian owned companies, 7 per cent had significant overseas ownerships and a further 18 per cent were subsidiaries of overseas companies. The total coverage of the survey is unknown, though it was believed to be about 90 per cent (ABS,1981b,p.5). The total IR&D expenditure incurred by private manufacturing industry was A$89.8 million, which represented 1.2 per cent of GDP by manufacturing industry in 1968/69[13] The highest level of R&D expenditure occurred in the chemicals, petroleum and coal product industry, which accounted for 21 per cent of total expenditure. The R&D expenditure statistics of the survey are presented in Table 3.2.

The second national survey of industrial R&D was carried out by the then Department of Manufacturing Industries for the financial year 1971/72. The survey covered 4600 manufacturing firms and it was claimed that it included practically all manufacturing firms in Australia

---

13 Use of GDP and value added measures to indicate the proportion of R&D resource allocation is discussed in OECD (1976)

undertaking R&D in 1971/72 (Dept. of Manufacturing Industry, 1974). The overall coverage of R&D industries is again unknown and believed to be around 95 per cent (ABS, 1981,p.5). The survey reported $129.6 million as IR&D expenditure, representing 1.34 per cent of GDP by manufacturing industry, which was 11.7 per cent higher than 1968/69 level. The survey also revealed that large companies with 1500 or more employees were responsible for more than half (59 per cent) of research conducted in the manufacturing sector, although they represented only 7 per cent by number of companies reporting R&D. Nearly half of the large companies were foreign owned. The major portion of R&D was conducted by the other machinery and equipment industry division, accounting for 21 per cent of total manufacturing expenditure. The transport equipment industries was responsible for 17 per cent of R&D expenditure. The chemicals, petroleum and coal product industries reported a decline in expenditure to 15 per cent. The food, beverages and tobacco industry shared 10 per cent, fabricated metal products was 9.6 per cent, and basic metal products was 9.1 per cent (Table 3.2)

The Department of Science conducted the third national survey of R&D expenditure for the 1973/74 period, but the Australian Bureau of Statistics (ABS) undertook the responsibility of surveying the private enterprise sector using a questionnaire and instructions prepared jointly by the Department of Science and the then Department of Manufacturing Industries (Dept. of Science, 1977). The survey included all industrial enterprises which had more than 140 employees and a sample of enterprises with 140 or fewer employees. The total sample included 6014 industrial enterprises and over 91 per cent responded to the questionnaire. Out of the remaining 9 per cent, about 5 per cent had ceased operations and approximately 4 per cent did not respond. When the survey results were first published in 1977 by the Department of Science in PROJECT SCORE, the reported R&D expenditure was $182.7 million. This figure was subsequently revised to $149.7 million by ABS (1979a) after adjustments to the expenditure reported by some companies due to inclusion of activity not strictly within R&D concepts. The revised figure represented 1.2 per cent of GDP by manufacturing industry comparable with the 1968/69 level. The interpretation of results of this survey is somewhat limited owing to high standard errors involved in aggregating data into industry classes and the aggregation of some industry classes to form a single group. For example, the fabricated metal product industry was combined with other machinery and equipment, thus accounting for a high 29.2 per cent of total R&D expenditure. The transport equipment industry was responsible for 13 per cent, chemical industries 12 per cent, basic metal products 8 per cent and food, beverages and tobacco 6 per cent of the total R&D expenditure (Table 3.2).

The fourth national survey of IR&D for the period of 1976/77 was conducted by ABS and the survey comprised a complete enumeration of private enterprises which were considered likely to conduct R&D and it is claimed that 98 per cent of R&D expenditure carried out in private enterprises was covered by the survey. The survey reported $124 million expenditure on IR&D representing 0.7 per cent of GDP by manufacturing industry. The percentage of GDP indicates a decline of 42 per cent from that of the previous survey.

Table 3.2 The Expenditure of Research and Experimental Development in Manufacturing Industries at current prices by Industry division from 1968/69 to 1978/79. (million dollars)

Year ASIC No.&Industry	1968/69	1971/72	1973/74*	1976/77*	1978/79	1981/82
21. Food,beverages	7.2	12.7	9.9	11.6	16.1	16.0
& Tobacco Prod.	(100)	(178)	(138)	(163)	(225)	(222)
23&24. Textile,clo.	1.5	4.0	3.9	2.1	1.4	0.8
&footwear	(100)	(265)	(258)	(137)	(90)	(53)
25. Wood, wood prod.	1.1	1.2	n.a.	0.9	1.6	2.1
furniture	(100)	(111)		(84)	(142)	(175)
26. Paper,printing	2.4	2.9	2.4	3.3	4.1	5.3
and publishing	(100)	(124)	(100)	(139)	(171)	(221)
27. Chemical, pet.	18.4	19.7	22.3	27.1	35.2	55.8
and Coal prod.	(100)	(107)	(121)	(147)	(191)	(303)
28. Non-metallic	1.9	5.1	n.a.	3.8	4.2	5.1
mineral prod.	(100)	(257)		(195)	(211)	(260)
29. Basic metal	11.8	11.9	14.6	19.0	20.9	28.0
product.	(100)	(101)	(124)	(162)	(178)	(238)
31. Fabricated metal	8.3	12.5	n.a.	3.9	4.5	7.3
products	(100)	(151)		(48)	(55)	(89)
32. Transport	16.1	21.8	25.4	14.6	15.6	29.7
equipment	(100)	(135)	(158)	(91)	(97)	(184)
33. Other machinery	17.9	26.6	55.6¢	33.9	48.6	56.0
& equipment	(100)	(141)		(189)	(271)	(313)
34. Miscellaneous	3.2	11.1°	15.6	3.5	5.9	6.8
manufac. n.e.c.	(100)			(111)	(186)	(213)
Total	89.8	129.6	149.8	123.9	158.1	212.9

Note
a) The statistics for 1973/74 are less accurate as it was based on a sample survey. Particularly, at industry level data contain high standard errors. For details see ABS(1979a) Research and development in private industries-1976/77. Cat.No. 8104.0
b) Figures in brackets represent index numbers based on 1968/69.
c) R&D expenditure in 1968/69 include an element of extramural expenditure.

° Includes sundry expenditures for research laboratories in coal, gas industries and industries not elsewhere classified.

* Represent revised figures by ABS since the first publication of statistics by the Department of Science

¢ Include R&D expenditure for fabricated metal products.

n.a. denotes not available.

Source a) Department of Trade and Industry(1972) Survey of Industry Research and Development Expenditure 1968/69, Canberra.
b) Department of Manufacturing Industry (1974), R&D in Manufacturing Industry 1971/72, Dept. of Manufacturing Industry bulletin No.11. Canberra,AGPS.
c) Department of Science(1976&1980) Project SCORE 1973/74 & 1976/77, Canberra,AGPS.
d) Aust. Bureau of Statistics (1979a&1981a) Research Development Expenditure in Private Enterprise Sector, 1976/77 and 1978/79 surveys. Cat.No. 8104.0, Canberra, ABS.

The other machinery and equipment industry spent the highest amount on R&D, 27 per cent of total expenditure. The chemicals, petroleum and coal industry was responsible for spending 22 per cent, basic metal products 15 per cent, transport equipment 12 per cent and food beverages and tobacco 9 per cent (Tàble 3.2).

The national statistics available on IR&D for the financial year 1978/79 report expenditure of $158.1 million (ABS,1981b). This survey had a similar coverage to the previous one. A slight improvement in the ratio of GDP by manufacturing industry at 0.74 was reported. The other machinery industry maintained its position as the highest spender, at 31 per cent of total R&D expenditure. The chemical industries were responsible for 23 per cent, basic metal products 13 per cent, transport equipment 10 per cent and food, beverages and tobacco 10 per cent.

The latest survey for the 1981/82 period indicates an increase of 25.7 per cent on current R&D expenditure from the previous survey figure to 212.9 million dollars. R&D expenditure as a percentage of GDP by manufacturing slightly increased to 0.78 per cent. R&D manpower further declined by 8.6 per cent from the previous survey level to 5445.7 person-years. These results indicate that the level of R&D has not improved substantially during the period from 1968/69 to 1981/82 and the R&D expenditure as a percentage of GDP by manufacturing has fallen below the 1 per cent level.

3.1.3. R&D Personnel Effort in the Business Enterprise Sector

R&D personnel was surveyed from 1968/69 to 1971/72 by a simple head count of persons employed at a particular reference time during the year. Manufacturing industry research employment in 1968/69 was 9383 full-time and 2994 part-time research persons. The research employment in 1971/72 was reported as 14207 full-time and 4170 part-time persons (Table 3.3). This method, however, does not provide an accurate measure of personnel input to R&D as it fails to account for time spent by scientists and technical personnel on related scientific activities such as testing and standardization, consulting and teaching, and routine production work.

Table 3.3 Research Manpower Employed in Manufacturing Industry Between 1968/69 and 1981/82 ('000)

Year Industry Class	1968/69	71/72	73/74	76/77	78/79	81/82
Food,bev.&tob.	.94(.83)	1.39(.12)	.80	.55	.54	.43
Textile,Clo.&footwear	.30(.23)	.48(.43)	.27	.11	.04	.03
Wood&furniture	.24(.18)	.21(.14)	n.a.	.05	.06	.07
Paper&pub.	.37(.28)	.37(.31)	.17	.15	.14	.13
Chemicals,pet.&coal	2.44(2.22)	2.02(1.79)	1.92	1.33	1.38	1.32
Non-metallic min.	.20(.18)	.36(.29)	n.a.	.17	.15	.15
Basic metal	1.15(1.03)	1.27(1.12)	.99	.90	.78	.70
Fabricated metal	1.07(.88)	1.61(1.36)	n.a.	.23	.20	.17
Transport eq.	2.04(1.93)	2.09(1.98)	1.45	.76	.60	.85
Other machinery&eq.	3.12(2.71)	3.30(2.75)	4.80	1.87	1.85	1.45
Miscellaneous manu.	.53(.42)	1.32(.80)	.96	.19	.21	.16
Total	12.38(10.88)	13.96(11.87)	11.36	6.30	5.96	5.45

Note: Figures presented in brackets refer to full-time equivalent (FTE) persons employed on R&D.

Source: Same as in Table 3.2.

The Department of Science decided to change the method of measuring R&D personnel resources in the 1973/74 survey. Instead of employing a head count of research persons at a particular reference time, the number of person-years spent on research activities during each year by a researcher in industry was estimated. The person-year of research was defined as,

> A single person working at the most of one man year in each year even though that person may have worked long hours and/or been extremely effective.
> (Department of Science,1980).

For example, a person who devotes on average 40 per cent of his working time to research for a half of the survey year was regarded as spending 0.4 x 0.5yrs = 0.2 person-years on R&D work. The major drawback of this concept was the difficulty in determining the exact time spent by each researcher on research activity. The concept of person-year, although providing an apparently precise measure of research personnel effort, is frequently based on subjective and arbitrary estimates of the percentage time devoted to research. A great deal of error is involved in such estimations. Furthermore it takes no account of varying hours or intensity of work by individuals.

In the 1973/74 survey year, the R&D personnel employed by the manufacturing industry was estimated as 11360 person-years. Research employment for the 1976/77 period was 6303 person-years, a sharp decline compared with the level in 1973/74. The research employment in manufacturing industry further declined to 5956 person-years during 1978/79 and 5446 person-years during 1981/82. The professional person-years employed in research activities is presented in Table 3.4.

There was a considerable decrease in the professional research employment in most of the industry classes during the period. The chemical and other machinery and equipment industries have employed the largest proportion of professional person-years compared with other industries. These two industry classes were responsible for 54 per cent in 1976/77 and 53 per cent in 1981/82 of the professional employment in manufacturing industries.

Table 3.4 The Composition of Professional Research Employment by Industry Class, 1971/72 to 1978/79 (in person years)

Year Industry Class	1971/72	1973/74	1976/77	1978/79	1981/82
Food,bev.&tob.	578	410	292	302	256
Textile,Clo.&footwear	136	60	49	16	11
Wood&furniture	71	n.a.	22	28	29
Paper&pub.	158	80	72	65	59
Chemicals,pet.&coal	1062	950	637	702	700
Non-metallic min.	152	n.a.	81	74	67
Basic metal	433	420	386	296	313
Fabricated metal	450	n.a.	86	70	83
Transport eq.	434	530	156	162	229
Other machinery&eq.	859	n.a.	825	692	593
Miscellaneous manu.	297	n.a.	96	106	79
Total	4630	2450	2702	2513	2419

Note Data for 1968/69 are not available and number of professionals are presented for 1971/72 period. Data presented for 1981/82 is preliminary.

Comparison of the data presented in Tables 3.2, 3.3 and 3.4 must be made with caution due to changes of concepts and survey methods between surveys. In particular, the surveys for the years 1968/69 and 1971/72 made no special attempts to include social science research carried out in industry compared with the surveys of 1973/74 and subsequent years. However, in the case of the manufacturing industry surveys, its effect may be regarded as minimal as all surveys requested the responding enterprises to report all types of R&D expenses incurred by industries. The reliability of the 1973/74 survey is limited because of the employment of a sample survey. The ABS warns that high standard errors exist for statistics at the industry level as a result of the change in survey methods (ABS, 1979a,p7). The concepts and methodology for collecting R&D statistics have been consistent since the 1973/74 survey.

R&D personnel statistics over this period suffer a significant drawback because of the change in the unit of measurement from number of persons to number of person-years in 1973/74 surveys, part-time research employees were reported separately. In order to account for total R&D personnel effort, it is necessary to convert part-time and full-time personnel effort to a common unit of measurement by allocating a fractional weight. A unit calculated in this manner is referred to as full-time equivalent (FTE) persons. Table 3.3 illustrates the FTE personnel effort calculated for the period from 1968/69 to 1971/72 assuming part-time personnel were employed for half of the working time of the year entirely on research.

Changes in survey concepts and methodology raise considerable difficulties in presenting trends of inputs to R&D, and examining the relationships between personnel and expenditure statistics. In spite of these drawbacks these surveys provide a reasonable description of the state of industrial research activity. In particular, the surveys since the 1976/77 can be confidently used for such analysis.

3.1.4 Type of R&D Cost in the Business Enterprise Sector

R&D statistics are reported according to three major expenditure categories. These are capital, current, and other current expenditures. The capital expenditure includes costs of buildings, plant and equipment and other structures. The current expenditure includes wages, salaries, and related labour costs. Other current expenditure consists of the costs of material, fuel and electricity, rent, leasing, maintenance, data processing reference material and other supporting services.

Labour costs constitute a large portion of R&D expenditure in the business enterprise sector. Capital expenditure on the other hand is much smaller (Table 3.5)

Table 3.5 Distribution of Type of Costs in Business Enterprises (million dollars)

Year Type of Cost	1971/72	1973/74	1976/77	1978/79	1981/82
Capital	13.5(11%)	14.8(10%)	8.4(7%)	15.5(10%)	23.2(11%)
Salary&wages	73.1(56%)	67.2(45%)	85.9(69%)	101.6(64%)	133.0(62%)
Other current	43.0(33%)	67.7(45%)	29.7(24%)	41.0(26%)	57.0(27%)

The Proportion of capital expenditure has not greatly increased since 1971/72, and there was a significant decline in 1976/77. Other current expenditure also declined over the period. A large proportion of R&D expenditure is devoted to salaries and wages and this proportion has increased substantially over the decade. It averaged 58 per cent during this period and increased at an annual average growth rate of 23 per cent from 1973/74 to 1978/79. The type of costs show more or less a similar percentage distribution for the different industry divisions.

3.1.5 Ownership and R&D Level in Business Enterprises

The criterion used in the classification of enterprises according to foreign and Australian ownership is based on the control of voting shares in the firms. An enterprise is classified as foreign owned if a foreign resident investor (individual, company or group of related companies) or foreign controlled enterprises holds at least 25 per cent of the paid-up value of voting shares in the enterprise, provided that there was no larger holding by an Australian controlled enterprise or Australian resident individual. All enterprises not classified under foreign control have been labelled as Australian controlled (ABS,1979a).

In the 1968/69 survey, overseas companies were responsible for nearly 50 per cent of the research expenditure incurred by manufacturing industry, although they presented only 18 per cent of the sample. In the 1971/72 survey, the foreign owned group of companies spent 55 per cent of the total research expenditure. The survey of 1973/74 also revealed that the percentage of total R&D performed by the foreign controlled companies employing 150 or more persons was as high as 67 per cent (Dept. of Science, 1977). The survey of 1976/77 revealed that foreign controlled companies represented 29 per cent of the enterprises reporting R&D and they were responsible for 51 per cent of the total R&D expenditure incurred. Foreign owned company involvement in R&D is not available since that date.

Table 3.6 indicates the number of enterprises undertaking R&D in Australian and foreign owned firms. The number of R&D enterprises have shown a general decline over the period, particularly among Australian companies.

The R&D expenditure incurred by these industries in selected years are presented in Table 3.7. It indicates the dominance of foreign owned companies in R&D activity has been largely reduced as a result of decreasing investment in R&D by these industries.

Table 3.6 Number of Private Manufacturing Enterprises Undertaking R&D by Ownership

Year Type of Ownership	1968/69	1973/74	1976/77	1978/79
Foreign Owned	328(25%)	330(41%)	236(29%)	n.a.
Australian Owned	993(75%)	470(59%)	576(71%)	n.a.
Total	1321(100%)	800(100%)	812(100%)	770(100%)

Note Data for 1973/74 available for those companies employing more than 150 employees.

Source Department of Science, (1977 and 1980) Project Score; Department of Trade and Industry (1972); ABS(1979b)Foreign Control in R&D, Cat. No.5330.0, Canberra.

However, Australian controlled companies were in the process of reaching the level of R&D investment of foreign controlled companies at the end of 1976/77.

Table 3.7 R&D Expenditure by Ownership in Selected Periods ($million)

Year Type of Ownership	1971/72	1973/74	1976/77
Foreign Owned	70.9(55%)	107.1(67%)	65.1(51%)
Australian Owned	58.7(45%)	52.1(33%)	61.8(49%)
Total	129.6(100%)	159.2(100%)	126.9(100%)

Note Total amounts presented for 1973/74 and 1976/77 surveys have been revised by ABS since first published and the 1973/74 survey reports statistics by foreign ownership only for industries employing more than 150 persons.

Source As in Table 3.6

Moreover, the statistics available in 1973/74 indicate that foreign controlled companies were responsible for 81 per cent of the basic research, 54 per cent of applied research and 69 per cent of research on new products carried out in manufacturing industries.

Manufacturing industries purchase know-how from Australian and foreign sources. More than 90 per cent of the payments for know-how were made to overseas sources and this percentage rapidly increased since 1973/74 (Table 3.8).

Table 3.8 Distribution of Payments for Technical Knowhow Among Local and Foreign Suppliers ($million)

Year Type of Supplier	1968/69	1971/72	1973/74	1976/77	1978/79
Local	1.6(5%)	4.6(9%)	4.4(7%)	1.4(3%)	1.3(2%)
Overseas	34.0(95%)	46.8(91%)	58.7(93%)	51.9(97%)	78.1(98%)
Total	35.6(100%)	51.4(100%)	63.2(100%)	53.3(100%)	79.4(100%)

These data indicate reliance on Australian sources for purchase of technical know-how is diminishing, whereas payments for overseas technology are rapidly increasing.

3.2.0 Industrial Research in Public and Higher Education Institutions on Manufacturing Industry Problems

In Chapter one, it has been pointed out that the sector of performance of R&D is an important determinant of the effectiveness and the rate of returns to R&D. Industrial research conducted in private firms is believed to produce results more directly connected to commercial interest than research conducted in government laboratories. Middleton (1970) has argued that public expenditure on R&D on industrial problems tends to decline as an industry become viable and expresses its identity in a range of technical activities. Although resources inputs to industrial research by government sources is meagre compared with private industry, the role of government R&D effort is a useful supporting strength to R&D activity undertaken in private sector. In particular, government R&D can explore high risks R&D areas, where most private industries hesitate to venture.

The higher education institutions in Australia perform relatively little research for industrial objectives as discussed in Chapter 2. The effectiveness and the contribution of public sector research to manufacturing industry problems can be partly examined through the resources allocated to R&D in this sector.

3.2.1 Resources Devoted to Industrial R&D by Government Sources Between 1973/74 and 1978/79

Commonwealth Government, State Government and Higher Education institutions are the major public sector contributors to research relevant to manufacturing industry. The R&D effort of these institutions has been reported since the 1973/74 survey. The most important public institutions, which has had a long standing responsibility for industrial research is the CSIRO. The extent of CSIRO involvement in industrial research is demonstrated in a report of the CSIRO Secondary Industry Committee (CSIRO,1972), which indicated that the level of expenditure on industrial fields was $16 million in 1968/69 and $25.3 million in

1971/72. According to these figures, the ratio of private manufacturing enterprises to CSIRO industrial R&D was 5.6 to 1 for 1968/69 and 5.1 to 1 for 1971/72.

A report of CSIRO to the Jackson Committee in 1972 commented that the

> Present situation involving private industry research : CSIRO ratio about 5 : 1 or 6: 1 does not appear unreasonable or point to a need for major modification in today's circumstances. (CSIRO,1974).

The statistics for the Commonwealth, State governments and private non-profit making institutions' R&D expenditure on manufacturing industry were first published by the Department of Science in their national surveys of R&D expenditure. A limited amount of information is available on direct industry funding to university research for 1973/74, 1976/77, 1978/79 and 1981/82.[14]

These data provide only the direct university expenditure on industry research and the indirect costs are difficult to assess. Tables 3.9 and 3.10 summarise the national IR&D effort in manufacturing industry research and indicate the relative strength of government and private enterprises in comparison with the gross national effort.

Industrial research in manufacturing industry from all sources grew from $175.5 million in 1973/74 to $221.5 million in 1978/79 at an annual average growth rate of 16 per cent. Government support for industrial research in manufacturing industry has increased substantially from 8 per cent in 1973/74 to 22 per cent in 1978/79. IR&D as a percentage of GDP also has declined from 0.34 per cent to 0.22 per cent between

14 See Liyanage, S. and Johnston, R. (1984).

this period. The period between 1973/74 and 1976/77 was marked by a particularly sharp decline.

Table 3.9 IR&D Effort in Commonwealth and State Government, Higher Education and Private Non-Profit Sectors, 1973/74-1978/79($'000 and personyears)

Year Sector	1973/74 Pers.	76/77 Pers.	78/79 Pers.	1973/74 Exp.	76/77 Exp.	78/79 Exp.
Comm.Govt.	1057	1134	1029	14047	27122	47038
State Govt.	13	116	42	127	2230	1133
Private non-prof.	n.a.	n.a.	n.a.	n.a.	188	n.a.
Higher Education	n.a.	n.a.	657	n.a.	5489	11177
Total	1070	1691	1728	16172	42707	59348

Source Department of Science,(1978 and 1980),Project Score; ABS(1981a. 1981b and 1979a).

Perhaps one of the most striking features of the Australian industrial research structure is the low level of contract research from private enterprises to other research institutions. From 1976/77 to 1978/79 an average of only 7 per cent of the total R&D budget of business enterprises was spent on extramural research of which nearly 60 per cent was spent in Australia and the remainder overseas.

Extramural expenditure reaching university and government research institutions is meagre indicating a weak link between industry and public institutions. The industrial R&D employment has declined steadily and it was this factor that was responsible for apparent growth of current expenditure per person-year from $14.1 thousand in 1973/74 to $21.1 thousand in 1977/77; $28.8 thousand in 1978/79; and $39.1 thousand in 1981/82. Over this period total IR&D as a percentage of national R&D has steadily declined.

Table 3.10 Gross Industrial Research and Development Effort in the Manufacturing, 1973/74-1978/79($'000 and personyears)

Year Sector	1973/74	1976/77	1978/79
Private ent.(intramural)	149700(85%)	123900(73%)	158100(71%)
Private ent.(extramural)	9682(6%)	4171(2%)	4013(2%)
Govt. organisations	14174(8%)	34800(21%)	48171(22%)
Higher Education	1998(1%)	5489(4%)	11177(5%)
Total IR&D	175554(27%)	168360(19%)	221461(21%)
-GERD in Australia	650687	873400	1053800
Total IR&D manpower	12430	7994	7684
IR&D as % of GDP by manu.	1.4	0.9	1.03
IR&D as % of GDP	0.34	0.20	0.22
GERD as % of GDP	1.3	1.05	1.03

Note 1976/77 survey represents revised statistics by the ABS since first published. Extramural R&D expenditure includes payments made to overseas R&D performers. The higher education data for 1973/74 and 1976/77 present only the direct funds available for university research.

Source Department of Science,(1978 and 1980),Project Score; ABS(1981a,1981b and 1979a) and ABS (1982a)Australian National Accounts-Gross Domestic Product by Industry, 1980-81, Cat.No.5211.0.Canberra.

After correction for inflation, the dramatic decline of the level of R&D resources during the 1973/74 and 1976/77 period and the subsequent flattening out at this level is shown in Table 3.11.

Table 3.11 Gross Industrial R&D Expenditure at Constant 1979/80 Prices (in million dollars)

Year Expenditure	1973/74	1976/77	1978/79
IR&D Expenditure	343.4(27%)	217.0(19%)	245.8(22%)
Gross National R&D(GERD)	1272.7	1125.8	1169.7

Note Deflator is based on gross domestic product (GDP) at 1979/80 prices.

Gross expenditure on IR&D (GEIRD) has declined at an annual average rate of 4.8 per cent. The national gross R&D expenditure (GERD) has declined at a slower annual average rate of 1.54 per annum during the period.

3.2.2 Type of Industrial Research Activities in Australian Manufacturing Industry

In general, industrial firms invest in R&D with the objective of achieving returns within as short a time as possible. Thus it might be expected that their effort would be concentrated more at the development end of the R&D spectrum. Nevertheless, they may conduct some basic research in pursuit of longer term goals. Table 3.12 describes the involvement of private enterprises in basic, applied and experimental development activities. Basic research is limited to an average of 2 per cent of the total expenditure on industrial research in private enterprises, except for the 1973/74 survey year.

Table 3.12 Expenditure on IR&D in Manufacturing by Type of Activity in Private Industry Between 1976/77 and 1978/79($'000)

Type of Activity Year	Basic	Applied	Exp. Dev.
1971/72	2592 (2%)	47952 (37%)	79057 (61%)
1973/74	15143 (9%)	32724 (21%)	87196 (55%)
1977/78	2681 (2%)	36750 (30%)	81579 (67%)
1978/79	3879 (2%)	40795 (26%)	113414 (72%)

Note Source as in Table 3.9.

Experimental development activity constitutes a major portion of R&D and applied research represents about a third of the total expenditure. There has been a shift towards more experimental development activity at the expense of applied research during 1978/79.

Government research institutions are involved in basic and applied research more heavily than is private industry. Government sources spent more than twice as much for basic research compared with the private industries and showed a low profile in experimental development (Table 3.13). The rationale for government support for basic industrial research can be described as its willingness to absorb more risks and to work to a longer time horizon in venturing into relatively unknown and uncertain areas than the private industry. Hence government programs in industrial research could be expected to spend more on basic research than private industry.

Table 3.13 R&D Expenditure in Manufacturing Sector by Type of Research Activity and By Performer Between 1976/77 and 1978/79($million)

Type of Res. Source&Year	1976/77	78/79	76/77	78/79	76/77	78/79
Private Enter.	2.7(2%)	3.9(2%)	36.8(30%)	40.8(26%)	81.6(67%)	113.4(72%)
Comm. Govt.	4.2(15%)	13.0(28%)	18.9(70%)	25.0(54%)	4.1(15%)	8.6((18%)
State Govt.	0.1(5%)	0.1(12%)	1.7(78%)	0.8(67%)	0.4(18%)	0.2(10%)
Non-prof.	n.a.	n.a.	.01	n.a.	n.a.	n.a.
Total	6.9(5%)	17.0(8%)	57.4(38%)	67.0(33%)	86.1(57%)	122.2(59%)

These statistics indicate that government institutions are the major source for basic industrial research, while private enterprises' effort is mainly concentrated on experimental development.

3.2.3 Sources of Finance for IR&D in the Manufacturing Sector

Funds available for R&D activity in the private enterprise sector originate from various sources. Although some assistance is available from non-industrial sources, private industry financed nearly 90 per cent of R&D expenditure in 1976/77. This percentage declined to 84 in 1978/79. The balance is funded mainly by various government sources such as the Australian Industrial Research and Development Incentives Board (AIRDIB), CSIRO, and other Commonwealth and State Government organisations. The major sources of funding for R&D in private enterprises are presented in Table 3.14.

Table 3.14 IR&D Expenditure by Source of Fund in Private Enterprises in 1976/77 and 1978/79($'000)

Year Source of Fund	1976/77	1978/79
Own Fund	108693 (90%)	133510 (84%)
AIRDIB Grants	2755 (2%)	10171 (6%)
Other Commonwealth	4489 (4%)	7421 (5%)
Other State	n.p.	393 (0.2%)
Other private	3500 (3%)	2025 (1%)
Private non-profit	n.a.	n.a.
Overseas	1573 (1%)	n.a.
Total	121010(100%)	158087(100%)

Note n.a. denotes not available.

Funds originating from government sources considerably increased from 1976/77 to 1978/79. In particular, funding by AIRDIB has sharply increased. The total funds available for industrial research activity from different sources are presented in Table 3.15.

Table 3.15 IR&D Expenditure by Source of Funds in 1976/77 ($million)

Performer / Source of Fund	Private	Commonwealth	State	Non-prof.	Total
Private Enter.	108.7	0.08	0.04	0.01	108.8(72%)
Comm. Govt.	4.5	26.8	0.10	n.a.	31.4(21%)
State Govt.	n.a.	0.06	2.08	0.01	2.15(2%)
Foundation	6.3	-	0.09	n.a.	6.35(4%)
Overseas	1.6	0.06	n.a.	n.a.	1.66(1%)

Note n.a. denotes not available.

These statistics are available only for the 1976/77 period. Funds originating from government sources account nearly one fourth of total industrial R&D. Governments also have spent a large proportion of their funds on extramural industrial R&D activity, while private industry has funded this very little.

3.3.0 Trends and Relationships of Private Investment in R&D in Manufacturing Industries

The rate of growth of R&D expenditure in different industry classes seems to fluctuate inconsistently during the period from 1968/69 to 1978/79. Although the actual R&D effort cannot be determined precisely, the available data provide only an indication of the trends in industrial research expenditure and personnel. One of the most striking features is the declining level of R&D personnel effort. A number of explanations are possible; the rise in wages, reduction in the number of enterprises undertaking R&D, reduction of auxiliary staff due to replacement of labour by capital as a result of technological development, lack of substantial profits to invest on R&D, lack of confidence due to uncertainty in returns to R&D, and insufficient incentives to undertake R&D activity.

As noted in Table 3.6, the number of enterprises undertaking R&D declined during 1976/77 and 1978/79; this was particularly evident in the case of the other machinery and equipment industries, in which the number of industries undertaking R&D declined from 290 to 255 during this period. As previously discussed R&D capital expenditure has not increased out of proportion to other expenditure items; however, a slight decline in auxiliary staff is noted from 3486.3 person-years to 3448.2 person-years during 1976/77 and 1978/79.

Growth of R&D resources in different industry classes show varying trends. While some industries fluctuate, others show a consistent decline or increase during the decade.

3.3.1 Growth Trends of R&D Expenditure in Different Industry Classes

The direction of changes of R&D expenditure and linearity of such changes with time can be tested by determining the correlation coefficient between the growth of R&D expenditure and time. The rate of growth of R&D expenditure at current prices in different industry classes shows a positive correlation with time for some industries significant at the 1% and for the others at 5% levels. A few industries, however, show a negative and non significant correlation coefficient indicating weak association and decline in growth rates of R&D expenditure with time (Table 3.16).

Table 3.16 Correlation Coefficient for the Growth of R&D Expenditure Between 1968/69 and 1978/79

Coefficients Industry Class	R	Sig.	r^2	F-value
Chemicals,pet.&coal	.94	.01	.88	21.4
Basic metal	.96	.01	.92	36.0
Food,bev.&tob.	.81	.05	.66	5.8
Paper&pub.	.84	.04	.70	7.2
Other machinery&eq.	.67(.95)	.11(.02)	.45(.91)	2.5(20.2)
Non-metallic min.	.29	.32	.08	0.28
Wood&furniture	.18	.39	.03	0.1
Fabricated metal	-.50(-.72)	.19(.14)	.25(.52)	1.0(2.2)
Transport eq.	-.28	.32	.07	.03
Textile,Clo.&footwear	-.25	.34	.06	0.2
Miscellaneous manu.	-.06	.46	.004	0.1

Note R,r^2, and sig. denote correlation coefficient, coefficient of determination and significance respectively. Figures in brackets represents regression coefficients excluding 1973/74 data.

The exclusion of 1973/74 data raises the correlation coefficient.[15]

These results indicate that R&D expenditure at current prices has increased at different rates in different industries with a varying degree of consistency. The chemical, basic metal products, food, paper, and other machinery and equipment industries show high positive correlation coefficients between R&D expenditure and time. This relationship is linear particularly in the case of basic metals and chemical. The direction of growth of R&D expenditure is positive in the case of non-metallic and wood, wood product and furniture industries, however, the association between growth of R&D expenditure and time was weak in these industries.

15 As noted previously, the survey of R&D for 1973/74 has a high standard error at industry level.

The correlation coefficient for R&D expenditure at constant 1979/80 prices is negative indicating a decline in rate of growth in all industry classes. Only t he basic metal products and paper industries show strongly negative and significant association (Basic metals R=-0.93, R^2 = 0.87,F=19.3,sig. 1% ; Paper R=-0.83, r^2 = 0.7, F=6.6, sig. 5%). Fabricated metal products and transport equipment industry divisions also show negative correlation coefficient (-0.72, and -0.74 respectively) significant at the 10% level. These industries show a steady decline in R&D expenditure at constant prices.

In terms of research personnel growth, almost all sectors have suffered loss of R&D personnel resources. Between 1976/77 and 1978/79 only three industry classes had a marginal increase in R&D personnel. These were the chemical, wood and miscellaneous manufacturing industries. Although the other machinery and equipment industry increased R&D expenditure significantly there was no comparable increase in R&D personnel effort. The food, beverages and tobacco, paper printing and publishing, non-metallic mineral products, other machinery and equipment and fabricated metal products industries remained constant, while the textile, clothing and footwear, basic metal products and transport equipment industries suffered a heavy decline in R&D personnel effort.

The annual average rate of growth of R&D expenditure in the other machinery and equipment was 15 per cent for the period between 1968/69 and 1978/79. The food, beverages and tobacco industries had an annual growth of 14 per cent. The chemical industries showed an annual average growth rate of 9 per cent and basic metal product had a rate of 7 per cent. The transport equipment and fabricated metal industries suffered a serious decline in expenditure during the period and failed to regain their momentum in recent years.

The pattern of industrial research in the public and private sector during 1976/77 shows that most of the research activity is concentrated in relatively few areas (Table 3.17). A large share of government funded research effort was directed to just three industry divisions. These industries are food, beverages and tobacco, chemicals, petroleum and coal products, textiles, clothing and footwear and they have received an approximately equal share of R&D expenditure. Although traditional industries such as textiles and food received substantial consideration in the government R&D program, there is no evidence to suggest that government research programs deliberately placed more emphasis on supporting weak R&D performers in the manufacturing industries.

Table 3.17 Composition of the Industrial Research Expenditure in Government and Private Enterprises During 1976/77($million)

Performer Industry Class	Govt. Inst.	Private Enter.	Total IR&D
Food,bev.&tob.	8.75(25%)	11.64(9%)	20.38(13%)
Textile,Clo.&footwear	7.64(22%)	2.08(2%)	9.71(6%)
Wood&furniture	0.69(2%)	0.94(1%)	1.63(1%)
Paper&pub.	1.43(4%)	3.34(2%)	4.78(3%)
Chemicals,pet.&coal	8.08(23%)	27.1(22%)	35.2(22%)
Non-metallic min.	0.59(2%)	3.84(3%)	4.43(3%)
Basic metal prod.	2.58(7%)	19.0(15%)	21.59(14%)
Fabricated metal prod.	0.26(1%)	3.98(3%)	4.25(3%)
Transport eq.	0.64(2%)	14.60(12%)	15.24(10%)
Other machinery&eq.	1.70(5%)	33.86(27%)	35.56(22%)
Miscellaneous manu.	2.50(7%)	3.52(3%)	6.02(4%)
Total	34.80(100%)	123.92(100%)	158.78(100%)

However, the overall industrial R&D component of traditional industries such as textiles, clothing, footwear, wood and wood products, paper and paper products has improved with the assistance of government industrial effort.

3.3.2. Growth Trends in R&D Expenditure at Constant 1979/80 Prices

The growth of R&D expenditure may be interpreted in different ways. In a time series analysis of the pattern of R&D expenditures, it is necessary to account for the purchasing power of R&D expenditure in different industry sectors and time periods. The inflationary trends applicable to R&D expenditure are not necessarily the same as for the expenditure in other sectors of the economy. The value of scientific equipment, materials, and salaries and wages of professional employed in scientific research may vary significantly depending on time and sector. In order to facilitate international comparisons and comparisons over time, it is necessary to derive constant price series for R&D expenditure. For this purpose various deflators have been developed. The different methods available for deflating R&D expenditure such as price deflators and research exchange rates are discussed in (OECD, 1976, 1977 and 1978). The need for a different deflator for the different sectors has been demonstrated by OECD (1977). The development of an R&D deflator needs a considerable period. Such a series of R&D indices is not available at present in Australia. In the absence of a specific R&D price deflator, the implicit price deflator for gross product is commonly used to convert current currency to constant currency (NSF,1979,p.43). This approach has considerable limitations because the inflationary trends for all economic activity and R&D activities do not have an effect on all sectors of economy[16] . However, it remains a useful approximation for use to deflate the national R&D expenditure.

