An Investigation into the Determinants of Innovation in the New Zealand Biotechnology Sector

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Abstract

This thesis synthesises theoretical and empirical knowledge from four strands of the innovation literature and then uses this knowledge to develop a framework for analysing the determinants of innovation. The framework is tested on one part of the New Zealand economy - the biotechnology sector - an area of rapid technological change where innovation is of particular significance.

Theoretical approaches to the economics of innovation and technological change are reviewed with particular reference to the neo-classical, endogenous growth, evolutionary and systems of innovation approaches. Alternative methods of measuring innovation output and innovation rate are also discussed. This is followed by a series of hypotheses regarding the determinants of innovation and a review of their place in the innovation literature. The thesis includes a detailed description of the New Zealand biotechnology sector based on a re-analysis of the first comprehensive (1998/99) survey of biotechnology in New Zealand, data from an original (2002) survey conducted by the author, data from interviews with senior management in a sample of biotechnology firms and a detailed review of secondary sources. This material is used in chapter 5 to address the question 'Does New Zealand have an innovation system for biotechnology?'

Count data regression models and data from the 1998/99 and 2002 surveys are then used to test the framework's innovation hypotheses. Hypothesis testing focuses on the effects of several determinants (firm size, firm type, conduct of R&D, involvement in modern biotechnology, specialisation, and alliances) on innovation output and the innovation rate. Results relating to the effect of demand, technological opportunity and appropriability are also reported. The analysis in this thesis confirms the importance of most of the innovation determinants included in the framework. It also provides a detailed examination of the biotechnology sector and empirical insights into the innovation behaviour of biotech enterprises in New Zealand. Prior to the analysis in this thesis, knowledge of the sector's parameters was very limited or absent.

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Data Access and Disclaimer

Access to data from the 1998/99 Biotechnology Survey was provided by Statistics New Zealand under conditions designed to give effect to the security and confidentiality provisions of the Statistics Act 1975. Standard Statistics' random rounding to base three has been applied to all output.

Disclaimer. The results presented in this study are the work of the author, not Statistics New Zealand

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List of Acronyms[1]

ANZSIC	Australia New Zealand Standard Industrial Classification
BERD	Business Expenditure on Research and Development
BPS	Business Practices Survey
CRI	Crown Research Institute
DBF	Dedicated Biotechnology Firm
DNA	Deoxyribonucleic acid
DSIR	Department of Scientific and Industrial Research
DTI	Department of Trade and Industry
EU	European Union
FDI	Foreign Direct Investment
FRST	Foundation for Research Science and Technology
FTE	Full Time Equivalent
GBAORD	Government Budget Appropriations or Outlays on R&D
GERD	Government Expenditure on R&D
GIF	Growth and Innovation Framework
GERD	Government Expenditure on Research and Development
IO	Innovation Output
IR	Innovation Rate
ISI	Institute for Scientific Information
MBE	Modern Biotech Enterprise
MBU	Modern Biotech User
MITI	The Ministry of Trade and Industry
MoRST	Ministry for Research Science and Technology
NBRM	Negative Binomial Regression Model
NIS	National Innovation System
NSI	National System of Innovation
NZBA	New Zealand Biotechnology Association
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
PCT	Patent Cooperation Treaty
PGSF	Public Good Science Fund
PRM	Poisson Regression Model
R&D	Research and Development
SCP	Structure – Conduct – Performance
SI	System(s) of Innovation
SNZ	Statistics New Zealand
TBE	Traditional Biotech Enterprise
TBU	Traditional Biotech User
TPP	Technological Product and Process (innovation)
ZINB	Zero Inflated Negative Binomial Regression Model
ZIP	Zero Inflated Poisson Regression Model

[1] Additional information about many of these terms is provided in Appendix 1.

Chapter 1 Introduction

1.1 Background

Economists have long recognised that innovation is central to economic growth, but until the 1950s excluded this area from the mainstream literature. Indeed, economists such as Marx and Schumpeter who tried to give innovation a more central role were "regarded as rogue elephants whose work, although certainly of interest, should not be taken too seriously"(Freeman, 1994, p. 463). Explanations for the relative neglect of innovation include: preoccupation with employment and the business cycle, the lack of quantitative data (Jewkes, Sawers, & Stillerman, 1958) and the 'black box' explanation, that "technical change was outside the specialised competence of most economists and had to be tackled by engineers and scientists" (Freeman, 1994). However in the last 50 years, there has been a great upsurge of interest in the economics of innovation and technological change ranging from empirical research through to fundamental theoretical analysis. It is now widely believed that research, science and technology are critical to ensuring national competitiveness, and innovation has become the latest 'buzz' word, used by media, politicians, and managers to refer to all manner of desirable activities.

Governments are taking an ever greater interest in science policy intervention, in direct contrast to the general trend towards market oriented policies in other areas of the economy. Many have focussed their attention on the transformation of developed economies into co-called 'knowledge societies', where information, knowledge and the service sector are expected to become ever more important. Policy makers around the world are searching for ways to encourage this transformation and often devote significant resources to policies for research, science, technology and the encouragement of innovation. This thesis makes a general contribution to the economics of innovation and a specific contribution to our knowledge of the determinants of innovation in the New Zealand biotechnology sector.

The origins of this thesis date back to my MSc dissertation which examined economic aspects of specific agricultural technologies (Marsh, 1980). I was particularly interested in the economic effects of technological change and of government policy in this area. On completing my MSc, I started work as a development economist, and in the mid-1980s was employed on an agricultural research project in Botswana. I conducted studies on the economic benefits of innovations emerging from research teams and provided an input to the process of setting priorities for research funding. My interest in fostering the use of economic methods in order to improve the management of research and innovation dates back to this period. This thesis can thus be seen as the continuation of a long-standing interest in economic aspects of research, technology and innovation.

New Zealand is an ideal place to undertake further research into economic aspects of research and innovation. It has been at the forefront of science reforms and the science funding system is relatively small and centralised. The economics of innovation has not been intensively studied in New Zealand, so application and development of some of the methods first used in other countries[1] brings significant benefits.

This thesis synthesises theoretical and empirical knowledge from four strands of the innovation literature in order to develop a framework for analysing the determinants of innovative output[2]. The framework is tested on one part of the New Zealand economy - the biotechnology sector - an area of rapid technological change where innovation is of particular significance. While there is a large and growing international literature on economic aspects of biotechnology innovation (see section 1.4), these studies concentrate on the United States and Europe. The New Zealand biotechnology industry may be expected to develop along a different trajectory as a consequence of a markedly different set of initial and framework conditions (see sections 1.3 and chapter 5). Data from the first comprehensive survey of biotechnology in New Zealand (Statistics New Zealand,

[1] Particularly USA and member states of the European Union.

[2] This will be referred to as ‘the innovation framework’ or ‘the framework’.

2000a) were extensively re-analysed by the author and combined with data from a follow-up survey, in order to provide the sectoral context for this study. It was supplemented by secondary sources and data from a scoping study involving semi-structured interviews with senior management in a sample of biotechnology firms and organisations.

A series of key innovation hypotheses emerging from the innovation framework are tested using data from the 2000 survey and from an additional survey conducted in 2002. The 2002 follow-up survey was designed and implemented by the author in order to investigate research questions not addressed in the earlier survey. It provides improved data on innovative input, innovative output, the number and impact of biotech alliances and an extensive set of other variables. This analysis confirms the importance of most of the innovation determinants included in the framework and provides specific results that enable application of the framework to the New Zealand biotech sector.

This thesis makes an original contribution to the literature in three main areas. First, a framework for understanding the determinants of innovative output is presented, based on a synthesis of current knowledge in different strands of the innovation literature. Second, data from two surveys are analysed in order to present a comprehensive analysis and description of the New Zealand biotechnology sector. This material is considerably more detailed than previous descriptions and also makes use of different analysis methods and new data collected by the author. Third, two original datasets are used in order to test the hypotheses that emerge from the innovation framework. This is the first time that this set of hypotheses has been tested in New Zealand and one of the first detailed investigations into the determinants of innovation in New Zealand.

1.2 Chapter Outline of Thesis

The remaining sections of this chapter assess New Zealand's innovation performance to date, outline the national policy framework for innovation and provide an introduction to the economics and meaning of biotechnology.

Chapter 2 describes and reviews the main theoretical approaches to the economics of technological change. The literature is organised into five main schools of thought and nine theories or concepts, with each being further classified as an equilibrium or evolutionary approach. The review concentrates particularly on neo-classical approaches, endogenous and new growth theories, evolutionary approaches and systems of innovation. It is followed by a discussion of the main criticisms of neo-classical and systems of innovation approaches and some conclusions that set the scene for the next chapter.

Chapter 3 starts with a discussion of the meaning of innovation and the methods by which it can be measured. The following sections are devoted to presentation of a series of hypotheses that aim to capture the determinants of innovation, alongside a review of their place in the innovation literature. The chapter concludes by describing a framework for understanding the determinants of innovation.

Chapter 4 provides a description of the New Zealand biotechnology sector based on original analysis carried out by the author and a review of secondary sources. This description is intended to set the scene and provide context for the study of the determinants of innovation described in Chapters 5 and 6.

Chapter 5 uses a combination of secondary sources and data from interviews in order to analyse the institutional setting for biotechnology in New Zealand. An earlier version of this chapter was published in the Elsevier journal Technovation in 2003[3]. Chapter 6 analyses the factors that affect the innovative output and innovation rate of enterprises in the New Zealand biotechnology sector. The analysis is based on the innovation framework developed in chapters 2 and 3. The final chapter draws together the main findings from each part, in order to present conclusions for the thesis as a whole, regarding the determinants of innovation both in general and in the particular case of the New Zealand biotechnology sector.

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[3] Marsh, D. (2003) *Does New Zealand Have an Innovation System for Biotechnology?* Technovation, 23(2) February, 103-112.

1.3 The National Context[4]

1.3.1 Innovation System[5] Performance

New Zealanders like to think of themselves as innovative people who can fix anything with a piece of No. 8 fencing wire[6]. This kind of innovation enabled many enterprises to develop and prosper while making do with local resources but is not suited to competing in the global economy where New Zealand's performance is relatively poor. Engelbrecht and Darroch (1999) used OECD data[7] to create a range of indicators to measure innovation, knowledge absorption and diffusion and compared the performance of New Zealand with other OECD economies. Overall they concluded that "New Zealand continues to have a weak NIS[8], despite the major changes to its research, science and technology sector since the late 1980s, and despite its openness to foreign direct investment".

Table 1.1 summarises results for four out of the 14 main indicators used in their study. New Zealand consistently scored below Australia and below the average for G7 and other small, high-income OECD countries. New Zealand had the poorest record of all 18 countries for R&D expenditure - their indicator for 'potential to produce knowledge'. The high level of FDI inflows and strong imports of manufactured goods mean that there should be plenty of opportunities for knowledge to flow into the country. However it had the lowest number of science graduates[9] of the 18 sample countries and was ranked lowest on indicators of whether diffusion had actually taken place (incidence of high and medium tech manufacturing). Engelbrecht and Darroch's findings are supported by another empirical investigation into the national innovative capacity of a sample of 17 OECD countries from 1973 to 1996, which found that a "group, including Italy,

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[4] Some of the material in this section was originally prepared as Marsh, D. (2000). *Fostering Innovation in a Small Open Economy: The Case of the New Zealand Biotechnology Sector*. Paper presented at the Eighth International Schumpeter Society Conference, Manchester, UK.

[5] Innovation system concepts are defined and reviewed in Chapter 2.

[6] The gauge of wire most commonly used on farm fences.

[7] "The data were taken from the OECD STAN Database, the 1988 and 1998 editions of OECD in Figures and the OECD Education Statistics 1992" Engelbrecht and Darroch (1999 p. 287).

[8] National Innovation System

[9] See Clark and Pavlovich (1999, p. 5) for anecdotal evidence on the shortage of science graduates.

New Zealand and Spain, lags behind the rest of the OECD over the full time period" (Stern, Porter, & Furman, 2000, p. 31).

Table 1.1 Selected Indicators of Innovation System Performance

Indicator of:	*Potential to Produce Knowledge*	*Inflows of Technology*	*Absorptive Capacity*		*Evidence of Diffusion Taking Place*
Indicator:	GERD[10] as % of GDP	FDI Inflows as % of GDP	University Graduates as % of Population[11]	Science Graduates as % of University Graduates	High and Medium Tech. Manufacturing as % of Total
All 18 Countries	2.03	1.57	0.35	23.4	43.2
G7	2.14	0.95	0.43	21.3	50.8
Small Countries[12]	1.99	2.01	0.28	24.9	37.4
Australia	1.62	1.55	0.60	18.5	38.1
New Zealand	0.98	4.21	0.41	14.5	24.8

Note: All of the above data is drawn from Engelbrecht and Darroch (1999) and relates mainly to OECD data for 1996 from various sources.

The strength of New Zealand's science base[13] is an important institutional factor influencing the amount of innovation introduced into the New Zealand economy. One indication of the strength of New Zealand science, relative to its competitors, is provided by data on international publishing and patenting rates.

Cole and Phelan's (1999) investigation into the scientific productivity of nations found that New Zealand has a high output of scientific papers relative to the size of its economy. In a study of 43 countries New Zealand ranked seventh ahead of the UK, Canada, Australia the USA and Japan. They then used the number of highly cited papers[14] as an indicator for the level of production of scientific

[10] Government Expenditure on Research and Development

[11] i.e. the number of students graduating in 1996 as a % of the total population. Australia is a high outlier; possibly because of the large number of overseas students.

[12] Austria, Belgium, Denmark, Finland, Ireland, Netherlands, NZ, Norway, Sweden, Switzerland

[13] See also chapter 5 on the importance of the science base and other factors in determining innovative output.

[14] Based on the number of papers published in 1987 which received 40 or more citations by the Science Citation Index between 1987 and 1991.

knowledge. By this measure New Zealand's science base is slightly below average, both relative to G7 and to other small developed countries. They found that the strongest correlate of high-quality papers published per capita is the number of research scientists per capita. This is consistent with the fact that New Zealand also has a below average number of scientists.

Further data on the relative quantity and quality of New Zealand science publishing is available from the ISI database for 1994-98 (Institute for Scientific Information, 2000). New Zealand authors wrote 0.56% of all 1994-98 science and social science papers on the database. New Zealand papers were heavily concentrated in areas such as agricultural, plant and animal sciences, geosciences, ecology and environmental sciences. The citation impact[15] of New Zealand papers in these areas was within 10% of the world average. Papers in pharmacology were frequently cited with a relative impact of +72%, while citations in microbiology and molecular biology, biology and biochemistry were all below average. Data from the SCI[16] database for 1980 –1995 paints a similar picture.

Overall, New Zealand's science base is relatively small (compared to G7 and small OECD countries) and is heavily skewed towards certain areas (e.g. biology, clinical medicine and agriculture). New Zealand scientists have a high productivity (measured by papers per scientist) but New Zealand science is not highly cited internationally except in a handful of specialist areas e.g. pharmacology.

1.3.2 The Science Reforms

Problems such as these and an economy wide programme of economic reform led to a series of major changes to the organisation of science funding starting in 1991. The 66-year old Department of Scientific and Industrial Research (DSIR) was dissolved and replaced by a system of nine Crown Research Institutes (CRIs) which operate as commercial companies with their own boards and two government ministers as shareholders. They must attain 'profit' targets; surpluses

[15] This is the same as Relative Citation Rate (see above).

[16] Unpublished data provided by the Ministry of Research, Science and Technology

of 'private' earnings over expenses set by the government, which are then retained for investment. The purchasing of science is carried out by the Foundation for Research Science and Technology (FRST) which distributes the Public Good Science Fund (PGSF).

The rationale for the reorganisation has commonly been characterised as the application of agency theory which suggests a split between the purchaser of science (now FRST), and the providers (now CRIs and others). However, Upton who was the Minister at the time, states that "the science reforms… were not a case of applying a theory to a sector. Rather particular outcomes were sought which the machinery of state sector reform ably aided and abetted" (Upton, 1995 p. 2). More recent science sector reforms have aimed to foster networks and increase the flow of knowledge between researchers, industry and business. An extensive foresight process was intended to focus science spending on specific science outcomes and various other initiatives have been announced to support innovative New Zealanders.

Whatever the original rationale, the big question now is whether the reforms have achieved their objectives. Jacobsen (1991, p. 35) suggested that "the changes in science policy to date have encouraged more efficient use of research resources". Pockley (1998) provides anecdotal evidence both for and against the reforms, while Simpson and Craig (1997, p. 75) state that "there is mounting anecdotal evidence to suggest that both the quality and quantity of the science [the CRIs] are producing is on the rise". Alston et al (1998, p. 30) are concerned over the possible effects of reform in New Zealand and other developed countries. They highlight two potentially serious adverse effects: the removal of long-term guarantees of employment may reduce incentives for competent and gifted individuals to embark on research careers, and the shift in research resources towards applied research which may have reduced the rate of return to public research investments[17].

[17] These effects are discussed in chapter 5.

Overall, it is too early to give a definitive answer to 'the big question' and in any case the necessary data collection and analysis has not been undertaken. All of the authors cited above base their views on theory or anecdotal evidence rather than on any representative quantitative analysis. There are bound to be substantial lags in the transformation process so the indicators collated by Engelbrecht and Darroch would not be expected to show the impact of the reforms. It has been claimed that the policy changes of the last decade have established a national innovation system in New Zealand which is unique amongst OECD countries (Winsley & Hammond, 1997, p. 277). The jury is still out on whether this system will foster innovation and assist New Zealand to compete in world markets.

1.4 The Economics of Biotechnology

This thesis applies a general framework describing the determinants of innovation to a specific part of the New Zealand economy – the biotechnology 'sector'. The following paragraphs provide a brief overview of the economics of biotechnology, followed by an introduction to the contentious subject of its definition.

Modern biotechnology has the potential to transform large parts of the global economy and to have a major impact on the way we live. Its birth is usually traced back to the development of the recombinant DNA technique in 1973 and hybridoma technology in 1975 (Orsenigo, 1989, p. 37). The rapid pace and widespread impact of developments in biotechnology since that time has often been referred to as the biotechnology revolution. This has a number of features which make it quite distinct from the traditional model of technological revolutions[18]:

> First, whereas the traditional model is derived largely from the study of radical shifts in *engineering knowledge* … the revolution in molecular biology represented a shift in the *scientific* knowledge base of an industry. Second, despite the sweeping nature of the molecular revolution, incumbent pharmaceutical companies have not been swept away by new entrants. Third, and relatedly the relationship between incumbents and entrants has entailed

[18] Some consider biotechnology to be the third revolution – the industrial and information technology (computer) revolutions being the first two. Biotechnology may also be viewed as a 'technoeconomic paradigm' e.g. steam power, electric power and computer technology

> not only competition but also cooperation and the establishment of complex interactions between firms (Henderson, Orsenigo, & Pisano, 1999, p. 268).

Eliasson and Eliasson (1997, p. 141) add that: "biotechnology originated in academia and therefore corresponds to the ideal concept of a science-based industry". It is also interesting because of its markedly different effects on industry structure in different parts of the world. This contrasts with the standard view of scientific advance as creating a 'free good', which is universally available.

There is a large and growing international literature on economic aspects of biotechnology innovation which McKelvey (2001) has characterised as "an area of research which attempts to explain how and why the new techniques and knowledge of modern biotechnology can have economic impacts". She goes on to point out that those who study the economics of biotechnology:

> … often come from different research fields and traditions, which are interested in innovation and economic change. They analyze which organizations contribute to the development of new techniques and knowledge, and they also analyze and compare the pattern of development and use in firms, sectors, regions, and national economies. Thus, on the one hand, the research field covers a broad range of issues about knowledge-intensive goods and services while on the other hand, it addresses specific issues in relation to modern biotechnology.

Carlsson (1997) and his co-workers used the concept of technological systems to analyse the development, diffusion and utilization of technology in various fields of economic activity including the "pharmaceutical and biotechnological competence bloc" (Eliasson & Eliasson, 1997). Orsenigo (1989), McKelvey (1996), and others described and explained the emergence and development of the biotechnology industry within an evolutionary framework. Zucker and Darby (1996) and their co-workers produced a range of detailed studies on factors influencing the development of the modern biotechnology industry in the United States and Japan. They focussed particularly on the first 10 to 15 years of the biotech revolution when innovations were characterized by naturally excludable knowledge in the hands of only a few star scientists. They found that generation of biotech knowledge in a specific location was the principal determinant of the growth of the biotech industry in that area.