The implicit price deflator for Gross Domestic Product (GDP) based on the production approach[17] is used in this study to convert current dollars to constant dollars. As demonstrated in OECD (1977), it is most appropriate to use deflators derived for different manufacturing industry groups. Table 3.18 presents the series of deflators calculated different years by different industry sectors.

Since 1971/72, R&D expenditure at constant prices shows a drastic decline in most of the industry classes. However, there is a slight increase in R&D expenditure since the 1976/77. Research expenditure, measured at constant prices has declined in almost all divisions since 1971/72. The worst affected industries were textiles, clothing and footwear, basic metals, transport equipment and fabricated metal products. The non-metallic mineral products, wood and paper, food and chemical industries have been marginally affected. Among the research intensive industries, the decline in R&D expenditure at constant prices was prominent in the transport industry.

---

16 The limitations of using GDP implicit price deflators is discussed in Liyanage, S. and Johnston, R. (1984) and Johnston and Liyanage (1983)

17 In the estimation of gross product using the production approach, data on the value of output and intermediate input of establishments classified to that industry are considered. This approach is more suitable for the purpose of this study than the other approaches based on, for example, income and expenditure. For details see ABS (1978).

Table 3.18 A Series of Deflators for the Conversion of R&D Expenditure Based on Gross Domestic Product at 1979/80 Prices

Year Industry Class	1968/69	71/72	73/74	76/77	78/79
Food,bev.&tob.	2.59	2.13	1.84	1.21	1.11
Textile,Clo.&footwear	2.37	2.17	1.82	1.20	1.05
Wood&furniture	3.00	2.44	1.93	1.16	1.07
Paper&pub.	2.50	2.14	1.82	1.18	1.03
Chemicals,pet.&coal	2.08	1.66	1.49	1.14	1.01
Non-metallic min.	2.43	2.03	1.87	1.18	1.11
Basic metal	2.92	2.60	2.24	1.37	1.13
Fabricated metal	3.13	2.70	2.22	1.27	1.09
Transport eq.	2.32	2.18	1.87	1.11	1.03
Other machinery&eq.	2.50	2.17	1.86	1.24	1.03
Miscellaneous manu.	2.36	2.08	1.84	1.27	1.14
Industry Average	2.50	2.17	1.87	1.21	1.08

Note Deflator for 1968/69 was calculated by extrapolating the trends of GDP data provided for 1974/75 and 1979/80 current and constant prices.

Source: ABS(1982)Australian National Accountants Gross Product by Industry,1980/81, Cat. No. 5211.0, November, Canberra.

The other machinery and equipment and chemical industries were the only divisions which were successful in maintaining R&D expenditure above the 1968/69 level. However, these industry groups also have encountered set backs in 1976/77 (Table 3.19).

Table 3.19 R&D Expenditure of Private Manufacturing Industry at Constant 1979/80 Prices($million)

Year / Industry Class	19689	71/72	73/74	76/77	78/79
Food,bev.&tob.	18.5	27.1	18.2	14.1	17.9
Textile,Clo.&footwear	3.6	8.7	7.1	2.5	1.4
Wood&furniture	3.4	3.1	n.a.	1.1	1.7
Paper&pub.	6.0	6.4	4.4	3.9	4.2
Chemicals,pet.&coal	38.3	32.7	33.2	30.9	35.6
Non-metallic min.	4.8	10.3	n.a.	4.5	4.6
Basic metal	34.3	31.0	32.7	26.1	23.6
Fabricated metal	25.9	32.4	n.a.	5.1	4.9
Transport eq.	37.3	47.5	47.5	16.2	16.1
Other machinery&eq.	44.6	57.8	103.4*	42.0	51.5
Miscellaneous manu.	7.5	22.9	28.7	4.5	6.7
Industry Average	224.2	280.0	275.2	149.9	171.0

Note * refers to expenditure including the fabricated metal products industry.

3.3.3 R&D Expenditure and Purchase of Know-how in the Private Business Enterprise Sector

While R&D expenditure is directed towards the acquisition of technological knowledge, it constitutes only a part of a series of activities to achieve technological advances. A significant portion of technological knowledge can be acquired by purchase of technological know-how, new capital equipment and intermediate products. Hence the actual expenditure of a firm to acquire knowledge should include expenditure on purchase of knowhow and some portion of expenditure on capital equipment and intermediate products. Table 3.20 illustrates the relative expenditure on R&D and the purchase of technical knowhow during the period from 1968/69 to 1978/79. Source

Table 3.20 Expenditure on R&D and Technical Know-how During 1968/69-1978/79 at Constant 1979/80 Prices($million)

Year Type of Expend.	19689	71/72	73/74	76/77	78/79
know-how	85.6(28%)	106.8(28%)	110.8(29%)	64.0(30%)	82.5(33%)
R&D	224.1(72%)	281.4(72%)	275.2(71%)	150.8(70%)	168.3(67%)
Total	309.7(100%)	388.1(100%)	386.0(100%)	214.8(100%)	250.8(100%)

Tables 3.20 and 3.21 indicate periods of growth of payments for technological knowhow in manufacturing industries. There has been a slight shift towards purchase of technological knowhow rather than undertaking research.

Table 3.21 Average Percentage Growth Rate of Expenditure on Purchase of Technological Knowledge and R&D Expenditure at Constant 1979/80 Prices

Year	19689 to 71/72	1971/1972 to 73/74	1973/74 to 76/77	76/77 to 78/79
Type of Expend.				
know-how	6.3	1.2	-10.5	9.6
R&D exp.	6.4	-0.7	-11.2	3.9
Average	6.3	-0.2	-11.0	5.6

Table 3.21 indicates the average percentage growth rate of expenditure on R&D and knowhow for different periods of time. The decline in the rate of R&D expenditure and payment for purchase of technological knowhow from 1973/74 to 1976/77 parallels the general retardation of economic growth during this period.

Freeman *et al.* (1982) argued that there is a tendency to decrease the level of R&D expenditure in firms during a severe economic recession.

The Bureau of Industry Economic Research (1979,p.27) reported that the manufacturing as a whole and the output of all industries declined, except for food, beverages and tobacco product industries. Table 3.22 presents the aggregated R&D expenditure and payments for know-how by industry class. It shows that high R&D spenders such as the chemical and other machinery and equipment industries stand out in their commitment to invest in developing and acquiring technology. The next group of industries, food, beverages and tobacco, basic metal products, and transport equipment have also committed a considerable amount of resources to technological advances.

All the other industries show a relatively low level of investment in technical advance. Most industry classes have decreased the level of investment in technical advances compared with the 1968/69 base year. The only exception is the non-metallic mineral product industry, which has almost doubled its investments with reference to the base year. On the other hand, fabricated metal products and transport equipment industries show a drastic reduction in resources committed to technical advances.

Table 3.22 Aggregated Expenditure on R&D and Know-how by Industry Classes During 1968/69-1978/79 at Constant 1979/80 Prices ($million)

Year Industry Class	19689	71/72	73/74	76/77	78/79
Food,bev.&tob.	22.9	35.3	18.2	17.6	22.3
Textile,Clo.&footwear	8.3	16.2	7.1	3.9	2.7
Wood&furniture	4.2	3.4	n.a.	1.2	1.7
Paper&pub.	7.3	8.2	4.4	4.6	4.2
Chemicals.pet.&coal	59.1	58.4	58.9	49.2	63.2
Non-metallic min.	5.5	13.8	n.a.	9.3	9.5
Basic metal prod.	39.1	38.9	32.7	30.3	28.1
Fabricated metal	33.5	44.8	n.a.	6.8	6.5
Transport eq.	43.8	59.0	56.9	21.4	26.5
Other machinery&eq.	73.5	83.2	144.7*	62.2	74.8
Miscellaneous manu.	12.5	26.8	63.1	8.4	11.2
Total	309.7	388.1	386.0	214.8	250.8

Note * refers to expenditure including the fabricated metal products industry.

3.3.4. Growth of Payments for Technical Know-how in Manufacturing Industry

The decline in R&D expenditure in some industry groups such as transport equipment and non-metallic mineral products has been substantially compensated for increases in payments for technical know-how. Chemicals, petroleum and coal products, basic metal products, transport equipment and other machinery and equipment show strong positive correlation coefficients between expenditure on know-how and time (Table 3.23).

Table 3.23 Growth of Payments of Know-how by Industry Classes Between 1968/69 and 1978/79 at Current Prices

Coefficient Industry Class	R	Sig.	r^2	F-value
Chemicals,pet.&coal	.87	.03	.75	9.2
Non-metallic min.	.83	.04	.70	6.9
Transport eq.	.81	.05	.65	5.7
Other machinery&eq.	.73(.92)	.08(.04)	.53(.85)	3.4(11.1)
Basic metal prod.	.51	.19	.26	1.0
Food,bev.&tob.	39	.26	.15	0.5
Miscellaneous manu.	.07	.45	.01	0.02
Textile,Clo.&footwear	-.45	.23	.20	0.7
Wood&furniture	-.85	.04	.72	7.6
Paper&pub.	-.54	.17	.29	1.2
Fabricated metal	-.46(-.66)	.22(.17)	.21(.43)	0.8(1.5)

Note Figures in brackets indicate the linear correlation without 1973/74 data as for this year data for corresponding industry classes were aggregated. R. and r^2 denote the simple correlation coefficient and coefficient of determination.

Wood, wood products and furniture, fabricated metal products, textiles, clothing and footwear and paper, and printing and publishing show a decline in know-how expenditure.

In terms of constant 1979/80 prices, only three industry divisions, chemical, non-metallic minerals and transport show a positive correlation indicating an increase in know-how expenditure at constant prices. Non-metallic minerals has a coefficient of 0.7, significant at the 10% level. All other industries show a negative correlation coefficient indicating a decline in growth. These negative correlation coefficients are significant in the case of wood, wood products and furniture (-0.87,sig. 1%), paper, printing and publishing (-0.71,sig. 10%) and fabricated metals (-0.69,sig. 10%).

3.4.0 Research Intensity and the Relation Between Industrial R&D Expenditure and Economic Variables

The relationship between R&D expenditure and economic variables such as turnover and value added are frequently used to illustrate a firm's undertaking in R&D activity in relation to its performance. This also allows the level of activity to be normalised for company size. Mansfield (1968) and Minasian (1969) found a significant correlation between R&D expenditure and turnover and value added of industries. The major drawback of these studies was their attempt to demonstrate the effect of present turnover in terms of present R&D investment and not by past investments. Investment in R&D expenditure and manpower may be regarded as variables which are directly influenced by turnover and sales of firms. When the economic performance of a firm is satisfactory, it will be able to afford high investment in R&D. On the other hand, an industry may have to take a risk on R&D investment before it can expect to achieve high turnover due to technological advances. The data on economic variables such as sales, turnover and value added are not available over the full R&D survey period. Only sales data by industry classes are available for 1968/69 and 1971/72. The turnover and value added data at industry level became available with the 1973/74 survey but no attempt was made to report sales statistics separately.

All three variables show a positive and significant correlation coefficient with R&D expenditure in different industry groups. The correlation coefficient between R&D expenditure and sales is 0.52 (sig. 1%) during the period between 1968/69 and 1971/72. R&D expenditure with turnover shows a correlation coefficient of 0.47 (sig. 1%) for the 1976/77 and

1978/79 period. Table 3.24 indicates simple correlation coefficients between R&D and economic indicators in different years. These results show that R&D expenditure is highly correlated with all these economic indicators of the same year. The highest correlation coefficient, which was significance at the 1% level, was obtained for 1976/77.

Table 3.24 Pearson Correlation Coefficient Between R&D Expenditure and Sales, Turnover, and Value Added

Variables	1968/69 R Sig.	1971/72 R Sig.	1976/77 R Sig.	1978/79 R Sig.
Sales	.65 (.01)	.42 (.09)		
Turnover			.77 (.003)	.67 (.01)
Value Added			.76 (.003)	.65 (.01)

The presence of a strong significant correlation between economic variables and R&D expenditure suggests that although turnover or value added[18] may not be directly influenced by present level of R&D investment, the R&D expenditure is controlled by the turnover and value added to a large extent. This means that even though there are some difficulties in determining the economic benefits of R&D investment, this investment is strongly influenced by financial performances of the industry.

R&D personnel employment also shows a significant correlation with economic variables. Table 3.25 presents simple correlation coefficients between R&D manpower and the economic variables between 1968/69 and 1978/79. On average total person-years employed on research show a

18 Value added is the basic measure of an industrys' contribution to the total production. (ABS, 1980, p.3)

lower correlation coefficient with turnover (R=0.43, sig. 1%) than the professional person-years on research (R=0.5, sig. 1%).

Comanor (1965,p.184) found that technical change appears to be primarily associated with the number of professional investigators.

Table 3.25 Pearson Correlation Coefficient Between R&D Employment and Sales, Turnover, and Value Added

Variables	1968/69 R Sig.	1971/72 R Sig.	1976/77 R Sig.	1978/79 R Sig.
Sales	.58 (.03)	.55 (.04)		
Turnover			.70 (.008)	.66 (.01)
Value Added			.67 (.01)	.62 (.02)

Note Manpower for 1968/69 and 1971/72 was measured in total number of persons and the remaining years it was measured as person-years.

Professional R&D manpower accounts for nearly 40 per cent of the total R&D employment in Australian manufacturing industry. The employment of professional staff has large variations from industry to industry. Table 3.26 presents the percentage variation of professional staff to total R&D manpower. The food, chemical, non-metallic minerals and miscellaneous industries have a high professional manpower ratio. The textiles, transport equipment, fabricated metal products and other machinery and equipment industries have employed relatively little professional manpower during the period from 1968/69 to 1978/79.

Table 3.26 The Average Professional R&D Manpower as a Percentage of Total R&D Employment in Manufacturing Industry

Year Industry Class	1971/72	1973/74	1976/77	1978/79	Average
Food,bev.&tob.	42	51	53	55	50
Textile,Clo.&footwear	24	22	46	38	33
Wood&furniture	34	n.a.	44	51	43
Paper&pub.	42	47	48	45	46
Chemicals,pet.&coal	53	48	52	51	51
Non-metallic min.	42	n.a	48	48	46
Basic metal prod.	34	42	43	38	39
Fabricated metal	28	n.a.	38	35	34
Transport eq.	21	21	29	27	24
Other machinery&eq.	26	n.a.	44	37	36
Miscellaneous manu.	38	n.a.	52	50	47
Mean	35	39	45	43	41

The economic variables shows a much higher correlation coefficient with professional R&D manpower than with total R&D employment in industry (Table 3.27).

Table 3.27 Pearson Correlation Coefficient Between R&D Professional Employment and Sales, Turnover, and Value Added

Variables	1968/69 R Sig.	1976/77 R Sig.	1978/79 R Sig.
Sales	.82 (.001)		
Turnover		.86 (.001)	.84 (.001)
Value Added		.90 (.001)	.88 (.001)

Note Manpower for 1968/69 was measured in total number of persons and the remaining years it was measured as person-years.

A comparison of the results obtained in Table 3.24 with Table 3.25 show that correlation coefficient for expenditure are stronger than for manpower. However, a comparison of Table 3.24 with Table 3.27 suggests that correlation for R&D expenditure is weaker than for professional manpower. These findings are similar to those of Comanor (1965) who found that R&D input was better correlated with total new product sale when R&D input was measured as professional rather than total R&D personnel. The findings of this study slightly deviate from that of McLean and Round (1978), who concluded that the most important proxy for R&D input was R&D employment as a portion of a firm's workforce, followed by proportion of professional R&D employees, and lastly the ratio of R&D expenditure to total sales.

This study shows that all three R&D inputs are equally important input measures but professional manpower may be the best. The relative importance of manpower and expenditure as a research intensive indicator is further discussed in Chapter Four.

3.4.1 Relationship Between Knowhow Purchase and Economic Indicators

Increase in payments for knowhow may depend on a number of factors including pressure to increase production efficiency and explore new markets. The decision to make payments for technological knowhow purchases is controlled, among other factors, by a) present level of R&D capability in the firm, b) the relative economies of conducting R&D or purchasing knowhow, and c) availability of knowhow and time required to obtain it.

Unlike R&D expenditure, payments for knowhow do not show a significant correlation with industry turnover, sales or value added variables.

The lack of significant correlation of expenditure of knowhow with turnover and value added variables suggests that inter-industry variation of knowhow is dissimilar to that of R&D, although the overall expenditure on knowhow shows a remarkably a similar trend to R&D expenditure with time as presented in Figure 2.

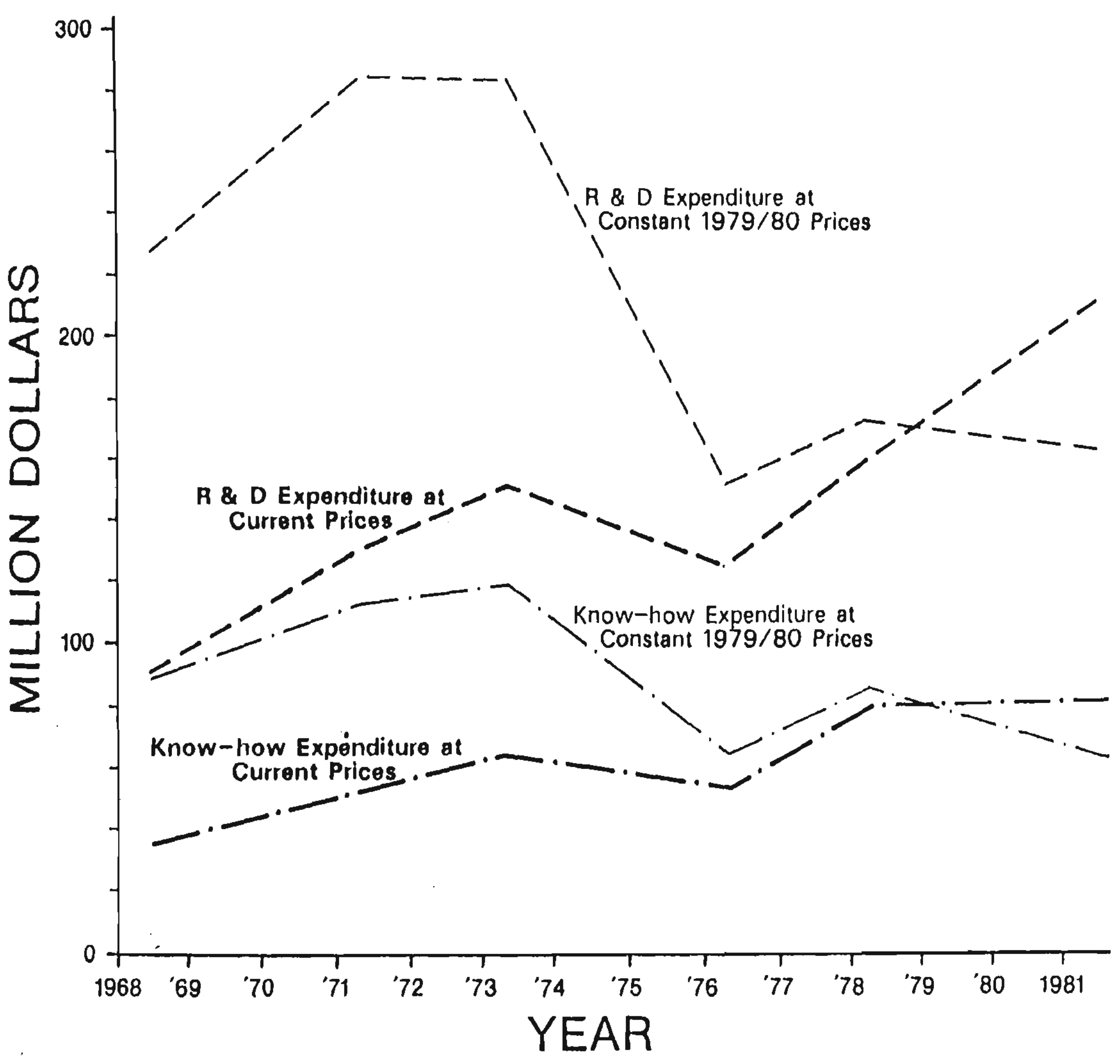

Figure 2 R&D Expenditure and Payments for Knowhow at Constant 1979/80 Prices from 1968/69 to 1981/82

3.5.0 R&D Intensity in Manufacturing Industry

Identification of the research and technological intensity of an industry is useful. However, measures of intensity of R&D activity in a particular industry vary widely. Kelly (1976 and 1977) has defined an industry as technologically intensive if the ratio of R&D to sales is higher than the overall industry average. Soete (1980) has pointed out that using more recent definitions of technological intensive parameters such as R&D/value added and patents/value added give very different results for the R&D intensities of different industries. He indicated that depending on the R&D input or output measures used, the industries identified as R&D intensive differ. Therefore, it is difficult to draw definite demarcation between research intensive and non-intensive industries. However, the above average ratios of R&D to value added, sales or turnover can be used to separate highly research intensive industries from others.

The strong correlation between R&D and turnover, value added and sales suggests that it is meaningful to represent R&D expenditure data as a ratio of these variables. Table 3.28 presents ratios of R&D expenditure based on sales and turnover by industries that performed R&D over the period from 1968/69 to 1978/79. It shows that the chemicals, petroleum and coal products, transport equipment and other machinery and equipment divisions spend a significantly high proportion of R&D expenditure per unit turnover and sales. It is important to note that relatively low R&D spenders such as the textiles, wood, paper, non-metallic minerals and fabricated metal products industries allocated more or less similar ratios of R&D/turnover to that of moderate R&D spenders such as the food, beverages and tobacco and basic metal products industries. It indicates that all industries have allocated a certain proportion of their turnover to R&D activity. The industry mean of R&D as a percentage of the economic variables shows a significant increase for the period from 1968/69 to 1978/79 (F=2.7, sig. 5%).

Table 3.28 R&D Expenditure as a Percentage of Sales, Turnover, and Value Added by Industry Classes that Performed R&D from 1968/69 to 1978/79.

Year Industry Class	1968/69 Sales	71/72 Sales	76/77 TO	 VA	78/79 TO	 VA
Food,bev.&tob.	.38	.32	.40	.99	.35	.93
Textile,Clo.&footwear	.45	.60	.46	1.06	.41	.92
Wood&furniture	.58	.76	.41	.86	.66	1.45
Paper&pub.	.62	.54	.46	1.20	.42	.96
Chemicals,pet.&coal	1.27	1.10	1.31	2.90	1.23	2.78
Non-metallic min.	.59	.59	.55	.98	.42	.82
Basic metal prod.	.99	.74	.52	1.00	.42	.82
Fabricated metal	.93	1.11	.64	1.20	.62	1.30
Transport eq.	2.02	1.64	.65	1.30	.82	1.80
Other machinery&eq.	1.66	1.88	1.24	2.70	1.44	3.30
Miscellaneous manu.	.63	2.40	.46	.97	.54	1.30
Mean	.92	1.07	.64	1.38	.67	1.49

Note TO and VA denote turnover and value added respectively.

Only three industry divisions, the chemicals, petroleum and coal products, transport equipment, and other machinery and equipment, exceed the average R&D expenditure to turnover or value added ratio. These three industries also show an above average ratio of R&D personnel to total industry employment for 1976/77 and 1978/79. Therefore these industries can be identified as "research intensive". Although the transport industry shows a general decline in R&D expenditure in real terms, it continues to contribute a sizeable proportion of turnover or value added to research expenditures.

The research intensive divisions were responsible for an annual average of 59 per cent of total expenditure and 61 per cent of total manpower resources devoted to R&D in the manufacturing sector between 1968/69 and 1978/79 (Table 3.29). These industries also had more access to R&D professional personnel. An average of 61 per cent of professional person-years was consumed by these three industry divisions during 1976/77 and 1978/79.

Table 3.29 The Distribution of R&D Expenditure and Manpower in the Research Intensive and Non-Intensive Industry Groups at Constant 1979/80 Prices ($million and person-years)

Year	1968/69	71/72	76/77	78/79
Research Intensive(n=3)				
Expenditure	120.2(54%)	138.2(49%)	89.1(59%)	103.2(61%)
Manpower	6851.0(62%)	6525.0(54%)	3962.0(63%)	3836.0(64%)
All other groups(n=8)				
Expenditure	103.9(46%)	143.1(51%)	61.7(41%)	65.1(39%)
Manpower	4032.0(38%)	5566.0(46%)	2341.0(37%)	2125.0(36%)

Note Data for the survey of 1973/74 was disregarded due to high standard errors involved in sampling. n denotes number of industry classes. Manpower for 1968/69 and 1971/72 survey years measures number of persons.

Such a high concentration of research expenditure and manpower by a few industry divisions means that the structure and changes in total industrial research system depend heavily on the performance of these industries. It also suggests that industrial research effort is largely focussed on selected technological fields. As a consequence the benefits of industrial research are enjoyed by a few industry groups confined to these technological fields.

Among the research intensive industries R&D expenditure per enterprise could be ranked in descending order as follows: chemicals, petroleum and coal industry, other machinery and equipment, and transport equipment.

The examination of knowhow purchase in the research intensive industry divisions shows that a large proportion of payments for knowhow is concentrated in research intensive industries. Table 3.30 illustrates the distribution of R&D and payments on technical knowhow between research intensive and all other industry. Research intensive industries not only engaged in more research activity but also make technological purchases more than other industries. Those companies, who opted for rapid technical progress by technological knowhow purchase are the ones involved in more research activity. These results indicate that in general R&D does not substitute for technological purchases and vice versa. Rather they are complementary.

Table 3.30 The Share of R&D and Technical Know-how Among Research Intensive Industry Divisions at Constant 1979/80 Prices($million)

Year	1968/69	71/72	76/77	78/79
Research Intensive(n=3)				
Knowhow	56.2(66%)	62.3(58%)	43.7(68%)	61.4(74%)
Knowhow&R&D exp.	176.4(57%)	200.6(52%)	132.4(62%)	164.6(66%)
All other groups(n=8)				
Knowhow	29.4(34%)	44.4(42%)	20.3(32%)	21.1(26%)
Knowhow&R&D exp.	133.3(43%)	187.6(47%)	81.9(48%)	86.3(34%)

Note Data for the survey of 1973/74 was disregarded due to high standard errors involved in sampling.

In comparison to R&D expenditure, payments for knowhow are much lower. The fluctuation of R&D and knowhow purchase during the decade shows a somewhat similar pattern indicating that factors affecting R&D investment in firms also influence purchase of technical knowhow.

Another noteworthy feature of research intensive industries is their export and import performance. Export performance is defined as the level of exports as a percentage of sales: similarly import performance is the level of imports as a percentage of sales. The export performance of the research intensive industries is relatively low whereas import performance is high. This is rather surprising as research intensive industries are normally expected to perform well in export areas.

Table 3.31 Import and Export Performance According to Research Intensity

Industry Group	Export Performance	Import Performance
Research Intensive		
Chemical,Pet.&coal	14%	44%
Transport eq.	11%	76%
Other machinery&eq.	6%	38%
Research Non-intensive		
Food, Bev.&tobacco	30%	4%
Textile.clo.&footwear	10%	37%
Wood,wood prod.&paper	2%	22%
Non-metallic min.	1%	10%
Basic metal prod.	36%	6%
Fabricated metal	3%	11%
Miscellaneous manu.	7%	35%
Industry Average	16%	24%

Source ABS(1982) Imports, Australia (Cat. No. 5406.0) and ABS(1982). Exports, Australia. (Cat. No. 5404.0)

Table 3.31 presents the import and export performance of the research intensive and non-intensive industries. It may be that a high level of competition and less comparative advantage for exports in technological intensive products and low motivations to develop such products owing to protection policies may have resulted in poor export performance of research intensive industries in export market areas.

The export performance of some of the research non-intensive industries such as the food, beverages and tobacco and basic metal industries are well above the industry average. Research intensive industries on the other hand show a high import performance compared to their export performance. However these results are somewhat misleading as it is necessary to consider the export of technologically intensive products and processes. Such data are not available for manufacturing industries.

3.5.1 Intensities of Industrial Research in Different Industry Classes

Among the research intensive industries, performance of R&D activity in some industry classes is much higher than others. The statistics available for 1976/77 and 1978/79 indicate that the chemical industry division is stronger in areas such as organic and inorganic chemical and pharmaceuticals (Table 3.32).

Table 3.32 R&D Intensity of the Chemical Industry Division($million and person years)

R&D Resource&Year Industry Class	76/77	78/79	76/77	78/79	76/77	78/79
Plastic mat.	1.5	1.8	78	73	2.0%	2.8%
Org.&Inorg.Chem.	10.8	13.2	503	474	4.9%	4.2%
Paintslacquers	3.7	3.8	244	193	3.0%	2.8%
Pharmaceu.&vet.prod.	4.5	9.8	173	362	3.3%	4.8%
Other chem.	3.7	6.6	222	278	1.0%	1.2%

A large amount of research expenditure and manpower in the chemical industry is controlled by the organic chemicals industries. The

R&D effort of these industry classes is much higher than for the pharmaceutical and veterinary products industries. However, the growth of research expenditure and personnel in the organic and inorganic chemicals industries was not so prominent as in the case of pharmaceutical and veterinary products. The chemical industry is highly controlled by foreign companies. Foreign owned companies were responsible for 77 per cent of the R&D expenditure incurred by the chemical industries. One of the prominent features of the R&D structure is that the total number of enterprises conducting R&D activities has increased only marginally from 113 to 118. The average expenditure incurred by a firm in the chemical industry increased from $214,000 in 1976/77 to $298,000 in 1978/79. Organic and inorganic chemicals showed an outstanding figure by spending $633,000 per firm during 1976/77, increasing to $879,000 during 1978/79.

Different industry classes in the chemical industry allocated different ratios of turnover or value added to R&D expenditure. Organic and inorganic chemicals and pharmaceuticals contributed a relatively high proportion of their turnover to R&D activity.

R&D activity in the other machinery and equipment division was dominated by the television, radio, electrical equipment, household appliances and other industrial machinery classes. A large proportion of expenditure and manpower resources is controlled by these industries as shown in Table 3.33.

Table 3.33 R&D Intensity of the Other Machinery and Equipment Industry Division($million and person years)

Resource&Year Industry Class	76/77	78/79	76/77	78/79	76/77	78/79
Photo.&sc. eq.	4.6	6.7	232	230	5.4%	6.5%
TV& elec. eq.	14.2	23.1	723	773	5.1%	5.9%
Household appl.	6.7	10.1	486	461	1.6%	1.8%
Agri.machine	2.8	3.6	150	173	3.0%	2.0%
Mat. handling eq.	0.5	1.3	32	50	2.7%	3.6%
Other indus.eq.	8.2	3.9	244	165	2.1%	1.8%

The overall level of R&D labour declined in the sector, although expenditure increased substantially. Foreign ownership of this division was almost 80 per cent. The photographic, professional and scientific equipment industry division showed the highest allocation to R&D as a percentage of value added. It was followed by television, radio and electrical equipment. The average contribution to R&D as a percentage of value added of the other machinery and equipment division was 2.95 per cent compared with 2.7 in the chemical industry. The number of enterprises undertaking R&D in the other machinery and equipment group significantly declined from 290 to 264 during the 1976/77 to 1978/79 period. The average R&D expenditure per firm increased from $117,000 to $184,000 during this period. The TV, radio and electrical equipment division had the highest expenditure allocation per firm increasing from $308,000 to $480,000 for the period between 1976/77 and 1978/79.

Research in transport equipment is mainly concentrated in motor vehicle and parts (Table 3.34). This industry class controls about 90 per cent of R&D expenditure and manpower in the transport industry group.

Table 3.34 R&D Intensity of the Transport Equipment Industry Division ($million and person years)

R&D Resource&Year Industry Class	76/77	78/79	76/77	78/79	76/77	78/79
Motor vehicle	13.5	14.0	694	553	1.3%	1.8%
Other Tran Eq.	1.1	1.6	67	50	1.1%	1.8%

Foreign control in the transport industry was much stronger than in other research intensive industries. Nearly 90 per cent of R&D expenditure was incurred by foreign owned industry. The number of firms undertaking R&D increased from 45 to 46 between 1976/77 and 1978/79. The average expenditure per firm increased from $320.000 to $332.000 during this period. The average firm expenditure in motor vehicle and parts was $438,000 compared with $95,000 in the other transport equipment class. The most striking feature was the similarity in the proportion of value added apportioned to R&D expenditure in both industry classes (Table 3.34).

3.5.2 R&D Expenditure as a Ratio of Manpower

Per capita research expenditure is presented as an indicator of R&D effort in some science policy studies.[19] Although this measure is useful in interpreting R&D costs per capita research effort, it is misleading to identify the increase in per capita expenditure as necessarily a growth of R&D effort. Increase in R&D cost per capita may result from factors such as

a) an increase in R&D supporting facilities such as capital and current expenditure related to materials and consumeables.

19 See Project SCORE, Department of Science, Canberra, 1980 for details.

b) a decrease in manpower employment,

c) changes in relative factor costs of labour and capital, and

d) changes in wage rates in different industry sectors.

It is necessary to consider the influence of these factors on the rates of growth in R&D expenditure and manpower statistics in order to isolate the trends of per capita expenditure costs. Technological development also has an influence on the introduction of capital equipment, such as improved analytical facilities, which can reduce the labour intensity of research. The employment of expensive capital equipment, which is reflected in R&D expenditure budgets, on the one hand does not necessarily reflect the inventive capacity of an industry, and on the other may not reflect real increase in R&D effort. An increase of per capita expenditure therefore cannot necessarily be interpreted as a growth of the R&D system. In the case of Australian private industry R&D expenditure, increase in the per capita research expenditure for different industries during the survey periods resulted from the difference in growth rates of expenditure and manpower. The statistics on IR&D cost suggested that Australian R&D has a higher labour costs than capital costs. Salaries constituted 71 per cent of total IR&D expenditure in 1976/77, declining to 60 per cent in 1978/79. R&D manpower declined considerably over the period, hence the growth of per capita expenditure reported between 1968/69 and 1978/79. Table 3.35 illustrates the changes of per capita R&D expenditure at constant 1979/80 prices for different industry classes.

Table 3.35 R&D Expenditure per R&D Person-year by Industry Class at Constant 1979/80 Prices($'000)

Year Industry Class	1968/69	1971/1972	1973/74	1976/77	1978/79
Food,bev.&tob.	22	24	23	26	33
Textile.Clo.&footwear	16	20	26	23	34
Wood&furniture	18	21	n.a.	22	31
Paper&pub.	21	20	26	26	29
Chemicals,pet.&coal	17	18	17	23	26
Non-metallic min.	26	35	n.a.	27	30
Basic metal prod.	33	27	33	29	30
Fabricated metal	29	25	n.a.	22	25
Transport eq.	20	24	33	21	27
Other machinery&eq.	16	21	22	23	28
Miscellaneous manu.	18	29	30	24	32
Mean	22	24	19	24	30

Note Manpower data for 1968/69 and 1971/72 is based on number of full time equivalent persons and for other years person-years employed on research.

The annual average per capita research expenditure at constant 1979/80 prices increased from nearly $22,000 to $30,000 between 1968/69 and 1978/79. At current prices the corresponding increase was from $8300 to $26500 respectively. In most industry classes, the change in R&D expenditure per capita was not very large during this period. In the presence of decline in manpower, this indicates a slow growth of R&D capital expenditure.

The difference of per capita R&D expenditure between the research intensive and the other industries is noticeable. The research intensive group shows a slightly lower per capita research expenditure than other industries. The major reason for this is perhaps the low person-year employment in non-intensive research industries. Table 3.36 illustrates the per capita research expenditure in the research intensive and other groups.

Table 3.36 Per Capita R&D Expenditure in Research Intensive and Other Industry Groups at Constant 1979/80 Prices($'000)

Year	1968/69	71/72	76/77	78/79
Research Intensive(n=3)	17.7	21.1	22.3	26.7
All other groups(n=8)	23.1	25.4	24.9	30.5

Note Data for the survey of 1973/74 was disregarded due to high standard errors involved in sampling. n denotes number of industry classes.

The change in per capita expenditure can be best interpreted by examining capital and current expenditures. R&D capital expenditure is defined as expenditure on new or second hand fixed tangible assets, less value of disposal on land, buildings, vehicles, plants and machinery and equipment. The capital equipment, instruments and new materials are intimately related to performance of R&D and inventive activity. In fact, most of the analytical equipment and instruments used in laboratories are vital to research (Freeman, 1974,p.107). Table 3.37 represents per capita R&D expenditure on R&D capital and labour at constant 1979/80 prices (deflator based on GDP by manufacturing industry) from 1976/77 to 1978/79.