One of the reasons why economists are so interested in modern biotechnology is because of the idea that it may be a generic technology of the kind that has so deeply transformed industrial economies in the past. Computers and micro-electronics provide the best known recent example of a pervasive and revolutionary technology. Electronic computing was introduced during and immediately after the Second World War. Some scientists and engineers thought that uptake would be rapid with immense social consequences including large-scale unemployment. However Diebold (1952) suggested that introduction and diffusion of revolutionary new technologies requires major changes in the capital stock, the skill profile and structure of industry and so usually takes decades rather than years or months. His analysis proved to be remarkably accurate. Even though the computer industry has grown very fast, it took a whole series of complementary changes before computer-based innovation could diffuse throughout the economy.

Chris Freeman (1995b), a leading innovation economist, suggests that a new group of technologies should meet the following conditions if they are to have major effects on the economy. They should:

i. create a new range of products accompanied by improvements in the technical characteristics of many products and processes;
ii. bring about a reduction in the costs of many products and services;
iii. be socially and politically acceptable;
iv. be environmentally acceptable; and
v. have pervasive effects throughout the economic system.

Modern biotechnology clearly meets the first condition. It created enormous excitement in the research community and was fuelled by an unparalleled explosion of private venture capital funding (particularly in the USA). The jury is still out on Freeman's second condition: "so far biotechnology has led to profitable innovations in only a relatively small number of applications in a few sectors in a few countries" (Freeman, 1995b, p. 15). New Zealand along with many other countries is in the middle of a heated debate about whether biotechnology is socially, politically or environmentally acceptable. The outcome with respect to these first four conditions will determine the extent to which it has

"pervasive effects throughout the economic system" – and whether it can accurately be described as a revolutionary technology.

1.5 Definition of Biotechnology

The term biotechnology was coined in 1919 by Karl Ereky, a Hungarian agricultural economist to refer to "all the lines of work by which products are produced from raw materials with the aid of living organisms"(Bud, 1989, p. 10). Since then "the word biotechnology has been re-developed at least four times and its definition changed on each occasion" (Kennedy, 1991, p. 218). For much of the twentieth century it has been a broad term applied to technologies ranging from the fermentation of products such as wine and beer through extraction and sewage treatment to the selective breeding of plants. However in recent years the term has become increasingly synonymous with genetic modification so for example, the recent Pew report on agricultural biotechnology states:

> For the purposes of this report … the term "biotechnology" refers to the use of recombinant DNA technology to take genes from one organism and insert them into the DNA of another plant or animal (Pew Initiative on Food and Biotechnology, 2001, p.4).

Modern biotechnology is usually traced back to the development of the recombinant DNA technique in 1973 and hybridoma technology in 1975 (Orsenigo, 1989, p. 37). Government, business, academic and media interest has tended to focus on modern biotechnology because of its potential to transform large parts of the global economy.

In New Zealand there has been strong resistance to redefinition of biotechnology to mean genetic modification. For example, Biotenz (2001, p. 9) suggests that this "will seriously undermine the ability of the New Zealand economy and New Zealanders to benefit from new knowledge and new technologies in traditional industries". Similarly, the New Zealand Biotechnology Association (NZBA) "represents the interests of people with an interest in biotechnology, and the biotechnology industry in its broadest sense" and defines biotechnology as "the application of scientific and engineering principles to the processing of material

by biological agents and the processing of biological materials to improve the quality of life"[19].

For the purposes of this thesis, *modern* biotechnology is defined as: (1) recombinant DNA technology, (2) use of antibodies (3) protein engineering (4) novel bioprocessing techniques[20] (Eliasson & Eliasson, 1997, p. 145; U.S. Congress, 1991, p. 5). The term "modern" is used to distinguish processes that have been developed in the last 30 years or so, from *traditional* biotech areas such as fermentation and extraction.

Biotechnology (including both traditional and modern biotechnology) is defined using the definition first drafted by the OECD "the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services" (Bull, Holt, & Lilly, 1982). It should be recognised that any definition of modern biotech will be somewhat arbitrary since there is a continuum from the most traditional biotechnologies e.g. fermentation through to the most modern e.g. proteomics.

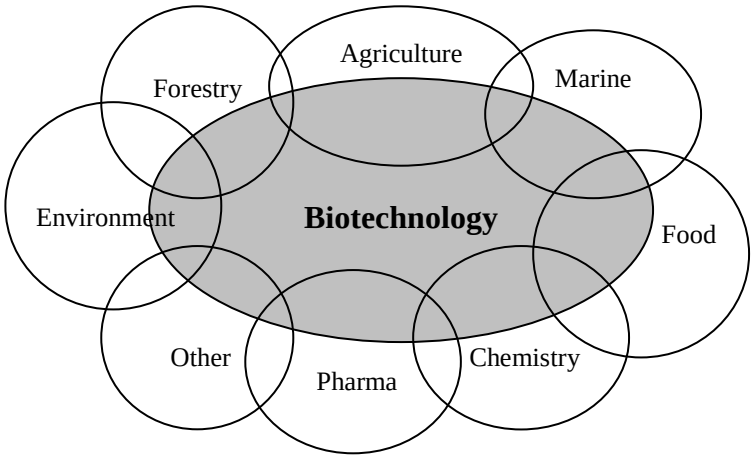
Modern biotechnology requires a multi-sectoral approach since its techniques are used in a number of different "biotechnology-based sectors"(Saviotti, 1998, p. 19) ranging from food and non-food manufacturing through various primary industries to health, diagnostic and environmental applications (see **Error! Reference source not found.**). The terms 'biotech industry' and 'biotech sector', although not strictly 'correct' are used in this thesis to denote the group of industries and sectors that use biotechnologies.

[19] http://www.biotech.org.nz/objectives.htm

[20] Eliasson and Eliasson (1997, p. 145) state that: "the biotech field is thought of as consisting of three or four sub-areas: (1) recombinant DNA technology, (2) use of antibodies including phage display, and (3) protein engineering". The U.S. Congress, Office of Technology Assessment (1991, p. 5) defined 'new' biotechnology as: "the industrial use of rDNA, cell fusion and novel bioprocessing techniques".

See Appendix 2 for further discussion of the definition of biotechnology. This appendix also contains the list-based definitions of biotechnology used in the 1998/99 and 2002 surveys.

Figure 1.1 Sectors Contributing to the Biotechnology 'Industry'



Source: Adapted by the author, based on Sandström et al. (2001, p. 2)

Chapter 2 Theoretical Approaches to the Economics of Innovation

2.1 Introduction

This chapter reviews the main theoretical approaches to the economics of innovation and technological change. In Chapter 3 these foundations are used to develop and justify a theoretical framework that can be used to describe the determinants of innovation. Before commencing the literature review, it will be useful to provide a brief introduction to the meaning of some of the key terms used in describing the economics of innovation and technological change.

i. *Technology* can be defined "as information: the specifications (in the engineering sense) for a product or a process. It must be more than just an idea: it must be something which, if built or produced according to specification will 'work'. The technology at any time is the 'book' of specifications or blueprints" (Hay & Morris, 1991, p. 466).

ii. *Technological change*[1] can be defined as "change in the book of blueprints"(Hay & Morris, 1991, p. 466), or "the process by which economies change over time in respect of the products they produce and the processes used to produce them" (Stoneman, 1983 p. 3).

iii. *Technological advance* implies that an increasing level of output has been obtained from the same level of input. This is achieved through the process of invention, innovation and diffusion.

iv. Freeman defines *invention* as:

> an idea, a sketch or a model for a new improved device, product process or system. Such inventions may often (not always) be patented but they do not necessarily lead to technical *innovation*s(Freeman, 1974, p. 22).

This is because "innovation, in the economic sense, is accomplished only with the first *commercial* transaction involving the new product, process, system or device".

[1] See Appendix 1 for discussion of the distinction between technical change (change in technique) and technological change (change in technology).

v. I*nnovation* can thus be defined as:

> The economic application of a new idea. Product innovation involves a new or modified product; process innovation involves a new or modified way of making a product. Innovation sometimes consists of a new or modified method of business organization"(Black, 2002)

It can be seen then, that innovation; the economic application of new ideas, is the driving force behind technological change. In practice, innovation is often used more loosely, to refer to the whole process of technological change and in common usage has become a buzz word, used to refer to all manner of desirable activities.

vi. *Diffusion* "occurs after the invention and innovation stages and refers to the process by which the innovation spreads across the market" (Stoneman, 1983 p. 8).

vii. *Research and development* (R&D) is generally undertaken with the aim of encouraging innovation. Most economic analysis of R&D is based on the idea of technology as knowledge. At any moment in time, firms and organisations have a pool of knowledge encompassing all known techniques. Research is seen as the process which changes the characteristics and content of the set of possible techniques by increasing the pool of knowledge (Smith, 1991 p. 1). There are two main avenues by which R&D may lead to economic benefits: product innovation that improves the performance characteristics of products and process innovation that improves production technology. Both types are closely associated and both are characterised as cost reducing activities within economic analysis. Product innovations generally reduce the cost to consumers of fulfilling some need[2], while process R&D reduces costs by shifting the production function outward (Smith, 1991 p. 2).

> R&D is thus seen as a process of knowledge creation, with the knowledge applicable as a production technique, either directly or indirectly. Enhanced knowledge improves the productivity of existing inputs and these productivity gains – taking the form of cost reductions – are the returns to R&D (Smith, 1991 p. 2).

[2] "Product innovation which enhances the qualities of products plays a lesser role" Smith (1991 p. 2).

The economic literature on innovation will now be reviewed, starting with a classification based on four parameters (school of thought, theory or concept, exogenous or endogenous treatment of growth, equilibrium or evolutionary). A brief historical review of 'mainstream' neo-classical approaches (2.3) and endogenous and new growth theory (2.4) is followed by sections on evolutionary (2.5) and systems approaches (2.6). Section 2.7 discusses and criticises the various approaches. Finally in section (2.8) some conclusions are drawn about the most appropriate framework within which to answer the research questions addressed in this thesis. This is followed in Chapter 3 by description of an innovation framework describing the determinants of innovation and discussion of the literature surrounding each of the research questions.

2.2 Classification of Theoretical Frameworks

Any attempt to classify the literature on technological change, must first address the ordering problem: which material should be placed in which boxes? A review of recent literature surveys (Antonelli & De Liso, 1997; Freeman, 1994; Stoneman, 1995) does not make this task any easier since all follow different classification systems. Often the authors themselves disagree with the boxes in which they have been placed. For example Antonelli and de Liso (1997, p. 14) regard Grossman and Helpman (1991) as falling within the neo-classical framework while the authors write that their "approach proceeds along Schumpeterian lines" (Grossman & Helpman, 1991, p. 42).