Table 3.37 Per Capita R&D Expenditure on Capital and Salary at Constant 1979/80 Prices($'000)

Year Industry Class	1976/77 Capital	76/77 Salary	1978/79 Capital	78/79 Salary
Food,bev.&tob.	2.4(1)	16.1(7)	6.6(1)	18.0(3)
Textile,Clo.&footwear	2.8(1)	15.6(6)	10.4(1)	17.2(2)
Wood&furniture	0.8(1)	16.9(23)	5.0(1)	15.8(3)
Paper&pub.	1.3(1)	17.1(13)	2.9(1)	19.6(7)
Chemicals,pet.&coal	1.2(1)	14.7(13)	1.2(1)	17.8(15)
Non-metallic min.	4.2(1)	17.0(4)	2.9(1)	16.3(6)
Basic metal prod.	3.0(1)	18.8(6)	3.5(1)	19.3(6)
Fabricated metal	1.3(1)	16.9(13)	2.6(1)	16.8(6)
Transport eq.	0.5(1)	16.4(29)	2.2(1)	16.9(8)
Other mach.&eq.	1.4(1)	16.6(12)	2.0(1)	18.4(9)
Miscellaneous manu.	1.7(1)	19.6(12)	7.4(1)	18.9(3)
Mean	1.1(1)	11.2(10)	1.9(1)	12.5(6)

Note Capital to salary ratio is presented in brackets.

Per capita capital research expenditure increased substantially during the period between 1976/77 and 1978/79 across all industry classes except non-metallic mineral products. Per capita expenditure in chemicals, petroleum and coal products remained unchange during this period, and also in this industry per capita capital expenditure per manyear was quite low compared with other industries. The food, beverages and tobacco products, textiles, clothing and footwear, wood, wood products and furniture, transport equipment and miscellaneous manufacturing industry showed a high growth of capital R&D expenditures. A significant growth of per capita capital expenditure in other machinery and equipment, fabricated metal products an basic metal products was recorded, indicating an increase in research facilities in these divisions. A sharp increase in per capita capital expenditure in textiles, clothing and footwear and wood, wood products and furniture was largely due to the heavy decline in R&D employment in these industries.

There was no drastic change in per capita salaries in most industry divisions. A slight fluctuation was noticed due to a rise in salaries and wages. Therefore, the fluctuation of per capita R&D expenditure was caused by changes in capital expenditures rather than changes in labour costs.

There was a significant difference in per capita R&D expenditure between R&D intensive and remaining industry. Table 3.38 indicates that research non-intensive industry has a higher capital expenditure person-year employed than the research intensive industry. This may be due to the employment of more capital intensive research methods and employment of relatively less research persons in these industries than in research intensive industry.

Table 3.38 Per Capita Capital and Labour Costs of Research Intensive and Other Industry Groups at Constant 1979/80 Prices($'000)

Type of Exp.	Year	Capital	Salary
Research Intensive(n=3)	1971/72	1.6	12.8
	1973/74	3.8	18.6
	1976/77	1.0	15.9
	1978/79	1.8	17.7
All other groups(n=8)	1971/72	4.01	12.7
	1973/74	1.84	17.8
	1976/77	2.18	17.3
	1978/79	5.16	17.7

The Pearson correlation coefficient of R&D with research salary shows a significant higher coefficient than that for capital costs. It suggests that the size of research budgetary allocation is more dependent on the research salary component than the capital component. Table 3.39 illustrates the Pearson correlation coefficient of R&D capital and salary costs with R&D expenditure, turnover and value added variables.

The allocation of research expenditure to capital and salary is determined by a number of factors such as intensity of manpower that may be allocated to research activity, and the type and objective of research activity undertaken.

Table 3.39 Relationship of Capital and Labour Cost with Total R&D, Turnover and Value Added of Industry-1976/77 and 1978/79

Year	1976/77	1976/77	1978/79	1978/79
Corr.Coe.	Capital	Labour	Capital	Labour
with R&D	0.69	0.91	0.71	0.98
with Turnover	0.86	0.75	0.88	0.64
with Valueadded	0.85	0.74	0.82	0.62

Note All correlation coefficients are significant at 1% level.

The relative abundance of labour and scarcity of resources to invest in capital in a firm may influence a decision towards employing more labour on R&D activity. The partial correlation coefficient for capital and labour costs tends to increase when employment in industry is controlled.

3.6.0 Behaviour Patterns of R&D Expenditure with Firm Size

The detailed statistics on size of enterprises and their R&D expenditure are not publicly available in national surveys. The only information available with respect to size is classified according to the turnover size of company and provides R&D expenditure by industry sub-divisions: the ABS (1982a) also provided statistics on value added with respect to different turnover sizes of industry. The turnover categories provided are in four groups: turnover a)less than $0.5 million,

b)$0.5-19.9 million,

c)$20 to 49.9 million,

d)more than $50 million,

The R&D expenditure and value added variables in these different turnover categories have been tested for correlation. The Pearson correlation coefficients indicate that R&D expenditure and value added pairs are highly correlated (R=0.88, sig. 1%) in companies with over $50 million turnover, whereas other turnover groups do not strongly correlate. Regression between R&D as a percentage of value added and R&D expenditure for each turnover size indicates that for industries over $50 million turnover there is a high correlation coefficient and a linear relationship (R=0.83, F= 536). The other groups do not show such a strong positive relationship. These results may suggest that there exists a strong connection between R&D expenditure allocation and turnover or value added in large firms. However, these results are tentative and the effect of firm size on R&D investment is examined in detail in the following chapter.

3.7 Conclusions

Industrial research in manufacturing industry has been relied upon limited capabilities of government and private research laboratories. During the 1960s both government institutions and private enterprises paid little attention to the development of in-house research and inventive capabilities. This situation slowly began to change with the intense competition and technological development in other countries, with the result that Australian industries could not avoid a commitment to undertake their own research in order to survive in a such a climate. Australian manufacturing industries continued to rely largely on imported technologies. These technologies need a varying degree of modification to suit local conditions, and thus require R&D in private enterprises. The extent to which each industry has been able to achieve it varies substantially.

There is no unique basis for determining the appropriate level of industrial research to maintain an industry. The nature of scientific research is such that it may not contribute to the industry growth in foreseeable future, or ever. On the other hand development of technology has been shown to be important in manufacturing growth. An important point to bear in mind is that the benefits of research cannot be always obtained overnight. It is necessary to maintain a certain level of research for a considerable time to achieve a position to obtain benefits.

The private industry R&D system in Australia has grown significantly during the last decade. However, the R&D strength is concentrate in a few industry divisions. According to the Australian Standard Industrial Classification (ASIC), the other machinery and equipment industry sub-division dominates technological activity in Australia, followed by chemicals, petroleum and coal products and food, beverages and tobacco products. Transport industry carried out a considerable amount of research but it has a diminishing importance as a R&D performer in industrial research system. The research manpower effort in industry has declined considerably which may have an adverse effect on the output of technological advances. The decrease in the employment of R&D manpower and the increase in capital expenditure is much noticeable. However, R&D capital growth has not occurred at a rapid rate. A high correlation is found between R&D expenditure and economic indicators such as turnover and value added in firms, the relationship being strongest in làrge firms. A similar correlation is not found in expenditure on purchase of technological knowhow suggesting that technological purchase is somewhat intermittent and erratic. However, there are indications to suggest that firms purchasing technical knowhow have also responsible for R&D activity, hence these activities are not interchangeable but are complementary.

The slow growth of industrial research in Australia can be attributed to a number of causes. The first is the rate of growth of the manufacturing economy. Another is the lack of dynamic forces such as competition and challenge to capture export markets. Although the tariff system helped a large number of industries, particularly those facing severe competition from overseas products, it may have acted as a disincentive to the technological development of manufacturing industry. The general manager of research and development division of BHP has pointed out that ,

> Tariff protection has been used to ensure the continued survivál of industries which are technically inferior to those overseas, of industries which suffer from the disadvantage of small-scale production necessitated by the nature of the Australian market, and those which suffer from competition from cheap-labour countries overseas.
> (Ward,1975,p.408).

Bastow, a chief executive of the CSIRO, reporting his survey of manufacturing industries in 1964 explained the low level of R&D in the following terms;

> So long as the local manufacturing industry can be protected by tariffs in the local market by the industries of more technically advanced countries, so long as local industry has no ambition for wider horizons, there is no inherent reason for firms to undertake research and development. (Bastow, 1964,p.N-38).

There seems to be a high research input in a number of important industry classes dominated by foreign owned companies. For example, in 1976/77 foreign companies were responsible for 77 per cent of research in the chemicals, petroleum and coal products industry class. In the transport equipment class it was as high as 90 per cent and in the other machinery, equipment and household division 49 per cent, 30 per cent in basic metal products division and 36 per cent in food, beverages and tobacco.

High research intensive industries in which the foreign control companies are concentrated apparently attract a bulk of government industrial research funds (Tisdell, 1973). However, some studies have indicated that in recent years this situation has changed and a shift towards increasing the share of Australian industries has been noted. The national survey results indicate a trend to increase in-house R&D capability and in particular, large companies spend more resources on IR&D than smaller counterparts. However, there are no empirical evidence to suggest that the effectiveness of R&D carried out in large firms are higher than small firms. It may be that the financial stability of a firm determines the level of R&D investment. The greater participation in research activity may also be attributed to certain structural changes in industry and changes in the government policy on tariffs, other export, taxation and research incentive schemes and increased competition in market place.

Reference Chapter Three

Australian Bureau of Statistics (ABS. 1978) Australian National Accounts Outline of Principle Sources and Methods, Cat. No. 5212.0, Canberra;ABS.

ABS, (1979a) Research and Experimental Development Private Enterprises 1976/77, Cat. No. 8104.0, Canberra: ABS.

ABS, (1979b) Foreign Control in Research and Experimental Development, Private Enterprises, 1976/77, Cat. No. 5330.0, Canberra:ABS.

ABS, (1981a) Research and Experimental Development in General Government Organizations Australia, 1978/79,Cat. No. 8109.0, Dec., Canberra, ABS.

ABS, (1981b) Research and Experimental Development in Business Enterprises Australia, 1978/79, Cat. No. 8104.0, Canberra, ABS.

ABS, (1982a) Research and Experimental Development All Sector Summary Australia, 1978-79, Cat. No. 8112.0, Feb. Canberra;ABS.

ABS, (1982b) Imports Australia-February 1982, Cat. No. 5406.0, Canberra;ABS.

ABS, (1982c) Exports Australia-March 1982, Cat. No. 5404.0, Canberra:ABS.

ABS, (1983) Research and Experimental Development in Business Enterprises Australia, 1981/82, Cat. No. 8104.0, Preliminary, Canberra, ABS.

Bastow,S.H. (1964) 'Research in the manufacturing industry in Australia', Journal of Institute of Engineers Australia, Vol.36(6), June,pp.N38.

Brash, D.T. (1966) American Investments in Australian Industry, Cambridge, Mass.;Harvard University Press.

Bureau of Industry Economics,(1979) Australian Industrial Development-Some Aspects of Structural Change, Report No. 2, May, Canberra: AGPS.

Comanor, W.S. (1965) 'Research and technical change in the pharmaceutical industry', Review of Economics and Statistics, Vol.47 (2),pp.182-90.

CSIRO, (1972) CSIRO and Secondary Industry, Report of the CSIRO Secondary Industry Committee, Canberra;CSIRO.

CSIRO, (1974) Green Paper Committee on Manufacturing Industry, A submission by the CSIRO, Oct. Canberra;CSIRO.

Department of Industry and Commerce. (1977) 'Manufacturing plant and equipment:capital consumption and investment',Journal of Industry and Commerce, Dec. No.15, pp.6-9.

Department of Manufacturing Industry, (1974) 'R&D in manufacturing industry 1971/72', Department of Manufacturing Industry Bulletin, Nov. No.11, Canberra.

Department of Science, (1977) Research and Experimental Development in Australia in 1974/74-Project SCORE, Vol.2, Canberra:AGPS.

Department of Trade and Industry, (1972) Survey of Industry Research and Development Expenditure in Australia, 1968/69, Canberra:AGPS.

Freeman, C.(1974) Economics of Industrial Innovation, New York;PenguineBooks

Freeman, C., Clark, J., and Soete, L. (1982) Unemployment and Technical Innovation, London;Frances Pinter.

Gannicott, (1982) 'Australia's dependence of foreign technology' Discussion Paper, Legislative Research Service, Canberra;Parliamentary Library.

Griliches, Z. (1973) 'Research expenditure and growth accounting' in B.R. William ed Science and Technology in Economic Growth, New York;Macmillan press.

Griliches, Z. (1980) 'Returns to research and development in the private sector', in J.W. Kendrick and B Vaccara eds New Developments in Productivity Measurement and Analysis, Studies in Income and Wealth, Vol. 44, New York;NBER.

Hirst, J. (1974) 'Foreign investment and industrial research and development' Paper presented to the Fourth Conference of Economists, Aug. Canberra;ANU.

Hunter, A. (1963) The Economics of Australian Industry, Melbourne:Melbourne University Press.

Johns, B.L. (1978) 'Technology as a resource', in Hasting.P. and Farran, A. eds Australia's Resources Future, Melbourne: Australian Institute of International Affairs.

Johns, B.L., Dunlop, W.C.,and Sheehan, W.J. (1978) Small Business in Australia-Some Problems and Prospects, London;George Allen&Unwin.

Johnston, R. and Liyanage, S. (1983) Australian Science and Technology Indicators Feasibility Study-Higher Education, Final Report, Department of Science, Canberra.

Kasper, W. (1978) 'Australia's economic and industrial structures:Past patterns and prospective trends', in Kasper W. and Parry, T.G (1978)eds op.cit. pp.90-124.

Kasper, W. and Parry, T.G.(eds) (1978) Growth, Trade and Structural Changes in an Open Australian Economy, Centre for Applied Economics, Sydney;University of N.S.W.

Kelly, R. (1976) 'The impact of research and development on United States trade' The Journal of Political Economy, Vol.57, pp.38-48.

Kelly, R. (1977) 'The impact of technological innovation on international trade patterns', Bureau of International Economic Policy and Research, Staff Economic Report, mimeo, ER-24, U.S. Dept. of Commerce.

Lamberton, D.M. (1970) Science Technology and the Australian Economy, Sydney;Tudor Press.

Liyanage, S. and Johnston, R. (1984) 'Reseach in the Australian Higher Education System', Search, Vol. 15 (No. 1-2,), Feb./March, pp.24-30.

Liyanage, S. (1983) 'Measurement of science and technological activity in Australia-some problems and solutions', Paper presented to the annual conference of the AAHPSSS, May, University of Wollongong.

Mansfield, E. (1968) Industrial Research and Technological Innovation- An Economic Analysis, New York; W.W. Norton&co.Inc.

McKern, R.B. (1976) 'The multinational enterprises and technology transfer in Australian manufacturing industry', Research Paper No. 102, School of Economic and Finance Studies, University of Macquarie.

McKern, R.B. (1981) 'Technology transfer in Australian firms', 51st ANZAAS Conference, May. Uni.of Queensland, Brisbane.

McLean I.W. and Round, D.K. (1977) 'Addendum: R&D expenditure and firm size in Australian manufacturing 1971-1972', in Tucker,K.A. ed. The Economics of the Australian Service Sectors, London;Croom Helm.pp.263-269.

McLean I.W. and Round, D.K. (1978) 'Research and product innovation in Australian manufacturing industry', The Journal of Industrial Economics, Sept. Vol. XXVII(1), pp.1-30.

Mellor, D.P. (1958) Australian in a War of 1939-1945: The Role of Science in Industry, Canberra.

Middleton, B.S. (1970) 'The role of government in the encouragement of research by industry', Proceedings of the Royal Australian Chemical Institution, Vol. 37(7), pp.169-179.

Minasian. J.R. (1969) 'Research and development, production function and rates of return' American Economic Review, May, Vol. 59(2). pp.80-85.

Morris, P.J. (1983) 'Australia's dependence on imported technology-Some issues for discussion' Prometheus, Vol. 1(1), June, pp.144-159.

National Science Foundation, (1979) Science Indicators, 1978, Washington; U.S.Govt. Printing Office.

Newman, M. (1968) 'Equating returns to R&D expenses' Financial Executive, April, pp.26-33.

Nixon, J.C. (1965) 'Some financial application in research and development in Australian manufacturing industry' Proceedings of the 8th Conference of Management, Canberra:A.N.U.

OECD, (1962) The Measurement of Scientific and Technical Activities-Proposed Standard Practice for Surveys of Research and Experimental Development-Frascati Manual, DAS/PD/62.47, 3rd revision, Paris;OECD.

OECD, (1970) The Measurement of Scientific and Technical Activities, DAS/SPR/70.40, Paris;OECD.

OECD, (1976) The Measurement of Scientific and Technical Activities-Frascati Manual, Paris;OECD.

OECD, (1977) Contribution to the OECD Workshop on R&D Deflators, DSTI/SPR/77.22, Paris;OECD.

OECD, (1978) Trends in Industrial R&D in Selected OECD Member Countries 1967-75, SPT/78.20 Annex 2, Sept. Paris;OECD.

Parry, T.G. (1974) 'Technology and the size of the multinational corporation subsidiary; Evidence from the Australian manufacturing sector, The Journal of Industrial Economics, Vol. 23,pp.125-34.

Parry, T.G. and Watson,J. (1979) 'Technology flows and foreign investments in the Australian manufacturing sector', Working Paper, Centre for Applied Research, Uni. of N.S.W.

Robertson, D.H. (1978) 'Australia's growth performance: An assessment', in Kasper and Parry eds op.cit., pp.69-89.

Soete, L. (1980) The Impact of Technological Innovation on International Trade Patterns: The Evidence Reconsidered, STIC/80.33, Aug. Paris;OECD.

Stubbs, P. (1968) Innovations and Research, A Study in Australian Industry, Institution of Applied Economic Research, Uni. of Melbourne.

Tisdell, C. (1973) 'The Australian research subsidy to overseas firms and other aspects of distribution of research grants' The Economic Record, Vol. 49, pp.194-214.

Tisdell, C. (1975) 'Science policy and the flow of Australian inventions', Search, Vol. 6(5), May, pp.174-178.

Tisdell, C. (1983) 'The International realpolitik of science and technology policy' Prometheus, Vol. 1(1), pp.127-143.

Tucker, K.A. (1977) The Economics of the Australian Service Sector, London:Croom Helm.

Ward, R.G. (1975) 'The case of government support to industrial R&D', Search, Vol. 6(10),pp.407-409.

Chapter Four

Strategy and Direction of Inventive Effort in Private Manufacturing Industry

4.0 Introduction

Industrial R&D effort at the national level, as examined in the previous two chapters, provides only limited information on the differences in innovativeness of particular industrial R&D structures. As reported in Chapter One, there has been only limited study of the process of generating innovations and of the relevant factors involved in accomplishing industrial innovation in Australia. This study seeks to rectify this situation through a detailed analysis of the microstructure of industry's R&D and inventive activity. The types of inventive effort, its effectiveness, and its relation to the industry's environment can only be adequately analysed by examining innovations at the level of the firm and even the project. The following three chapters are devoted to an examination of factors which instigate and assist innovation in Australian manufacturing industry.

Most R&D management studies have treated industrial innovation as a rational process which is subjected to prediction, regulation and control. However, another viewpoint suggests that innovation is self-organizing and is neither a mechanical nor a goal-oriented process (Sahal, 1983a). While it is recognized, as shown in Chapter One, that innovations are shaped by a multitude of factors, it is generally agreed that two forces are most influential: the in-house investment policies of companies and policies of government for science and technology. It is not the purpose of this study to evaluate the effectiveness and interaction of such policies. Instead, it seeks to recognize and determine some of the vital factors in stimulating inventive input of companies through a detailed analysis of their R&D and inventive structure. These findings can be used as guides in the formulation of effective industrial R&D policies.

This chapter describes some intrinsic features of R&D structures with respect to the level and composition of R&D resources, the institutional and strategic variations, and their implication for directing and planning inventive activity. It has been noted that the total R&D effort and its microstructure are important elements in deciding the efficiency of an R&D structure, and that individual innovations do not reflect the failure or success of the overall R&D structure or programme of the firm (Braun,1981). It is recognized that non-R&D factors such as production and marketing are vital in determining the outcome of innovations. However, it was neither practical nor possible to obtain detailed data on the non-R&D factors which are related to the preformance of the many individual innovation because of the restrictions in the availability of data. Hence the focus is more on the microstructure of inventive activity, rather than the effectiveness of it.

It has now become recognized that R&D activity itself is highly differentiated and can usefully be brokendown by type of research (basic versus applied research) and orientation (product versus process development research) (Sahal,1983b). Analysis using these categories, measured in terms of expenditure, has proved instructive, revealing not only new connections between various types of R&D and economic preformance but also raising important implications for regulating the process of innovation (Link,1982). Moreover, the effect of institutional and environmental factors on various components of R&D differs considerably. For example, R&D systems in different countries have concentrated their effort on different elements of the R&D process (McGraw Hill, 1975, Schott, 1976 and Mansfield *et al.*, 1977). Mansfield *et al.*, (1977) further illustrated that the principle objective of most R&D expenditure is to improve existing products rather than developing new products and processes. It may be that industrial success at the national level is partly determined by this microstructure of R&D. The composition of various inventive activities in Australian industries and their impact on R&D structure are investigated in this chapter.

4.1 Strategies of Firms for Inventive Activity

Research has revealed that a wide range of organizational and environmental characteristics play a role in determining the R&D strategy of an individual firm. Nystrom (1979) found that firms employ different R&D strategies according to their internal structure and external environment. According to rational analysis, a decision to undertake a particular inventive strategy is made systematically by the firm. Thus it has been argued

> there will be a strong mutual relationship between a firm's choice of a strategy and its environment and given its strategy, between the types of product and process innovations that a firm undertakes and the way its productive

resources will be deployed.
(Abernathy and Utterback,1975,p.640)

Type of R&D activity is also influenced by position of the firm in the life cycle of an industry. Utterback and Abernathy (1975) have suggested that the proportion of product and process innovations undertaken by firms differs consistently with the stage of development. As the firm matures, it undertakes more process development innovations at the expense of product development innovations. Abernathy and Utterback (1978) developed their argument to suggest that changes in innovative pattern, productive process, and scale and kind of production capacity all occur together in a consistent, predictable way. Similarly, Maier and Haustein (1980) have emphasized the shift of industry inventive activity from a product to a process orientation as industry production becomes standardized. Such changes can take place even within the life cycle of a particular product or process. For example, Etienne (1981) has suggested that both the nature and rate of product innovation change over the life of a product. Therefore, different kinds of R&D activity have a significant role to play at different stages of industry development and production. Moreover, the breakdown between product and process innovation is, or should be, a systematic product of the firms' internal and external environment.

Distinguishing between product and process inventive effort, however, may not be an easy task, due to the symbiotic relationship between product and process innovations. Myers and Marquis (1969) argued that some product innovations require the firm to undertake process innovation because product and process are so intimately bound that changes in one necessitate changes in the other. Moreover, classification of product and process innovation can vary with the context. Abernathy and Townsend (1975) have stated that what is a product innovation for a small technology based firm often becomes the process equipment adopted by firms producing standard products in high volume. This suggests that the product and process innovations must be seen from the perspective of the innovating firm and suggests that definitions are a matter of some importance. Utterback and Abernathy (1975) have defined product innovation as a new technology or combination of technologies introduced commercially to meet a user or a market. A process innovation is defined as a system of process equipment, workforce, task specification, material inputs, work and information flows, etc. that are employed to produce a product or service.

The OECD (1980) has provided a descriptive definitions in terms of the kinds of changes sought or achieved. These are for products:

a) change in material,

b) change in characteristics of product or detail improvement

c) change in functional characteristics, and d) development of new product.

For processes:

a) change in procedures in production systems,

b) improvement in automation,

c) change in technical and organizational structure, and

d) change of economies of scale.

The inventive effort of a firm may be primarily aimed at developing one or more of these components. Furthermore, determining industrial inventive input according to each of these components may not be an easy task. Hence a more useful categorization would be based on a distinction between the development of new and existing technologies. Inventive input effort can therefore be identified according to four categories in terms of the objective of development:

a) new product,

b) new process,

c) existing product, and/or

d) existing process.

The strategy adopted in undertaking R&D on existing products and processes differs significantly from that for new products and processes. The development of existing products and processes is largely undertaken as a protective measure to stabilize and to expand already established markets whereas the development of new products and processes is directed towards obtaining new markets. Wulfsberg (1978) has described the R&D into existing product and process as a defensive mechanism which is necessary to protect the viability of existing products and markets from new technologies being developed by others. The factors which influence the generation of product and process innovations have been thoroughly investigated in a number of studies.[20] Identification of market and/or technical potential is now regarded as the major criteria for undertaking innovations. Myers and Marquis (1969) concluded that recognition of demand is more important in innovation than recognition of technical potential. Langrish *et al.,* (1972) also concluded that need identification was the most influential factor in industry innovation.

20 For a critical survey of studies on the process of innovation by firms see Utterback (1974) and also refer Rosenbloom(1974) for a study of existing practices on changes in the innovative process.

Wulfsberg (1979) pointed out that 70 per cent of innovations have resulted from need identification and the remainder from technical potential. The importance of market factors in inducing innovations has also been recently emphasized by Scherer (1982). However, Mowery and Rosenberg (1979) have shown that these studies have concentrated on a relatively narrow concept of industry innovations.[21] A recent study by Utterback (1979) emphasized the importance of market, technical and cost reduction stimuli for innovation at different stages of industry development.

The patterns of development of new products and processes in a firm at a given time also depend on the competitive strategies of firms. Utterback and Abernathy (1975) have argued that the characteristics of performance-maximizing, sale-maximizing and cost-minimizing strategies of firms can be systematically related to the approach to product innovation.

4.2 Inventive Patterns of Manufacturing Industry

Many studies have been made on the structure of industrial R&D in Australia. Industrial research effort is generally regarded as weak (Johnston,1982) and the research into existing product and process is lacking (Thompson, 1983). The OECD (1977) has reported that the industrial research structure is small compared with the other sectors and dominated by short-term immediate problem solving activity. However, most of these reports have relied on highly aggregated data. As the

21 Mowery and Rosenberg (1979) have discussed some of the limitations in the interpretation of concepts of innovation and the methodology used in these studies.

previous argument has shown, it is necessary to go beyond general levels of R&D expenditure to a disaggregation in terms of focus on new versus existing and product versus process development.

McLean and Round (1978) have analysed a sample of 980 firms selected from an R&D survey in 1971/72. They commented on the product innovativeness of manufacturing industries and identified the food, beverages and tobacco division as the least product innovative and the other machinery and equipment and textile, clothing and footwear divisions as the most product innovative industries. They did not investigate the resources devoted to process innovations because of lack of data. However, it is necessary to consider all type of innovative inputs in order to be able to analyse the innovativeness of firms.

The sample of manufacturing industry selected in this study was derived from two industry populations. In order to include industry with a formal research practice 450 firms which applied for project grants from the Industrial Research and Development Incentive Board between 1978 and 1980 selected. Another sample of 180 firms, which are likely to undertake R&D, was randomly selected. All these firms were surveyed to determine the level of resource allocation to various inventive activities, the composition of R&D activity and the reasons for selecting certain R&D strategies during the period between 1976/77 and 1979/80. Those non-R&D activities relating to other stages of innovation such as tooling, manufacturing and marketing start-up were not included because of the difficulty in obtaining such data at the industry level.

470 out of 630 firms answered, giving a response rate of 75 per cent. Of these, 273 firms engaged in research and inventive activity during

this period. The remaining 197 firms had either not engaged in R&D activity, or ceased their R&D operations, or could not quantify R&D resources. The 273 firms engaged in R&D provides a sizeable sample of the enterprises undertaking industrial R&D in 1978/79.[22] For example, the manpower reported in this sample for 1976/77 was 32 per cent and the expenditure was 39 per cent of the national input levels in manufacturing industries. On this basis, the findings of this study may be considered to be representative of manufacturing industry.

The major issues considered in this chapter include

a) inventive input patterns;

b) strategy in deploying resources to inventive activity;

c) magnitude of resource allocation in different industry groups;

d) types of inventive activities and their growth and direction;

e) factors influencing inventive input effort; and

f) effect of organizational structure on inventive activity.

g) factors influencing development of inventive activity.

4.3.0 Level of Resource Allocation to Inventive Activity in Industry

The determinants of the level of R&D resource commitment are numerous as noted in Chapter One. The size of the R&D budget of a firm can be related to technical, organizational, strategic and economic factors. Technical requirements and the level of previous budgetary commitment

22 770 manufacturing enterprises reported undertaking industrial research in the 1978/79 national R&D survey.(ABS,1980), so the sample constitutes 35 per cent of companies performing R&D

to R&D are amongst the most important criteria in determining the level of the R&D budget. Herkert and Wilson (1967) emphasized the importance of planning technical program as a factor determining the R&D budget and argued that the previous level of R&D budget determines the size of the current R&D budget. Company commitment to maintain R&D laboratories, personnel, on-going R&D projects, and technological competitiveness are among the factors which maintain the present level of R&D activity.

In another study, Burrows (1981) has argued that among factors such as budgeted sales, liquidity position, previous R&D budget, budgeted profits, planning of technical program and R&D workforce, the most influential factors controlling the R&D budget of a firm are the intensity of the R&D workforce and the planning of the technical program.

This section examines the level of R&D spending and employment and changes over time, the intensity of R&D activity and resource allocation, and factors influencing R&D investment decisions.

4.3.1. Level of Resource Allocation to R&D Over Time

The amount of resources allocated to inventive activity by firms partly reflects their long-term objectives. However, the extent of industry resources, allocated to inventive activity has been shown to be significantly influenced by economic fluctuations and to be related more to the availability of investment funds than to the recognition of R&D opportunities (Twiss, 1980). The level of R&D expenditure and researcher effort allocated, aggregated by different industry class, is presented in Table 4.1.

Table 4.1 R&D Expenditure and Personnel Effort by Industry Classes(constant 1979/80 prices in $million and person-years)

Type of Resource	Exp.	Exp.	Exp.	Pers.	Pers.	Pers.
Industry Class & Year	76/77	78/79	79/80	76/77	78/79	79/80
Food,bev.&tob.	0.9	1.6	1.3	43	52	51
Textile,clo.&footwear	0.1	0.4	0.6	4	11	21
Paper&Wood	2.8	3.1	4.2	122	121	119
Chemical,pet.&coal	4.2	5.6	6.3	250	271	266
Non-metallic mineral	2.4	3.3	3.9	47	67	73
Basic metal prod.	1.5	5.1	4.1	68	88	69
Fabricated metal	1.8	1.5	1.8	39	43	48
Transport equip.	8.1	8.9	11.7	49	27	69
Other machinery	23.3	33.7	42.0	164	214	242
Miscellaneous	3.7	4.2	5.0	105	103	107
Total	48.9	71.2	80.9	890	997	1065

R&D expenditure and manpower in this sample of firms increased substantially over the period. The growth of expenditure, however, was more pronounced than the growth of manpower. The variation of resource allocation in different industry classes was quite strong with the other machinery and equipment industry division responsible for nearly 50 per cent of R&D expenditure. All industry classes, with the exception of metal industries, showed an increase in R&D expenditure. The metal industries also reported a decline in R&D expenditure in the national surveys, as illustrated in Table 3.19 in Chapter Three.

The growth of expenditure in the sample studied had a higher rate than the rate of growth of national R&D expenditure. For example, R&D expenditure at constant 1979/80 prices between 1976/77 and 1978/79 showed an annual average growth rate of 15.3 per cent in this sample whereas the comparable national rate was 4.7 per cent. R&D manpower was also highly concentrated in a few industry classes such as the other machinery, chemicals, and transport equipment industry. The level of R&D personnel remained steady or slightly declined in a number of industries. However, the overall level of manpower showed an increase. This was against the national trend which shows a steady decline as described in Chapter Three. The greater increase in R&D resources reported in this sample of firms compared with the national totals indicates the greater inventive intensity of the firms in this sample.

Both Freeman (1962) and Mueller (1966), admittedly some time ago, showed that R&D budget allocations varied little from year to year. However, in this sample, at the industry division levels, there is considerable annual variation in both expenditure and manpower. Between 1976/77 and 1979/80, one fifth of firms reduced their level of resource allocation to R&D compared with the previous year's levels. The percentage change in R&D personnel from year to year was smaller than changes in expenditure. Thus, the average annual percentage change of manpower remained constant for 39 per cent of firms compared with 9 per cent of firms having constant expenditure levels between 1976/77 and 1979/80.

A good proportion of the Australian firms showed considerable changes in R&D budget and manpower allocation. About 50 per cent of the firms showed more than 10 per cent of change of R&D expenditure at constant prices in either direction between 1976/77 and 1978/79 and this increased to 66 per cent between 1978/79 and 1979/80. With regard to annual change of R&D manpower, the corresponding figures were 37 per cent and 55 per cent respectively. Nearly 20 per cent of the firms decreased their R&D

expenditure and manpower more than 10 per cent during 1978/79-1979/80. The fluctuation of annual expenditure was slightly higher than changes in R&D manpower. A slow change in manpower allocation is noted in a previous study by McLean and Round (1978) and they concluded that,

> R&D employment varies less from year to year than R&D expenditure.
> (McLean and Round, 1978, p.6)

However, manpower level in this study showed a considerable annual fluctuation in some firms. Not only the low level of R&D resource allocation, but the extent of fluctuation from year to year may suggest some instability in the industrial R&D structure. Olin (1973) has argued that it is considered detrimental to a company's R&D effort if it was changed by more than 5 to 10 per cent annually in any direction. A marked variation of R&D budget from one period to another was found to be strongly related to the variation in total sales and profits of a firm rather than factors specific to R&D (Burrows, 1981). Therefore the erratic fluctuations observed may reflect in part performance and uncertainty about the economic climate and in part a weakness in R&D structure. Freeman *et al.*, (1982) pointed out that firms tend to reduce their R&D activity during the more severe economic depressions. Although Australian industries have undergone a recession during this period, a number of firms have shown a considerable increase in R&D expenditure. As far as most Australian industries are concerned, it is difficult to consider the previous year's R&D budget as a determinant of current R&D budget due to high annual fluctuation of R&D budget.

4.3.2 Inventive Intensity in Manufacturing Industry

The research or inventive intensity of a firm was described using a number of measures in Chapter Three.[23] The ratio of R&D expenditure to industry's turnover measures the financial commitment to inventive activity, whereas the ratio of R&D manpower to employment is a measure of the labour intensity of inventive activity.[24] These two indicators vary by industry according to capital and labour intensity of development, though they are obviously inter-related.

Table 4.2 Distribution of Percentage of Expenditure to Turnover(E1) and Personnel to Employment(M1) Allocation-1979/80.

Industry Class	E1	M1	E1/M1
Food,bev.&tob.	0.8	2.6	0.3
Textile,clo.&footwear	2.4	1.3	2.3
Paper&Wood	1.7	2.1	0.6
Chemical,pet.&coal	1.7	4.5	0.6
Non-metallic mineral	1.9	2.9	0.8
Basic metal prod.	0.7	2.4	0.3
Fabricated metal	1.8	2.4	0.7
Transport equip.	1.2	2.6	1.3
Other machinery	3.8	5.3	0.7
Miscellaneous manu.	1.8	3.6	0.6
Total	2.3	3.8	0.7

The inventive intensity, according to these two measures, shows a considerable variation in the average mean for different industries (Table 4.2). One-way analysis of the variance suggests that the means of different industry classes is different from each other at the 5 per cent significance level for both expenditure and employment. The

23 See Johnston and Carmichael(1981) for a detailed discussion.

24 Scherer (1967) has taken this measure to define the R&D intensity of a firm.

average ratio of expenditure to turnover is 2.3 per cent, whereas the corresponding national figure for the 1978/79 survey of Business Enterprise Sector was 0.7 per cent.[25]

The average R&D manpower to employment ratio was 3.8 per cent compared to a national figure for 1978/79 of 1.4 per cent. The difference of average research intensities between the national survey and the industries surveyed in this study could be explained by a considerable increase in industry R&D expenditure during 1979/80. However, this is extremely unlikely, as the preliminary results of the 1981/82 national survey indicate an overall decline in R&D resources (ABS,1983). Hence, it must be concluded firstly that resource allocation to R&D differs not only according to different industry classes but also within an industry class.[26] Secondly, the sample of this survey largely represents the special group of highly research intensive firms in Australia.

Those industries with above the average research intensity are categorized as research intensive industries. As discussed in Chapter Three, only three industry classes namely the chemical, petroleum and coal products, transport equipment and other machinery and equipment industries were identified as research intensive according to national statistics. Inventive intensity measured in terms of manpower and expenditure varies considerably in different industries. Some industries

25 The national surveys of the Business Enterprise Sector (ABS,1979,1981) indicate that these intensity ratios have remained more or less unchanged for the period 1976/77-1978/79. A similar ratio for other countries averaged around 2 per cent. See Dept. of Industry(1974) and NSF(1979)

26 It was noted in Chapter Three that even among research industry classes resource allocation varies considerably in different industry sub-classes.

allocated a high expenditure but a low manpower ratio or vice versa. Only the other machinery and equipment and textile, clothing and footwear industries were research intensive in terms of expenditure. However, research intensity measured in the chemicals, petroleum and coal products and other machinery and equipment industry divisions were research intensive by manpower measures. Thus, the interpretation of research intensity of an industry depends upon the measure selected. In general the two measures are complementary.

These two indicators can be combined as a ratio of E1 to M1, to provide a relative measure of the expenditure per R&D staff (normalized for company size). As Table 4.2 shows, this measure of 'capital intensity' of industry R&D reveals very considerable variation between industry groups. However, it should be recalled that capital intensity is a relative measure. The high figure for the textile, clothing and footwear industry is a function of its very low level of R&D employment.

The frequency distribution of the ratio of R&D expenditure to turnover indicates that a majority of firms (58 per cent) spent less than or equal to 1 per cent of their turnover on R&D during 1979/80 (Table 4.3). A significant number of firms, about 32 per cent, spent more than 1 and less than or equal to 5 per cent of their turnover on R&D, and only 11 per cent allocated more than 5 per cent of turnover to R&D. It should be remembered that this sample is of the most highly R&D intensive firms in Australian manufacturing industry.

Table 4.3 Frequency Distribution of Industries According to Ratio of Turnover and Employment Allocation on R&D -1979/80

Ratio	Firms-Turnover	Firms-Employment
Up to 0.10	53(21%)	51(20%)
0.11-0.20	22(9%)	9(4%)
0.21-0.50	37(14%)	21(8%)
0.51-1.00	35(14%)	29(12%)
1.01-2.00	39(15%)	25(10%)
2.01-5.00	42(16%)	66(26%)
5.01-10.0	16(6%)	34(14%)
Over 10.0	13(5%)	16(6%)
Total	257(100%)	251(100%)

The ratio of R&D personnel to total employment shows a slightly different distribution. Nearly 44 per cent of the firms devoted no more than 1 per cent of employment to R&D activity. The percentage of firms allocating between 1 and 5 per cent of employment to R&D was 36 and nearly 20 per cent of firms committed more than 5 per cent of the firm employment on R&D activity

The average R&D expenditure per firm among different percentage groups of turnover ratios shows a large variation. On the average high R&D spenders are concentrated in the turnover ratios between 0.51 and 1.0 per cent. For example, firms in this turnover range spend an average of $285,000 per firm whereas the firms spending over 5.1 per cent of turnover on R&D averaged $104,000 per firm. These results indicate that firms allocating high turnover ratios on R&D were not necessarily large firms. However, firms spending a relatively small amount of turnover also generally had a low R&D expenditure indicating that these firms had a low level of inventive activity.

On the basis of these results, at least two types of firms can be identified in relation to R&D spending, - firms spending a high proportion of their turnover on R&D, and firms with a high R&D expenditure. Firms with a larger expenditure/turnover ratio may not necessarily be large firms. Indeed these figures reveal that the majority are small in terms of turnover. Hence while they have strong commitment to inventive activity, their impact on industry R&D expenditure was small compared with large firms who spent a low percentage of a high turnover on R&D.

This pattern of small companies being highly research intensive in terms of their relative investment in R&D is quite common in industrialised countries, particularly in the newer 'high technology' or 'sunrise' industries. What is remarkable and special about the Australian situation is that while large firms may be investing large sums as a proportion of turnover they are in general not in the research intensive category. In other words Australia lacks large firm commitment to inventiveness. Clearly policies designed to improve the Australian industrial economy need to take this structural feature into account.

4.3.3 Factors Influencing Inventive Investment in Industry

There have been many studies of differences between firms in R&D expenditure .[27] Some of the important factors identified include the firm's profitability, market concentration, diversification, managerial control, and government incentives. An attempt was made to isolate some

27 For a detailed discussion of determinant of R&D see Kamien and Schwartz (1982) and Scherer(1980)

of the organisational and managerial factors that influence the level of R&D investment and direction in Australian manufacturing industry. R&D managers were asked to state the reasons for investing in R&D, constraints on R&D investments, and reasons for abandoning R&D. Their responses are briefly discussed in this section.

The profit level of firms can influence R&D decisions in at least two ways. Firms with declining profits may need to develop and introduce innovations to restore their position; on the other hand, increase in profits may act as a catalyst for some firms to increase or maintain a sizeable R&D budget. The results of this study showed that for 93 Australian firms (36%) it was a continued level of adequate profitability which allowed the maintenance and even increase of the R&D function. This is in keeping with the findings in a number of studies in other countries. Link (1982) found that profitability, diversification and federal support to R&D are significantly related to R&D intensity. Gerstenfeld (1978) found that profits is an overridding drive for R&D project undertaking. Similarly, Kamien and Schwartz (1982) pointed out that a firm earning high profits from it current products or facing little innovational rivalry was better suited to finance R&D from current profits than one earning low profits or facing intense competition.

Mansfield (1971) emphasized the importance of competition as a major driving force for innovation. Further evidence was provided by Grabowski and Mueller (1978), who found that rivalry and concentration influenced the level of R&D investment in industry. For the Australian industries, market concentration or competition was also found as important reasons for conducting R&D in 74 firms (29 per cent). The role of managers also played a important role in R&D investment. McEachern and Romeo (1978) and Link (1982) found the type of managerial control to be an important determinant of the level of R&D investment. Managerial decisions and intervention was cited as the major reason for undertaking R&D in 43 firms (17 per cent). The cost reduction of process and product was the primary aim of 29 firms (11 per cent) undertaking R&D. Governmental R&D incentives and assistance apparently induced 16 firms (6 per cent) to undertake R&D investment. These responses indicate that firms undertaking R&D have primarily considered the level of profitability, competition and market pressure as the reasons for maintaining their R&D activity. Government assistance was not a prime force in instigating R&D activity in most firms.

Out of 470 firms 22 had abandoned R&D activity, mostly during the 1970s. Seven firms ceased R&D after 1 year of operations, 5 after 2 years; 2 after 3 years; 3 after 4 years; 2 after 7 years; and 3 after 10 years. The primary reasons for abandoning R&D activity were listed as the difficult financial situation (4 firms), constant failure of R&D operations (8 firms), high cost of R&D (4 firms), availability of easy access to licensing and technological transfer methods (3 firms) and uncertainty in the outcome of R&D activity (3 firms or). Although the number of firms which ceased their R&D operations is too small to draw a definite conclusion, these results indicate that failure of R&D activity and financial constraints have been a major set back for continuing R&D operations in industry.

4.4 Product and Process Inventive Activity

The deployment of resources to various kinds of inventive activity reveals an interesting pattern. As already mentioned, inventive effort from a firms perspective can be separated into four major categories of product and process innovations: new products, new processes, existing products, and existing processes. New products and processes are defined as technologies new to the firm and new to the market whereas, existing products and processes are defined as established and marketable technologies already known to the firm. The composition of R&D activity in firms and the role of different R&D components in developing industry's inventive strategy is discussed in this section. R&D expenditure allocated to these four categories of development at constant 1979/80 prices is presented in Table 4.4.

Table 4.4 R&D Expenditure Allocated to Product and Process Development from 1976/77 to 1979/80 ($'000 at constant 1979/80 prices)

Year	1976/77	1978/79	1979/80
New Product	32457(58%)	42922(58%)	47689(59%)
Existing Product	8057(14%)	9108(12%)	10297(13%)
New Process	10417(18%)	14935(20%)	15183(19%)
Existing Process	6082(10%)	7581(10%)	7521(9%)
Total	57013(100%)	74546(100%)	80922(100%)

Note Constant prices are based on GDP implicit deflator by manufacturing industry

The overall R&D expenditure in these companies increased in real terms at an annual average growth rate of 12 per cent during the period. Most companies allocated the great majority of their R&D expenditure to new product development; the remainder was shared among the remaining three types of inventive activity. Product development accounted for almost three-quarter of industry's inventive activity. The development of new innovations was even more dominant, accounting for almost 80 per cent of investment on product research. This is, however, not very different from other industrial structures. For example, it was noted in U.S. about 86% (McGraw Hill, 1975) and in U.K. about 63% (Schott, 1976) of the R&D expenditure spent on product development.

Clearly, the objective of firm's R&D was aimed at new product development to which firms spent an average of $245,000 (standard deviation $2,319,000). For new process development firms spent an average of $117,000 (standard deviation $681,000). R&D expenditure allocated to existing products was $80,000 (standard deviation $189,000) and the allocation to existing process was an average of $72,000 (standard deviation $166,00). High standard deviations suggests that the variation of expenditure allocation to different inventive activity in firms was quite high. The reasons for such variation is discussed later in this section. R&D expenditure allocation on new and existing products, as a percentage of turnover during the 1979/80 period showed that the 23 per cent of firms spent more than 1 per cent for new product, 9 per cent of firms for existing product, 7 per cent of firms for new process, and 2 per cent of firms for existing process. Clearly, firms had their preference in directing inventive effort to particular type of inventive activity than others.

The pattern of inventive effort remained almost completely unchanged during the period surveyed. This situation is interesting as it suggests that industries have maintained a consistent strategy in deploying their resources in inventive activities over the period.

A high proportion of research manpower was concentrated in the new product development activity. However, the manpower distribution was not so highly concentrated in product development as in the case of expenditure. For example, research manpower devoted to product development was 61 per cent whereas R&D expenditure was 71 per cent. This suggests that somewhat higher manpower support is given for process development (Table 4.5). The allocation of R&D manpower, as a ratio of employment in firms, showed that 34 per cent of firms spent more than 1 per cent for new product, 17 per cent of firms for existing products, 11 per cent of firms for new process, and 6 per cent for existing process. The rate of growth of manpower was much less than that of expenditure. The annual average rate of growth of manpower was 4.7 per cent for the period from 1976/77 to 1979/80. However, this trend opposed the direction of national surveys which show a steady decline in research manpower in the manufacturing sector during the period from 1976/77 to 1978/79. If the sample of this study is accepted as representative, it suggests that the decrease in manpower in national surveys may be attributable to the reduction in number of enterprises undertaking R&D activity. However, even in this sample of industries the growth of manpower level was much lower than that of expenditure.

Table 4.5 R&D Employment on Product and Process Development from 1976/77 to 1978/79 (person years)

Year	1976/77	1978/79	1979/80
New Product	290(32%)	340(34%)	401(38%)
Existing Product	229(26%)	246(25%)	251(23%)
New Process	169(19%)	198(20%)	210(20%)
Existing Process	202(23%)	213(21%)	203(19%)

R&D employment figures for different inventive activities indicate that only new product and process development show a healthy growth. The annual average growth rates were 13.2 per cent for new products; 7.3 per cent for new processes; 3.0 per cent for existing products; and -2.0 per cent for existing processes. Therefore, manpower resources have shown a slow retreat from existing product and process development.

R&D expenditure per research person-year increased only marginally between 1976/77 and 1979/80 (Table 4.6).

Table 4.6 Per Capita R&D Expenditure on Product and Process Development from 1976/77 to 1979/80 ($'000/person year at constant 1979/80 prices)

Year	1976/77	1978/79	1979/80
New Product	112	126	119
Existing Product	35	37	41
New Process	30	36	37
Existing Process	64	75	76

R&D expenditure per person year for both new product and process innovations slightly declined for the period 1978/79 to 1979/80. One of the striking features of the expenditure to manpower ratio in these industries was the low R&D expenditure intensity in existing product and process development. The expenditure per researcher allocated to new product development was far in excess of other inventive categories. This suggests that the development of new products is more costly and more capital intensive than other inventive activities. Yet most industries a have high resource commitment to develop new products and concentrated their effort primarily on it. Clearly, it is new product development which is regarded as the most important route to new technology and improved productivity.

There is a general preference for new product development in manufacturing industry, but a substantial amount of inventive effort was directed to process innovations as well. Inventive activity directed towards developing products can act as a catalyst for initiating process innovations because, as mentioned earlier, product and process activity are intimately connected. However, the variation in resources spent on different inventive activities is primarily controlled by the requirements of individual firms. The investment strategy of firms considered here displays a commitment to the development of new products. This situation in Australian industries is in marked contrast to that of most other industrial systems where the emphasis was on developing existing products rather than new products and processes (Mansfield *et al.*, 1977). For example, a survey carried out by McGraw Hill (1975) on a sample of U.S. industries between 1975 and 1978 found that 50 per cent of R&D expenditure was aimed at existing product development and 14 per cent at new processes. In the U.K., Schott (1976) found that a 37 per cent expenditure for process innovation for 300 firms between 1971 and 1972. The dominance of the new product development activities is apparent contrast to the findings of a number of previous studies (e.g. Johnston *et al.,* 1981) and clearly in need of explanation. This issue will be examined further in the conclusions.

4.5 Connection Between R&D Input and Firm Output

The relationship between the inventive input and economic output of an industry can be measured by examining the relative strength of inventive input efforts in relation to the industry's economic variables. As already noted in Chapter Three the common economic measures used for this purpose are turnover, value added, sales, export and import performance and employment. Soete (1980) has discussed the importance of some of these measures. There are distinct drawbacks in using these measures, as all R&D activities carried out in industry do not have an impact on all areas of industry activity. Ideally, a particular inventive activity should be regarded as having a direct or indirect impact on selected areas of industry activity. However, isolation of such effects from a particular project undertaken in industry is a difficult task.

Furthermore, the inventive input cannot be taken as directly related to inventive output. Inventive input is usually taken as a surrogate for inventive output (McLean and Round, 1978). This is mainly because of the difficulties in quantifying the causal relationship between inputs and outputs. Some studies have attempted to use inventive output such as patents (Comanor and Scherer, 1969), sales of new products (Comanor, 1965) and export sales (McGuinness and Little, 1981). These studies have shown that there is a close association between inventive input and output variables. However, knowledge of the precise relationship between input and output remains very limited (Walker, 1979). There is no empirical evidence to suggest that R&D input leads to increased export sales(Bollinger *et al.*, 1983). A number of drawbacks have been identified in the above mentioned studies. For example, it was difficult to identify sales at different stages of product cycle and sales figures included marketing variables, such as price, advertising and distribution in sales figures (Nystrom, 1979). Taylor and Zilbertson (1974) argued that patent statistics have many limitations as a measure of inventive output.

In this study turnover and employment variables have been used to assess the relationship between industry resource commitment and economic performance. An attempt was made to collect export and domestic sale figures related to industry research activity but this proved to be impossible. Most firms surveyed were unable to supply reliable sales figures arising from their R&D activity.

The correlation coefficient between R&D expenditure between 1976/77 and 1978/79 and turnover for 1979/80 shows a positive and significant(at the 1% level) relationship. A similar relationship was found between R&D employment and manpower. The relationship between R&D manpower and employment was much stronger than the relationship between R&D expenditure and turnover (Table 4.7).

Table 4.7 Relationship Between Inventive Input and Economic Output-1976/77 to 1979/80.

	Multiple R	r^2
	With Turnover	
R&D Exp.1976/77	0.510(F=50)	0.26
R&D Exp.1978/79	0.572(F=70)	0.33
R&D Exp.1979/80	0.571(F=69)	0.33
	With Employment	
Personnel 76/77	0.76(F=189)	0.57
Personnel 78/79	0.78(F=220)	0.61
Personnel 79/80	0.79(F=241)	0.63

Note All correlation coefficients are significant at the 1 per cent level.

These relationships also show that past R&D investment has a close connection with the current economic activities of the firm. A similar relationship between inventive input and economic output measures was reported in the study of McLean and Round(1978). These results suggest that manpower intensity measure may be a better indicator of innovativeness of a firm than the expenditure intensity.

The relationship between the economic variables and the inventive input to product and process innovations for the same period gives some what different results (Table 4.8). Although the simple correlation coefficients showed a positive and significant relation at the 1 per cent level for both manpower and expenditure components, the correlation coefficient for new product innovations was relatively low. In all these categories R&D inputs of the past years show a strong correlation with economic variables in the current year. This confirms the established view that the level of R&D investment in past years has an influence on present economic activity as shown by many studies. However in the past this has been demonstrated mainly at the national level (Pavitt and Walker, 1976).

Table 4.8 Correlation Coefficient Between Turnover and R&D Expenditure and Manpower and R&D Personnel in Product and Process Development-1976/77 and 1979/80.

	New Pd.	New Pc.	Ex.Pc.	Ex.Pd.
Employment with				
Person years 1976/77	0.37(86)	0.76(133)	0.55(76)	0.62(111)
Person years 1978/79	0.30(101)	0.63(156)	0.58(85)	0.66(124)
Person years 1979/80	0.34(110)	0.71(165)	0.59(85)	0.67(128)
Turnover with				
Expend. 1976/77	0.32(85)	0.71(133)	0.52(75)	0.52(111)
Expend. 1978/79	0.32(106)	0.71(103)	0.59(89)	0.62(127)
Expend. 1979/80	0.24(115)	0.72(173)	0.60(75)	0.60(133)

Note Figures in parenthesis indicate the sample size.

The relatively weak correlation coefficient between new product inventive resources and output is perhaps deserving of further comment. This weak association may be simply due to disproportionate resource allocation to new product development, suggesting that resource allocation to new product development takes place independent of economic fluctuation. Companies may decide to carry on with ambitious new product development simply because of the previous commitments to R&D activity or because of a hope for increased returns in future. The difference in correlation coefficients between overall R&D expenditure and expenditure on various R&D components suggests that economic factors are bound more strongly with some R&D components than others. The linear relationship between economic variables and various inventive activity is presented in Table 4.9. The relationship was particularly strong in the case of existing process and product development.

Table 4.9 Regression Analysis of R&D Inputs with Turnover and Employment-1979/80

	Multiple R	r^2
Turnover with		
Exp. New Pc.	0.56(F=66)	0.30
Exp. New Pd.	0.22(F=7)	0.05
Exp. Ex.Pc.	0.59(F=75)	0.34
Exp. Ex.Pd.	0.63(F=93)	0.39
Employment with		
Person years New Pc.	0.71(F=145)	0.50
Person years New Pd.	0.34(F=19)	0.10
Person years Ex.Pc.	0.60(F=81)	0.37
Person Years Ex.Pd.	0.63(F=92)	0.39

Note Figures in parenthesis indicate degrees of freedom.

As already established, it is useful to investigate the intensity of inventive input as a ratio of turnover and employment for different inventive activity. Table 4.11 presents the distribution of ratios of R&D expenditure to turnover in different kinds of inventive activity by industry classes. Different industries have supported various inventive activities with different intensities. The paper, printing, publishing and wood industries, for example, not only allocated a relatively large share of their turnover to new product development but were also least innovative where new process, existing product and existing process innovations are concerned. For new product development, the most innovative industries were the other machinery and equipment, paper and wood, fabricated metal product and miscellaneous manufacturing industry. Those industries concentrating on new processes were the textile, clothing and footwear, and other machinery and equipment. The non-metallic mineral product industries were the most intensive existing process innovative industry group. The non-metallic mineral product and other machinery and industry group can be also identified as the most existing product innovative industry sectors.

Table 4.10 Average Ratio of R&D Expenditure to Turnover for Process and Product Development by Industry Classes-1979/80.

	New Pc.	New Pd.	Ex.Pc.	Ex.Pd.	All R&D
Food,bev.&tob.	0.26	0.40	0.26	0.47	0.80
Textile,clo&footwear	2.20	0.48	0.11	0.13	2.42
Paper&Wood	0.15	1.87	0.12	0.11	1.68
Chemical,pet.&coal	0.50	0.75	0.22	0.41	1.67
Non-metallic mineral	0.55	0.38	0.83	1.05	1.93
Basic metal prod.	0.19	0.33	0.19	0.30	0.74
Fabricated metal	0.13	1.36	0.14	0.54	1.84
Transport equip.	0.61	0.89	0.18	0.23	3.56
Other machinery	0.77	2.97	0.33	1.05	3.78
Miscellaneous manu.	0.73	1.02	0.33	0.39	1.78
Industry Average	0.59	1.62	0.28	0.66	3.25

Inventive effort on existing products and processes compared with new products and processes varied considerably among industries. The non-metallic mineral product industries, for example, showed a high inventive intensity in existing product and process development but their effort on new product and process development was extremely weak. A large number of industry groups were heavily involved in the new process and product development compared with existing product and process activity. The chemicals, petroleum and coal product, transport equipment, and miscellaneous industries, in particular, showed a tendency to favour new product and process development. The combination of inventiveness differs greatly with industry sector. However, the low inventive industries in all frontiers can be identified as the food, beverage and tobacco products and basic metal products industries. These results indicate that R&D spending, as a percentage of turnover and employment, differs substantially according to the composition of R&D and also varies with industry classes.

The inventiveness of industries in terms of industry employment provides a somewhat different trend. A comparison of Table 4.10 and 4.11 suggests that the difference was quite significant in the case of some industry classes. Therefore, it is necessary to make a clear distinction in interpretation of the

Table 4.11 Average Ratio of R&D Personnel to Employment for Process and Product Development by Industry Classes-1979/80

	New Pc.	New Pd.	Ex.Pc.	Ex.Pd.	All R&D
Food,bev.&tob.	0.72	1.31	1.28	1.28	2.59
Textile,clo&footwear	0.81	0.68	0.37	0.51	1.28
Paper&Wood	0.32	1.79	0.24	0.21	2.12
Chemical,pet.&coal	1.53	2.18	0.75	0.96	4.53
Non-metallic mineral	0.91	0.87	1.54	1.11	2.95
Basic metal prod.	0.49	1.40	0.57	0.96	2.42
Fabricated metal	0.27	1.99	0.27	0.94	2.46
Transport equip.	1.61	1.54	0.26	0.22	2.56
Other machinery	1.31	3.75	0.63	2.07	5.37
Miscellaneous manu.	1.26	2.00	0.65	0.76	3.66
Industry Average	1.08	2.49	0.7	1.33	3.90

The growth of R&D expenditure, which was directed at various types of inventive activity, in different industries represents the rate of development of inventive effort in those industries. Table 4.13 presents the annual average growth rate of R&D expenditure at constant 1979/80 prices between 1976/77 and 1979/80. The rate of growth of types of inventive activities varied considerably in different industries. Existing product and process development effort declined in the food, beverages and tobacco industry. The fabricated metal products industry showed a decline in new product and process development but strengthened its existing product and process effort. The textile, clothing and footwear industry showed a high rate of growth in process development. New process development grew at a high rate in the other machinery and equipment industry and new product development was prominent in the basic metal industry sector. Similar growth rates are evident for manpower allocation.

Table 4.12 Percentage of Annual Rate of Growth of R&D Expenditure for Product and Process Development by Industry Classes (at constant 1979/80 prices)

	New Pc.	New Pd.	Ex. Pc.	Ex.Pd.
Food,bev.&tob.	21.9	13.0	-6.5	-0.5
Textile,clo&footwear	374.0	41.6	832.0	41.4
Paper&Wood	12.1	1.3	17.2	19.1
Chemical,pet.&coal	9.1	13.8	8.9	9.3
Non-metallic mineral	11.6	22.9	1.3	11.4
Basic metal prod.	30.5	90.4	25.5	31.6
Fabricated metal	-16.4	-4.8	12.2	16.3
Transport equip.	15.6	16.8	15.6	22.0
Other machinery	67.8	10.8	4.7	8.3
Miscellaneous manu.	11.9	2.2	0.3	0.7
Industry Average	11.7	13.6	5.8	13.0

There are some indications to suggest that inventive effort in different industry classes have grown quite differently, with some industries showing a móre interest towards increasing R&D expenditure on existing products and processes. For example, fabricated metal products showed a substantial increase in their R&D effort towards existing product and process development at the expense of new product and process development in that industry class. The tendency to shift from product to process development is further investigated in the next Chapter using a sample of R&D projects.

On the basis of the findings of this study, four groups of industries can be identified with respect to their preference for the various inventive activities.

a) Industries seeking cost-reducing and production efficiency increasing innovations. eg. textiles, clothing and footwear and other machinery and equipment;

b) Industries seeking new product development; eg. basic metal product industries and the chemical, petroleum and coal product industry;

c) Industries aiming at protecting existing products and processes and expanding existing markets; eg. non-metallic mineral product, and fabricated metal product industries;

d) Industries involved in exploiting new markets and technology, protecting existing technology and reducing cost in production technology; eg. other machinery and equipment and chemical, petroleum and coal products.

Such a categorization reflects overall industry behaviour and is not intended to demarcate firms strictly into any one of the categories. Neither can these strategies can be used as the basis for prescriptions as to what is appropriate for a particular sector of industry; individual needs of companies determine the adequacy and appropriateness of innovations undertaken. Nevertheless, this breakdown first of all serves to emphasis the extent of differentiation within Australian manufacturing industry. Different firms, and to some extent different industry classes, have quite different needs and objectives with respect to the introduction of technology, and hence need to draw on quite different resources and support systems to achieve their goals. The implications for government policies to support technological development are considerable.

Take

4.6 Effect of Firm Size on Inventive Activity

The influence of firm size on inventive activity has been thoroughly examined in a number of overseas studies.[28] Some of the major findings are that relatively small firms are engaged more on new product development as a response to market needs with high performance products (Abernathy and Utterback,1975); small firms introduce a disproportionate share of commercially oriented innovations to the market place (Roberts,1980); small business has produced a significant number of the key innovations (Roberts,1980); small firms are particular suited to encouraging major product innovations (Abernathy and Utterback, 1979); relatively smaller firms tend to be more successful in R&D in terms of both the number of new products and the number of patented inventions in relation to R&D effort in person-years (Nystrom and Edwardsson,1980). On the other hand, large firms are considered to have greater incentives to innovate than small firms especially in the cost reducing process technology (Sahal, 1983b). This may be due to the relatively large market share of large firms which enables them to capture a sizeable proportion of sales and profits arising from new innovations. However, the effect of firm size on inventive activity is not conclusive (Griliches, 1980,p.440). Sahal (1983b) has also pointed out that there is no optimum firm size or industry structure most conducive to inventive activity.

In Australian industries, Johns *et al.* (1978) have shown that small firms (employing less than 150 employees) undertaking R&D generally spend more

28 See Chapter one for an extensive review of literature. A detailed discussion of firm size, innovation and market structure is found in Kamien and Schwartz (1975) and Scherer (1980).

in relation to their sales revenue than do large firms. Mclean and Round (1977) suggested that R&D effort is likely to increase more than proportionately with size at least up to some 'threshold' size of firm. This section examines the effect of firm size on generating industrial innovations and the ṙole of small-sized firms in inducing innovations compared with their large counterparts.

The definition of firm size, however, is not consistent. The level of firm employment, sales, and turnover have been used to identify the size categories. However, a firm with few employees may produce a large turnover. The Wiltshire Committee report (1971) took into account a number of criteria, including the managerial control of the firm, to define size. The Bolton Committee report (1972) considered a small share of market, absence of formalized management structure, and freedom in decision making ability as features of a small firm. Rothwell (1982) has pointed out that the concept of size of firm can vary enormously from country to country as well as from sector to sector within a country. They defined small-sized firms as having less than 500 person in total employment. It is clear that size of firms cannot be adequately defined in terms of employees, assets or turnover and other statistical quantity. It is necessary to consider a number of factors such as share of the market, type of management, and type of ownership together with these statistical measure. In Australia, Johns *et al.*, (1978) considered that fewer than 100 employees constitutes a small firm. This selection criterion is rather, for research intensive industries it may be appropriate to set the employment level at even less than 100 for Australian industries[29] .

In this study firms are divided into three size groups based on the total number of employees. These categories are

a) 1-50 -Small

b) 51-500 -Medium

c) over 500 -Large

A similar quantitative measure has been adopted in West Germany to define small, medium and large firms (Stroetmann,1979).

Another quantitative measure adopted to define firm size in this study is the turnover of firms. National definitions of firm size according to turnover size can also be vary from $1 million to $5 million (Rothwell, 1982). Inventive effort was first examined according to different employment sizes. The findings according to turnover sizes showed no significant difference from those according to employment size. Therefore, it was decided to use only employment sizes to explain variation of inventive activity according to company size.

R&D spending according to firm size is set out in Table 4.13 and 4.14.

29 Australian manufacturing Council reported that approximately 80% of Australia's manufacturing enterprises employ fewer than 100 persons(Australian Manufacturing Council, 1975)

Table 4.13 Total R&D Expenditure by Firm Size ($'000)

Firm Size	1976/77	1978/79	1979/80
Small(1-50)	1334(21)	2228(29)	2435(28)
Medium(51-500)	4682(75)	6522(85)	7910(93)
Large(over 500)	17969(544)	22519(536)	25928(617)
Total	23985(152)	31269(160)	36273(169)

Note Figures in parenthesis indicate average expenditure per firm.

The level of R&D expenditure and manpower allocated increases with firm size. Small firms collectively contributed only 7 per cent of the total R&D expenditure and 9 per cent of the total manpower. In contrast, large firms, which numbered 38 firms, were responsible for 71 per cent of R&D expenditure and 58 per cent of research effort measured in terms of research staff. Thus, in terms of total effect, the vast majority is performed by the large firms.

Table 4.14 Total R&D Manpower by Firm Size (person-years)

Firm Size	1976/77	1978/79	1979/80
Small(1-50)	76.4(1.3)	96.8(1.3)	103.5(1.3)
Medium(51-500)	242.2(3.9)	278.0(3.7)	293.0(3.6)
Large(over 500)	507.4(16.4)	567.8(14.9)	558.6(14.7)
Total	825.9(5.4)	942.6(5.0)	955.1(4.7)

Note Figures in parenthesis indicate R&D manpower per firm.

However, research intensity, measured by the ratio of R&D expenditure to turnover, by firm size (Table 4.15) provides a different picture. Small manufacturing firms are the most research intensive, allocating a relatively higher proportion of resources to R&D than medium and large firms. This is quite interesting as studies by Nelson *et al.* (1967) and Mansfield (1968) have shown that the largest firms in most industries spend no more, as a percentage of sales, on R&D than do smaller firms. In Australian industries opposite is true. Most small firms spend higher resources on R&D, as a percentage of turnover, than do medium and large firms.

Table 4.15 Research Intensity (R&D Expenditure/Turnover) by Industry Classes According to Firm Size-1979/80

Firm Size	Small	Medium	Large
Food,bev.&tob.	1.1	0.8	0.04
Textile,clo.&footwear	-	3.0	0.7
Paper&Wood	5.5	0.4	0.4
Chemical,pet.&coal	2.4	1.4	0.3
Non-metallic mineral	4.2	0.7	1.3
Basic metal prod.	1.5	0.6	0.4
Fabricated metal	1.8	2.0	0.2
Transport equip.	3.5	0.3	0.7
Other machinery	5.5	1.7	1.2
Miscellaneous manu.	2.2	1.7	1.0
Industry Average	3.7	1.6	0.6

With the exception of the textile, clothing and footwear and fabricated metal divisions, the small group of firms are the most research intensive in each industry class. In particular, small firms of the other machinery and equipment, paper, printing and wood, and non-metallic mineral product industries showed and outstanding research intensity with ratios well above the industry average. Medium-sized firms of fabricated metal products and textile, clothing and footwear industries showed a high research intensity. Large firms in the other machinery and non-metallic mineral product industries have a research intensity well above the average for firms of their size. Although the small chemical industries were more research intensive than medium or large chemical firms, the research intensity of chemical industries in general was well below the average. The most research intensive was the other machinery class.

Research intensity measured as a ratio of R&D personnel to total industry employment for different firm sizes and industry groups also shows small firms to be more research intensive. In most industry classes small firms allocated a higher percentage of industry employment to R&D activity (Table 4.16).

Table 4.16 Research Intensity (R&D personnel/Employment) by Industry Classes According to Firm Size, 1979/80.

Firm Size	Small	Medium	Large
Food,bev.&tob.	5.0	2.4	0.2
Textile,clo.&footwear	-	1.7	0.2
Paper&Wood	10.0	0.8	0.8
Chemical,pet.&coal	6.3	4.6	1.4
Non-metallic mineral	5.8	0.9	1.9
Basic metal prod.	4.5	2.0	1.1
Fabricated metal	3.5	1.5	0.8
Transport equip.	11.7	1.2	0.4
Other machinery	7.5	2.8	1.4
Miscellaneous manu.	5.2	2.3	1.5
Industry Average	6.3	2.6	1.1

The other machinery and equipment, transport equipment and paper and wood industry classes had the most research intensive small firms. The medium-sized firms of the chemical and other machinery industry classes showed a high research intensity. Among large firms, the firms in the other machinery and equipment, chemicals, non-metallic mineral products and miscellaneous industries had a relatively high research intensity. The small firms, however, was responsible for only 11 per cent of R&D employment, whereas the medium and large firms had 31 and 58 per cent research employment respectively during 1979/80. In some industry classes there is a considerable variation between the two R&D research intensity measures. It is of interest to examine whether firm size is an important factor in commitment to product versus process and new versus existing technology development.

Table 4.17 Average R&D Expenditure per Industry on Product and Process Development by Firm Size($'000)

Firm Size	New Pc.	New Pd.	Ex.Pc.	Ex.Pd
Small(1-50)	9.3(n=36)	19.8(n=77)	5.9(n=24)	7.8(n=48)
Medium(51-500)	28.2(n=46)	56.2(n=61)	29.7(n=32)	37.4(n=52)
Large(over 500)	148.2(n=33)	255.0(n=35)	184.9(n=31)	189.0(n=33)
Average	56.7(n=115)	80.2(n=173)	78.4(n=87)	64.3(n=133)

Note n denotes number of cases.

The allocation of R&D expenditure per firm (Table 4.17) increased from small to large firms in all types of inventive activity indicating that inventive input increases as firm size increases. The average R&D expenditure per firm in small and medium sized firms was well below the industry average. The difference between the average R&D expenditure per firm in large and the combined small and medium firms was quite significant.

Small firms devoted most of their effort to new product innovations. The average expenditure per firm in all firm sizes was greatest for new products; however, medium and large firms demonstrated an increasing interest in other inventive activities as well. The overall pattern indicates that new process development is given a relatively low priority, whereas the development of new products and existing products was the major objective of industry's inventive effort.

Similar results were obtained for manpower allocation. The average person-years spent on R&D during 1979/80 by firms in various inventive activity indicates a significant variation according to their sizes (Table 4.18).

Table 4.18 Average R&D Personnel per Industry in Product and Process Development by Firm Size($'000)

Firm Size	New Pc.	New Pd.	Ex.Pc.	Ex.Pd
Small(1-50)	0.48(n=33)	0.83(n=72)	0.29(n=23)	0.4(n=44)
Medium(51-500)	1.01(n=47)	2.07(n=62)	1.11(n=33)	1.3(n=54)
Large(over 500)	4.07(n=30)	4.0(n=35)	5.4(n=29)	5.1(n=30)
Average	1.68(n=110)	1.91(n=165)	2.35(n=85)	1.89(n=128)

Note n denotes number of cases.

The manpower allocation per firm increased substantially with firm size. Small firms allocated relatively fewer person years per firm than large firms. New product innovations received a high priority in small firms. Medium-sized firms also followed a similar trend. Large firms allocated a high proportion of manpower to existing process development. The overall manpower allocation by firm size suggests that existing process development has been slightly favoured and once again new process development has been the least pursued.

The average R&D expenditure per person year on the different inventive activities for various firm sizes exhibits little variation (Table 4.19). Within a particular size of firm, per capita expenditure among different inventive activities provides very little difference. Medium-sized firms have a higher tendency to allocate slightly more expenditure per person year than others. This suggests that the average expenditure allocation per person year to the various inventive activities does not differ much. Apparently the capital intensity of the inventive activities are all approximately the same, irrespective of firm size.

All industries show a consistent pattern of resource allocation per capita to the different inventive activities. Small firms had a low per capita R&D expenditure compared with medium and large-sized firms. This indicates that in small firms capital cost was not high compared with medium and large firms. Rothwell and Zegveld (1978) have concluded from a study of number of R&D systems in industrialized countries that small firms played a vital role in total sectoral innovation in areas where capital costs were low and R&D requirements were not too high.

Table 4.19 Average R&D Expenditure per Research Person on Product and Process Development by Firm Size($'000)

Firm Size	New Pc.	New Pd.	Ex.Pc.	Ex.Pd.
Small(1-50)	21.3(n=32)	25.9(n=71)	23.7(n=22)	25.0(n=42)
Medium(51-500)	31.7(n=43)	31.2(n=58)	33.2(n=31)	30.4(n=50)
Large(over 500)	27.1(n=29)	29.2(n=30)	27.7(n=28)	28.2(n=29)
Average	27.2(n=104)	28.5(n=159)	28.7(n=81)	27.9(n=121)

Note n denotes number of cases.

One of the arguments supporting the important role of large firms in innovation is that it is only with their considerable resource that long-term and risky project can be pursued. The average ratio of R&D expenditure to turnover for various inventive activities and sizes of firms shows a considerable variation (Table 4.20). Small firms allocated a relatively higher turnover ratio than the medium and large firms. Small firms spent a high proportion of their turnover on new product innovations and existing product development also received considerable support. In general it has been argued that small firms are predominantly active in new product development. New products and other radical innovations tends to come out of new entrants to a market, especially new small firms (Sutton, 1980; Utterback,1979). The extent of existing product development may reflect the extent to which many companies in Australia are small not because they are new entrants, but because they seek or able to achieve only small markets.

Medium-sized firms also have allocated a high ratio of turnover to new product inventive activity. On the other hand large firms have distributed their resources evenly among different inventive activities.