Antonelli and de Liso (1997) start their survey with the classical economists. They trace early writings on the economics of technological change as far back as Galileo[3] and go on to discuss the contribution of Smith and Ricardo to analysis of what we today call technological change. They continue their survey using a classification that divides the literature into eight distinct areas[4]. Metcalfe (1995a) follows a much simpler approach by focussing on the differences between

[3] Galileo (1638) talked about the principle of learning-by-doing in *Dialoghi delle Nuove Scienze;* see Antonelli and de Liso (1997, p. 41 note 5), as did Beccaria (1771) *Elementi di Economia Publica* (Elements of Public Economy).

[4] Classical approaches, neoclassical approaches, Schumpeter's analysis, multi-sectoral models, neo-Keynesian models, Hick's neo-Austrian model, evolutionary approach, systemic analyses.

equilibrium and evolutionary schools of thought; while Stoneman (1995, pp.10-11) adopts four main headings: neo-classical, the structure-conduct-performance paradigm, evolutionary and game theoretic approaches.

Table 2.1 represents a synthesis of these various methods of classification. The literature is organised into five main schools of thought and nine theories or concepts, with each being further classified as an equilibrium or evolutionary approach, where technical change is treated as being either exogenous or endogenous.

Work within the equilibrium paradigm includes the classical writings of Smith, Ricardo and Malthus and neo-classical growth accounting exemplified by Solow (1957). Work under the industrial organisation banner is now regarded as 'mainstream micro' rather than a distinct school of thought. Endogenous and new growth theory were developed by the neo-classical school in response to dissatisfaction with exogenous growth models. Evolutionary approaches are commonly dated back to Schumpeter – or to Alchian for the modern development of the subject. They include attempts at model building and theory development e.g. Nelson and Winter (1982) and work on systems of innovation as developed by Lundvall, Freeman and Nelson.

This review will start from the modern origins of the subject in a series of growth accounting studies conducted after the Second World War under the neo-classical framework. Dissatisfaction with early models led to the development of various endogenous theories (section 2.4); many of these are consistent with the neo-classical framework while others are specifically evolutionary.

Table 2.1 Theoretical Approaches to the Economics of Innovation

	Schools of Thought		Theories and/or Concepts	Characteristics and/or Assumptions	Some Key References	Comments and Criticisms/
Equilibrium	Classical		Adam Smith, *An Inquiry into the …Wealth of Nations.* Ricardo and Malthus, *Principles of Political Economy*	Technical change is accelerated by division of labour. Principle of diminishing returns. Introduction of new machinery can harm workers. Pressure of growing population on land will drive wages back to subsistence levels (Malthus).	Smith (1776/1976) Malthus (1820) Ricardo (1821/1951)	Ricardo and Malthus failed to foresee the impact of technological progress.
	Neo-Classical *"characterised by microeconomic theoretical systems constructed to explore conditions of static equilibrium"*(Bannock, Baxter, & Davis, 1992)	Exogenous	Production function approach Neo-Keynesian approaches Growth accounting	In the simplest form, Ouput (Q) is a function of capital (K) and labour (L). $Q_t = A_t f(K_t L_t)$ If K and L are held constant then any change in output is attributed to improvement in technology, A_t.. In later studies output also depends on the stock of past expenditure on R&D.	Harrod (1939) Domar (1946) Solow (1957) Griliches (1958)	Does not explain long-run growth because technical progress is exogenous.
		Endogenous	Industrial organisation *Structure-conduct-performance*	Branch of applied microeconomics. Suggests causal chain between *structure* (# of buyers/sellers) *conduct* (e.g. pricing) and *performance.*	Mason (1959) Scherer (1980) Bresnahan (1989)	Work on factors determining nature and extent of R&D; appropriability, markets and opportunities.
			Endogenous growth theories *Some are developments of the neo-classical framework others are evolutionary*	e.g. Romer (1986) long-run growth is driven primarily by the accumulation of knowledge by forward-looking profit-maximizing agents.	Romer (1986) Aghion (1992)	Attempt to address the main weakness of the neo-classical framework; that technological change is exogenous and so not explained.
			New growth theory *The neo-classical 'response' to evolutionary theories*	Continuing growth at endogenously determined rates. Growth path is treated as general equilibrium of a [not necessarily perfectly competitive] market (McKenzie, 1998, p. 9).	Lucas (1988; 1993) Romer (1990) Krugman (1995)	Work on the economics of *clustering* draws on new growth theory and several other traditions (see discussion in text).
Evolutionary	Schumpeter and Neo-Austrian Approaches		Induced innovation theory	Hicks argued that labour saving technology can be induced by rising wages.	Hicks (1973)	Hicks is sometimes classified as a Neo-Austrian.
			Theory of economic growth *based on explicit recognition of role of technical innovation*	Firms innovate in order to increase their profits. Innovations enable firms to reduce costs or increase market share. Firms will increasingly compete through innovation thus sending waves of 'creative destruction' through the economic system (Schumpeter, 1912/1934).	Schumpeter (1912/1934) Schumpeter (1939)	Extensive empirical efforts to test Schumpeter's theory that "bigness and fewness encourage technological advance" (Stoneman, 1987, p. 80) See also (Cohen & Levin, 1989).
	Evolutionary		Evolutionary theories of economic change	Concerned with how economic structures develop over time and the consequent changes in patterns of resource allocation in a world of uncertainty and boundedly rational decision making (Metcalfe, 1995a, p. 414).	Alchian (1950) Rosenberg (1976) Nelson & Winter (1987) Hodgson (1988)	Evolutionary school formed through merging of neo-Schumpeterian and neo-institutional schools.
	Systemic Analyses	Endogenous	Systems of Innovation (SI)	The network of institutions in the public and private sector whose activities and interactions initiate, import, modify and diffuse new technologies (Freeman, 1987, p. 1).	Freeman (1988) Lundvall (1992b) Nelson (1993b) Carlsson (1995) Edquist (1997)	Various approaches: Nelson and Rosenberg version Aalborg versions (Lundvall et al) Sectoral approach and technological systems (Carlsson et al).

Source: Author's analysis and classification of the literature on growth, technological change and innovation.

2.3 Neo-classical Approaches

According to Hodgson (1994, p. 129) neo-classical economics has three main distinguishing characteristics:

i. "the assumption of rational, maximizing behaviour by agents with given preference functions;
ii. a focus on attained, or movements towards, equilibrium states;
iii. the absence of chronic information problems."

Perhaps most important of these is the focus on theoretical systems "constructed to explore conditions of static equilibrium" (Bannock et al., 1992); i.e. conditions where the forces that determine the behaviour of some variable are in balance, resulting in no pressure for change. Under conditions of perfect competition it can be demonstrated that states of equilibrium are characterised by market prices which measure the marginal valuations of inputs and outputs attributable to individuals as consumers, producers and suppliers of production inputs. These perfectly competitive equilibria are Pareto efficient and correspond with output maxima, given the resources deployed[1].

Freeman suggests that "economists have always recognised the central importance of technological innovation for economic progress" (1974, p. 16). Adam Smith (1776/1976) emphasised the importance of improvements in machinery in his first chapter, Marx's model of the capitalist economy gave a central role to technical innovation and Marshall described knowledge as the chief engine of progress in the economy. Yet although most economists acknowledged the central importance of technological change there were few attempts to examine it in any detail. This was partly because flows of new knowledge and innovation were treated as exogenous variables outside the framework of standard economic models. This approach was initially maintained in the 1950s when technical progress began to emerge as a major issue through a series of studies on economic growth.

[1] "Barone (1908/1935) first stated exactly and proved that a competitive equilibrium under quite general conditions, realizes a Pareto optimum" (Takayama, 1974, p. 186).

2.3.1 Growth Models

These studies were based on the development and analysis of production function models within a neo-classical framework. They aimed to distinguish between output growth that could be accounted for by increased use of capital and labour and growth due to other factors. Growth that could not be explained by increases in the availability of factors of production was called the residual and was mainly attributed to technical progress (i.e. growth in total factor productivity).

This growth model in its simplest form specifies a production function where output (Q) is a function of the inputs capital (K) and labour (L).

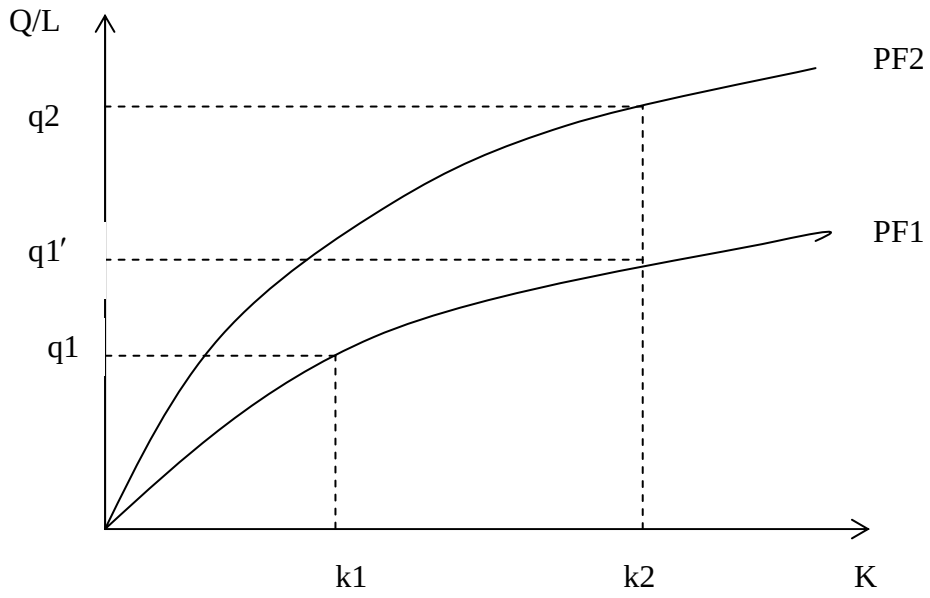
$$Q_t = A_t f(K_t, L_t)$$

A_t is a constant that changes with time. If K and L are held constant (in quantity and quality), then any change in output is attributed to improvement in technology, A_t. Put another way, any output growth that is not attributable to input growth is assigned to the residual.