In general, there is some evidence to believe that inventive activity in small firms is intensive and directed towards specific industry requirements. These results further strengthen the findings of Johns *et al.*, (1972) who argued that small Australian firms spent a high proportion of firm resources on R&D relative to their size. Small firms have also been relatively active in product development, both existing and new. Medium-sized firms, in particular, have low inventive input intensities and constitute a real weakness into the industrial research structure. Medium-sized firms are particularly strong in new product and new process development and payed little attention to existing product and process development. It may be that medium-sized firms have captured a sizable market and enjoyed monopolistic market conditions under government protection policies, and hence do not perceive a need for improving existing products. On the other hand, they may prefer to be involved in completely new technological areas due to increasing competition from overseas products and diminishing profits as result of rising labour costs.

Large firms dominate the industrial research activity presently being carried out. They also have the capacity to spend more of their resources to R&D activity. Large firms have directed more or less similar intensity of R&D activity towards all types of inventive activities, suggesting their need to develop a broad portfolio of inventive activity.

Table 4.20 Average Ratio of R&D Expenditure to Turnover for Product and Process Development by Firm Size($'000)

Firm Size	New Pc.	New Pd.	Ex.Pc.	Ex.Pd
Small(1-50)	0.9(n=36)	2.7(n=77)	0.5(n=24)	1.3(n=48)
Medium(51-500)	0.7(n=46)	1.0(n=61)	0.2(n=32)	0.4(n=52)
Large(over 500)	0.2(n=33)	0.3(n=35)	0.2(n=31)	0.2(n=30)
Average	0.6(n=115)	1.6(n=165)	0.3(n=82)	0.7(n=133)

Note n denotes number of cases.

4.7 Conclusions

The results of the survey of the industrial R&D structure of 273 Australian manufacturing firms detailed in this chapter reveal a number of clear characteristics. There are general patterns concerning level of R&D performance, the objective of innovation, the types of inventive activity, and their relationship to firm size. But perhaps the most striking finding is the great level of diversity between different industrial classes, and different firms. Hence, it is necessary to bear in mind always in seeking to understand the nature of industrial R&D in Australia, or to plan policy to affect it, that the manufacturing industry is anything but homogeneous. It has many different characteristics which need to be taken into account in these considerations.

These results also must be interpreted with the recognition that the sample studied in this survey reflects the cream of Australian industrial R&D performing and technology developing firms. Hence, the characteristics of this elite group will not necessarily, and indeed are quite unlikely to, reflect the larger group of manufacturing firms. However this smaller group, to the extent that it does represent the technology intensive firms, can be regarded as the most dynamic and perhaps most important element of Australian manufacturing industry and therefore in need of detailed study in its own right.

Even in this sample of research intensive companies, a major proportion of firms (58%) spent less than 1% of their turnover on R&D. The range of R&D spending varied considerably but nearly 88% of small firms, 46% of medium firms, and 20% of large firms spent less than $50,000 on R&D. Only three industry classes, namely chemicals, petroleum and coal products, transport equipment and other machinery equipment, devoted sufficient research resources to development of technology to be rated as technology intensive. It is of value to note that these industries were also the outstanding three with regards research intensity as early as the 1940's, as indicated in chapters 2 and 3. While the actual industrial activity under these general classes varied over time, the fact that these three classes have remained dominant ones as far as technology development is concerned over forty years indicates a remarkable stability, or one might say rigidity, in the Australian manufacturing industrial structure. One particular characteristic of the industrial R&D structure is that level of R&D performance is not a measure of R&D intensity. In general large firms spent a relatively small proportion of turnover on R&D whereas small firms spent a relatively high proportion of their turnover. In fact it was the small firms who were research intensive, and not the large firms, though, of course, large firms still contributed, in absolute terms, the largest amount to national industrial R&D budget. These findings suggest, firstly, that it is the small companies in Australia who have a fairly strong orientation toward innovation and technology development; and secondly there is likely to be a threshold limit of R&D expenditure required for successful innovation, and that small firms will have to allocate a substantial proportion of turnover in order to reach this minimum limit.

Another remarkable feature to emerge from this survey was that nearly half of the number of firms examined altered their annual R&D budget by more than ten percent between 1978 and 1979. Rather remarkably, more than 30% increased their budget beyond the ten percent level and somewhat less than 20% decreased it by more than 10% . This suggests a remarkable instability in the Australian manufacturing industry R&D, with firms making marked increases, or decreases in their budgets from year to year. Given the generally long term nature of R&D objectives, and the need to have a clear view of the way in which the R&D function will contribute to corporate objectives, this suggests that R&D is poorly understood and managed in Australian firms.

Of those who substantially increased their R&D commitment, two thirds were large firms and one third were small firms. No medium sized firms increased their level of expenditure. This reflects the extent to which the industrial R&D structure in Australia is bifurcated, dominated by large firms and small firms with medium sized firms playing relatively little part - a point we will return to later. In addition, the firms increasing their investment in R&D substantially were to a very significant extent (about 53%) those within the three research intensive classes.

A high orientation of industry towards new product development discovered by this survey has already been commented on. These findings appear to be in some contrast to previous studies, which suggested that the industrial R&D structure in Australia focuses primarily on adaptation, minor modification, and development of imported technology, with very little new technological advances. More recently, Thompson (1983)has pointed out the inadequacy of R&D activity in existing product and process development, and the heavy concentration in Australian industry on new product and process innovation.

Abernathy and Utterback (1975 and 1979), have demonstrated the need for different types of inventive activity during different stages of development of firms, and their products. The product and industry life-cycle theory they advanced showed that during the early stages of manufacturing organizations focused on product innovation, but as the organization grows and matures, its focus shifts to major process innovations. The argument in favour of product innovation springs from the need for continual development in firms due to the short life cycle of products, particularly in high technology areas. This product cycle theory has been further extended by Maier and Haustein (1980) to include the changes in capital and labour inputs to an industry. They argue that the underlying nature of technical change in firms shifts from new products to new processes in accompaniment with substitution of capital for labour. Firms tend to undertake more process innovations as labour costs escalate. Of course, new product developments also require capital, but process innovations, with implications for major changes for methods of production, require much more working capital. On this basis, under Australian conditions of relatively high wages, it has been argued that there has been considerable pressure for process innovation. Utterback (1979) has also stressed that product changes are particularly appropriate to new entrants to an industry, and business growing around the generation of new products, because of their need to obtain a market share in a situation where there are many competitors. However, process innovations, with their emphasis on reduction of production costs, are more appropriate to holders of large market shares. Studies of industry concentration in Australia suggest that a number of industry classes, such as the basic metal and transport industries, exhibit a high level of concentration. Hence, in these areas, it might be expected that process innovation would predominate over product innovation.

The data from this survey show a few industry classes. such as the non-metallic mineral product industries, have been exclusively involved with existing process and product development and this may relate to the state of technological requirements in these mature industries. If the nature of inventive activity can be taken as a direct measure of immaturity of industries, as implied by Utterback and Abernathy (1975), the implications of this for Australian manufacturing industry is that either most industries have not reached the maturity phase, or that most mature industries are attempting to diversify their commercial activity. Certain mature industries such as the textile, clothing and footwear, and non-metallic mineral product industries, did spend a high proportion of their resources on process development. The rate of growth of R&D expenditure indicates that the textile, food, and basic metal products, and other machinery and equipment industries increased their R&D expenditure on new process development activity to some extent at the expense of product development. However, before seeking to interpret these results further, it is necessary to examine carefully their basis.

There are a number of reasons to suggest that the sample surveyed here incorporates a number of biases, which are in part responsible for the high new product development orientation which was noted. Firstly,it is important to remember that the samples studied here constitute the elite technology intensive companies in Australian manufacturing industry. According to these measures, one would therefore expect the companies to be more innovative, more prepared to take risks, and hence to focus more on new product development than the whole sample of Australian manufacturing industry. In other words, this particular sample may be selecting out those risk-taking companies which have an unrepresentatively high portion of new product development.

Secondly, a large part of this sample of companies was selected from t hose who applied for Australian Industrial Research and Development Incentive Grants. It has been argued (Johnston *et al.*, 1981), that the requirements of this scheme in terms of the conditions which must be fulfilled in applying for grants and spending the money, and the particular characteristics that are sought bias the recipient very heavily towards new product development. Modifications that exist in products and processes, and to a significant extent the development of new production techniques are much less able to be described in terms that will meet the IR&D Incentives Board requirements and demonstrate the kind of market which can be expected from the investment. Hence, this sample may have a further significant bias towards new product development. Not only does the influence of the IRDI Scheme provide an explanation for the bias in the samples quoted here, but more importantly it provides evidence that the scheme may be significant to the extent of encouraging only new product innovation. Such an objective might be quite appropriate, particularly as it has been argued that there is insufficient orientation towards new product innovation in the Australian industry. However, it is important to recognize that if the main objective of R&D is new product development, it has to be well supported by various other activities such as prototype development, bench scale and pilotplant research, and market and commercial development activities (Mansfield *et al.*, 1977). It is quite insufficient to simply support the R&D component of new product development and hope that this will, of itself, lead to successful commercial activity. Enhancement of this kind of R&D without the necessary infrastructure within companies may have a very high failure rate.

A third explanatory feature for the high level of new product development may rest in the make up of Australian manufacturing industry. The high proportion of small firms which we have already noted, with their limited capital resources are far more likely to be oriented towards new product development than to process development.

However, allowing for all these biases and explanations, there still appears to be a need to seek an understanding of a relatively high orientation to new product development. The assumptions made in most studies are that new products involve new technology. However, as shown in the next chapter, the level of technology involved in product development is rarely at the international forefront. Frequently a new product rests only on technology which is new to that particular company; hence, it appears to be a feature of the Australian economy that companies develop new products for markets which they are fairly assured of and which do not incorporate significant advances in technology. This emphasis on 'new products and old technology' may in fact be a reflection of the general import substitution policy which still shapes industrial activity in Australia. Companies are primarily seeking to develop products which can compete with or replace exports, with the assistance of various protective measures, and hence where technological competitiveness is not a critical feature. Hence, it may well be that in the Australian environment new product development should not be equated necessarily with high risk taking activity. This would be supported by the finding of a very low level of investment in improvement in existing products which suggests that once a product has been manufactured there is very little attempt to further develop it.

The possible implications of directing most of R&D to product development may be considerable. If there is a high level of uncertainty, then it is likely that technical and commercial failures of new products will be quite common,which may well have contributed to the dampening of enthusiasm of Boards of Directors to commit resources to research departments. Moreover, an excessive focus on new product developments may lead to a failure to protect existing products through technological development and market maintenance, so that firms fail to capitalise on potential opportunities to expand already established technological bases in a firm. There are also implications for Government policy, which will be taken up later.

With regard to the product and technology life cycle theory, it may well be that its general characteristics do not hold in the Australian context because of the particular features of our economic and industrial structure. In particular, the assumption that the development of new products as a means of entrance to the other stages of industrial development may not be appropriate in an economy where the dynamic features on which it rests are not present. New product development may simply be a way of diversifing product ranges and in new areas with relatively little cost to establish a significant share of a captive market.

However, to understand further the dynamics of technology development in Australian industry and in particular to focus on product development it will be necessary to examine activities at the level of the project rather than at the level of the firm. This will be done in the next chapter.

The relationship of R&D input and economic output of firms examined in this study support the established relationship between economic output and the R&D inputs. It is evident that there exist a strong association between R&D expenditure and manpower with firms' turnover and employment. The relationship is stronger in the case of manpower and employment than expenditure and turnover. This suggests that R&D manpower intensity may be a better indicator than expenditure. The correlation coefficient has fluctuated according to different type of inventive activity. In particular, new product development has a lowered its coefficient while others showed an increase. This indicates that new product development in firms do not strongly affect by economic fluctuations because even at adverse situations new product development may be continued uninterrupted.

Firm size, as discussed in Chapter 2, has often been seen as a critical factor in determining the capability and achievements of industrial R &D. In this survey, the relationship between size of firm and inventive activity in industry indicates that small firms were the most research intensive. Large firms spent a relatively large amount of resources per firm but their research intensity measured in terms of R&D expenditure to turnover and R&D personnel to manpower is low. Small firms in all industry classes showed a higher research intensity than medium and large firms and small firms were generally interested in new product development. It indicates that small firms may have less capacity to be involved in process changes due to high cost and rigidity in technological investment in small firms. However, it is important to note the high innovativeness and the concentrated product development effort of small industries in the formulation of government science policy. Dunlop (1976) argued that small business enterprises has flexibility and adaptability which provides additional important opportunities for product and process innovation. Existing product development was largely pursued by large firms. Medium firms generally showed a low profile in R&D activity.

These results by an large provides a useful basis for the development of government science policies. The policy implications arising from this study can be examined according to:

a) development of industrial R&D capabilities;

b) promoting product and process innovations;

c) encouraging new and existing innovations; and

e) providing special incentives according to institutional differences and innovative intensities.

Although the industrial research effort remains confined to a relatively small number of firms, there is an increasing number of small and highly innovative firms engaged in inventive activities. These firms possess only a limited capabilities and the mechanisms provided by the institutions are not sufficient to increase the innovativeness of such firms. The governments should recognize the need for developing special mechanisms such as specialized institutions, appropriate inventive assistance schemes and encouragements to use such schemes to develop technological bases of small firms. There exist convincing evidence to suggest that medium sized firms were lack of dynamism in developing inventive activities. It may be necessary to formulate completely a different kinds of policies to encourage inventive activities in small and medium sized firms and this may be easily achieved through development of regional services. The government policies also should accommodate a conducive environment for product development activity through provision of factors such as prototype and pilotplant development. marketing and management skills,and venture capital. The interaction of other policy mechanisms such as tariff, industrial protection and tax incentives should be evaluated in the light of different industry requirement in developing technological advances in firms.

Reference Chapter Four

Abernathy, W.J. and Townsend, P. (1975) 'Technology, productivity and process change', Technological Forecasting and Social Change. Vol 7(4),pp 379-396.

Abernathy, W.J. and Utterback, J.M. (1975) 'A dynamic model of process and product innovation', Omega, Vol. 3(6), pp.639-656.

Abernathy,W.J. and Utterback, J.M. (1978) 'Patterns of industrial innovation', Technology Review, June/July,Vol80(7),p.41-47.

ABS, (1979) Research and Experiment Development Private Enterprises 1976/77,Cat.No. 8104,Canberra;ABS.

ABS, (1981) Research and Experiment Development Private Enterprises Australia 1976/77, Cat.No. 8104, Canberra;ABS.

ABS, (1983) Research and Experiment Development Private Enterprises Australia 1981/82,Preliminary, Cat.No. 8104, Canberra;ABS.

Australian Manufacturing Council (1975)

Bollinger, L., Hope, K., and Utterback, J.M. (1983) 'A review of literature and hypothesis on new technology-based firms', Research Policy, Vol. 12(1),Feb.pp.1-14.

Bolton Committee Report, (1972) Small Firms-Report of the Committee of Inquiry on Small Firms, Cmnd 4811,London;HMSO.

Braun, E. (1981) 'Constellation for manufacturing innovations' Research Management, Vol. 9(3), pp.247-253.

Burrows, G.H. (1981) ' Factors influencing the size of firm budgets for research and development', Accounting and Finance, Vol. 21(2), pp.87-96.

Comanor, W.S. (1965) 'Research and technical change in the pharmaceutical industry', Review of Economics and Statistics, Vol. 47(2), May, pp.182-90.

Comanor, W.S. and Scherer, F.M. (1969) 'Patent statistics a measure of technical change', Journal of Political Economy, Vol. 77(3),May/june,pp. 392-398.

Department of Industry, (1974) 'Resources devoted to research and development by manufacturing industry',Economic Trend, March, No. 245 pp. 33-44.

Dunlop, W.C. (1976) 'The small firm', in Lindgren, K.E. and Aislabie, C.W ed, The Australian Firm, Sydney;McGraw Hill, pp.145-157.

Etienne, E.C. (1981) 'Interactions between product and process technology',Research Management, Vol. XXIV(1), pp.22-27.

Freeman, C. (1962) 'Research and development: a comparison between British and American Industry'National Institute Economic Review May, pp.21-39.

Freeman, C., Clark, J. and Soete, L. (1982) Unemployment and Technical Innovation, London; Frances Pinter(Pub.).

Gerstenfeld, A. (1978) 'Technological innovation and government regulation. Examples for building, construction and pharmaceutical industries', Paper presented at the National Conference on the Advancement of Research, U.S.A. September.

Griliches, Z. (1980) 'Returns to research and development in the private sector', in Kendrick, J.W. and Vaccara, B. eds, New Development in Productivity Measurement and Analysis,New York;NBER.

Grabowski, H.G. and Mueller, D.C. (1978) 'Industrial research and development, intangible capital stocks, and firm profit rates', Bell Journal of Economics, Vol. 9, pp.328-43.

Herkert, J.B. and Wilson, J.D. (1967) Business Budgeting and Control, New York; Randal Press.

Johns, B.L., Dunlop, W.C. and Sheehan, W.J. (1978) Small Business in Australia-Problems and Prospects, London;George Allen&Unwin.

Johnston, R. and Carmichael, S. (1981) Australian Science and Technology Indicators Feasibility Study-Private Sector Final Report, Dept. of Science, Canberra.

Johnston, R., Newton, J. and Smythe, B.M. (1981) The Effects of Government Support for Australian Industrial Research and Development, Commissioned by the Department of Science and Technology, Canberra.

Johnston, R. (1982)

Kamien, M.I. and Schwartz, N.C. (1982) Market Structure and Innovation, Cambridge; Cambridge uni. press.

Langrish, J., Gibbons, M., Evans W.G. and Jerons,F.R. (1972) Wealth from Knowledge, New York;Macmillan.

Link, A. (1982) 'An analysis of the composition of R&D spending', Southern Economic Journal, Oct.,Vol. 49(2), pp.342-349.

Maier, H. and Haustein, H.D. (1980) Innovation,Efficiency, Cycle and Strategy Implications,IIASA, Laxenberg, Austria, June(Mimeo).

Mansfield, E. (1968) Industrial Research and Technological Innovation, New York; Norton.

Mansfield, E., Rapport, J., Schnee, J., Wagner, S. and Hamberger, M. (1971) Research and Innovation in Modern Corporation, New York; Springer-Verlag Inc.

Mansfield, E., Rapoport, J., Romeo, A., Villani, E., Wagner, S., and Husic, F. (1977) The Production and Application of New Industrial Technology, New York, W.W. Norton & Co.

McEachern, W.A. and Romeo, A. (1978) 'Stockholder control, uncertainty and the allocation of resources to research and development, Journal of Industrial Economics, Vol. XXVII, pp.349-61.

McGraw Hill (1975) Business Plans for R&D Expenditures 1975-1978, New York; McGraw Hill.

McGuinness N.W. and Little, B. (1981) 'The impact of R&D spending on the foreign sales of new Canadian industrial products', Research Policy, Vol. 10 pp.

McLean, I.W. and Round, D.K. (1977) 'Addendum:R&D expenditure and firm size in Australian manufacturing, 1971-1972',in Tucker,K.A. ed. The Economics of the Australian Service Sector, London:Croom Helm.

McLean, I.W. and Round, D.K. (1978) 'Research and product innovation in Australian manufacturing industry', Journal of Industrial Economics, Vol. XXVII(1), pp.1-12.

Muller, D. (1966) 'Patent, research and development and the measurement of inventive activity' Journal of Industrial Economics, Vol. 15, pp. 26-37.

Myers, S. and Marquis, D.G. (1969) Successful Industrial Innovations, National Science Foundation, 69,17 Washington;NSF.

Mowery, D. and Rosenberg N. (1979) 'The influence of market demand upon innovation-a critical review of some recent empirical studies', Research Policy, Vol. 8, pp.102-153.

National Science Foundation (1979) Science Indicators-1978,Washington DC; Govt. Printer.

Nelson, R., Peck, M. and Kalacheck, E. (1967) Technology, Economic Growth and Public Policy, Washington; Brooking Institute.

Nystrom, H. (1979) 'Company Strategies for research and development', in Baker, M.J. ed. Industrial Innovation, London: MacMillan, pp. 417-441.

Nystrom, H. and Edwardsson, B. (1980) 'Research and development strategies for Swedish companies in the farm machinery industry', in Sahal, D. ed. Research, Development and Technological Innovation, London;Lexington Books.

OECD (1977)Review of National Science Policy Australia, Paris;OECD.

OECD (1980) Technology Transfer to Developing Countries. Study No 4, 1st revision, DSTI/SPR/80.16, Oct. Paris;OECD.

Olin, J. (1973) 'R&D management practices: Chemical industry in Europe' R&D Management, Vol. 3, pp.125-35.

Pavitt, K. (1980) ed. Technical Innovation and British Economic Performance, London; McMillan press.

Pavitt, K. and Walker, W. (1976) 'Government policies towards industrial innovation' Research Policy, Vol. 5(1), pp. 11-92.

Roberts, E.B. (1980) 'Getting new ventures off the ground'. Management Review, June,pp.

Rosenbloom, R.S. (1974) ,Technological Innovation in Firms and Industries;An Assessment of State of Art, Working Paper,HBS74-8,Harvard Business School, Boston.

Rothwell, R. (1982) 'Government innovation policy - Some past problems and recent trends', Technological Forecasting and Social Change, Vol. 22(1),pp.3-30.

Rothwell, R. and Zegveld, W. (1978) Small and Medium Sized Manufacturing Firms: Their Role and Problems in Innovation-Government Policy in Europe, the U.S.A., Canada, Japan and Israel, Report to the six countries programme on innovation, TNO, Netherlands.

Sahal, D. (1983a) 'Invention, innovation, and economic evaluation'Technological Forecasting and Social Change. Vol. 23(3), pp.213-235.

Sahal, D. (1983b) 'Technology, productivity and industrial structure', Technological Forecasting and Social Change, Vol. 24(1), Sept. pp. 1-13.

Scherer, F.M. (1967) ,'Research and development resource allocation under rivalry', The Quarterly Journal of Economics,Vol. LXXXI(3),Aug. pp.359-394.

Sherer, F.M. (1980) Industrial Market Structure and Economic Performance. Chicago; Rand McNally.

Sherer,F.M. (1982) 'Demand-pull and technological invention:Schmookler revisited',The Journal of Industrial Economics. Vol XXX(3),pp.225-237.

Schott, K. (1976) 'Investment in private industrial research and development in Britain', The Journal of Industrial Economics, Vol.XXV(2), pp.81-99.

Soete, L. (1980) The Impact of Technological Innovation on International Trade Patterns-The Evidence Reconsidered,STIC/80.33,Paris;OECD.

Stroetmann, K.A. (1979) 'Innovation in small and medium-sized industrial firms-A German perspective', in Baker,M.J ed. Industrial Innovation London;MacMillan Press.

Sutton, C.J. (1980) Economics and Corporate Strategy, Cambridge; Cambridge Uni. press.

Taylor, C.T. and Zilbertson, Z.A. (1974) The Economic Impact of the Patent System;A Study of British Experience,Cambridge;Cambridge U.P.

Thompson, J.W. (1983) Quality-An Essential Requirement in the Australian Manufacturing Industry,Report No.4/83,Canberra;Institution of Engineers,Aust.

Twiss, B. (1980) Managing Technological Innovation,2nd.edition,London;Longmann.

Utterback, J.M. (1974) 'Innovation in industry and the diffusion of technology',Science, Vol. 183, pp. 620-626.

Utterback, J.M. (1979) 'The dynamics of product and process innovation in industry' in Hill, C.T. and Utterback, J.M. ed. Technological Change for a Dynamic Economy, New York; Pergamon press.

Utterback, J.M. and Abernathy, W.J. (1975) 'A dynamic model of process and product innovation', OMEGA,Vol. 3(6), pp. 639-656.

Walker, W. (1979) Industrial Innovation and International Trading Performance, Greenwich;JAI press.

Wiltshire Committee Report (1971) Report of the Committee on Small Business,Canberra;Dept. of Trade and Industry.

Wulfsberg, A.H., (1978) 'Productivity-management to rescue',IEEE Spectrum,Vol. 15(10), Oct. pp.74-78.

Chapter Five

R&D Project Formulation and Management: Directing Industrial R&D in Manufacturing Industry

5.0 Introduction

Inventive activities undertaken in industries to advance technology and productivity are most commonly selected and/or assessed on an annual basis and are conducted through specific R&D projects. The efficiency of industrial R&D organization is largely dependent on the successful performance of the R&D project portfolio of a company. Examination of individual R&D projects offers the possibility of a more detailed analysis of the innovative process and its effectiveness in industry. Too many studies have been severely limited by the high level of aggregation of data. But in addition, only analysis at the project level will permit an assessment of issues such as the source of idea generation; the appropriateness of proposed or on-going projects to industry requirements; the determinants of selection, evaluation and success of projects; the factors involved in project formulation policy; and the improvement of resource allocation to R&D projects.

R&D activities of firms can be classified into two types according to objective. Some inventive activities are incremental in the sense that they make gradual changes in technological advances particularly in the areas of existing technologies. The other type of inventive activity is the radical or major innovations, which can bring about new technologies. Both types of inventive activities are essential for industrial growth (Abernathy and Utterback, 1978). The significance of minor and major technological advances can be assessed by their contribution to the net advantages of application in industry (Bela, 1981).

Understanding of the process of R&D project selection, the external and internal factors influencing the R&D project portfolio of firms, their impact on technological development and their influence on industrial performance is still quite limited. In particular, the determinants of the type of current R&D projects, the level and composition of resource commitment, the direction of firm economic, market, and technological strategies, and the influence of organizational and environmental factors on R&D projects have inadequately been examined in Australia. A better knowledge of these factors and their relationships is urgently required to increase the efficiency of the limited industrial R&D effort and to improve the basis for policy formulation.

A large amount of literature on the international experience in idea generation, selection, evaluation and resource allocation to R&D projects is available.[30] Many of these studies, however, are speculative (Baker, 1974) and only a few have concentrated on industry financed R&D in firms with a formal and on-going research program.[31] It has been found

30 A comprehensive analysis of existing literature on descriptive and normative models in these areas is found in Baker and Pound (1964), Brandenberg (1966), Baker (1974) and Cooper (1981)

31 Cooper (1981) pointed out that project selection models are based on arbitrarily developed check-lists and variables and there are only a few empirical studies available at firm or project level.

that most of the theoretically developed checklists on project selection and evaluation models are seldom used in practice by R&D managers (Baker,1974 and Cooper, 1981).

The major objective of this chapter is identification of the salient features of industrial R&D project portfolios in Australian industry. There are many areas that need extensive study, limitation of time and data have led to focus on the areas of project selection, evaluation, budgetary decision and organizational behaviour with respect to on-going and proposed R&D projects.

The first section of this chapter analyses the determinants of project size and the level of resource allocation to R&D projects. An understanding of the inter-connection between cost, manpower and duration of projects is necessary for making and evaluating R&D budgetary decisions. It is obvious that firms select projects of varying sizes according to financial and personnel resources. However, the ability to select different sizes of projects, and the reasons for selecting such projects, differ from industry to industry. The level of cost and personnel allocation to a project was examined in the explanation of success and failure of R&D.

Baker (1974) has argued that the likelihood of technical, commercial and economic success are a function of the total cost of a project. There is some evidence to suggest that the level of R&D personnel commitment is associated with the success of projects. For example, Robertson (1972) has shown that the only size measure which clearly distinguished between success and failure of a project was the size of the project team at the peak effort of the project. Gerstenfeld (1976) also found that project progress and success was associated with average level of personnel allocated to the project, where success rate was high in the project with high personnel allocation. Project performance can be monitored by manipulating the level of resource allocation to projects and controlling the external factors affecting project variables.

Section two examines the process whereby firms direct their R&D and technological strategies through specific R&D projects. The deployment of R&D resources to different types of project activities is considered. The type of activities undertaken in R&D projects can vary from product to process; from research to development; from labour intensive to capital intensive and from new technologies to existing technologies. These components exert a different impact on technological advances and industry growth. Different stages of projects may also require different types of inputs. Link (1982) and Mansfield (1981) claimed that the impact of different components of R&D on productivity growth varies substantially. The composition of resources allocated to projects and their significance in directing industries R&D and inventive activity are discussed in this section.

The third section examines the strategies of firms in project selection decisions. Some strategic factors, such as expected technological advances, company R&D capability, physical resource development. expected employment generation and market expansion are important in examining the effectiveness of portfolio selection and determining its success. The direction of R&D activity in firms is partly explained by the different technological, market and economic strategies adopted.

Section four examines the institutional variation on project selection decisions and types of projects being selected. In particular, size of firm and ownership can directly affect the level, composition and strategies of R&D project portfolios. Usually, arguments concerning the advantages and disadvantages of relative size of firms are centred around the scale of operation. Large firms are generally regarded likely to undertake more R&D and produce more innovations (Griliches, 1980). Most studies on firm size and R&D activities have been made at the level of the firm or industry (Rothwell and Zegveld, 1982). The behaviour of small, medium and large-sized firms in the selection, formulation and resource allocation to individual R&D projects are examined in this section.

5.1 Previous Studies Concerning R&D Project Selection, Evaluation and Budgetary Allocation

Studies of industry R&D structure at project level have concentrated largely on three major areas of R&D decision making. These are
a)selection,
b)evaluation, and
c)budgetary controls of R&D projects.

The decision to undertake an R&D project is influenced by a multitude of factors. Various studies suggest that the most important are company objectives and strategies, goals of profit-maximization, budgetary control, the previous level of R&D, and technical competition or rivalry. A knowledge of users' needs has been identified as a prominent and important feature in selecting successful projects (Rothwell, 1972). It is noted that most industrial projects are of a strategic nature and profit maximization is an important criterion in selecting R&D projects (Baker,1974 p.166). Recent studies have concluded that the selection of projects is based on the consideration of certain project-specific characteristics such as expected rate of return, probability of technical success, and expected payback period rather than being part of a firm's strategy to adapt to its larger environment (Schwartz and Kertinsky,1980). However, the reasons for selecting a particular project are not easy to ascertain. Long checklists for selecting projects have been prepared in a number of studies such as those of McGuire (1973), Albala (1975), Ramsey (1978) and Cooper (1981). Among these factors, the most important ones appear to be the realization of a need, market potential, technical potential, resource availability, identification of risks, and economic returns. Decision criteria also vary according to different industry classes. Mantel *et al.* (1983) out that the selection of potential process development projects is even more complex than projects on product innovations. On this basis both projects-specific and more general environmental conditions are important.

Resource allocation to individual R&D projects is also determined to some extent by factors that control the overall R&D budget in a firm. Chiu and Gear (1979) have argued that R&D resource acquisition and allocation to a firm involves:

a) a variety of technical, organizational, behavioural and economic factors,

b) multiple and conflicting objectives and priorities at various levels in organization.

c) varying degrees of subjectivity in predicting outcome of action and estimating related probabilities,

d) complex sequential interactions between projects and with the "outside world".

It has been argued that number of projects being undertaken by firm is influenced by the previous level of R&D budget (Herkert and Wilson, 1967) and allocation of expenditure to R&D project is determined by the budgeted profits (previous profits) of a firm (Burrows, 1981). R&D projects undertaken in a firm can also be determined by the realization of post inventive activity. The National Association of Accountants (1955) and Quinn (1968) have argued that the ability to finance R&D activity of a firm depends on

a) ability to finance R&D itself and

b) ability to finance the implementation of technology being developed.

Usually, the cost of R&D activity is considered to be small compared with other inventive costs. Post inventive activity, which includes development and commercialization of technologies, involves a large proportion of the cost. Mansfield and Wagner (1975) found that for sixteen innovations in five chemical firms in the United States, 39 per cent of total expenditure occurred for R&D, while 61 per cent was spent on the implementation phase which included tooling, product promotion and employee training. Thus firms may and certainly should examine estimated overall development costs before embarking on a R&D project.

However, Mansfield *et al.* (1977) found that cost of R&D and other innovative activities differ substantially according to the particular innovation. Some innovations have a higher R&D component than others.

It is difficult to generalise all circumstances leading to a certain level of R&D budget. Some firms select their R&D project portfolios annually while others may decide on projects from time to time as necessity arises. Anthony(1952) has argued that it is difficult for firms to predict all projects they might wish to undertake at the time of preparing an R&D budget. Firms may allocate extra funds to R&D projects as a result of the emergence of unforeseen problems. The uncertainty in both technical programming and determining project length may cause a variation from budgetary estimations (Ackoff,1966; Ritchie,1970). Firms may also decide to allocate funds for R&D projects after assessing the merits of individual projects. Also more project objectives than returns on investment are considered (Palk *et al.* 1966). Naslund and Sellstedt (1973) in a study of 63 Swedish firms found that as a rule, firms decided on projects one at a time and did not specify in advance a fixed level of the R&D budget. Bela (1980) has argued that the greater uncertainty concerning the timing and magnitude of potential R&D outcome often serves to disadvantage budgetary requests for major projects.

In summary, the considerable range of studies indicate that the process of project selection, budgetary allocation and evaluation is a complex but a vital area of R&D decision making in a firm. The reasons for supporting current projects and proposing new projects are shaped by a large number of factors. The rationale for selecting a particular project portfolio by a firm is inevitably to some extent unique to the company and its situation. However, some general rules can be identified.

5.2 Characteristics of R&D Project Selected in Australian Industries

It is important to recognize the threshold limits of resources required to complete a project successfully. The efficiency of an overall R&D structure is determined to a large extent by the accuracy of estimation of resources needed for each on-going and proposed project. The mismanagement, misdirection, and over estimation of resources will be detrimental to the effectiveness of innovative effort of industry.[32]

A sample of 585 current and proposed R&D projects from 403 manufacturing firms was selected in this study.[33] This sample is by far the biggest ever compiled to study R&D and inventive activity in Australian industry. All the projects were formulated by the R&D managers in industries and most were submitted to the government industrial assistance scheme during the 1979/80 period. The total project cost of the sample amounted to $142 million, compared with the gross national manufacturing industry R&D input of $158 million in 1978/79. While not all these projects would have been conducted, the sample nevertheless reflects a substantial

32 The implications of these issues on project success is discussed in Chapter Six.

33 The sample size is also relatively large compared with previous similar studies overseas. See Utterback(1974)

proportion of the industrial R&D activity.[34] Submission for a project grant from the Australian Industrial Research and Development Incentive Board (AIRDIB) requires that firms possess proven previous research capability. Therefore firms with little R&D experience, particularly some small firms, would not be eligible and hence be outside this sample. However, the sample of industries examined here represents more than half of the industries undertaking R&D in Australia.[35] The reliability of reporting of details of projects was expected to be high because of the stringent requirements of projects submitted for government incentive schemes. Therefore, the findings of this chapter provide a reasonably accurate description of determinants of R&D project portfolios in manufacturing industry.

5.2.1. Distribution of R&D Projects by Industry Classes

The majority of R&D projects in this sample were formulated by companies in a small number of industry classes. The confinement of industrial effort to a few industry areas was also noted in the national statistics as demonstrated in Chapter Three. The number of projects undertaken by the other machinery and equipment and chemicals, petroleum and coal products industries amounted to 40 and 14 per cent of the total projects, respectively. The number of projects submitted by the textile, clothing and footwear, wood, wood products and furniture and paper,

34 18 projects were withdrawn due to various technical, market and financial reasons.

35 The number of manufacturing firms reporting R&D during 1978/79 national survey amounted to 770.

printing and publishing industries was relatively small. The projects proposed by the wood, wood products and furniture industries was very low, so this industry division was combined with the paper, printing and publishing industry division to facilitate further analysis. Table 5.1 presents the distribution of projects by industry divisions.

Table 5.1 The Distribution of R&D Projects by Industry Classes-1979/80

Industry Classes	No. of Projects	(Percentage)
Food,beverage&tobacco prod.	55	(9%)
Textile,clothing&footwear	13	(2%)
Wood,wood prod.&furniture	3	(1%)
Paper,printing&publishing.	8	(1%)
Chemical,pet.&coal	82	(14%)
Non-metallic mineral prod.	43	(7%)
Basic metal prod.	30	(5%)
Fabricated metal prod.	47	(8%)
Transport eq.	58	(10%)
Other machinery&eq.	216	(40%)
Miscellaneous manufac.	30	(5%)
Total	585	(100%)

The distribution of projects within industry classes showed that some industry sub-divisions were better represented than others. For example, the household appliances and electrical equipment industry sub-class of the other machinery and equipment industry accounted for nearly half of the projects in that industry class. The chemicals, petroleum and coal products industries directed nearly 61 per cent of their projects to the paints, pharmaceuticals, soap, detergent, cosmetic, ink and other chemical products sub-class. Table 5.2 illustrates the frequency distribution of projects by industry sub-class where 10 or more projects were undertaken. The concentration of major R&D projects in a small number of industry sub-classes could suggest that inventive activity, and related government industrial assistance are enjoyed by a relatively small group of manufacturing firms. Therefore, the technological advances achieved through R&D projects are originated from limited sectors of industry, leaving a wide range of areas with little commitment to technology-led performance and growth.

Table 5.2 The Distribution of R&D Projects (10 or more) by Industry Sub-Divisions-1979/80

Industry Classes	Number of Projects
Milk Products.	11 (20%)
Bread,cakes&biscuits	10 (18%)
Basic chemicals	15 (18%)
Other chemical&related prod.	50 (61%)
Cement concrete prod.	18 (42%)
Basic iron&steel	17 (57%)
Non-ferrous basic metal	13 (43%)
Other fabricated metal	21 (45%)
Motor vehicle parts	17 (29%)
Other transport eq.	30 (52%)
Photographic,prof.&sc.eq.	35 (16%)
Household&elec.appl.	98 (45%)
Other machinery&eq.	81 (38%)
Plastic and related prod.	20 (67%)

Note The percentages presented in brackets are based on the proportion of respective industry classes.