In Solow's classic article 'Technical Change and the Aggregate Production Function' (1957) technical change is a function of time and is considered to be an exogenous phenomenon. Using Solow's framework it is common to distinguish between increases in production due to increases in mechanisation and increases in production for a given capital labour ratio. This latter form of technical progress is termed disembodied since the change occurs independently of any change in inputs. The neoclassical approach also describes embodied technical change where improvements are embodied in new capital goods and retrained labour.

These concepts can be demonstrated using a production function diagram (Figure 2.1). Output per worker (Q/L) is a function of capital (K). Under the initial conditions the economy operates on production function PF1. A change in the level of K without a change in technology (e.g. increased mechanisation using existing technology) results in movement along the production function e.g. from k1 to k2 resulting in a productivity increase from q1 to q1′.

Figure 2.1 Effect of Technical Change on the Production Function



Source: Eveleens (1995, p. 18)

Disembodied technical change brings about a productivity shift from q1′ to q2, shifting the production function to PF2 while holding the capital to output ratio constant.

Solow (1957) estimated the production function for the US economy from 1909 to 1949. He found that 13 percent of the increase in productivity could be attributed to changes in capital and labour and attributed the remaining 87 percent (the residual) to a broad definition of technical change[2]. Denison (1985) followed a similar method to analyse US growth from 1929 to 1982 but included data on quality adjustments to the labour force. The effect of his modifications was to reduce the relative importance of technical change from 87 to just 37 percent of growth (p. 22).

[2] Solow used "technical change as a shorthand expression for any kind of shift in the production function. Thus slowdowns, speed ups, improvements in the education of the labour force and all sorts of things will appear as technical change" (1957, p. 312).

Use of the residual as a measure of technological change suffers from severe measurement difficulties. In particular measurement error in any of the observable growth rates will affect estimates of total factor productivity growth[3]. For instance, if the growth rate of the labour force or the capital stock is underestimated, then measured total factor productivity growth will be overestimated. Total factor productivity growth has been described as a catch-all expression for everything that affects growth but cannot be observed[4], while some authors have argued that it does not measure productivity growth at all (Lipsey & Carlaw, 2002)[5]. Despite these criticisms, formal growth modelling has made a substantial contribution to our understanding of economic growth; namely that growth of output per worker in industrialised nations came predominantly from the application of "new, superior production techniques by an increasingly well trained work force" (Scherer, 1980, p. 407). It also led to an explosion of empirical studies into innovation and technological change; many of these carried out within the newly developing field of industrial organisation.

2.3.2 Industrial Organisation and the Mainstream

Edward S Mason[6] and his colleagues and students at Harvard such as Joe Bain developed the field of industrial organisation in the 1940s. The two main approaches to the study of industrial organisation are the Structure-Conduct-Performance (SCP) paradigm and price theory. SCP, which was almost synonymous with industrial organisation in the 1940s, provides an overview of industrial organisation that suggests a causal chain between market *structure* (number of buyers and sellers, degree of product differentiation etc), firm *conduct* (pricing, product positioning, advertising etc) and firm/industry *performance* (Carlton & Perloff, 2000); see Figure 2.2. The field of industrial organisation has changed rapidly in recent decades as SCP gave way to techniques such as game theory, transaction cost analysis and contestable market analysis. These

[3] Technological progress or the growth of total factor productivity is estimated as a residual from the production function. See Lipsey and Carlaw for a detailed discussion (2002).

[4] Many economists believe that estimates that find a large value for total factor productivity growth reveal our ignorance about the sources of economic growth e.g Griliches (1994).

[5] They argue that TFP does not measure technological change but is instead a measure of the returns over and above opportunity cost that may accompany such change.

techniques and microeconomic models are used in price theory approaches to explain firm behaviour and market structure.

The principal long-run consequences of technological change are increases in productivity and in the quality of consumption; subsidiary effects include changes in the structure of demand for labour, international trade patterns and market structure (Scherer, 1980, p. 408). Much of the empirical work within the IO field was concerned with a possible causal flow in the opposite direction from market *structure* to technological innovation. In particular efforts were directed at testing Schumpeter's hypothesis that large monopolistic firms were best suited to introducing technological innovation, the impact of other factors on the innovative performance of firms and the role played by demand (Schmookler, 1966), technological opportunity (Rosenberg, 1976) and appropriability (Arrow, 1962b) in determining innovative behaviour.

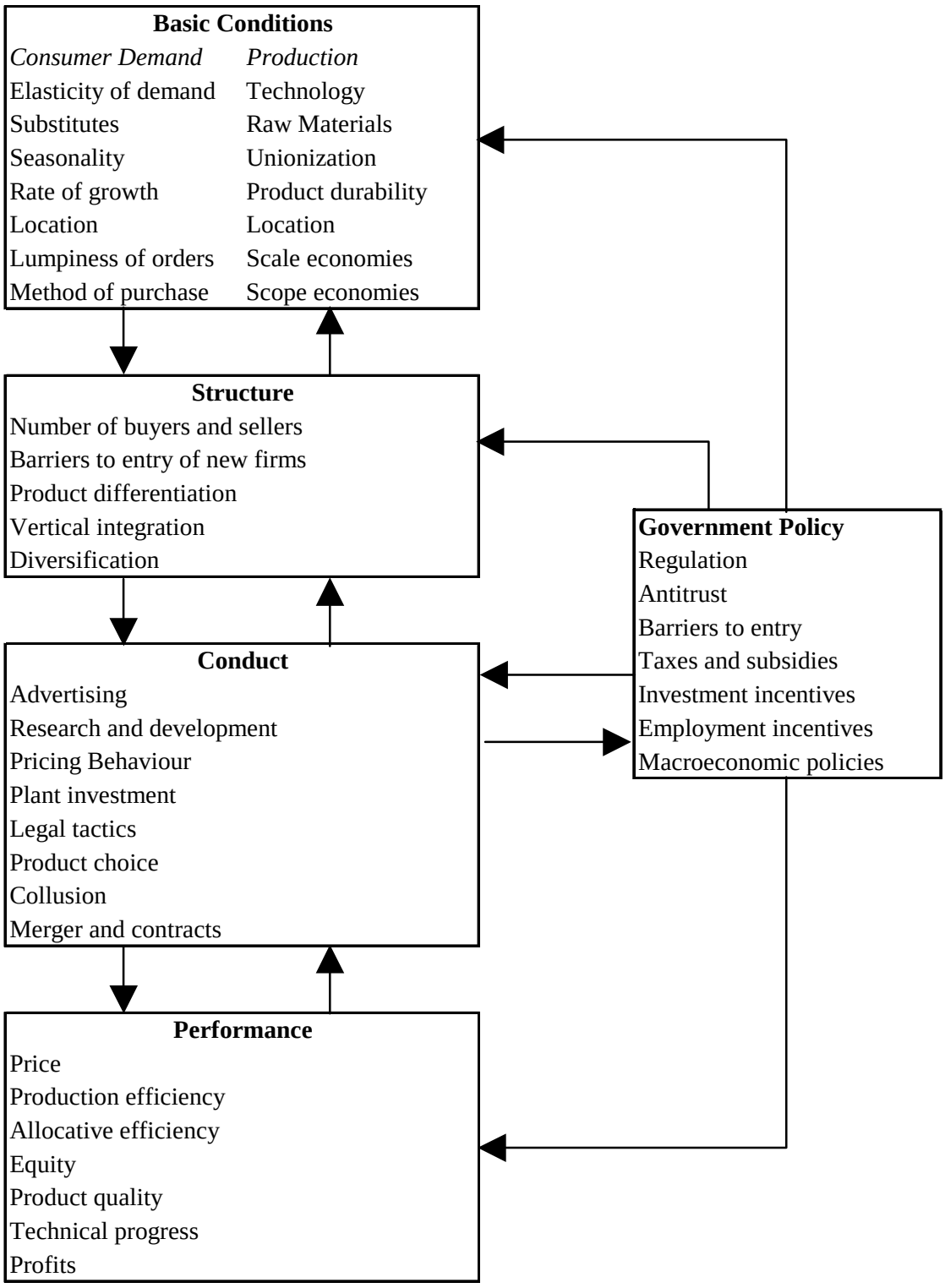
Simple models of the determinants of innovative effort generally start from the standard profit maximisation premise where innovative effort depends on the expected difference between the profit a firm can earn once it has successfully innovated and that which would be earned otherwise. This can be extended to describe firm conduct with respect to R&D, for example "firms seek to conduct their research and development projects in such a way as to maximise the surplus of expected revenues over expected costs" (Scherer, 1980, p. 426).

R&D can be seen as an important aspect of firm *conduct* through which they engage in non-price competition.

> R&D expenditure designed to locate new or improved products and to lower manufacturing costs of existing products influences the *structure* of the industry. At the same time, industrial structure is a determinant of the incentives that firms possess for engaging in such forms of non-price competition (Dasgupta, 1987, p. 7).

[6] See for example Mason (1959).

Figure 2.2 Structure, Conduct and Performance



Source: Carlton and Perloff (2000, p. 4)

Investment in R&D produces knowledge or information that has some of the attributes of a pure public good; namely incomplete appropriability[7]and non-rivalry. Goods with these characteristics are expected to be undersupplied in the market thus providing a possible justification for government intervention. This was one of the main points stressed in Arrow's classic 1962 article. More recent work (Dasgupta & Stiglitz, 1980) suggests that the degree of appropriability depends on technological opportunities, the legal code and on industrial structure. However industrial structure depends on degree of appropriability thus creating an interesting case of mutual dependence.

Another important characteristic of the production of knowledge (through R&D or otherwise) is that the process is permeated by uncertainty, much of which cannot be insured against because of knowledge asymmetries and moral hazards. This absence of adequate risk markets provides another argument for government intervention. Overall:

> Three features therefore stand out; that knowledge has the attributes of a public good, that there are strong scale economies involved in its production and use, and that the uncertainties involved in its use and production are acute... The welfare economics of R&D investment is a perfectly viable subject. But it will not be an easy one to master (Dasgupta & Stoneman, 1987, p. 5).

2.4 Endogenous and New Growth Theories

Endogenous and new growth theories were developed in an attempt to address the main weakness of the neo-classical framework; that technological change is exogenous and so not explained. Endogenous theories treat invention, innovation and diffusion as deliberate activities thus providing a theory in which change over time in respect of the products produced and the processes used to produce them (i.e. technological change) is explained within the model.