5.3.0 Relationship Between Cost, Project Length and Personnel in R&D Projects

Project variables such as cost length and manpower employment are generally employed to describe the levels of R&D spending and composition of R&D activity. In the explanation of inter-industry R&D variations, both the level and composition of R&D resource spending are used (Mansfield, 1981; Link, 1981 and 1983). The cost of a project can be used as an indicator of both the relative size and the importance of the project. Project duration is a function of the rate at which resources are expended (Mansfield *et al.*, 1971; Marshak *et al.*, 1967; and Scherer, 1963) and therefore reflects the degree of urgency of the objectives. The manpower employed by the project is also an important indicator of the commitment to the project. Success of some projects is determined more by capital components than labour components and vice versa.

These project variables are closely interconnected. The size of the research team required to complete a project directly influences the project cost. The duration of a project may depend on both manpower and cost inputs. It may be necessary to incur high expenditure and manpower inputs if the project is to be completed within a short period. It is therefore important to examine the extent to which the project variables are interchangeable and/or complementary.

5.3.1 Financial Resources Devoted to R&D Projects

Most of the R&D projects had relatively high estimated project costs. 33 per cent of the projects had a cost of over $200,000. Nearly 23 per cent of the projects had an estimated cost of between $10,000 and $50,000, 22 per cent between $50,000 and $100,000, and 20 per cent between $100,000 and $200,000. Only 2 per cent of projects had an estimated cost of less than $10,000. The minimum project cost reported was $5000 and the maximum was $2,940,000. This distribution indicates that R&D budgeting for most industrial firms is based on a reasonably high expenditure allocation to their projects. More than 75 per cent of projects had an estimated project cost of over $50,000 - a sizeable budgetary commitment for a single project. Some studies have suggested that a better approach to determine R&D expenditure of a firm would be to build up the research budget from a project base (Reeves, 1958; Trattner and Zidaroin, 1972; Gover and Sranavasan, 1972 and Foster,1971). Therefore, the presence of large projects may reflect not only the potential success and significance of the project but also the intensity of the firms' and industrys' R&D activity.

A considerable variation in the average mean project cost in different industry classes was found (Table 5.3). A large proportion of costs were confined to a few industry classes. Some industry classes such as the basic metal products had more large projects with a high average project cost. Comparison of Tables 5.1 and 5.3 indicates that the pattern of distribution by number of projects and cost shows a high degree of consistency. This suggests that the average expenditure per project is more or less similar for all industry classes, and differences in R&D budget are a function of the number of projects being conducted.

Small and large projects are fairly evenly distributed, with no apparent tendency to concentrate large projects in a few industry classes. The research intensive industry groups - chemicals, transport equipment and other machinery and equipment (as identified in Chapter Three) - , were responsible for 63 per cent (356 projects) of project expenditures; all other industries accounted for only 37 per cent (229 projects). The mean costs of projects lay fairly close to the all industry average of $243,000 for most industry classes, though there was considerable variation in cost within each class.

Table 5.3 The Distribution of R&D Project Costs by Industry Classes. ($'000)

Industry Classes	Costs (%age)	Mean	S.D.
Food,bev.&tob.	14550 (10%)	265	468
Textile,clo.&footwear	1665 (1%)	128	155
Paper&Wood	2367 (2%)	215	169
Chemical,pet.&coal	18987 (13%)	232	405
Non-metallic min.	9818 (7%)	228	363
Basic metal prod.	10078 (7%)	336	591
Fabricated metal prod	7990 (6%)	170	287
Transport eq.	11998 (8%)	207	339
Other machinery&eq.	58244 (41%)	270	473
Misc.manufacturing	6467 (5%)	216	271
Total	142164(100%)	243	421

Note S.D. denotes standard deviation.

The standard deviation is very high in all industry classes, indicating a wide range of distribution of large and small projects in each industry. The textile, clothing and footwear, paper & wood and miscellaneous manufacturing industries had relatively more small projects, with their mean project cost being below the industry average.

5.3.2 Distribution of Project Length by Industry Classes

The average length of research projects varied considerably in different industry groups. Most projects in West Germany had a relatively short project length, usually 4 years (Gerstenfeld, 1976). In this sample, the shortest project length was 2 months and the longest was 5 years. This is in accord with many studies (Jewkes *et al.* 1958; Hamberg 1963, Lynn 1966, Schott 1976), which showed that industrial R&D projects are generally characterised by a relatively short length, and according to Hambergs' definition, less than 5 years.

Most projects (70%) were intended to be completed within 2 years. A large proportion of projects, nearly 88 per cent, showed a project length of less than three years. A project length exceeding three years is evidently a 'long' project in the case of the Australian industrial sector. Table 5.4 presents the frequency distribution of projects at different intervals of duration by industry class.

Table 5.4 The Distribution of R&D Project Length by Industry Classes. (length in years)

Industry Classes	0.0-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0
Food,bev.&tob.	12	22	11	3	7
Textile,clo.&footwear	8	3	1	1	0
Paper&Wood	5	2	4	0	1
Chemical,pet.&coal	23	25	21	8	5
Non-metallic min.	16	17	6	4	0
Basic metal prod.	8	10	6	2	3
Fabricated metal prod	21	18	6	1	1
Transport eq.	20	23	6	6	3
Other machinery&eq.	79	79	35	17	6
Misc.manufacturing	8	11	6	4	1
Total	200	210	102	46	27

Most industry classes fitted the general pattern of projects of no more than 2 years. The notable exceptions were the food, beverages, and tobacco, chemicals, petroleum and coal products and other machinery and equipment industries where 12, 18 and 31 per cent of projects, respectively, exceeded 2 years.

Mean project length varied significantly between different industries. Some industries such as the textile, clothing and footwear, non-metallic mineral, fabricated metal and other machinery classes had relatively more projects with short durations. All other classes had an average greater than the overall industry average (Table 5.5).

Table 5.5 The Distribution of Mean Project Length by Industry Classes

Industry Classes	Mean (years)	S.D.
Food,bev.&tob.	2.40	1.29
Textile,clo.&footwear	1.51	1.07
Paper&Wood	2.09	1.3
Chemical,pet.&coal	2.25	1.26
Non-metallic min.	1.81	1.03
Basic metal prod.	2.28	1.34
Fabricated metal prod	1.68	0.95
Transport eq.	2.03	1.23
Other machinery&eq.	1.93	1.10
Misc.manufacturing	2.28	1.11
Total	2.03	1.16

Note S.D. denotes standard deviation.

The mean length of manufacturing projects was 2 years. The analysis of variance shows a statistically significant difference of mean project length among different industry classes at the 1 per cent significant level ($F=2.41$, degrees of freedom 9,574). The food, beverages and tobacco industry class had the highest mean project length and textiles, clothing and footwear the shortest.

These results indicate that some industry classes selected more short-term projects than others. Most research portfolios in manufacturing industries were typified by a large number of short projects, indicating some urgency of the expectation of outcome and/or confining industrys'

R&D effort to relatively low risk, short-term areas. Long term projects were mainly confined to a few industry classes - food, beverages and tobacco, chemicals, petroleum and coal, and other machinery and equipment, with 18%, 16%, and 10 % respectively of projects longer than 3 years. This might suggest either that there is less urgency in R&D projects of these industry classes, or that they invest in more risky projects. The length of the projects alone is insufficient to distinguish between these alternatives.

5.3.3 R&D Personnel Effort on R&D Projects

The maintenance of a significant level of R&D workforce in an industry can be taken as an indicator of the potential strength of inventive effort in firms. The manpower measures have an advantage over expenditure measures because, as noted in Chapter four, they are not subject to rapid fluctuation over a period. As stated previously, the level of manpower allocation is treated as an important determinant of project success. In addition, a high level of R&D employment requires the allocation of a sizeable proportion of funds to an R&D project.

The R&D personnel intensity of a firm can be expressed in terms of both the level and composition of personnel. Three personnel measures have been constructed to assess the manpower intensity in R&D projects in this study. The first and second indicate the level of personnel involvement as indicated in Table 5.6. The third is the composition of manpower which is presented in Table 5.7. These measures are examined below.

The amount of research personnel employed in project varies from 0.5 to 45 person-years. The distribution of projects according to R&D manpower employed indicates that 28 per cent of the projects employed less than or equal to 1 person-years, 25% between 1.1 and 2.0 person-years, 26 % between 2.1 and 5.0 person-years, 15 % between 5.1 and 10.0 person-years and about 10 % over 10 person-years. Therefore, most projects were characterised by the employment of a relatively high level of manpower resources.

The R&D manpower available per project averaged 4.36. The standard deviation was rather high in most industry classes indicating a wide distribution of results. However the average manpower employment in some industry classes such as the textiles, clothing and footwear, non-metallic minerals, basic and fabricated metal classes was relatively low.

Table 5.6 The Average R&D Personnel Effort per Project and Project Cost per person-year by Industry Classes ($'000)

Industry Classes	Person-year/Project	Cost/Person-year
Food,bev.&tob.	4.82 (4.6)	48 (32)
Textile,clo.&footwear	2.50 (2.4)	69 (57)
Paper&Wood	4.79 (3.6)	89 (96)
Chemical,pet.&coal	4.44 (5.9)	66 (54)
Non-metallic min.	3.11 (3.8)	87 (74)
Basic metal prod.	3.01 (5.7)	226 (361)
Fabricated metal prod	2.94 (2.9)	92 (127)
Transport eq.	4.20 (6.9)	57 (50)
Other machinery&eq.	5.10 (6.7)	68 (71)
Misc.manufacturing	4.80 (6.4)	43 (20)
Industry Average	4.36 (5.9)	75 (106)

Note Standard deviation is presented in brackets; Missing cases 109 or 19%.

The cost per person-year is a measure of the relative abundance of finance in relation to R&D employment for projects. The basic metal product industry, in comparison with other industry classes, showed a high cost per researcher, indicating apparently heavy capital costs of research in this industry group. Most of the research intensive industry classes, such as the chemicals, petroleum and coal products, transport equipment and other machinery and equipment showed below industry average costs per person-year. This may have arisen from high R&D employment and/or relatively low capital costs involved in these industries. These results indicate that capital and labour costs involved in R&D projects vary significantly according to industry classes.

Table 5.7 presents the R&D person-years spent by professional and non-professional staff on research projects by industry class. The overall ratio of professional to non-professional staff was 10 to 1. This ratio was higher than the comparable national ratio.[36] This employment of a high proportion of qualified staff in R&D projects reflects the high calibre of research activity in the companies in this sample. Thus, these firms are least likely to suffer the effects of Walsh *et al*.'s findings (1980) that a shortage of technically qualified manpower imposed limits on innovation and growth.

36 The national IR&D statistics do not measure manpower by qualification, however, assuming all researchers and technicians possess professional qualifications, the ratio of professional to other supporting staff for the 1978/79 survey was 4 : 1.

Table 5.7 Professional and Non-Professional Personnel Effort by Industry Classes (in person years)

Industry Classes	Professional	Non-Professional	Total
Food,bev.&tob.	202	5	207 (10%)
Textile,clo.&footwear	23	7	30 (1%)
Paper&Wood	24	0	24 (1%)
Chemical,pet.&coal	319	10	329 (16%)
Non-metallic min.	108	1	109 (5%)
Basic metal prod.	73	3	76 (4%)
Fabricated metal prod	78	34	112 (5%)
Transport eq.	175	29	204 (10%)
Other machinery&eq.	813	91	903 (44%)
Misc.manufacturing	72	10	82 (4%)
Total	1886	190	2076(100%)

Note Missing cases 109 or 19%.

Most of the industry classes showed a high proportion of employment of professional manpower. With the exception of the fabricated metal product industry, the utilization of non-professional staff in these R&D projects was apparently small. The other machinery and equipment industry was by far the largest employer of research manpower, employing nearly half of the total R&D staff.

5.3.4. The Relationships Between Project Cost, Length and R&D Personnel

The factors which were significant in determining the budgeted cost of a research project were the R&D personnel commitment and the project duration. The project duration would also be in past determined by the amount of personnel and finance and the uncertainty of the R&D.[37] The estimation of the R&D manpower required to complete a project is

37 Both Marschak *et al.*, (1967) and Mansfield *et al.*,(1971) have argued that uncertainties of R&D is a major problem in estimating project dimensions.

necessary to formulate the project cost. Once the manpower requirement is determined, the changes in project cost are controlled by the capital and other overhead costs. The project length can be manipulated by changing the rate of resource spending on a project. Therefore, the interconnection between these variables is important in making decisions on budgetary allocation and project selection.

The relationship of cost, duration and manpower was examined by determining the correlation coefficient between these variables. The project cost showed a positive and strong association with R&D manpower(R=0.804, sig.1%, n=473). The correlation between project cost and length was positive but less strong than the correlation between cost and manpower (R=0.45, sig.1%, n=584). The relationship between project duration and R&D manpower also showed a positive and strong association (R=0.58, sig.1%, n=473). These results indicate that all three variables show a close relationship with each other, but that the association was strongest between project cost and the employment of R&D personnel. The strong associations may suggest that determinants of project cost and manpower are common or related and project duration is interconnected with project cost. It was noted in Chapter Four, that a substantial proportion of the R&D expenditure in firms is constituted of salaries and wages of R&D personnel.

Furthermore, the partial correlation between project cost and R&D employment, controlled for project length showed a positive and significant association (R=0.74, sig.1%, n=472). This suggests that project cost is largely determined by the level of R&D employment for a given project length. There is also a tendency for R&D employment to increase with project cost. On the other hand, the partial correlation between project cost and project length, while controlling for R&D employment, showed a negative association (R=-0.015, sig.10%, n=472). This suggests that project length decreases as project cost increases when R&D manpower is held constant. It would appear that R&D managers favour a heavy resource allocation to reduce the estimated length of a project, once they have allocated available R&D staff.

The extent of the linear relationship of these associations is summarized in Table 5.8. Nearly 64 per cent of the variation in project cost can be explained by project duration and manpower employment, and manpower employment has a more intimate connection with project cost than with project length.

Table 5.8 Multiple Regression of Project Cost with Project Length and R&D Employment in Projects

Ordinary Regression with Project Cost

Correlation coefficient(R)	0.804		
Coef. of determination(r^2)	0.646		
F-value	432		
Independent Variable	Beta	F-value	r^2 change
Personyears	0.81	583	0.44
Length	-0.01	0.1	.21
Stepwise Inclusion	Beta	F-value	r^2 change
Manyears(in equation)	0.804	866	0.647
Length(not in equation)	-0.01	0.1	.0001

Moreover, the multiple regression of project cost with project length and manpower employment for different industry classes is in agreement with anticipated relationships (Table 5.9). The weakest regression coefficients were found in the textile, clothing and footwear and paper and wood industries. A strong relationship was shown by the research intensive industry group. The multiple regression of project cost with length and manpower for the research intensive industries (chemicals, transport and other machinery) showed a strong linear association ($R=0.86, r^2=0.73$, Beta=0.859, F=1010). The regression of all other industries was less strong, but was still positive and significant ($R=0.71$, $r^2=0.45$, Beta=0.71, F=112). The intimate connection between R&D cost and personnel in projects offers some explanation for the variation of research intensities observed in Chapter Four. The project cost and manpower are determined by closely related factors, so that the total budget and manpower allocation are intrinsically connected. Some projects, however, have large capital or labour costs. In such cases, the level of R&D budget or manpower intensities differ significantly.

Table 5.9 Regression Analysis of Project Cost with Length and Personnel Allocation of R&D Projects by Different Industry Classes

Industry Classes	R	r^2	Beta	F value
Food,bev.&tob.	0.89	0.80	0.89	164
Textile,clo.&footwear	0.56	0.32	0.56	5
Paper&Wood	0.62	0.43	0.63	2
Chemical,pet.&coal	0.94	0.87	0.94	504
Non-metallic min.	0.66	0.44	0.66	26
Basic metal prod.	0.82	0.67	0.82	46
Fabricated metal prod	0.57	0.33	0.57	17
Transport eq.	0.81	0.67	0.82	96
Other machinery&eq.	0.85	0.71	0.85	448
Misc.manufacturing	0.89	0.80	0.89	60

Note Beta, R, and r^2 denote standardized regression coefficient, correlation coefficient and coefficient of determination

The relatively weak relationship between project cost and project length noted in the previous analysis may have arisen due to the following reasons:

a) Unlike project cost and manpower, project length does not have a normal distribution as it tends to be clustered at particular intervals such as 1, 2, 3, ...years.

b) The estimation of project length is much more arbitrary due to the uncertainty of R&D.

5.3.5 Influence of Project Length on Size of Projects

The distribution of project cost according to length indicates that the average cost of a project increased by an average factor of 1.82 for an increase of project length by one year. The average cost of projects per year, on the other hand, remained more or less constant for projects up to 4 years and increased considerably for projects between 4 and 5 years duration (Table 5.10).

Table 5.10 The Mean Average Project Cost at Different Intervals of Project Length

Project Length(yrs)	Cost($'000)	Std.Deviation	Cost/Year
0.0-1.0	91	123	113
1.1-2.0	195	338	103
2.1-3.0	346	468	118
3.1-4.0	457	486	115
4.1-5.0	989	875	198
Average	243	370	129

The average project cost per person year showed only a marginal change for projects of different length and the analysis of variance suggested that the variation was significant at the 10% level(F=2.11, degrees of freedom 4,471). Although this variation was not so strong, there was a noticeable tendency to lower the per capita project cost as project length increased (Table 5.11). The low average of the project cost per person-year for projects with longer duration may indicate that,

a) an increase in manpower employment was not uniform with increase in project length.

b) there seemed to be a relatively large increase in person-years for projects with longer duration,

c) projects with shorter duration needed, in general, higher project cost per person-year than longer projects.

Table 5.11 The Mean Average Project Cost per Person-year at Different Intervals of Project Length ($'000 per year)

Project Length(yrs)	Cost/person-year	Std.Deviation
0.0-1.0	91	149
1.1-2.0	79	111
2.1-3.0	53	32
3.1-4.0	56	30
4.1-5.0	53	29
Average	75	111

Note Missing cases 109 or 19%.

The decrease in cost per person-year and increase in project cost per year as project length increases suggest high manpower employment in projects with longer duration.

5.4 The Composition of R&D Project Spending

In most studies, R&D is treated as a homogeneous activity. However, in practice, R&D resources are committed to a variety of activities. These activities can be identified in terms of industry objectives to which the R&D was directed. For a given amount of R&D resources in a firm, the composition of R&D may be a most influential factor in determining the effectiveness of the R&D operation. It was found that various R&D components have a different effect on industry productivity (Mansfield, 1980 and Link,1981). Similarly, the effect of process and product innovation in industry growth has been emphasised by Abernathy and Utterback (1978) as already described in Chapter Four. Link (1982) pointed out that there was inadequate knowledge of the determinants of the composition of R&D at inter-industry level. Therefore, it will be of value and as data permits in this study to identify the variation in the composition of R&D at firm level and the preference of R&D managers for different types of R&D activity.

5.4.1 Types of Project Costs Involved in Industrial R&D Projects

The items of cost reported in R&D projects can be used to identify the composition of R&D spending. Five distinct categories of cost items associated with industrial projects were used: expenditure on personnel; construction of prototypes; pilot-plant development; contract research expenditures, and other miscellaneous current and capital costs. The amount of resources allocated to each of these cost items in a project can be influenced by a number of factors such as the nature of the research problem involved, company goals, research capabilities, market factors, sophistication of the technological advance sought and the necessity to meet project dead-lines. For example, a high proportion of project cost allocation to contract research may reflect a lack of expertise to tackle such problems in industry and the relative advantages of conducting research outside industry premises. A study of the composition of expenditure on research projects allows an understanding of the industry attitude towards R&D spending and the effect of different cost components on efficient R&D performance.

In accord with earlier findings, the major cost component of R&D was the salaries of R&D staff who were exclusively involved in R&D projects. The salaries accounted to 34 per cent of total expenditure of all R&D projects. Overseas studies have indicated that salary and wage cost are a significant component of R&D cost. For example, in the United Kingdom, the expenditure of all product groups on wages and salaries accounted for almost half of R&D expenditure, with a range of 40 - 60% (Dept. of Industry, 1974). In contrast, the average salary and wage costs of Australian projects revealed in this study ranged from 16 - 40% - comparatively a much lower proportion of costs. Some industry classes had a high labour cost, whereas in others, more expenditure was devoted to other project activities. Given that Australian salaries are not low by international comparison, it would appear that a feature of industrial R&D in Australia is a relatively low level of research staff per project.

The cost of prototype development, including the cost of construction, development, and improving test models, claimed an average of 19 per cent of total project cost. Almost 9 per cent of total research cost was devoted to pilot-plant development, 13 per cent to contract research which includes payment to research associations, universities and government research institutions for conducting research on firms' behalf, and 25 per cent was devoted to other expenditure which included purchase of scientific and technical information, material, chemicals, consumeables and other current expenditures.

Although most industry groups have maintained the salary component of project cost at a reasonable level the other cost items vary considerably. For example, the transport equipment, and textile, clothing and footwear industries showed in general, a relatively low plant expenditure, while allocating a high amount of expenditure to prototype development. The expenditure on contracted research was heavy in the case of the other machinery and equipment, non-metallic mineral product and basic metal product industries. The basic metal industries showed a rather low salary expenditure while the prototype development and contract research component was high (Table 5.12). These results suggest that the allocation of resources to various costs is influenced by individual industry requirements. The generally low level of contract expenditure with the exception of the non-metallic mineral and basic metal industries, suggests a strong reliance by companies on their own R&D capability.

Table 5.12 Average Percentage Allocation of Different Project Costs by Industry Class

Industry Classes	Salary	Proto	Plant	Contract	Other	Total
Food,bev.&tobacco	37	19	12	7	25	100
Textile,clo.&footwear	27	45	3	5	20	100
Paper&Wood	35	12	19	11	23	100
Chemical,pet.&coal	34	15	7	9	35	100
Non-metallic min.	21	18	11	33	17	100
Basic metal prod.	16	24	12	27	21	100
Fabricated metal prod	27	26	14	12	21	100
Transport eq.	32	23	5	14	26	100
Other machinery&eq.	39	20	8	10	23	100
Misc.manufacturing	40	11	10	10	29	100
Average	34	19	9	13	25	100

Note Missing cases 1.

The high percentage of expenditure allocation to prototype and pilot-plant development in some industry classes suggests that these industries concentrated more on the design and development of product and process activity. Thus, it can be concluded that a large proportion of the R&D cost of a project goes for development rather than research.

5.4.2 Process and Product Development Strategies in R&D Projects

The importance of product and process development activities and their effect on industrial development was discussed in Chapters One and Four. It was noted in Chapter Four that the Australian industrial research structure concentrated heavily on product development, particularly on the development of new products. In fact, the R&D activity undertaken in a large sample of the manufacturing industry between 1976/77 and 1979/80 indicated that an average of 71% of their financial resources were devoted to product and 29% to process development. As pointed out in Chapter Four, this is in agreement with the average effort devoted to product and process development in other countries such as the U.S. and U.K. (about 86% and 63% respectively spent on product development research). The balance between product and process development activity rests upon type of project portfolio selected by firms.

R&D projects showed a strong orientation towards developing products. However, a large proportion of on-going and proposed projects were also involved in process development. The R&D effort devoted to product and process development varied considerably in different industry classes (Table 5.13).

Table 5.13 The Distribution of Project Cost on Product and Process Development by Industry Classes ($'000)

Industry Classes	Product	Process	Total
Food,bev.&tobacco	5189 (36%)	9361 (64%)	14550
Textile,clo.&footwear	863 (52%)	802 (48%)	1665
Paper&Wood	1060 (45%)	1307 (55%)	2367
Chemical,pet.&coal	5847 (31%)	13140 (69%)	18987
Non-metallic min.	2951 (30%)	6867 (70%)	9818
Basic metal prod.	777 (8%)	8519 (92%)	9296
Fabricated metal prod	2969 (37%)	5021 (63%)	7990
Transport eq.	10474 (87%)	1524 (13%)	11998
Other machinery&eq.	50019 (86%)	7640 (13%)	58244
Misc.manufacturing	5802 (90%)	665 (10%)	6467
Total	85950 (61%)	55432 (39%)	141382

Note Missing cases 1. Total expenditure presented here do not reflect total firm expenditure and it refers to major R&D projects in firms.

The other machinery and equipment industry was responsible for more than 50 per cent of the total project expenditure reported in all industries. This industry class together with transport equipment and miscellaneous manufacturing industry were strongly oriented towards product development. Process development activity was prominent in food, beverages and tobacco, chemicals, petroleum and coal products, non-metallic mineral products, fabricated metal products, and basic metal products. Some industries were geared more towards process development, for example, the chemical manufacturing industries were largely responsible for process innovations (Mansfield, *et al.*, 1977). Clearly, these results illustrate that there exists an important difference between product and process inventive activity in different industry classes. The source of product and process innovations can be expected to originate from different classes of manufacturing industries. However, the emphasis on product and process development may be regarded as time bound and firms may shift their focus from product development to process development as the industry matures (Abernathy and Utterback,1978). The industrial projects examined here suggest that there was a shift towards undertaking more process development projects in a number of industries. This pattern compared with the findings of the preceding chapter indicate an industrial research structure in transition with some industries shifting their emphasis from product to process development. Several factors such as increasing market share, labour cost, profit rates and limitations in available working capital may act as a precursor for a shift from product innovation to process innovation. Gerstenfeld (1978) pointed out that high inflation rates may cause a shift of product research to process research due to the large capital investment required for product development.

The average mean project cost for different industries in product development showed a significant difference at the 1 per cent significant level (For products F=3.69, degrees of freedom 9,575; for process F=3.82, degrees of freedom 9,975). Table 5.16 indicates a high average project cost for product development in the other machinery and equipment, transport equipment and miscellaneous manufacturing industries. The basic metal products, food, beverage and tobacco, chemicals, petroleum and coal products industries showed a high average cost per project for process development. It may be that the differentiation of sources for product and process innovation has taken place as a result of undertaking a relatively large number of product or process projects in some industry classes.

The inventive effort in product development among different industry classes fluctuated over a wide range. The traditional industry classes, such as the basic metal product industry, had a low average project cost of $26,000(S.D.$52,000) on product development, whereas fast growing new technology industries, such as the other machinery and equipment industry devoted a high average of $232,000(S.D. $464,000) for product development. On the other hand, basic metal industries spent a high average of $284,000(S.D.$599,000) per project for process development, while the average project cost of other machinery and equipment was $38,000(S.D.$145,000) for process development (Table 5.14). Hence there is no simple correlation between research intensity and average project cost. Most traditional industries and also chemical industries undertook large projects on process development. It is important to note that new technology areas such as other machinery and equipment showed relatively little interest in process development. It is quite clear that different industries have separate priorities in directing their R&D to product and process development. According to these results it may be fair to expect sources of product and process innovation to be derived from different industry classes.

Table 5.14 The Average Project Cost of Product and Process Development by Industry Classes

Industry Classes	Products	Process
Food,bev.&tob.	94(174)	170(470)
Textile,clo.&footwear	66(157)	62(91)
Paper&Wood	96(130)	119(164)
Chemical,pet.&coal	71(121)	160(416)
Non-metallic min.	69(126)	160(362)
Basic metal prod.	26(52)	284(599)
Fabricated metal prod.	63(88)	107(296)
Transport eq.	181(340)	26(93)
Other machinery&eq.	232(464)	38(145)
Misc.manufacturing	193(281)	22(56)
Average	147(329)	95(305)

Note Missing cases 1. Standard deviations are presented in barckets and these are quite high due to interindustry variation in project costs.

The research intensive industries such as chemicals, petroleum and coal products, transport equipment, and other machinery and equipment industry spent 74 per cent of their project cost on product development (Table 5.15). The research non-intensive industries devoted 62% of project cost to process development activities. This implies that high research intensive industries are involved in product diversification while research non-intensive industries are looking for increasing the efficiency of their production technology by cost reducing process innovation.

Table 5.15 Product and Process Development Effort of Projects in Research Intensive Industries ($'000)

Industry Group	Products	Process	Total
Research Intensive	66340 (74%)	22389 (26%)	89229
All Other Industry	19610 (38%)	32543 (62%)	52153

The rationale for the emphasis on product development in research intensive firms, among other things, could be related to their large market share and their comparative advantage in product diversification as discussed in Chapter four. The other machinery and equipment industries showed a heavy orientation to product development and the industry concentration of this industry class was the lowest with a rate of 0.34 in 1978/79 (ABS, 1979). Some of the research non-intensive industries classes such as basic metal products and non-metallic mineral products showed a high rate of industry concentration at 0.87 and 0.67 respectively during 1978/79 and these industries were strong in process innovation.

The dominance in product development activity by research intensive industries may suggest that the presence of a strong research capability is necessary to be come involved in risky new technology development activities. Furthermore, it maybe argued that more product development signifies the presence of relatively more new entrants to manufacturing. This would mean that research non-intensiveness is associated with those industries which are mature and unwilling to venture into new areas of technology. Those industries apparently prefer to be involved in the process development characteristic of a mature industry (Abernathy and Utterback, 1978). It has been argued, in a discussion of innovativeness of an industry it is important to examine both product and process inventive effort. The results obtained in this study suggest that although some industries such as basic metal products, food, beverages and tobacco products, and non-metallic mineral products were less product innovative, they were certainly the most process innovative industries. The lower product innovativeness of these industries was noted in a previous study (McLean and Round, 1978). In contrast to a steady pattern of product and process innovativeness of firms exhibited during 1976/77 to 1979/80, the proposed R&D activity in manufacturing firms show a tendency to undertake more process development activity. This may be an indication of a realization of a more appropriate direction of R&D strategies and effective utilization of different types of R&D to meet industry needs.

5.4.3 Types of R&D Activity in Manufacturing Research Projects

Research activity conducted in the private industry sector is often considered as short-term, problem solving or mission oriented and mainly directed towards design and development activity. Schott (1976) reported that private industrial research in British manufacturing industry performed very little basic research (3.5% of R&D expenditure between 1971 and 1972) and concentrated on applied and development types of activity.

The type of R&D activity undertaken in Australian firms can be categorized into five groups according to the major objectives of these projects. These groups are:

a) mainly design, modifications and development,

b) design and experimental development with substantial amount of applied research,

c) mainly applied research with little experimental development,

d) applied research and fair amount of basic or fundamental research,

e) mainly basic research with a small amount of applied research.

Table 5.16 presents the distribution of project costs according to these objectives. It indicates that most R&D expenditure was directed towards design and development activity. Applied research also accounted for quite a large percentage of project costs. Engagement in basic or fundamental research in these firms was very low. The average cost per project was distinctly high for those projects involving mainly applied or basic research. The relatively low cost per project for design and experimental development categories may suggest that these projects involved less complicated problems.

Table 5.16 Distribution of Project Cost According to Different Types of R&D Activity($'000)

Type of R&D Activity	Project Cost	Av. Cost/Project
a) Mainly design&dev	31651(28%)	185
b) Design&applied res	26507(24%)	255
c) Mainly applied&dev.	40837(37%)	312
d) Applied &basic res.	9610(9%)	641
e) Mainly basic	2076(2%)	415

Note Missing cases 159 or 27%.

The type of R&D activity and its relationship to product and process development objectives showed that projects involved in product development favoured more design and development(Table 5.17). The greater tendency towards undertaking design and experimental development in product development suggests that firms are responding more to market demands in order to improve existing products and introduce new products. Process development projects tend to undertake more applied research. Apparently process dèvelopment involves more research of a somewhat more extensive kind than does product development.

Table 5.17 Influence of Type of R&D Activity on Product and Process Development

Type of R&D Activity	Product	Process
a) Mainly design&dev	130(45%)	40(29%)
b) Design&applied res	68(24%)	35(25%)
c) Mainly applied	78(27%)	53(39%)
d) Applied&basic res.	06(02%)	09(07%)
e) Mainly basic res.	05(02%)	-
Total	287(100%)	137(100%)

Missing cases 159 or 27%.

The general tendency, however, showed industrial research was directed to more design and experimental development indicating firms were more concerned with the utilization of existing scientific and technological knowledge than searching for new knowledge. Thus reinforces the view that industrial R&D projects are characterized by their short-term nature and a problem solving or trouble-shooting strategy of firms.

It can be argued that the success of a project depends at least in part on the type of technical risk involved in that project; the greater the technical risk the less the probability of success. The presence of more R than D in R&D activity presumably suggests more uncertainty in project outcome. Most projects selected in Australian firms had a higher D than R component. The evidence presented here suggests that most R&D project do not involve exploration of new technology areas and are dominated by short-term, product-oriented and developmental type innovations. However, it is recognized that development is one of the most important part of the innovation process (Mansfield *et al.*, 1977). The dominance of development type activity was more prominent in product development than process development oriented projects. The lack of fundamental research in Australian industry has been clearly demonstrated in national R&D surveys. Only 2 per cent of total R&D expenditure was devoted to basic research during the 1978/79 survey period.

5.5.0 Firm Objectives in R&D Projects

The objectives of undertaking R&D projects are numerous. Among these some of the most influential are to increase technological advances, improve profit rates, explore new markets, reduce costs of production, and to decrease overseas dependence on raw material and technology. In this study project selection according to some expectations of managers on technological advances, raw material utilization, employment generation and capturing local and export markets are investigated.

The state of technological advances expected or sought in the R&D projects undertaken was examined to assess the level of technological sophistication aimed at in R&D projects. The R&D projects were classified according to five groups depending on their relation to technology advances. These are

a) Traditional, old or obsolete technology,

b) Standard technology being commonly used in Australia,

c) New technology to the firm,

d) New Technology first to use in Australia,

e) New World leading technology.

Usually, high technology development requires high R&D inputs. The state and art of technology being used in different industries varies immensely depending on the type of products and production processes used. Table 5.18 presents the project cost on the basis of type of technological advances intended. The number of projects aimed at high technology areas was small. The majority of firms directed their R&D projects to relatively modest technological advances.

Table 5.18 Project Cost According to Intended Technological Advances in Projects ($'000)

Type of Technology	No. of Projects	Project Cost	Cost per Proj.
a) Old Technology	140(33%)	24106(21%)	172(220)
b) Standard Technology	176(41%)	45475(40%)	258(486)
c) New to firm	41(10%)	10145(9%)	247(253)
d) First in Australia	58(13%)	23817(21%)	411(553)
e) World Leading Tech.	15(3%)	10006(9%)	671(1159)
	430(100%)	113069(100%)	264(462)

Note Missing cases 155 or 26%. Standard deviations are presented in brackets.

Only a small percentage of project expenditure and number of projects were devoted to world leading technological development. The average cost of research projects involved in world leading technological development was not surprisingly more than three times the cost of routine or simple technological advances. In fact project costs increased steadily with the level of technology development.

The percentage of projects directed at known technology was as high as 74% and utilized nearly 61% of the total R&D project expenditure. These results indicate that project selection in Australian firms is primarily aimed at modest technological development rather than sophisticated new technology areas. It was noted in the previous chapter that firms showed intense activity in new product development, and such new product development seemed to be based on well known technological developments rather than new technology areas. The presence of high development activity also confirms that industries relied heavily on utilizing already known technological knowledge rather than producing new technological knowledge.

Those who responded to the questions (59% or 342 projects) have indicated that nearly 55% of the projects were intended to be developed to utilize more than 75% of Australian raw materials. 20% of the projects were designed to utilize local raw material between 25% and 75%. Another 25 % of the firms were heavily based on foreign raw materials and local material contributed less than 25%. Therefore, most of the industrial projects intended to utilize local raw material and import substitution appears to play a role in project selection.

The expectations on the employment generation of these projects showed that 305, or 53 per cent of projects estimated only a marginal increase in employment. Projects representing nearly 71 per cent of total cost intended to employ up to 20 persons, if the project was a success. Firms with 20 per cent of the cost of projects undertaken intended to employ up to 100 persons, and 9 per cent more than 100 persons. Most industrial R&D projects had quite a low expectation of labour employment. Hence the innovation effort was not seen as having significant effect on employment levels. In other words, technological development expected in these projects was not intended to achieve a great increase in firm employment.

The development of domestic and overseas markets was treated as one of the prime expectations of these projects. Out of 585 projects, 32 projects were exclusively involved in export markets, 235 exclusively for domestic markets and 119 had interest in both export and domestic markets. The cost of projects according to estimated market size showed that a large share of R&D project cost was incurred by firms with exclusive domestic markets (Table 5.19). The average spending per project was low in firms with a small share of the domestic market.

Table 5.19 Distribution of Project Cost by Domestic Market Size($'000)

Market Share	Project Cost	Cost/project
a) Less than$0.5 million	14544	161
b) $0.5-1.0 million	15540	176
c) $1.1-2.0 million	9799	362
d) over $2 million	10995	367

Note Numbers of firms 235.

Firms with an exclusively export market seemed to spend sparingly on R&D projects compared with firms having an exclusively domestic market orientation (Table 5.20). However, these results must be treated as tentative due to sample size. The greater R&D spending in the area of domestic markets may be explained in a number of ways. Either most of the firms undertaking R&D activities have less favourable conditions to compete with export markets and products, or these firms enjoy a monopolistic position in the domestic market and hence are mostly rewarded by exploiting local markets.