New Growth Theory is distinguished by two principal characteristics: "there is continuing growth at endogenously determined rates, and the growth path is treated as a general equilibrium of a competitive market, but not necessarily a perfectly competitive market" (McKenzie, 1998, p. 9). While some endogenous

[7] *Incomplete appropriability* is synonymous with *non-excludability*

theories e.g. Romer (1990) can be regarded as developments of the neo-classical framework; others e.g. Nelson (1982) cast off many of the standard neo-classical assumptions and so are best classified as evolutionary.

The recent development of the endogenous approach can be traced back to Romer's paper 'Increasing Returns and Long-Run Growth' in which he suggested that "long-run growth is driven primarily by the accumulation of knowledge by forward-looking, profit-maximizing agents" (1986, p. 1003). His model was based on three key elements:

i. the amount of new knowledge produced as a function of research and other effort exhibits diminishing returns;
ii. the creation of new knowledge by one firm has positive externalities for other firms; and
iii. knowledge inputs to the production of consumption goods have increasing marginal productivity.

The last element is a development of the argument put forward by Arrow (1962b) that increasing returns arise because new knowledge is discovered as investment and production take place.

Romer's contribution in this paper was to demonstrate that growth can continue indefinitely because the returns to investment in capital goods (including human capital) do not necessarily decrease as the economy grows. Inclusion of the role of research and development and imperfect competition into the framework began with Romer (1990; 1987) and continued with major contributions by Aghion (1992), Grossman and Helpman (1991) and others. In these models "technological advance results from purposive R&D activity, and this activity is rewarded along the lines of Schumpeter (1934), by some form of ex post monopoly power" (Barro, 1997, p. 6).

Romer's 1990 paper was based on three main premises:

i. "that technological change … lies at the heart of economic growth";

ii. "that technological change arises in large part because of intentional actions taken by people who respond to market incentives" – endogenous technological change; and

iii. "that instructions for working with raw materials are inherently different from other economic goods" (Romer, 1990, p. S72).

These instructions (otherwise known as technology) are assumed to have the unusual property of being excludable and yet non-rival whereas conventional economic goods are both rivalrous and excludable[8]. An economic theory, a mathematical result, or a piece of software are non-rival in the sense that any number of people can 'consume' them without their value being reduced. In this model "growth is driven fundamentally by the accumulation of a partially excludable, non-rival input" (Romer, 1990), namely the stock of ideas. Non-rival goods can be accumulated without limit whereas a piece of human capital e.g. the ability to conduct multiple regressions cannot. People have only a limited life span in which to acquire skills. When they die, their skills are lost but any non-rival goods that they produce – a scientific law, a principle of mechanical engineering; or a blueprint - live on after the person is gone. Romer went on to demonstrate that the only way to accept all three of his premises is to explicitly introduce market power into the model; he then found that equilibrium is reached with monopolistic competition.

Endogenous growth models build on the neo-classical approach by developing a theory of technological change in which intentional investment in R&D is driven by the stock of ideas and partial appropriability of the benefits of R&D in an imperfect market structure. The premises behind endogenous models appear to be reasonable reflections of reality and model results have proved useful in furthering our understanding of the mechanisms underlying technological changes. The evolutionary framework provides an alternative and sometimes complementary

[8] Public goods are non-excludable and non-rivalrous by definition.

way of explaining these mechanisms. This approach is discussed in the next section.

2.5 Evolutionary Approaches

The use by economics of concepts related to evolution in the biological sciences is commonly referred to as evolutionary economics. Nelson's (1995) literature review in the Journal of Economic Literature provides an appropriate source for a current definition[9]. He wrote:

> I choose to use the term 'evolutionary' to define a class of theories, or models, or arguments, that have the following characteristics. First, their purpose is to explain the movement of something over time … that is, the analysis is expressly dynamic. Second, the explanation involves both random elements which generate or renew some variation in the variables in question, and mechanisms that systematically winnow on extant variation. Third, there are inertial forces that provide continuity of what survives the winnowing (Nelson, 1995, p. 56).

A useful introduction to the distinguishing characteristics of this school of thought is provided by Metcalfe who argues that the role of entrepreneurial behaviour is only intelligible within an evolutionary perspective "since an equilibrium theory cannot, as a matter of logic, determine the rewards to entrepreneurship which are necessarily transitional" (1995a, p. 448). Hodgson (1994) expands this point:

> Clearly, an evolutionary process cannot be an optimizing one, at least in the strict sense, because for evolution to work there must always be a variety of forms from which to select. Indeed, without variety there would be no evolution. Furthermore, for selection to work there must be rejection, and the process must thus involve ceaseless error making as well.

Evolutionary views of economic development and technological change are not a recent development (Clark & Juma, 1988, p. 199). Their antecedents can be seen in the work of the classical economists and were developed by Marx and Engels among others. Schumpeter was one of the first economists to both question the equilibrium framework of neo-classical economics and to suggest an alternative approach. His theory of economic development includes a strong evolutionary flavour: "The essential point to grasp is that in dealing with capitalism we are dealing with an evolutionary process" (Schumpeter, 1942, p. 82). He expanded on

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[9] A simple and all encompassing definition is provided by Kenneth Boulding (1991, p. 9) "…evolutionary economics is simply an attempt to look at an economic system, whether of the whole world or of its parts, as a continuing process in space and time".

the biological metaphor:

> [These changes] illustrate the same process of industrial mutation – if I may use that biological term – that incessantly revolutionizes the economic structure *from within*, incessantly destroying the old one, incessantly creating a new one. This process of creative destruction is the essential fact about capitalism (p. 84).

Contemporary evolutionary theories are commonly traced back to Alchian who tried to replace the equilibrium concept of maximization with the biological concept of natural selection.

> The suggested approach embodies the principles of biological evolution and natural selection to interpreting the economic system as an adaptive mechanism which chooses among exploratory actions generated by the pursuit of 'success' or 'profit' (Alchian, 1950 p. 211).

His revisions of neoclassical economics included assumptions of imperfect information and rule-bound behaviour and he regarded the decisions coming out of the economic system as being more important than those made by the individuals in it. The next landmark in the development of evolutionary economics was Nelson and Winter's book on *An Evolutionary Theory of Economic Change* (1982) in which they presented a family of models where firms are naturally selected by the economic system and modify their own behaviour through processes of search and selection.

In the twenty years since Nelson and Winter's book the research agenda in evolutionary economics can be divided into three main areas:

i. the behavioural rules by which firms set innovation strategies;
ii. the limits to variety generation (the innovation possibility frontier); and
iii. the wider institutional structure which supports the innovative activities of firms.

According to evolutionary theory the behaviour of firms can be explained by 'rules of thumb' rather than through the assumption of profit-maximising behaviour. The complexity of decision making, the limited cognitive capabilities of individuals, the cost of acquiring additional information and the role of the organisation in filtering and translating individual knowledge all combine to make this assumption unrealistic. In equilibrium theory all such issues are ignored: firms have full knowledge of all the available options. Evolutionary theory takes

an entirely different approach. Firms are boundedly rational and are assumed to take decisions based on routines and 'rules of thumb'. This results in the variety of behaviour which drives the competitive process.

In both the profit-maximising and evolutionary frameworks a firm's spending on R&D may be modelled as a function of: expected market size, expected growth in market size, present value factor, margin and the proportion of net profits allocated to R&D. However spending by a behavioural firm[10] would also be influenced by "the elasticity of the innovation possibility function and by the two decision routines for price setting and allocating funds to R&D" (Metcalfe, 1995a, p. 452).

An array of empirical evidence (David, 1975) (Dosi, 1988; Rosenberg, 1976) has shown that technological accumulation is not random; rather it is cumulative and firm specific, leading to the creation of identifiable technological trajectories[11]. Any new or improved product and its associated design processes are based on a particular set of interrelated principles and a design configuration that "are linked to a knowledge base in science and engineering and an associated set of skills identifying the relevant technological community" (Metcalfe, 1995a, p. 458). Design configurations are regarded as providing the framework within which technologists and company strategists work. They also determine the problems that will be solved and the areas where improvements will be sought, thus leading to the development of clearly identifiable technological trajectories.

Malerba (1992) pointed out that firms learn in a variety of different ways. He distinguished six categories of learning activity and argued that different kinds of learning generate different technological trajectories. This then is another source of the diversity that is central to the evolutionary approach. Innovation and the innovation possibility frontier are also influenced by the wider institutional

[10] A behavioural firm is one that behaves with bounded rationality.

[11] Technological trajectory: "the activity of technological progress along the economic and technological trade-offs defined by a paradigm"(Dosi, 1988).

structure that supports the innovative activities of firms – the system of innovation. This is the subject of the next section.

2.6 Systems of Innovation

2.6.1 Introduction

Starting in the late 1980s many evolutionary economists (Freeman, 1988; Lundvall, 1992b; Nelson, 1993b) started to converge on a new way of analysing growth and innovation in national economies through the concept of 'systems of innovation'[12](SI). Central to this concept is the idea that the overall innovation performance of an economy depends not so much on how specific organisations perform but on how well they interact with each other. Although the first explicit use of the term national systems of innovation is generally cited as being Freeman's 1987 book on Japan, Freeman prefers to give credit to Lundvall[13] as "the first person to use the expression 'National System of Innovation"(Freeman, 1995a, p. 5). Lundvall points out that the idea goes back at least to Friedrich List's concept of the 'National System of Political Economy' (List, 1841/1904).

Papers on national systems of innovation by 'the founding trio' of Lundvall, Freeman and Nelson appear in a 1988 book: 'Technical Change and Economic Theory' edited by Dosi, Freeman, Nelson, Silverberg and Soete. Lundvall's paper stresses user-producer interaction within the national economy. He argues that geographical and cultural closeness facilitate effective interaction and goes on to suggest that national boundaries tend to coincide with the boundaries of technological networks which make up national innovation systems.

According to Lundvall (1992b, p. 17) the approach which he and his colleagues take is characterised by "the emphasis put upon interactive learning anchored in the production structure and in the linkage pattern of production". This may be

[12] The term 'National System of Innovation' as used by (Freeman, 1988), (Lundvall, 1992b) and many others may be regarded as being synonymous with the term National Innovation System as used by (Nelson, 1993b), (Patel & Pavitt, 1994) etc.

[13] According to Sornn-Friese (2000, p. 3), Lundvall wrote an essay in 1985 where he referred to a system of innovation and national systems of production … "this essay was foundational to the NSI approach".

contrasted with the traditional linear approach to innovation which puts greater stress on formal research and development expenditure as the main driver of innovation.

Freeman concentrates on social and institutional changes and attributes Japanese technological progress to major changes in the national system of innovation; in the role of MITI[14], in the role of firms and in education, training and social innovations. He reaches similar conclusions when discussing the institutional changes that enabled Germany and the United States to overtake Britain in the latter part of the nineteenth century. Richard Nelson follows a similar approach in emphasising mechanisms by which technological knowledge is shared and the role of the public sector:

> There is much more to the capitalist innovation system than for profit firms in rivalrous competition. There are … a variety of mechanisms through which firms share technological knowledge, and cooperate on certain kinds of R&D. There are universities in it, and professional societies. There are public monies as well as private funds (Nelson, 1988, p. 315).

Lundvall, the modern originator of the term national system of innovation defined it in the following way:

> … a system of innovation is constituted by elements and relationships which interact in the production, diffusion and use of new and economically useful knowledge and that a national system encompasses elements and relationships, either located within or rooted inside the borders of the nation state (1992b, p. 2).

He went on to explain that the national system of innovation (NSI) is a *social* system which has learning; a social activity involving interaction between people at its centre. It is also a *dynamic* system, characterised both by dynamic feedback and reproduction.

Lundvall's definition is so inclusive and general that it is consistent with most definitions which have been proposed since (see Table 2.2). Nelson and Rosenberg interpret the term innovation broadly since their interest is in the factors influencing national technological capabilities. Their concept of a system

[14] The Ministry of International Trade and Industry (MITI) defines long term strategies for the development of Japanese industry and the economy.

is "of a set of institutions whose interactions determine the innovative performance… of national firms" (1993, p. 4); it does not include any presumption that the system was ever consciously designed or even that the different components work together smoothly. This last aspect of the NSI concept was put very ably by Mowery and Oxley in the following quotation:

> Like the Holy Roman Empire, which was not holy, Roman, or an empire, innovation systems may be international, rather than national, in scope and structure; they may influence diffusion as much as innovation; and they often are ad hoc, rather than strategically conceived, in origin (Mowery & Oxley, 1995, p. 80).

Table 2.2 Definitions of National Systems of Innovation

the network of institutions in the public and private sector whose activities and interactions initiate, import, modify and diffuse new technologies (Freeman, 1987, p. 1).
the *narrow definition* [italics added] would include organisations and institutions involved in searching and exploring - such as R&D departments, technological institutes and universities. The *broad definition* … includes all parts and aspects of the economic structure and institutional set-up affecting learning as well as searching and exploring – the production system, the marketing system and the system of finance present themselves as sub-systems in which learning takes place (Lundvall, 1992b, p. 12).
A national system of innovation is the system of interacting private and public firms (either large or small), universities, and government agencies aiming at the production of science and technology within national borders. Interaction among these units may be technical commercial, legal, social, and financial, inasmuch as the goal of the interaction is the development, protection, financing, or regulation of new science and technology (Niosi, Saviotti, Bellon, & Crow, 1993, p. 212).
the national institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change generating activities) in a country (Patel & Pavitt, 1994, p. 79).
that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skill and artefacts which define new technologies (Metcalfe, 1995a, p. 463).

The distinction between the Lundvall's version[15] (stressing social interaction) and Nelson's version (stressing institutions) has continued to the present day, although both schools continue to work closely together.

Niosi, Saviotti, Bellon and Crow (1993, p. 210) saw NSI as the last step in a trend towards an increasingly complex and encompassing theory of industrial innovation. Starting from a simple description of the entrepreneur and the isolated firm as innovating units, new elements of the firm's environment have gradually been included, culminating in the concept of the national system of innovation. They felt that the "semantic contents and operational underpinnings [of the term were] … still vague, and its links with more established concepts … less than clear" and so wrote a paper which set out to fill these gaps. While the paper was successful in fleshing out the bare bones of the NSI concept, their definition (See Table 2.2) still includes a wide range of actors and interactions.

There have been continuing attempts to firm-up the NSI concept, for example Wijnberg (1994) suggested that a description of an NSI should allow one to make statements about the selection environment and the selection process that could be of relevance to policy makers. In order to achieve this he redefined the concept in terms of public policies and their effects, not in terms of actors or networks. His suggestion has not achieved critical mass, so at the present state of the art, the definition of NSI remains broad. This is perhaps inevitable and was recognised by Lundvall during the initial development of the concept:

> a definition of the system of innovation must, to a certain degree, be kept open and flexible regarding which sub-systems should be included and which processes should be studied. It also follows that we cannot insist upon one single approach to the national system of innovation as the only legitimate one. Different theoretical perspectives bring forward different aspects of the system (1992b, p. 13).

The NSI concept falls very much within the evolutionary framework. Although this is not always explicitly stated, 'the founding trio' of Lundvall, Nelson and Freeman are all committed evolutionists. Nelson a leading contributor to both NSI

[15] Lundvall's version might also be termed the 'Aalborg School' since it is was developed by a group of researchers based at the University of Aalborg, Denmark.

and evolutionary economics, argued in his 1988 article on the US innovation system that "in capitalist countries, technical change is set up as an evolutionary process" (p. 313). Nelson and Rosenberg's 1993 article does not mention evolutionary theory, but it is clear from Nelson's (1995) review of the literature on evolutionary theory that he remains a strong proponent of these theories.

The Aalborg version of the NSI approach is strongly rooted within the evolutionary camp (Dalum, Johnson, & Lundvall, 1992, p. 301), with its emphasis on interactive learning and the importance of institutions. Freeman classifies himself as an evolutionary economist in the introduction to his (1990, p. xiii) collection of papers on the economics of innovation. Carlsson (1995), one of the originators of the systems of innovation approach at the sub-national level also chose an evolutionary approach "because of its ability to bring within a single conceptual framework the institutional/organizational as well as cognitive/cultural aspects of social and economic change".

This thesis follows a common approach to describing the theoretical framework of the NSI concept. It starts by reviewing the meaning of system and innovation individually (Edquist, 1997; Lundvall, 1992b; Nelson, 1993b; Niosi et al., 1993). This will be followed by a discussion of the overall national systems concept and its variants (e.g. regional, technological and sectoral systems). The empirical evidence for systems of innovation is reviewed in section 2.6.5 and some conclusions regarding the 'state of the art' and the usefulness of the approach are drawn in sections 2.7.2 and 2.8.

2.6.2 The Meaning of Innovation and System

Schumpeter (1912/1934) divided technological change into three phases: invention, innovation and diffusion (see 2.1). The national system of innovation is generally taken to include all three phases, thus for example Lundvall refers to "production, diffusion and use of new and economically useful knowledge" (1992b, p. 2) while Metcalfe specifies "development and diffusion of new technology" (1995a). The country studies included in Nelson's (1993b) book

concentrate on technical innovations[16] and only discuss organisational, institutional or social innovations in passing. This bias is perhaps a reflection on the innovation literature up to that period where studies of innovation tend to concentrate on product and process innovation, largely because this type of innovation is more measurable. Elsewhere the view of innovation has included a strong emphasis on the importance of institutional and organisational innovations, starting with Freeman's pioneering work on Japan's NSI (1988).

In the standard neo-classical growth model e.g. (Solow, 1957) technical change is considered to be an exogenous phenomena; it is not explained by the model but arrives as 'mana from heaven'. Lundvall (1992b, p. 8) contrasts this idea of innovation as an extraordinary event coming from outside, with the evolutionary approach where innovation is characterised as being ubiquitous, gradual and cumulative. Almost all innovations arise from existing knowledge combined in new ways, so it is clear that innovation depends on what has gone before. Learning also takes place in the course of carrying out routine activities (Arrow, 1962a) which leads to the conclusion that innovation must be rooted in the prevailing economic structure and institutional set-up:

> if innovation reflects learning, and if learning partially emanates from routine activities, innovation must be *rooted in the prevailing economic structure*. The areas where technical advance will take place, will primarily be those where a firm, or a national economy, is already engaged in routine activities (Lundvall, 1992b, p. 9-10).

An important historical example is provided by the establishment of in-house R&D departments within large firms during the latter part of the last century (Freeman, 1992). This institutional innovation had a great influence on the NSI of affected countries and was one of the factors that accounts for Britain's loss of technological leadership in the 1880s and 1890s.

Nations and institutions can also make a conscious effort to expand their areas of technical knowledge through various kinds of searching and exploring activities. Crises often trigger a search for alternative products, processes and markets,

[16] Strictly technical innovations would involve change in *technique* (i.e. process) however they include process and product innovations under this heading (Nelson & Rosenberg, 1993, p. 4-5)

although such a search is often limited to the broad areas which are already well known. Searching also takes place in organisations dedicated to this task e.g. market analysis, R&D organisations and laboratories. Lundvall uses the term 'exploring' to describe searching by academic and science-oriented organisations. Exploring is less goal-oriented than profit-oriented search and "will sometimes result in breaks in cumulative paths and create the basis for new technological paradigms" (Lundvall, 1992b, p. 11).

The Aalborg school argues that innovation reflects learning and that interactive processes are the most important forms of learning (Johnson, 1992). Learning takes place through interactive processes inside firms, among firms and between firms and a variety of other institutions (universities, R&D organisations, government etc). Differences in the factors influencing these different interactive processes have been one of the foci for research into national systems of innovation.

The Concise Oxford Dictionary defines a system as a "complex whole; a set of things working together as a mechanism or interconnecting network" (1999) while Boulding gives the "broadest possible definition of a system … as anything that is not chaos" (1985, p. 1). More specifically "a system is constituted by a number of elements and by the relationships between these elements" (Lundvall, 1992b, p. 2) where the elements of the system include economic agents, private firms, the industrial structure, a variety of institutions and the nation as a whole. An alternative approach is provided by Carlsson and Stankiewicz who defined technological systems as "knowledge and competence networks supporting the development, diffusion and utilization of technology in established or emerging fields of economic activity" (1991). However they do not clearly specify exactly which agents and institutional structures are involved in the "development, diffusion and utilization of technology". Edquist (1997) suggests that a system can be defined "to include in it all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion, and use of innovations" (p. 14). He goes on to suggest that, in principle the limits of the system should be so defined as to include all factors which contribute to innovation. An advantage of this very comprehensive definition of a

system is that it does not exclude any determinants of innovation. An obvious disadvantage is that we are unable, at the present state of the art, to fully specify which elements should be included.