Table 5.20 Distribution of Project Cost by Export Market Size($'000)

Market Share	Project Cost	Cost/project
a) Less than$2 million	750	125
b) $2.1-3.0 million	1519	190
c) $3.1-4.0 million	2617	374
d) $4.1-5.0 million	503	168
e) over$5 million	2868	359

Note Numbers of firms 32.

The type of R&D project selected and the pattern of project selection in Australian manufacturing industry seem to favour fairly straight forward, technologically uncomplicated and domestic market oriented innovations. The tendency to undertake new technological development or to back up such activity through basic research activity was rather weak. Such technological activity is therefore better suited to import substitution policies and capturing domestic markets rather than competitive export markets. In fact a majority of projects were not oriented towards export markets. These results suggest that although there appears to be considerable strength of in-house R&D activity in this sample of manufacturing firms, a stronger orientation is needed to compete with overseas technological development in most R&D project areas.

5.6.0 The Effect of Institutional Variation on R&D Projects

Some institutional features such as a firm's previous R&D capability, facilities provided for R&D and firm size can exert a significant influence on both the level and composition of project R&D activity. The size and ownership of firms can be taken as determinants of R&D spending and research intensity in firms. Mansfield (1981) investigated the effect of firm size on different types of R&D and found that large firms showed a difference in selecting types of R&D, compared with small-sized firms. McEachern and Romeo (1978) showed that ownership was also important in determining R&D intensity in firms. In the following sections the effect of internal R&D organization, firm size and ownership on R&D project portfolios are examined.

5.6.1 Research Capabilities of Firms Conducting R&D Projects

The technical success of projects undertaken in firms depends largely on the previous experience and current capabilities of research staff and the environment provided in which to conduct research. The methods available to determine the R&D capabilities of a firm are quite diverse. A number of factors, such as the presence of qualified and experienced staff, systematic R&D activity, research facilities and high success of previous R&D work can be used in determining the R&D capability of firms. The firms in this survey are categorized into five groups according to the following criteria.

1) No specific R&D facilities, unqualified part time staff, no systematic R&D activity, and no successful previous R&D experience,

2) Some R&D facilities, unqualified and some qualified R&D personnel, systematic R&D activity and limited success in previous R&D activity,

3) Adequate R&D facilities, experienced and qualified full-time research staff, organized systematic R&D activities and successful R&D results,

4) Good R&D facilities with adequate supply of equipment, laboratories and qualified, trained and experienced staff, and advances in technological innovations and successful R&D activity,

5) Excellent research facilities, well equiped modern R&D facilities, qualified and well known and highly trained research staff and well organized R&D programmes with major technological achievements.

The firms were classified into one of the groups mentioned above. The diversity of firm R&D capabilities makes it difficult to have an unbiased rating. However, the wide scale adopted provided some flexibility in separating firms into these categories. The analysis of project cost by R&D rating of firms suggests that relatively small amount (15%) of R&D is undertaken by firms with good or excellent R&D facilities. A large amount of project cost originated from firms having adequate or less than adequate R&D facilities and capabilities (Table 5.21).

Table 5.21 Distribution of Project Cost by R&D Rating of Firms($'000)

Type of Facility	Project Cost	Cost/project
a) Poor facility(n=69)	14664(10%)	212(320)
b) Marginal facility(n=205)	37238(26%)	182(301)
c) Adequate facility(n=198)	55393(39%)	280(500)
d) Good facility(n=99)	25088(18%)	253(389)
e) Excellent facility(n=12)	9533(7%)	794(877)
	141916(100%)	243(420)

Note Missing cases 2 or 0.3%. n denotes number of projects. standard deviations are presented in brackets.

Although the deficiency in the availability of good facilities may not necessarily mean poor R&D performance, it may be a serious impediment to the effective progress of R&D activities. It has been argued that a certain threshold limit of R&D is needed for effective innovation, particularly in new technology areas (Rothwell and Zegveld, 1982). There is an apparent need to up-grade inhouse R&D facilities in Australian industries.

5.6.2 The Effect of Firm Size on Project Selection

As noted previously, firms are classified as small, medium or large according to the number of employees in the firm. Firm size could greatly influence the project variables. For example, it might be expected that large firms would have a greater capability to support large and longer projects than small firms.

The analysis of project variables according to size categories indicates that firm size exerts a considerable influence. The ratio of number of projects undertaken in small, medium and large firms was 1 : 1.3 : 1.5. Large firms were able to allocate larger sums of expenditure per firm (average $458,000) than small (average $296,000) and medium-sized (average $289,000) firms. Small firm were responsible for 22 % of the total cost of projects with an average project cost of $263,000. Medium-sized firms were accountable for 31 % of the total cost of projects, with an average project cost of $197,000. Large firms were responsible for 47 % of total project cost with an average cost per project of $275,000. Although the difference between the average cost of projects undertaken by large and small firms was not very large, small firm investment was much less than that of the large firms. Medium-sized firms have shown a low R&D budget per project compared with small firms. This is discussed later.

The distribution of project cost according to firm size indicates that the inventive strength of different firm sizes largely depends on firms in particular industry classes. The only exception is the other machinery and equipment industry class, which had relatively high R&D expenditure in all firm sizes. The small firms, for example, were strongest in the other machinery and equipment and fabricated metal products industries. Medium-sized firms showed greater strength in the textile, clothing and footwear, paper and wood and chemicals, petroleum and coal product industries. Large firms dominated the food, beverages and tobacco products, non-metallic mineral products, and basic metal product industries (Table 5.22).

Table 5.22 Project Expenditure According to Firm Size by Industry Classes ($million)

Industry Class	Small	Medium	Large
Food,bev.&tobacco	2.6(9%)	3.6(8%)	8.3(12%)
Textile,clo.&footwear	.03(.1%)	1.3(3%)	.32(.5%)
Paper&Wood	.2(.8%)	1.2(2%)	.99(1.5%)
Chemical,pet.&coal	1.4(4%)	7.8(17%)	9.8(15%)
Non-metallic min.	.4(1%)	1.6(4%)	7.7(12%)
Basic metal prod.	1.8(6%)	2.2(5%)	6.0(9%)
Fabricated metal prod	3.3(11%)	1.6(4%)	3.1(5%)
Transport eq.	3.2(10%)	1.8(4%)	7.0(10%)
Other machinery&eq.	16.7(54%)	20.9(47%)	20.6(31%)
Misc.manufacturing	1.4(4.1%)	2.2(5%)	2.9(4%)
Average	31.1(100%)	44.2(100%)	66.7(100%)

Note Missing cases 1.

Johns *et al.,* (1978) have attempted to explain the apparent high intensity of research effort in small firms by two factors. The first is that small firms are obliged to spend a larger proportion of their sales on R&D than large firms because it is necessary to spend a certain threshold amount of expenditure to obtain the benefit of research. The second factor is that small firms are required to exert a greater intensity of R&D effort to overcome the barriers of entering into a technologically advancing industry. In addition, small firms may be more inclined to license a new product or process from another source because of limited resources for R&D. However, the results obtained in this study suggest that there are no reasonable grounds for arguing that small firms behave in a very different way from large firms in undertaking major R&D innovative projects. Table 5.23 indicates that small firms also allocated a relatively high proportion of R&D manpower.

Table 5.23 Average R&D Employment in Projects by Firm Sizes (person years)

	Small	Medium	Large
Manyears/firm	4.0(5.2)	2.9(3.7)	4.5(6.7)
Manyears/project	4.4(5.5)	3.2(4.0)	4.8(6.8)

Note Missing cases 109 or 19%. Standard deviation is preesnted in brackets.

Perhaps the difference between small firms and large firms is more evident in terms of the ability of large firms to employ more R&D personnel per firm. Small and medium-sized firms allocated more or less similar levels of R&D personnel to projects. Walsh *et al.,* 1980 pointed out that a shortage of R&D employment imposes limits on innovation and growth, particularly in small firms. Large firms displayed a greater ability to support more research personnel and also, even though the average cost or manpower of a project did not differ greatly among different firm sizes, most small firms in this sample had no more than one research project whereas large firms had several major projects.

Large firms sponsored big projects and maintained a high level of activity. Although there were indications to suggest that large firms devoted high level of R&D expenditure and personnel to their projects, there was no strong evidence to support this pattern. Infact small firms operated at almost the levels of large firms. This may have been caused by the fact that, quite apart from the firm size, all firms may have been required to maintain a certain level of project expenditure to attain a degree of technological change in advanced in this sample manufacturing. Perhaps the weakest link in the R&D system emerges not so much from the low intensity of R&D in small firms but in medium sized firms (employment between 51 and 500). Medium firms have shown quite low averages both in terms of expenditure and of manpower per firm. The balance of inventive activity in Australia may be peculiarly distorted by the weak R&D intensity in medium-sized firms.

5.6.3 Influence of Firm Size on Type of Project Costs

The allocation of R&D resources to different types of costs in projects show variations according to firm size. Salaries accounted for nearly a third of the project cost in all firms with large firms in particular having a high salary expenditure. Small firms in general contributed a high proportion of resources to prototype development and also undertook more contract research than medium and large firms (Table 5.24). Rothwell (1982) has argued that contract research was more appropriate in the case of small firms as they often required rapid solution to specific problems.

Table 5.24 Distribution of Project Cost According to Firm Size ($million)

Firm Size	Salary	Plant	Proto	Other	Contract
Small	9.5(31%)	2.9(9%)	8.2(26%)	6.4(21%)	4.1(23%)
Medium	14.5(30%)	4.7(11%)	9.7(22%)	10.8(27%)	4.5(10%)
Large	24.0(36%)	5.5(9%)	9.6(14%)	18.1(27%)	9.2(14%)

Note Missing cases 1.

The high proportion of R&D expenditure on contract research in small firms may have resulted from the limited R&D facilities available in these firms. In general, firm size did not exert a great deal of influence on the type of project cost, although there was a notable variation in some cost items in small and large firms.

5.6.4 The Influence of Ownership on Project Selection

The ownership of firms is considered to have an influence on the R&D spending. It has been shown in different industrial structures that foreign controlled companies spent relatively more R&D expenditure than local-based companies and vice versa. De Melto *et al.* 1980 found that in Canada there was a clear tendency for foreign controlled Canadian-based firms to spend less than Canadian-controlled firms on R&D per dollar of sales. It is generally argued that foreign controlled companies do little research in host countries, largely conducting their home-based parent company. The dominance of foreign controlled companies in manufacturing industries in Australia, their relatively insignificant role in undertaking R&D in Australia and the importance of transfer of technological knowhow were discussed in Parry and Watson (1979). They found, however, that Australian R&D constitute a small part of total group expenditure and large proportion of R&D expenditure directed at modification of overseas technology. The influence of ownership on project selection is considered in this section.

The ownership of a business enterprise can be categorized according to the control of voting shares. There are three major categories of ownership as defined according to ABS (1979) guidelines as described in Chapter Three.

a) Individual Australian Firms

b) Australian Controlled Firms

c) Foreign Controlled Firms.

A large share of the project cost originated from individually owned firms. The average project cost did not show a great variation according to firm ownership. This indicates that the resource allocation to industrial projects was independent of ownership of firm. 25 % of the project cost was originated from overseas controlled firms and 47 % was from individually controlled Australian firms. Furthermore, there was no significant change in the patterns of resource allocation to different project activities by ownership of firms. For example, foreign owned firms spent only a slightly higher percentage on salaries and wages than Australian firms. This suggests that the composition of R&D project expenditure is independent of ownership.

The project expenditure by ownership and firm size showed a considerable variation with regard to resource allocation. Individually owned firms incurred 72 per cent of the total project expenditure of all small firms. The project expenditure of this group was equivalent to the effort of large foreign owned firms. Amongst the medium sized firms, those controlled by Individual and Australian ownership spent a higher proportion than foreign owned firms. The low level of R&D project expenditure in medium size firms was primarily due to the weak commitment of individual and foreign controlled firms to fund R&D projects sufficiently. Foreign controlled firms based in Australia has undertaken a significant proportion of R&D project activities and this confirms that foreign owned firms have some interest in conducting R&D in the host country. Parry and Watson (1979) also found a significant involvement in R&D activity by foreign controlled firms. In particular, large foreign controlled firms were active in undertaking R&D projects.

Table 5.25 Project Expenditure by Firm Size and Ownership($million)

Ownership	Small	Medium	Large
Individual	22.2(72%)	18.6(42%)	25.8(39%)
Australian	5.5(18%)	16.7(38%)	18.0(27%)
Foreign	3.3(10%)	8.9(20%)	23.0(34%)
Total	31.0(100%)	44.2(100%)	66.8(100%)

Note Missing cases 1.

The analysis of project expenditure according to industry classes showed that nearly 50% of project expenditure was contributed by R&D projects belonging to small individual firms in the other machinery and equipment industry. R&D projects of food, beverages and tobacco products and non-metallic mineral products companies were supported most by individually owned large firms. R&D project cost in the basic metal industry was mainly dependent on large Australian owned firms, whereas in the transport equipment industry large foreign owned firms were active. The other machinery and equipment industry, unlike the rest of the industry classes, was extensively supported by all types and size of firms. This industry group gave a strong impetus to the research achievements of small firms.

R&D project cost in textiles, clothing and footwear, paper and wood and non-metallic mineral products were exclusively supported by individually owned and Australian owned firms. The individually owned firms were quite active in undertaking R&D projects in these industry divisions (Table 5.26). Foreign owned firms were prominent in supporting the chemical and transport industry divisions and Australian owned firms were dominant in the basic metals and fabricated metal products.

Table 5.26 Percentage Distribution of Project Cost by Ownership by Industry Classes

Industry Classes	Individual	Australian	Foreign	Total($'000)
Food.bev.&tobacco	67%	16%	17%	14550
Textile.clo.&footwear	67%	32%	1%	1665
Paper&Wood	76%	24%	-	2367
Chemical.pet.&coal	22%	35%	43%	18987
Non-metallic min.	65%	34%	1%	9818
Basic metal prod.	36%	43%	21%	10078
Fabricated metal prod	25%	55%	20%	7990
Transport eq.	45%	10%	45%	11998
Other machinery&eq.	49%	28%	23%	58244
Misc.manufacturing	62%	12%	26%	6467

These results suggest that ownership has a considerable influence on R&D project selection in firms. Also the size of firms must be taken into account in considering the effect of ownership on R&D investment. A large portion of R&D project expenditure in small firms originated from individually owned firms, whereas foreign owned companies actively pursued R&D projects through large firms. This differentiation also varied according to industry classes with some industry classes showing intense R&D activity in foreign owned firms. In particular, the research intensive industry classes such as the chemicals, petroleum and coal products and transport equipment industries showed a high proportion of activity through foreign owned firms.

5.6.5 The Influence of Firm Size and Ownership on Product and Process Development in R&D Projects

The decision to become involved in product and process research is determined by economic, technological and environmental reasons. Firms' behaviour in R&D investment is influenced by institutional differences such as firm size and ownership. A firm may be compelled to undertake more product development research because of the relatively high expense involved in process development. Small firms in particular, may be receptive to such arguments. The commitment of small firms to a particular type of technology and process and the high replacement cost of new processes leave little option for technological advances in these firms. Thus, small firms may prefer to develop product rather than process technologies.

R&D projects undertaken in small firms concentrated mainly on product development and consumed a large amount of their resources. As the size of a firm increases, a shift towards process development is shown. In general, all firms showed a preference towards product development. This may be due to the comparative advantage in the market place of large companies. Process development was more prevalent in large firms than in small or medium firms (Table 5.27). Thus the predominance of product development is in part a consequence of the predominance of small firms in the R&D oriented industry structure.

Table 5.27 Project Expenditure on Product and Process by Firm Size ($million)

Firm Size	Product	Process	Total
Small	21.7(70%)	9.4(30%)	31.1
Medium	29.2(66%)	15.0(34%)	44.2
Large	35.1(53%)	30.9(47%)	66.1
Total	85.9	55.4	141.4

The effect of ownership and firm size on project cost suggests that product development was largely supported by small individually owned firms. Amongst the medium sized firms, Australian owned companies had a high proportion of R&D project expenditure and amongst the foreign owned firms, the large firms had the highest expenditure (Table 5.28). Piatier (1980) has reported studies of the orientation of French managers to the creation of new product as a prime aim increased with the size of firm but the reverse was true concerning the product improvement.

Table 5.28 Product Development Activity by Firm Size and Ownership ($million)

Firm Size	Individual	Australian	Foreign
Small	17.2(41%)	1.5(7%)	2.9(12%)
Medium	12.3(29%)	11.2(55%)	5.7(24%)
Foreign	12.4(30%)	7.7(38%)	15.0(63%)
Total	41.9(100%)	20.4(100%)	23.7(100%)

In the case of process development, large individual firms were most active. This group of firms was responsible for nearly 44 per cent of process development activity in manufacturing projects . Foreign controlled firms accounted for 21 per cent of the process expenditure of R&D projects. Large firms were the major performers of process development (Table 5.29).

Table 5.29 Process Development Activity by Firm Size and Ownership ($million)

Firm Size	Individual	Australian	Foreign
Small	5.0(20%)	4.0(21%)	0.4(4%)
Medium	6.3(26%)	5.5(29%)	3.2(28%)
Foreign	13.4(54%)	9.5(50%)	7.9(68%)
Total	24.8(100%)	19.0(100%)	11.6(100%)

One of the important findings was that the direction of R&D in industries to product and process development was controlled not only by the maturity of industrial technology as demonstrated in Utterback and Abernathy (1978) but was also affected by institutional characteristics. such as firm size and ownership.

Product and process inventive effort also varied according to industry class and firm size. For example, large and medium firms in the chemical industry division played a significant role in process development. Large firms in the non-metallic mineral products and basic metal products could also be regarded as process research intensive industries. Small firms showed a high process R&D activity in the fabricated metal industry class.

The size of firm did not appear to exert a great influence in determining the type of activity undertaken in projects. All three firm sizes showed more or less similar patterns in directing their research projects to different R&D activities. Although small firms might be expected to engage in little basic research. they had more basic industrial research projects than large and medium firms. A definite conclusion on the relationship between firm size and performance of research cannot be drawn from this sample of projects alone. However. these results indicate that some small firms had a growing interest in undertaking projects with a basic research component.

Firm R&D rating and its relationship with firm size indicates that small and medium-sized firms have largely poor R&D facilities. This may be expected as small and medium firms find it difficult to support expensive R&D facilities and conduct their R&D projects with minimum facilities. Nearly 75 per cent of the cost of projects in small firms originated from firms with less than adequate facilities. Medium sized firms also showed 37 per cent of project cost arising from firms with less than adequate facilities. About 19 per cent of project costs originated from large firms with poor and marginal facilities (Table 5.30). There are grounds for considerable concern over these results. Remembering that this sample is made up of the atypical minority of innovation-minded firms, it is extremely disturbing that 74 % of small firms, 53 % of medium firms, and 29 % of small firms had inadequate R&D facilities, by their own judgement. This is both a reflection of the low importance ascribed to R&D and an explanation of the poor innovative performance.

Table 5.30 Distribution of Project Cost by R&D Rating and by Firm Size ($million)

Type of R&D Activity	Small	Medium	Large
a) Poor facility	8.5 (31)	5.3 (33)	8.7 (5)
b) Marginal facility	14.9 (56)	10.9 (84)	11.4 (65)
c) Adequate facility	6.2 (24)	22.0 (79)	27.2 (95)
d) Good facility	1.6 (7)	5.6 (25)	17.9 (67)
e) Excellent facility	-	.13 (1)	9.4 (11)
Total	31.1(118)	43.9 (222)	65.9 (243)

Note Numbers in brackets indicate the number of firms.

5.7 Conclusions

The distribution of industrial development projects has revealed a considerable diversity in terms of industry class, objectives and nature. In accord with the findings of the previous chapter, projects are concentrated particularly in the three research intensive industry classes - other machinery and equipment, chemicals, petroleum and coal products, and transport equipment.

Project costs vary greatly from $5,000 to $3,000,000. 75% of the projects had an estimated cost of over $50,000 and 33% of the projects had a cost of over $200,000. These figures would suggest that at least a substantial proportion of the projects involve very significant expenditures. However the other characteristics of the projects do not provide a picture of intense resource commitment to technology development. The average project length of two years and average personnel commitment of four person-years, are both relatively low, certainly compared with industrial R&D projects in other countries. This suggests that the majority of industrial R&D in Australia is short term, goal specific, and low risk.

These findings are supported by the findings that three quarters of the projects involve technology which can be described either as old or standard , only 13% are directed towards being the first introduction of a new technolo gy in Australia and only 3% concern the development of world-leading technolog y. Hence, the objectives, by and large, are relatively modest in technological t erms. In terms of general objectives, the majority of the projects were oriente d towards satisfying domestic markets. It would therefore appear that project s election is influenced far more by fulfilling recognized market need considerati ons rather than the possibility of opening up new markets. This is. of course. a relatively modest strategy. In general. managers expected specific results in the short term. and industrial R&D strategy emphasises the solution of immediat e industry problems related to market demands rather than long term technology-l ed strategies for growth. In general then, the orientation towards risk taking is remarkably low.

A significant linear relationship between project cost and R&D personnel employment was found. Of course. this relationship is in part in reflection of the extent to which salary and wages make up project costs. but as shown. these represent on average only a third of project costs. Hence the assignment of people to a particular project is clearly the strongest measure of company commitment to the completion of that project. While the cost per person declines with the length of the project. the cost per year remains remarkably constant and at about $113,000 over four years. This would imply that non labour costs increase throughout the project. However. there is a remarkable jump in projects which have a duration of greater than four years. in which total cost doubled and the average cost per year increased to $200,000 per year. It would appear that we have discovered some kind of step function between projects up to four years in length which generally have comparable characteristics and projects greater than four years which involve much greater resource commitment.

The average salary and wage costs of Australian projects. ranging from 40% to 60 % depending on industry class. is relatively low when compared either with the other sectors in Australia. or with overseas experience. For example, the Government sector has an average salary cost of 65% and Universities have a salaries cost as high as 71%. Also. in the United Kingdom industrial expenditure on wages and salaries accounted for almost half the expenditure. Hence. in relative terms the salary component of R&D (industrial only) expenditure is low in Australia. The cost of prototype development. including construction. development and proving test models, and pilot development. together came to an average of 28% of project costs. This figure is substantially lower than often quoted, and suggests either that these costs are not as great as many industrialists have often claimed or that funds available for this kind of activity are insufficient. Certainly there is no evidence here for a substantial increase in the level of incentives through. for example. the IR&D Incentive Scheme. for the funding of the prototype and pilot plan. The low level of contracting out discovered here confirms previous studies that Australian industry tends to have relatively little co-operation with the other research performers such as universities.

The breakdown of projects according to their objective of product or process development confirms the findings of the previous chapter of a strong emphasis on product development. The average proportion for projects. at 61 % to 39% is rather less than that found for companies in the previous chapter 80% to 20% , but still indicates a considerable orientation to product development. However. analysis at the project level reveals that this orientation towards product development is largely a feature of the high proportion of small companies in the sample and secondly of the research intensive industry classes. The combination of these characteristics lends a greater propensity to risk taking. There is also a strong orientation towards import substitution and the development of new markets. and lack of available funds for major process development. Hence it is the structure of Australian manufacturing industry, more than anything else. which is responsible for this orientation towards new product development.

The contribution of small industry to Australian industrial R&D effort is a remarkable feature; although their number of projects is low. the cost of the project was as the same level as that for large firms. It would appear that the innovative power of Australian industry could be substantially improved by providing support and encouragement for these small firms.

The structure of Australian industry and technology development in terms of size shows a remarkable dichotomy between the small firms and large firms which made a significant contribution and a relatively poor performance from medium sized firms. The picture is one of large firms devoting modest proportions of their resources. though in absolute terms this is a significant amount. to a mixture of product and process development through a range of projects. This activity is complemented by a substantial number of small firms devoting a considerable amount of their resources to a small number of projects strongly oriented towards new product development. As noted previously. Johns *et al.* (1978) attempted to explain the apparent high research intensity of small firms by their need to spend a large proportion of their sales on R&D and their need to overcome the barriers of entering a technologically advancing industry. The results of this analysis at the project level more or less confirm these findings. In particular it is apparent that the size of project in small firms is not relatively different from that in large firms and that there is a minimum threshold of expenditure required. However, small firms carry out fewer projects than large firms.

It is of interest to note that small firms, apparently being more research oriented, conducted a large proportion of basic research than did the large or medium companies. This would indicate, in accordance with findings elsewhere, that it is the small firms which are likely to be working at the forefront of development in new technology.

A particular feature which should be a matter of concern to policy makers is the high level of small companies with less than adequate R&D facilities. Overall 36% of costs of the projects surveyed were conducted with sub-standard facilities. However this proportion is much higher in small companies in which projects representing 75% of costs were conducted in facilities which were assessed by the firms themselves to be less than adequate. This would appear to be an area for considerable improvement. It may therefore be necessary to develop policies which take particular account of the needs of small firms. Furthermore, such inadequacies of available R&D facilities in most firms warrant increased contract research activities, by which industry resources can be efficiently deployed for new technological development.

With regards to ownership, it is apparent that foreign owned firms displayed the ability to meet higher project costs than did individually or Australian owned companies. However, this is largely a consequence of the fact that foreign owned firms are concentrated quite strongly in the 'large' catagory. There do not appear to be other significant variations with foreign ownership which can not be explained either by the size of the company or by the industry class in which they are represented. The considerable influence of foreign owned firms is not a consequence of their different behaviour or strategy. Rather it is simply a feature resulting from their heavy concentration in the research intensive industries and their size.

Reference Chapter Five

Abernathy, W.J. and Utterback, J.M. (1978) 'Patterns of industrial innovation', Technology Review, June/July Vol. 80.(7),pp. 41-47.

ABS (1980) Census of Manufacturing and Electricity and Gas Establishments - Industry Concentration Statistics, Australia 1977-78, Cat. No. 8207.0, Canberra.

Ackoff,R.L. (1966) 'The ideal solution to the budgeting problem',in Yovits, M.C., Gilford,D.M.,Wilcos,R.H.,Stanley,E., and Lerner, H.D., ed Research Programme Effectiveness, New York;Gordon&Breach.

Albala, A. (1975) 'Stage appraoch for the evaluation and selection of R&D projects', IEEE Trans. Eng. Management, Nov. Vol. EM-22, pp. 153-164.

Anthony, R.N. (1952) Management Controls in Industrial Research Organization, Harvard University, Graduate school of Business Management.

Anthony, R.N. and Reece, J.S. (1979) Management Accounting, Test and Cases, Richard D.Irwin, Homewood, Illinois.

Baker, N.R. (1974) 'R&D project selection models; An assessment' IEEE transactions on Engineering Management, Vol.EM-21(4), Nov. pp.165-171.

Baker, N.R. and Pound, W.H. (1964) 'R&D project selection: Where we stand' IEEE Trans. Eng. Management, Dec. Vol. EM-11, pp. 124-134.

Bela, G. (1980) 'Strengthening the technological capabilities of domestic industries: Pressure, determinants, and policy alternatives' Omega, Vol. 8(5), pp.583-599.

Bela, G. (1981) 'Technological diffusion in industry:Research needs and shortcomings', The Journal of Industrial Economics, Vol. XXIX(3), March, pp.247-269.

Bolton Committee Report (1972) Small Firms-Report of the Committee of Inquiry on Small Firms Cmnd 4811, London;HMSO.

Brandenberg, R.G. (1966) 'Project selection in indsutrial R&D: problems and decision processes', in Yovits, M.C. ed. Research Program Effectiveness, Gordon and Breach.

Burrows, G.H. (1979) An Investigation into Problems of Accounting for Research and Development Expenditure, M.Com. Thesis, Uni. of Melbourne.

Burrows, G.H. (1981) 'Factors influencing the size of firm budgets for research and development', Accounting and Finance, Vol. 21(2), pp. 87-96.

Chiu, L. and Gear, T.E. (1979) 'An application and case history of dynamic R&D portfolio selection model', IEEE Transactions on Engineering Management, Vol. EM-26(1),Feb. pp.27-

Cooper, R.G. (1981) 'An empirically derived new product project selection model', IEEE Trans. Eng. Mangement, Vol. EM28(3), pp. 54-61.

De Melto, D.P., McMullen, K.E. and Wills, R.E. (1980) Innovation and Technological Change in Five Canadian Industries (Preliminary Report), Discussion Paper No,176, Economic Council of Canada, Ottawa, October, of Industry (1974) 'Resources devoted to research and development by manufacturing industry', Economic Trends, No. 245, pp. 33-45.

Foster, R.N. (1971) 'Estimating research pay off by internal rate of return method' Research Management, Vol.14, pp.27-43.

Gerstenfeld, A. (1976) 'A study of successful proejcts, unsuccessful proejcts, and projects in process in West Germany', IEEE Tran. Eng. Mangement, Vol. EM-23(3), Aug. pp. 116-123.

Gerstenfeld, A. (1978) 'Technological innovation and government regulation: Examples from building construction and pharmaceutical industries', Paper presented at the (National Conference on the Advancement of Research, U.S.A. Sept.

Gover, D.P. and Sranavasan, V. (1972) 'Allocating resources between research and development- A macro analysis', Management Science, Vol. 18, pp.492-501.

Griliches, Z. (1980) 'Returns to research and development in the private sector', in Kendrick, J.W. and Vaccara, B eds. New Developments in Productivity Measurement and Analysis, New York; NBER.

Hamberg, D. (1963) 'Invention in the industrial research laboratory', Journal of Political Economy, April, pp. 95-115.

Herkert, J.B. and Wilson, J.D. (1967) Business Budgeting and Control, New York; The Ronald Press.

Heyel, C. ed. (1968) Handbook of Industrial Research Management, New York;Reinhold.

Jewkes, J., Sawers, D. and Stillerman, R. (1958) The Source of Invention, New York; St. Martin Press.

Johns, B.L., Dunlop, W.C. and Sheehan, W.J. (1978) Small Business in Australia-Problems and Prospects, Sydney;George Allen&Unwin.

Link, A.N. (1981) Research and Development Activity in U.S. Manufacturing, New York;Praeger.

Link, A.N. (1982) 'An analysis of the composition of R&D spending', Sothern Economic Journal, Vol. 49(2),Oct.pp.342-349.

Lynn,F. (1966) An Investigation of the Rate of Development and Diffusion of Technology in Our Modern Industrial Society, Report to the President of the National Commission on Technology, Automation and Economic Progress., Washington D.C.

Mansfield, E. and Rapport, J. (1975) 'The cost of industrial product innovation',Management Science,Aug. pp.1380-1388.

Mansfield, E., Rapport, J., Schnee, J., Wagner, S. and Hamberger, M. (1971) Research and Innovation in the Modern Corporation, New York;Springer-Verlag Inc.

Mansfield, E., Rapport, J., Romeo, A., Villani, E., Wagner, S. and Husic, F. (1977) The Production and Application of New Industrial Technology, New York; Norton.

Mansfield, E. (1980) 'Basic research and productivity increase in manufacturing', American Economic Review, Dec., pp. 1111-12.

Mansfield, E. (1981) 'Composition of R&D expenditure:Relationship to size of firm,concentration, and innovative output', Review of Economics and Statistics, Vol. pp.610-14.

Marschak, T., Glennan, T.K. and Summers, R. (1967) Strategy for R&D;Studies in Microeconomics of Development, New York;Springer-Verlag Inc.

Mantel, S.J., Tipris, V.A., Watwe, U. and Ravigani, G.L. (1983) 'Economic evaluation of potential process innovation', OMEGA, Vol. 11(1), pp.33-40.

McEachern, W.A. and Romeo. A.A. (1978) 'Stockholder control, uncertainty and the allocation of resources to research and development', The Journal of Industrial Economics, Vol. XXVI(4), June, pp.349-361.

McGuire, P.E. (1973) Evaluating New Product Proposals, New York; Conference Board.

McLean, I.W. and Round, D.K. (1978) 'Research and product innovation in Australian manufacturing industry', Journal of Industrial Economics, Vol. XXVII(1), pp. 1-12.

National Association of Accountants (1955), Accounting for Research and Development Costs, Research Report 29, New York.

Naslund, B. and Stellstedt, B. (1973) Setting Budgets for Research and Development: An Empirical Study of 69 Swedish Firms, Working Paper No. 73-7, European Institute of Advanced Studies in Management, Stockholm.

Palk, J., Meister, J. and Veit, K.A. (1966) U.S. Production Abroad and the Balance of Payments: A Survey of Corporate Investment Experience, National Industrial Conference Board, Washington D.C.

Parry, T.G. and Watson J.F. (1979) 'Technology flows and foreign investment in the Australian manufacturing sector', Australian Economic Papers, Vol. 18(2), pp.103-116.

Piatier, A. (1980) Innovation et les Obstacles qu'elle Recontre, Report for the Director General XIII, EEC, Brussels.

Quinn, J.B. (1968) 'Budgeting for Research', in Heyel, C ed. Op.cit.

Ramsey, J.E. (1978) Research and Development Project Selection Criteria, UMI Press.

Reeves, E.D. (1958) 'Development of research budget' Research Management, Vol. 1, pp.133-42.

Robertson, A. (1971) 'The SAPPHO project: Success and failure in the innovation process', SPRU, University of Sussex, Brighton.

Ritchie,E. (1970) 'Research on research-Where do we stand?', R&D Management, Oct, pp.-10.

Rothwell, R. (1972) 'Factors for success in indsutrial innoations', Project SAPPHO-A Comparative Study of Success and Failure in Industrial Innvoation, S.P.R.U. Brighton , Sussex.

Rothwell, R. (1981) 'Government innovation policy-Some past problems and recent trends', Technological Forecasting and Social Change, Vol. 22(1), pp.3-30.

Rothwell, R. and Zegveld, W. (1982) Innovation and the Small and Medium Sized Firms, London;Frances Pinter(Pub.)

Scherer, F.M. (1963) 'Government research and development programmes' in Dorfman,R. ed. Measuring Benefits of Government Investments,

Schott, K. (1976) 'Investment in private industrial research and development programs', The Journal of Industrial Economics, Vol XXV(2), December, pp.87-99.

Schwartz, S.L. and Vertinsky, I (1980) 'Information preferences and patterns in R&D investment decisions', in Sahal, D. ed. Research, Development and Technological Innovation, Lexington, Mass.; Lexington Books. pp. 5-38.

Trattner, E. and Zidaroin, C. (1972) 'Economic optimization of technical scientific research plans' R&D Management, Vol. 2. pp. 83-86.

Walsh, V.M.,Townsend, J.F., Senker, P.J. and Huggett, P.M. (1980) Technical change and skilled manpower needs in the plastic processing industry SPRU, Occasional Paper, Series No. 11, Sept. Uni. of Sussex.

Wiltshire Committee (1972) Report of the Committee on Small Business, Dept. of Trade and Industry, Canberra;AGPS.

Yovits, M.C., Gilford, D.M., Wilcox, R.H., Stanley, E. and Lerner H.D. eds. (1960), Research Program Effectiveness, New York;Gordon&Breach.

Chapter Six

Effectiveness of Private Industrial R&D Effort

6.0 Introduction

The composition, level and direction of inventive effort of manufacturing firms and their R&D projects were examined in detail in the previous two chapters. A large number of firms directed their R&D effort to short-term, market specific goals. The effectiveness of the organisation and conduct of industrial research can be evaluated by examining the rate of success of projects. However the evaluation of R&D activity is not an easy task. All projects are not expected to generate positive results; and same may give rise to intangible products difficult to evaluate.

A number of empirical studies have been carried out to identify the determinants of project success or failure. Various studies have used the innovative project as a basic unit of study when evaluating success of innovation in industry. This approach has been subjected to some criticism as innovative projects cannot be regarded as independent from all other activities of a firm. Thus, Russel (1970) has pointed out that the criteria for better project evaluation should include reducing R&D projects to a common economic basis and the R&D program must be treated in total and not as a series of individual projects. Furthermore, Braun (1981) has suggested that the process of innovation should be regarded as a constellation of problem-solution-implementation. However, in practice, it is difficult to account for all types of inventive activities and factors relevant to success or failure of R&D effort simultaneously. Most studies, therefore, have selected individual projects in their analysis.

The effectiveness of industry R&D effort, in the first place, is determined by the nature and type of project selected by the R&D managers. Slowter (1964) pointed out that R&D managers must be aware of the following factors in project selection and evaluation:

a) actual return on investment compared with estimated return;

b) accuracy of estimates of research time and cost;

c) effect of research on overall operations, customer good-will, employee morale, and stockholder support, and national interest.

Various studies have conducted on determinant of project success and failure.[38] With regard to project failure, Cooper (1975) studied a sample of 114 actual product cases and identified four major reasons for new product failure: the strength and/or competitive position in market; overestimated number of potential users; products price set too high, and technical difficulties or deficiencies with products. Technological and market related factors were examined for eleven successful and eleven unsuccessful projects in West Germany by Gerstenfeld (1976) and he found that a number of factors such as demand pull versus technology

38 See Utterback (1974), Mowrey and Rosenberg (1979) and Cooper (1983) for a comprehensive survey of literature and critical analysis of the available concepts.

push, level of effort, process versus product, and the motivating forces for projects in work had different affects on success and failure of projects. He confirmed that failure is related to technology push and success is related to demand pull and high level of personnel devoted to projects.

All these studies have emphasized two types of regulatory factors that influence the project progress. These are:

a) economic and market factors which control the resource allocation, utilization and project extension.

b) technical and scientific factors which control the ability to produce results within a given period and generate successful ideas.

There is a lack of knowledge of the management planning strategies for R&D projects and their effect on project success in Australian industry. Cost and time estimates for R&D projects, particularly in high technology industry, demand a high level of precision in planning, analysis and imagination of managers (Moore, 1976). Managers need to be aware of 'known unknowns' and anticipate 'unknown unknowns' of R&D projects. The previous experience of failure and success can be useful in project management, planning and evaluation. The objective of this chapter is to examine problems in the estimation of project variables such as cost, duration and personnel, magnitude of cost and time overrun, factors influencing project success, problems encountered in completing projects and the influence of market and technical factors on project success.

A sample of 81 major R&D projects undertaken between 1976 and 1980 by 79 firms were available for this study. This sample, however, represents only a small number of projects completed by firms, hence results should be treated with some caution. In the absence of previous empirical studies on project success, failure and progress at inter-industry level in Australia, the findings of this study are intended to provide only tentative conclusions on R&D project performance. Only the project cost and duration were reported in most projects and R&D managers found it difficult to estimate the personnel utilized in projects because R&D staff worked simultaneously on a number of R&D projects and other industry activities.

The first section of this chapter examine the reasons for project success and magnitude of resource allocation to successful and unsuccessful projects. The second section examines overrun in project cost and time estimates, factors affecting cost and time overruns and reasons for delays in completing R&D projects.

6.1 State of the R&D Project Undertaken in Firms

The projects examined in this study are classified into four groups according to the state of project progress and success. These categories are:

a)completed - successful,

b)completed/abandoned - unsuccessful,

c)continuing - on schedule,

d)continuing - behind schedule.

The completed projects had achieved the expected targets in some cases and failed in others. The failures were attributed to technical, market or commercial difficulties and economic infeasibilities. In this sample, 72 per cent of the R&D projects had been completed and the remainder were on-going. Out of the completed projects, nearly 70 per cent were successful. The rate of success in the sample examined was very high. Successful projects were responsible for 80 per cent of the total project cost for this sample. These results indicate that most of the projects were able to achieve the expectations of R&D managers. The high rate of success suggests either a remarkable effectiveness of R&D personnel or more likely the selection of fairly certain projects with low technical risk by R&D managers.

Nearly half of the continuing projects had progressed on schedule without any setbacks but others were lagging behind schedule. The reasons for delays in projects are discussed later in this chapter. The level of resources allocated to these projects is presented in Table 6.1.

Table 6.1 Mean Average Cost($'000), length(months) and Personnel (personyears) Input Effort by State of Project

State of Project	Act. Cost	Act. Len.	Est. Cost	Est. Len.
Successful(n=40)	141(146)	17.4(9.0)	149(150)	13.8(7.0)
Unsuccessful(n=14)	106(70)	17.6(8.0)	143(78)	14.3(8.0)
Progress on time(n=16)	-	-	198(124)	22.6(8.9)
Progress behind(n=11)	-	-	210(195)	18.7(5.0)

Note: n, Act., Est., and Len. denote number of projects, actual, estimated and length respectively. Standard deviation is given in brackets.

As already stated, evidence from previous studies suggests that R&D project success or failure is caused by a number of factors which are related to the R&D itself, organisational characteristics, external factors such as market and competition, and social and economic factors. The level of resources allocated to projects is also regarded as critical to R&D project success (Gerstenfeld, 1976). In this sample of projects, R&D expenditure allocated to successful projects was slightly higher than that for unsuccessful projects. The standard deviations were, however, very large as noted in Table 6.1, High standard deviations can be largely attributed to different compositions of projects (product vs process) and difference in firm sizes which cause great variation in the size of projects undertaken.

Successful and unsuccessful projects lasted about the same time indicating a large consumption of R&D resources before projects were discontinued. This suggests that R&D managers take a long time to identify an unsuccessful project and abandon it. The failure to identify and abandon potentially unsuccessful projects at early stages could result from either R&D managers continued support for a project in the hope of resolving the problem or inadequate review of the progress of the project.

R&D project success and failure according to firm size indicated that small firms were slightly ahead in the success rate with 80 per cent of projects completing successfully compared with the rate of 75 per cent for their large counterparts. Resources allocated to successful R&D projects in small firms averaged \$73,000 (Standard Deviation(SD) \$68,000) and \$37,000 (SD \$10,000) for unsuccessful projects. Within small firms the variation in project expenditure between successful and unsuccessful projects was quite large. However, large firms spent an average $192,000 (SD $171,000) for successful projects and $128,000 (SD $68,000) for unsuccessful projects. The expenditure allocation to successful projects in medium-sized firms was $119,000 (SD $141,000) and $110,000 ($75,000) for unsuccessful projects. The high standard deviations preclude definite judgement on the effect of firm size on management practices. However, small firms tend to show a high success with high expenditure allocation. There was no significant difference in time taken to complete successful and unsuccessful projects in large and medium firms. Small firms, however, have taken a slightly shorter time for successful projects (13 months, S.D. 6 months) than unsuccessful projects (17 months, S.D. 6 months).

The performance of projects according to product and process development objectives indicate that both product and process oriented projects had a high success rate of 73 and 78 per cent respectively. Process research utilized on average more R&D expenditure than product research. The projects aimed at process development spent an average of $192,000 (SD $198,000) for successful projects, compared with $137,000 (SD $136,000) for unsuccessful projects. The successful product development projects spent an average of $129,000 (SD $133,000) compared with $100,000 (SD $62,000) for unsuccessful projects. Once again it is not possible to make definite conclusions from this sample due to high standard deviations which can be attributed to the different size of projects and the variation according to industry classes.

The reasons for the failure and success of projects were examined and a wide range of responses was obtained. In this sample, three projects failed due to technical problems. Some of the technical problems were caused by impossibility of the original conception of the problem involved, the high precision required in the technology, and constant failure of one or more stages of the project. One of the project managers reported that the original plan to use a sub-sonic axial compressor has been scrapped because the compressor blade requirements have been shown to be critical, and hence require high technology. The firm was unwilling to venture into the sophisticated technology required in the project because of the limitations in the firms' R&D capabilities and finances. Some of the technical difficulties consumed a considerable amount of resources and provided little success in meeting the quality required by the project leaders. One firm reported that because of the extreme difficulty controlling heat dissipation from different cross sectional areas of moulding, it had not been able to produce a lens of the required optical quality. The reasons for technical failure of a project may be attributed to either the inability to pursue technical knowledge beyond a certain limit or clear recognition of the technical infeasibility of the problem.

Commercial factors caused failure of six projects. Market factors are identified as the major factor for project failure more than any other factors in overseas studies (Robertson *et al.*, 1972, Rubenstein *et al.*, 1974, Utterback *et al.*, 1976, and Myers and Sweezy, 1978). The commercial failure was often caused by direct competition from rivals, high production costs and failure to find buyers. In one case, the project was discontinued following a release of a similar product overseas. The firm was skeptical about its ability to compete with the overseas product or produce a superior quality product within price constraints. Domestic competition also caused the failure of some R&D projects. One of the firms abandoned its project due to the low profits resulting from a competitor dumping cheaper imports. The high cost of production of some innovations inevitably led to commercial failures. In the case of some projects, it was difficult to draw a clear distinction between technical failure and commercial failure. For example, one project was found to be technically feasible, but financially unacceptable due to the long period of time required to dissolve the starting material which caused the escalation of production cost.

Four projects failed due to organisational and managerial problems, such as improper managerial decisions on resource allocation, indecisiveness in R&D priorities, and incompetence in project management. The shift of industry resources to other urgent problems in one firm caused serious setbacks to some projects which were abandoned subsequently. The unavailability of a project leader and delays in resource allocation were serious impediments to progress. Excessive government regulation was the major stumbling block according to one firm in which the manager described the action of government officials as unnecessarily rigid, unreceptive and highly bureaucratic. One of the projects was terminated under most peculiar circumstances. The firm stopped further development of the project after securing a healthy overseas order, as it was of the opinion that further development of the existing product was no longer warranted.

These results suggest that failure of R&D projects can be caused by a variety of factors, but that market and management problems were more frequent than technical failure.

A number of projects yielded a high return for their R&D investments. For example, a project involved in the production of herbicide cost $146,000 and yielded sales of $1 million in the year of launch, rising to $3 million in the second year giving a return to investment ratio of 20.5. Another project on cooling coils had a ratio of 3.2 after the first three month of launch, rising to 7.8 in the next seven months. Some projects had a low ratios. The most striking feature is the confidence of managers in a market of their product or process. Project managers had set targets and were certain about the market for their products, and directed projects with a confidence in market potential. A majority of projects secured outstanding sales orders while the project was on the drawing board. This suggests that R&D managers usually look for commercially sound projects as well as technically simple projects. They embarked on R&D projects with a clear view towards developing a commercially viable product. This in part explains the long time taken to abandon a project.

The success and failure of R&D projects examined in this relatively small sample reveal some of the important features of R&D projects. Most projects completed with desired results had a clear profitability. Market factors acted as a major driving force for undertaking projects. The high standard deviation make it difficult to make a positive conclusion on the level of R&D resource spending and project success although there was some trend to allocate more R&D expenditure to successful projects. There is a little difference in the time taken for both successful and unsuccessful projects. All firm sizes showed a equal rates of project success. Market and managerial factors were identified as the most frequent cause of project failure. The high rate of success also suggests that firms generally tend to select fairly safe projects. Indeed orders were obtained before projects were completed - a remarkably low-risk operation.

6.2 Estimates of Cost and Time in Industrial R&D Projects

The accurate estimation of cost and time of an R&D project for designing market strategy, timing of products, and planning investment activity. Cost and time variations can produce great problems. Overruns partly reflect the inability of managers to identify underlying factors which influence their estimates. Mansfield *et al.,* (1971) have pointed out that the accuracy of estimation can be simply represented as a ratio of actual to estimate. Therefore accuracy of estimates can be presented as;

$$\text{Cost Factor} = \frac{\text{ActualCost}}{\text{EstimatedCost}}$$

$$\text{Time Factor} = \frac{\text{ActualLength}}{\text{EstimatedLength}}$$

Table 6.2 Frequency Distribution of Projects According to Cost and Time Overruns for Completed R&D Projects

Ratio (Cost&Time Factor)	Cost No. of Proj.	Time No. of Proj.
0.00-0.50	4(7%)	1(2%)
0.51-0.75	14(25%)	1(2%)
0.76-0.90	6(11%)	2(3%)
0.91-1.00	10(18%)	17(29%)
1.01-1.10	13(24%)	4(6%)
1.11-1.50	6(11%)	23(39%)
1.50-2.00	2(4%)	11(19%)
	55(100%)	59(100%)

The frequency distribution of the cost and time factors in Table 6.2 indicate that time overrun was more frequent than cost overrun. 42 % of projects had costs within 10% of estimates. However actual length tends to extend more towards 1.5 times the estimated length. In a majority of projects, the actual project duration overran the estimates. On average, the ratio of actual to estimated cost was 0.9 and the ratio of actual to estimated time was 1.29. That overall costs should be less than estimated is a remarkable indication of the modesty of the projects involved.

These results differ considerably from the findings of Marshall and Meckling (1962), Mansfield *et al.*(1971) and Norris (1971) where large overrun in estimated resources was noted.[39] Marshall and Meckling (1962) pointed out that estimates of development project are quite inaccurate and cost increases of the order of 200 to 300 per cent and development time extended by 1/3 to 1/2 were common. Norris (1971) studied 475 British industry projects and found that project duration was 1.39 to 3.04 times longer than estimated and costs were 0.97 to 1.51 of estimates. Evidently their sample differed in size, types of problems involved and types of technology advances sought from the projects studied in this study. The low overrun in cost and time estimates in this sample may be attributed to one of the two factors. Either

39 Mansfield's study estimated cost of 49 projects and time of 50 projects between 1950 and 1967 and found that the estimated length and cost had shown large variations from the actual.

1) a managerial judgement and experience of R&D project estimation is remarkably high; or

2) projects undertaken in Australian industries are so precisely defined, and lacking in uncertainty that accurate estimates can be easily made.

It was noted in Chapter Five that project cost is strongly associated with research employment and that project duration has a relatively less significant association with cost. This is further supported by the fact that projects were completed well within the estimated cost while a large number of projects failed to be completed within the estimated time. It could be expected that the estimated project cost would increase as the expected time increased. However, a majority of projects remained well within the estimated cost. This indicates that although a projects' life may extend, it has little effect on the project's cost. The original estimation of R&D personnel requirements was adhered to but over a long time. Perhaps one of the important factors to note is that project cost and project length are not generally interchangeable but are complementary. Delays in obtaining end products in these projects were not primarily due to limits in financial resources.

6.3 Effect of Institutional Factors and the Composition of R&D on Cost and Time Overrun

The effect of institutional and environmental factors on the determinants of cost, length and personnel allocation to R&D projects needs consideration. Some of the important variables studied are the firm size, ownership, product versus process development, nature of development attempted, advances in technology sought, and type of R&D activity undertaken. These organisational and project composition factors can exert a significant influence on project selection as well as progress of the projects. The difference in the behaviour of different industries is associated with the nature of management of projects, resource availability and flexibility in firms to alter or redirect their resources.

The cost was significantly over-estimated in small firms but the time factor was more accurately estimated in large firms. These results suggest either that small firms tend to be more careful in project design by allowing for uncertainty or that most of their projects are quite modest - a result not in accord with the findings of the previous Chapter. On the other hand medium and large firms were able to estimate their project costs accurately but failed to complete their projects on deadlines (Table 6.3).

Table 6.3 The Variation in Cost and Time Factors and Level of R&D in Completed Projects of Small, Medium and Large firms

Firm Size	Cost Factor	Time Factor
Small(n=11)	0.78(0.38)	1.18(0.20)
Medium(n=22)	0.91(0.28)	1.41(0.74)
Large(n=20)	0.96(0.34)	1.27(0.33)
Average	0.90(0.32)	1.31(0.52)

Note: n denotes the number of firms and standard deviation is presented in brackets.

The total R&D employment in firms is treated in this study as a more significant factor in project success than the R&D personnel assigned to individual projects. This is mainly because of the fact that most industries tend to shift their manpower resources from project to project. In addition ideas are generated by various type of personnel including production staff, R&D managers, R&D staff, technical staff and other supporting staff. In this sample of projects, small firms assigned a low level of total R&D personnel (average person-years 5, SD 4) compared with medium and large firms - 16 (SD 14) person-years and 42 (SD 101) person-years respectively.

The effect of ownership on the cost factor was low. Both the Australian controlled and foreign controlled firms have a relatively high and a similar accuracy in cost estimation. The composition of R&D spending in projects according to different type of development activities showed a similar overrun in cost factor but for all types the time factor was very high for pilot plant scale development(Table 6.4).Some of the reasons for this are discussed in the following section. The level of cost involved also varies according to different types of activities. The rate of success in development of pilot plant was 80 per cent and the development of prototype had more failures with a success rate of 68 per cent. The projects with high applied research content also had a high success rate of 88 % indicating that projects involved more research are not necessarily more likely to fail. The average cost for successful projects involving pilot plant were $246,000 compared with $125,000 for unsuccessful projects. The successful prototype projects also had a high project expenditure (av. $107,000) compared with the unsuccessful projects(av.$98,000).

Table 6.4 The Variation in Time Factor and R&D Level of Completed projects by Type of Development Activity

Activity	Cost Factor	Time Factor
Pilot plant(n=5)	0.92(0.11)	1.94(1.2)
Prototype(n=32)	0.91(0.4)	1.27(0.4)
Applied R&D(n=17)	0.91(0.3)	1.20(0.3)
	0.91(0.3)	1.30(0.5)

Note: n denotes number of firms. The average cost is given on $'000 and av personnel is given in person years and standard deviation presented in brackets.

The accuracy of estimation of both cost and time factors might be expected to decline with the magnitude of the technological change sought. However, in the very small sample of high technology developments cost estimates were highly accurate, but project length was underestimated by half(Table 3.5).

Table 6.5 The Variation in Time Factor and R&D Level of Completed Projects by Advanced Technology Strategies

Advanced Tech.	Cost Factor	Time Factor
High Tech.(n=4)	1.00(.41)	2.12(1.4)
New to Aust.(n=10)	0.96(0.30)	1.14(0.3)
New to Firm(n=22)	0.87(0.34)	1.31(0.3)
Standard Tech.(n=2)	0.84(0.24)	1.08(0.11)
	0.91(0.33)	1.31(0.5)

Note: n denotes number of firms.

6.4 Factors Affecting Cost and Time Overruns

The accuracy of estimates of cost and length of projects can be influenced by a number of factors including the technological advances sought by the projects, company IR&D rating, relative size of project, project duration and firm size. The degree of technical advances sought in a project can influence the variation in project estimation. The high technological content of a project may cause greater uncertainty in project outcome than with less complex projects. The availability of previous research experience, trained staff and good R&D facilities can influence the level of ambitious projects undertaken in firms. Firms with better R&D facilities may tend to undertake more sophisticated projects, so that, cost and time overruns in such project may be high. Another variable which can affect the cost and time overrun is the absolute size of the project. Mansfield (1971) has found that the greatest inaccuracy occurred with the more ambitious projects in terms of size and length. The high level of accuracy in the Australian sample apparently reflects a lack of ambition.

Firm size also can control the progress of projects. In particular, large firms may have a flexibility in resource allocation to speed up and alter the course of a project when it lags behind. Small firms on the other hand may be restricted by their inability to undertake a wide range of technological advances.

In previous studies (Mansfield, *et al.*, 1971) the effect of different factors on time and cost overrun have been examined. A multiple regression model of the logarithm of the ratio of actual to estimate and the logarithm of variables likely to affect overrun was used.[40] A similar multiple regression model used in this study is given by

$$\ln R^i_c = \alpha_0 + \alpha_1 \ln T^i + \alpha_2 \ln I^i + \alpha_3 \ln C^i + \alpha_4 \ln L^i$$

where $\ln R^i_c$ is the logarithm of the ratio of the ith project's actual to estimated R&D cost, α^i is a constant, $\ln T^i$ is the logarithm of the ith

40 See Mansfield *et al.*, (1971) for an explanation of using logarithm.

project's estimated technological advance rating, ln Ii is the logarithm of the firm's R&D rating, $\ln C^i$ is the logarithm of estimated project cost, and ln Li is the logarithm of actual duration of the ith project.

The resulting regression equation for the cost overrun in the sample of project studied here is

$$\ln R^i_c = 0.86 + 0.2T^i + 0.48I^i - 0.13C^i - 0.22L^i$$

The coefficient of determination=0.32, R=0.57, F=5.9(degrees of freedom 4,48).

These results provide some insight into the relationship between cost overrun and a number of variables causing such overrun. It appears that the regression coefficient of the logarithm of the technological advance rating, industrial R&D rating, and project duration have a positive influence on increase in cost overrun. According to the equation, cost overrun tend to be greater for projects attempting greater technological advances. For a 1 per cent increase in the technological advance rating there is a 20 % increase in cost overrun. Similarly a 1 per cent increase in the IR&D rating was associated with a 48 per cent increase in cost overrun. This indicates the better the R&D facilities, the more uncertain the projects which seem to be undertaken. The cost overrun tend to be bigger for longer projects with a 1 per cent increase in project length being associated with a 22 per cent increase in average cost overrun. Finally, cost overrun seemed to be smaller for bigger projects, an increase in 1 per cent of average cost reducing the cost overrun by 13 per cent. This indicate that there was a tendency for a small overrun in project cost for expensive projects. These results are in agreement with the findings of Mansfield *et al.*(1971). However, these variables explains only one third of the variation in cost overrun.

The above relationship varied according to firm size. As the firm size increase from small to large the above relationship became stronger. In the case of large firms 84 per cent of the cost overrun was explained by these variables.The resultant equation for large firms is

$$\ln Rl^{i} = 0.19 + 0.83T^{i} + 1.2l^{i} - 0.49C^{i} + 0.74L^{i}$$

Coefficient of determination 0.84, R=0.92, F=6.6(degrees of freedom,4,5).

A similar regression for time overrun did not show a significant relationship indicating the variability of factors associated with time overrun.

6.5 Reasons for Delay in Project Progress

The delay in the progress of on-going and completed projects are caused by several factors which act on projects at various stages of project development. Most of the technology related delays were caused at early stages of projects. Management related causes of delays were critical through out the project and final stages were delayed by tooling, testing and production related factors. A few projects were delayed intentionally due to uncertainty in the market.

Some of the common technical problems that cause delay were failure of components, difficulties encountered in stages of product and process development and inherent uncertainty in research. The under-estimation of technical problems was another cause of project overrun.

The most common factors causing project delay were external or management related. Inadequate research facilities were a major constraint in keeping up with the project schedule. Shortage of experienced research personnel, equipment, funds, and inaccessibility of technical information were cited as some of the serious problems. Delays were caused by administrative and management inefficiencies. A number of project delays were blamed on delays in supplying certain components and other material, and sub-standard material supplied by the sub-contractors. Management decisions to divert personnel and financial resources to more urgent problems also seriously affected the progress of some projects. The lack of availability of a project leader or inadequate supervision were also given as a reasons for project delays. Most of these problems, however, could have been avoided by more efficient R&D project management.

6.6 Conclusions

The results obtained in the study of a small sample of 40 successful, 18 unsuccessful and 23 on-going manufacturing industry projects indicate number of important features of the effectiveness of industrial R&D in Australia.

One of the outstanding results reported in this chapter is the high success rate (69%) of projects. Most of these projects were submitted by the research intensive other machinery and industry class. There was a noticeable tendency in these projects to allocate high average R&D expenditure to successful projects compared with unsuccessful projects. The decision making process of R&D managers indicates that the identification of potential failures was rather slow. Projects were terminated only after utilizing a considerable amount of resources. The delay in recognition of failure in part explains the weakness in R&D project management and in part reflects the failures of projects at their later stages of development.

The high success rate of projects can be attributed to the relatively short duration (average 2 years) and high market orientation of projects with relatively moderate technological development objectives. Therefore the potential risk of projects was relatively low compared with high technology and more research oriented projects. A large number of project failures were attributed to market and management factors (87%) and the rest to technical factors. There is a tendency for Australian firms to undertake relatively simple, short-term, market specific and technologically unsophisticated projects. The risks taken in such projects can be expected to be fairly low. Poor management and market uncertainty were identified as the major road-blocks to the success of most projects.

In terms of the accuracy of estimating project dimensions such as cost and duration, the sample of project examined in this study showed that Australian firms have quite a high accuracy compared with overseas studies where overrun of cost and time was in the order of 2 to 3 times (Mansfield, 1971). On average Australian firms tended to slightly overestimate the project cost and underestimate the project duration. This is again a reflection of type of project selected by managers. Evidently, as discussed in the previous chapter, most R&D projects are directed towards low risk technical development objectives, and there is a general reluctance to undertake high risk and high technology development. This strategy can be regarded as utilizing existing technical knowledge rather than developing new knowledge. In one sense, this can be treated as a sensibly cautious policy. However, in the long run firms may be disadvantage by not possessing adequate competence to compete with overseas technological development. Hence, in the long run firms will be severely restricted in capturing international markets.

Firm size also affected the cost overrun with large firms showing a very strong connection between percentage overrun and variables examined. Small firms were able to estimate project duration much accurately, although they tend to overestimate project cost. The accuracy of estimation of project cost and duration did not greatly vary in foreign and Australian controlled firms. This suggest that both foreign and local firms attempt very similar types of problem solving. Among the most influential factors involved in project overrun were the industrial

R&D rating, degree of technical complexity of project and project length. The more ambitious and long term projects had high errors in cost estimates.

References Chapter Six

Baker,N.R., Siegman, J. and Rubenstein, A.H. (1967) 'The effects of perceived needs and means on the generation of ideas for industrial research and development projects' IEEE Transaction on Engineering Management, Vol. EM-14(4), Dec. pp.156-163.

Braun, E. (1981) 'Constellations for manufacturing innovation', OMEGA, Vol. 9(3), pp. 247-253.

Balachandra, R. and Raelin, J.A. (1980) ' How to decide when to abandon a project', Research Management, July, Vol. XXIII(4), pp.24-29.

Cooper,R.G. (1975) 'Why new industrial products fail', Industrial Marketing Management, Vol. 4 pp.315-26.

Cooper,R.G. (1981) 'An empirically derived new product project selection model' IEEE Tran. Engineering Management, Vol. EM-28 (3), pp.

Cooper, R.G. (1983) 'A process model for industrial new product development', IEEE Transaction on Eng. Management, Vol. EM30(1),Feb.pp.2-11.

Gerstenfeld, A. (1976) 'A study of successful projects, unsuccessful projects and projects in progress in West Germany', IEEE Transaction on Engineering Management, Vol. EM23(3), Aug. pp 116-123.

Marshall, A.W. and Meckling W.H. (1974) ' Predictability of the cost, time and success of development' in NBER ed. The Rate and Direction of Inventive Activity, Princeton:Princeton U.P.

Mansfield,E., Schnee, J. Wagner,S. and Hamburger, M. (1971) Research and Innovation in the Modern Corporation New York;W.W. Norton & Co. Inc.

Moore,J.R. (1976) 'Unique aspect of high technology enterprise management', IEEE Transaction on Eng. Managment, Vol. EM23(1),Feb.pp.10-20.

Mowery, D. and Rosenberg, N. (1979) 'The influence of market demand upon innovation-a critical review of some recent empirical studies', Research Policy, Vol. 8, pp. 102-153.

Myers, S. and Marquis, D. (1969) Successful Commercial Innovation, NSF 69-71,Washington:NSF.

Myers, S. and Sweezy (1978) 'Why innovation fails' Technological Review, March/April, Vol. 8(5), pp.41-46.

Norris, K.P. (1971) 'The accuracy of project cost and duration estimates in industrial R&D ' R&D Management, Vol. 2 Oct pp.

Robertson, A.B., Achilladeis, B., and Jervis, P. (1972) Success and Failure in Industrial Innovation: Report on Project SAPPHO, London; Centre for the Study of Industrial Innovation.

Rothwell,R. (1972) 'Factors for success in industrial innovations', Project SAPPHO, A Comparative Study of Success and Failure in Industrial Innovation', Sussex, SPRU.

Russel, E.J. (1970) 'R&D evaluation-The Total program approach', Financial Executive, Dec pp.21-29.

Rubenstein,A.H., Chakrabarti, A., O'Keefe, R. (1974) Final Report on Field Studies of the Technological Innovation Process, Dept. of Industrial Engineering and Management Science, The Technological Institute, Northwestern University, Evanston, Illinois.

Slowter, E.F. (1964) 'Budgeting and financial control of research, Financial Executive, Oct. pp.17-24.

Utterback, J.M.(1974)'Innovation in industry and the diffusion of technology', Science Vol. 183, pp.620-626.

Utterback, J.M., Allen, T.J., Hollomon,J.H., Sirbu, M.A. (1976) 'The process of innovation in five industries in Europe and Japan', IEEE Tran. Engineering Management, Vol. EM-23(1),Feb. pp.3-9.

Chapter Seven

Summary and Conclusions

The poor capabilty of Australian industry with regard to technology development and introduction which has been the matter of much analysis and attempted remedy in the last few years has been shown to have a considerable history. The limited technological achievements in some industry areas can be largely attributed to occasional individual efforts, accumulation of capital and experience of the workforce rather than organized advances in industrial technology. Nor can these weaknesses be blamed solely on the oft-cited disadvantages of manufacture in Australia, such as government policies, international competition and other market factors. It is significantly due to managerial limitations, industry attitudes towards R&D investment and organizational inefficiencies.

The development of industrial R&D effort over the period 1900-1968 was shown to be limited by both government policies and the negative response from private industries. The major concern of industrial firms in this period led to a restriction of the objectives of technological innovation to adoption of imported technology and minor improvements and modifications necessary for exploiting domestic markets. There is hardly any evidence to suggest increasing enthusiasm for or reliance on technological development in the early part of the century. The Government role in promoting science and technology was evident as early as 1916 when the Advisory Council of Science and Industry was appointed to develop scientific and industrial research on a more organized basis. These initiatives, however, were directed primarily towards solving problems in the agricultural domain and little industrial research was conducted in government research insititutions. This was partly due to the dominance of the pastoral interests and partly due to the colonial influence which encouraged imports of products from the U.K. Private industries developed a tradition of relying on the supply of components, intermediate products, and production technology from overseas sources. The institutional strategies and government protection policies created very little competition among existing industries and contributed to the development of industrial innovation strategies restricted to short-term trouble-shooting and relatively simple technological advances.

The need for government intervention in organizing and promoting industrial research at the national level was demonstrated in 1937 with the appointment of a Parliamentary Committee to report on Secondary Industries Testing and Research. Although a number of measures, including an increase in R&D activity and research incentive for private industries, were suggested, it was apparently difficult to change the deep seated tradition of agricultural oriented research activity in the government institutions. The major emphasis of governmental policies was therefore on indirect measures such as assistance to industries, protection from overseas competition, and taxation incentives.

A conscious effort to develop in-house R&D activity in private industry was realized with the post-second world war industrial expansion. However, a few large companies dominated the research frontiers in those industries oriented towards technology such as chemicals, scientific instruments, electrical equipment, and other machinery and equipment.

However both private and public sector interest in industrial R&D increased significantly in the past two decades. Private industry R&D effort not only grew compared with the levels of the 1950s, but new capital investment was shifted from building and land to new equipment - an indication of a greater recognition of the importance of product technology.

However, growth in R&D in real terms stagnated from the mid 1970s onwards and a decline in resources in some industry areas was pronounced. This can be attributed in part to the poor performance of the Australian and world economy. However, other more structural weakness appear to have contributed as well. As a result the pattern of concentration of R&D activity in the chemicals, petroleum, coal products, other machinery and equipment, and transport equipment industries continued. Most companies in these classes focussed on development activity and little basic research was conducted. The research intensive industries were also characterized by their high import performance. This may indicate that R&D activity in the research intensive industries was not aiming at technological superiority in export products but rather with adoption of imports.

A close association between R&D input and economic output indicators suggests that R&D investment is closely linked to the performance of firms. Although knowhow payments grew more than did R&D expenditure, these activities are usually not at the expense of each other. A decline in R&D was generally followed by a decline in payments for knowhow.

Structural difference at the firm and project level provided a considerable explanation of the R&D structure in industries. Although the sample of firms studied here represent only the highly research active firms, this group is perhaps the most important as they represent the industrial trend-setters. Although the national IR&D declined between 1968/69 and 1978/79, the sample studied showed a slight improvement in R&D activity in real terms, though this did not apply to all industry classes. A remarkable variation was found in year to year R&D investment, suggesting a short term orientation to immediate problems rather than a major means for achieving company objectives.

Firms generally commited only a small amount of their resources to R&D but a few firms, mostly small (employment less than 50 persons) devoted a significant percentage of their resources to R&D. Nevertheless the bulk of R&D is still conducted in large firms. Medium sized firms had in general a very low commitment to R&D.

One result of considerable significance to emerge from this study was the orientation towards new product development. This form of tehnological development is normally considered to involve the greater risk, and to be a characteristic of the strategy of small firms in the early stages of development of a technology. This is not in accord with the general picture presented of sluggish, defensive firms in Austrlia.

Part of the explanation may lie in the preponderance of small firms in the sample and the fact that it does represent the technological elite of Australian companies. However, closer examination of these projects showed that in most cases the technological improvements in the new product development were relatively modest, and were associated more with product diversification and cosmetic changes rather than major technological advances. In other countries many of these items would not have been considered new products. Hence the apparent emphasis on new product development is more a consequence of the perceptions of firms than of substantial innovative strategies.

The majority of firms continued to concentrate on short-term, development type R&D with a low technological content. New avenues were rarely explored and there was a reluctance to take any substantial risks in developing technology. Many firms sought sales before their new product was developed.

One notable feature was a marked inadequacy in the R&D facilities available in firms, despite considerable financial and human resource commitments to inventive projects. The objective of R&D projects was to satisfy immediate consumer needs and potential markets. There was little concern with new technology development and ventures into new technological markets.

Management forecasting of cost and duration of R&D projects showed a remarkable degree of accuracy when compared with the results of other overseas studies. However, this was largely because most R&D projects contained relatively little technical complexity. The low risk nature of most projects made the task of project selection and formulation comparatively easy for R&D managers. There was however a notable weakness in decision making concerning when to abandon potentially unsuccessful projects. Most projects were terminated at very late stages of project development and often consumed a considerable proportion of the estimated project cost, even though the average cost of unsuccessful projects was significantly lower than successful ones. This is a reflection of poor project management and evaluation. The failure of projects resulted largely from market driven factors rather than technological driven factors in this small sample.

Thus it can be concluded that there has been a long history in Austrlia of conservatism and lack of awareness with regard to the importance of technology in industrial development. In particular there is a very strong risk aversion, and an emphasis on short term product development projects, which is apparently a consequence of managerial attitudes, the limitation of the Australian market, the structure of Ausralian industry and to some extent the degree of penetration by foreign-owned companies of the industry classes where technology is a more important factor.

The results of this study demonstrate the importance of recognising the heterogenity of industry, along many dimensions. Generalisations of the level of performance of industry as a whole have been shown to be to a significant extent meaningless or worse misleading. When it comes to understanding the dynamics of technology development and introduction, and the factors affecting decisions, and even more considering policy proposals, it is vital to recognise the different markets, capabilities and practices in different industry classes. Added to this basis of differentiation, size, and to a lesser extent ownership have been shown to be important in shaping decision making.

The composition and extent of R&D activity has been shown to be determined most directly by an interplay between estimations of actual or potential markets and firm strategy. The technology cycle theory of Utterback and Abernathy undoubtedly has some application, and the position on the technology trajectory is one determinant of technology development and R&D.

However, the fast that by far the majority of firms are in mature industries using mature technologies has not produced the very strong emphasis on process improvement that technology cycle theory would suggest. In the Australian situation where the major business strategy of manufacturing industry rests on satisfying the domestic markets, there is a strong and understandable orientation towards producing new products. As has been noted however, these do not usually involve a very substantial technological content and most frequently rely on imitation or adaptation of foreign products.

These findings would suggest that tehnology cycle theory should be evaluated more closely in different industries and different countries. It does appear that factors other than technology are more influential in determining strategies of industrial development in countries with smaller markets than the U.S. and with a lesser level of industrialization.

The influence of firm size on technology development strategies found in this study has been largely in accord with the findings of surveys in other countries. A certain proportion of small firms showed considerable dynamism and strong commitment to technology-led company strategies. Large firms were responsible for the greatest part of national industrial R&D but tended to emphasis development rather than research, and a defensive approach.

These findings on the structure and determinants of Australian R&D activity, at a level far more detailed than previously available, provide an improved basis for policy making with the objective of supporting technology development in industry.

The demonstrated different aims, approaches and capabilities of firms of different sizes has significant implications for policy. Firms that are small are by and large the most adventurous, but also the most in need of support. Ma ny were attempting to develop substantially new technology with inadequate facilities. For companies in these categories, subsidies provide the most suitable form of support and hence the AIRDI Scheme would appear appropriate. However, the requirements for a project grant of reasonably well-established facilities and some evidence of achievement may provide a considerable barrier. Hence grants to small companies might be usefully suplemented by a facilities and equipment grant.

For medium sized firms, with a conservative approach to satisfying a known local market, R&D subsidies are unlikely to have much effect, except as a general source of revenue for the company. It might be most appropriate to seek to support these companies by bringing their performance and management up to best practice. This can be achieved by intensive campaigns of information delivery and education and demonstration of the returns to be achieved from the incorporation of appropriate technology.

There is relatively little possibility of direct influence on the innovative behaviour of large firms through subsidies. Moreover they choose their research programme largely in accord with their quite well established assessment of market opportunities. Hence taxation incentives are likely to prove the most appropriate means for improving the level of technology development. An effect upon the kind of technology development could only be achieved through establishng Australia as a base for export of technologically sophisticated products to some significant proportion of the world market (such as South-East Asia) or persuading and/or coercing multi-national firms to allow a world product mandate for some goods produced in Australia.

One of the inhibitors to more effective technology development appears to be the costs of skilled staff, and expensive equipment and facilities necessary for these activities. While there is a need to maintain the confidentiality of proprietary information, this does not appear to provide an inseparable barrier to a much greater level of extra-mural research. Two means which suggests themselves are first contracting out of research needs to universities and CSIRO, with a certain level of support from Government to discount the cost of these activities. Secondly, companies may be encouraged to form research consortia to conduct research of mutual value in technologically advanced areas again with a certain level of direct or indirect financial incentive.

One of the major limitations on the development of a more aggresive technology orientation in Australian products is the very strong focus on the domestic market alone. Hence support and encouragement for moving towards a greater export orientation will produce the requirment of a much greater recognition of the importance of product quality, particularly as achieved through the development and introduction of technology.

Finally, there is a need for a change in the perception and attitude of Australian managers towards the contribution of technology to their business. One approach to this would be the continuation and improved coordination of an commiunity of the declining place of Australian in the world economy and the need to develop a much stronger technological competitiveness. This compaign will be aided most by the ability to point to a number of specutacular Australian successes as a demonstration model of what can be achieved.