There is some discussion in the literature as to the extent (if any) to which systems are deliberately created. Carlsson and Jacobsson believe that the objective of government technology policy is to improve the functioning of existing technological systems and enhance the creation of new ones (1997a, p. 304). Nelson and Rosenberg's (1993) concept of a system does not include any presumption that the system was ever consciously designed or even that the different components work together smoothly. The truth is undoubtedly somewhere between these two extremes (Edquist, 1997, p. 13); some systems have to a large extent been deliberately created e.g. in the command economies of the former Soviet Union. Other systems seem to be almost entirely a product of the free market economy; they evolved over time and at no stage were constructed according to a planned system design. "However all are marked by significant pockets of government overview" (Nelson, 1992, p. 508). This is the case even in strongly free market economies such as the Unites States where government roles in funding university research and defence R&D since World War II have profoundly changed the nature of the innovation system. An important implication of the systems approach is that innovation depends on a set of inter-dependent elements and is not simply 'pushed' by investment in R&D.

2.6.3 Systems of Innovation Concepts

There are several levels at which systems of innovation (SI) may be analysed. A simple classification includes:

i. the global innovation system;[17]
ii. regional innovation systems – e.g the European or American system;
iii. national systems of innovation;
iv. local (regional)[18] innovation patterns within a national economy (section 2.6.4.1); and

[17] Kenneth Boulding (1985) in his book "The World as a Total System" argues that the world has moved a long way toward becoming a single economic, cultural, and communication system in the last century.

v. enterprise specific innovation styles; and maybe even several competing modes of innovation within the same company.

Alternative ways of 'cutting the cake' include technological systems (section 2.6.4.2) and sectoral innovation systems (section 2.6.4.3). According to Johnson (1992, p. 38) "it is not at all obvious from which level of aggregation this diversity of innovation should be considered". However several authors have provided convincing arguments to support the view that systemic elements within national economies are more important than elements across national boundaries, as is implied by the concept of national systems of innovation.

The concept is supported by the observation that "modern nations states in the Western World have worked as engines of growth" (Lundvall, 1992b, p. 3-4). Each country has its own distinct national characteristics as highlighted by Metcalfe:

> the element of nationality follows not only from the domain of technology policy but from elements of shared language and culture which bind the system together, and from the national focus of other policies, laws and regulations which condition the innovative environment (Metcalfe, 1995a, p. 463).

Some of the other factors which support analysis of innovation at the national level are provided by Lundvall (1992b, p.13) and Niosi et al. (1993):

i. national differences in history, language and culture bring about differences in:
   a. the internal organisation of firms
   b. the relationships between firms
   c. the role of the public sector
   d. the institutional arrangements in the financial sector
   e. R&D intensity and R&D organisation
   f. the national education and training system;

ii. natural resources, markets, consumer revenues and tastes;

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[18] in order to distinguish between the two uses of the word regional Freeman (1995a, p. 21) defines "nether region" as much smaller sub-national 'regions' .. in contrast to 'regional trading blocs' e.g. NAFTA or the South-East Asian 'region' which he calls an "upper region".

iii. user-producer and other types of informal collaboration are more frequent within the national economy than internationally;

iv. technically-based interdependencies are more common within the national economy e.g. Japanese leadership in the TV industry led to the development in that country of the VCR and other related innovations; and

v. political factors e.g. science and technology policies which are predominantly national in scope.

Lundvall suggests that "The Competitive Advantage of Nations" (Porter, 1990) may be read as a work on national systems of innovation. Porter uses the concept of a diamond whose four sides are made up of: i) factor conditions (skills, technology, capital etc), ii) demand conditions, iii) links to related and supporting industries; and iv) firm strategies, structure and rivalry. He uses these four national attributes to explain the environment faced by local firms in ways that promote or impede the creation of competitive advantage. He refers to these attributes as a system (1990, p. 75) and argues that the level at which the system works most strongly is national (and local) rather than international and global.

A strong case has been made for the analysis of systems of innovation at the national level (Lundvall, 1992b; Metcalfe, 1995a; Niosi et al., 1993). Different nations clearly have distinct characteristics that in many cases are important in explaining differences in growth rates between nations. Nelson and Rosenberg wrote:

> although its shape and character differ, in virtually all fields one must understand technical advance as proceeding through the work of a community of actors… To what extent are there 'national communities'? To what degree, and through what mechanisms, do the individuals and institutions that advance technology divide up into 'national systems'?. We suspect that the answer to this question varies over time and from field to field (Nelson & Rosenberg, 1993, p. 15).

Analysis at other levels of aggregation can also contribute substantially to our understanding of innovation. Increased levels of integration between nations mean that "the limitations of *national policies* are increasingly emphasised and the relevance of *national* systems increasingly questioned" (Freeman, 1995a, p. 20). At the opposite end of the spectrum it has been demonstrated that systems of innovation can usefully be analysed at the unit of the region, the sector or the

technological system. These other units are discussed in the following sections of this chapter.

2.6.4 Other Systems Approaches

2.6.4.1 Regional Systems of Innovation

As the systems of innovation literature has matured, so an increasing number of authors have explored the possible existence and form of regional innovation systems. For example Howells (1999) argues that Freeman's definition of a national system of innovation as "the network of institutions in the public and private sector whose activities and interactions initiate, import, modify and diffuse new technologies" (1987, p. 1) can also be applied at the regional level. Freeman himself acknowledges the existence of such systems:

> The work of geographers as well as economists … has convincingly demonstrated the importance of nether regions for network developments and new technology systems. They have argued that local infrastructure, externalities, especially in skills and local labour-markets, specialised services and not least, mutual trust and personal relationships have contributed greatly to flourishing nether regions (1995a, p. 21).

The 'founding trio' of Lundvall, Freeman and Nelson initially considered the idea of regional innovation systems, but put it to one side in favour of an explicitly national focus. It has been argued that nation states are losing their power and influence both upwards to supra-national institutions (the EC, UN organisations, multinational companies etc.) and downwards to sub-national organisations e.g. provincial, urban or local authorities (Ohmae, 1990). Freeman (1995a, p. 21) acknowledges these trends but concludes that "nation states, national economies and national systems of innovation are still essential domains of economic and political analysis, despite some shifts to upper and nether regions"[19]. Lundvall (1992a, p. 3) agrees stating that globalisation and regionalisation make it even more pertinent to understand the role and workings of national systems of innovation.

Analysis at the regional level has a long history including Marshall who discussed the benefits of industrial localisation in his 'Elements of Economics'

[19] these terms were defined in footnote 18.

(1932/1890). Much more recently Dosi explained localisation by "technological externalities that can sometimes be a *collective asset* of groups of firms/industries within countries or regions" (1988, p. 1146). Studies have revealed significant differences in research and technical activity and technological specialisation between regions (Howells, 1999, p. 70) thus making it dangerous to assume that the nation is always the most appropriate level of analysis.

Work on regional systems of innovation is closely linked with other active areas of research; for example the new economics of geography which is concerned with spatial aspects of the economy e.g. Fujita, Krugman and Venables (1999) and the active and expanding research on economic aspects of networks and clusters e.g. Freeman (1991), Enright (1996) and Filippi (1999).

Cooke (1998), a pioneer of regional innovation systems described how these researchers from various disciplines have been drawn together into what he calls the 'new regional science'. He identified a number of common themes:

i. the increasing importance of *regions* as foci for global economic competitiveness;
ii. the importance of the *institutional* setting for regional economic competitiveness;
iii. a recognition of informal networks as well as more formal organisations as mechanisms for sustaining *high-trust* relationships to minimise transaction costs;
iv. reevaluation of the importance of geographical *proximity* for facilitating tacit-knowledge exchange and other externalities; and
v. recognition of the importance of an institutional and organisational *learning* propensity to regional economic performance.

Supporters of the regional approach do not see it as replacing national innovation systems; most would support Howells who sees it "as providing another layer or conceptual lens to the whole system of innovation" (1999, p. 67). Lundvall and Freeman focussed on the national level because national economies vary according to their production system, institutional framework, historical experiences, language and culture, while Nelson and Rosenberg (Nelson &

Rosenberg, 1993) put greater stress on the role of institutional actors in explaining national differences in innovative performance. However Howells (1999, p. 71) points out that:

> most regional geographers and regional economists would have no difficulty in identifying significant regional variations in the components identified by Lundvall above, and indeed such an integrated systems view of regions can be traced back a long way in geography...Moreover all the key proponents of national systems of innovation have indeed accepted that there could also be other types of systems of innovation which operate at a sectoral, transnational or indeed regional level (Freeman, 1995a, p. 21; Lundvall, 1992a, p. 3; Nelson & Rosenberg, 1993, p. 5).

The prevalence of distinct regional systems of innovation will vary from country to country depending on the relative importance of regional governance structures, the development and evolution of regional industry specialisation and additional core/periphery differences in industrial structure (Howells, 1999, p. 72). Thus Wiig and Wood (1995) found that the innovation system in the Norwegian Møre and Romsdal region was limited in extent while Cooke and Morgan (1994) found a strong regional economy based on a robust economic system in the German region of Baden-Wurttenberg.

Overall, analysis at the regional level provides an additional layer, rather than a substitute for the national approach. Location and its associated externalities have a powerful influence on knowledge flows, learning and innovation often resulting in distinct regional or local systems of innovation. Regional systems of innovation have much in common with national systems; however they should be seen more as layers within a knowledge system than as 'proto' national systems (Howells, 1999).

2.6.4.2 Technological Systems

The concept of technological systems (TS) was developed and first brought to prominence[20] by Carlsson and Stankiewicz; they wrote that:

> A *technological system* may be defined as a network of agents interacting in a specific *economic/industrial area* under a particular *institutional infrastructure* or set of infrastructures and involved in the development, diffusion and utilization of technology. Technological systems are defined in terms of knowledge/competence flows rather than flows of ordinary goods and services. They consist of dynamic *knowledge and competence networks*. In the presence of an entrepreneur and sufficient critical mass, such networks can be transformed into *development blocs*, i.e. synergistic clusters of firms and technologies within an industry or group of industries (Carlsson & Stankiewicz, 1991).

Most recent TS work follows their conceptual framework although De Liso and Metcalfe (1996, p. 72) defined a technological system from first principles as "the set of principles and entities that interact and define a particular group of related artefacts". They go on to explain, "in this sense a fountain pen is a system as is a drug and as is a modern airplane". They then introduced the concept of a Technological Support System (TSS) as "the set of institutions that individually and jointly support the operation and development of a technology"; this corresponds with Carlsson and Stankiewicz's concept of a technological system.

In contrast to the national and regional levels of analysis that focus on geographical boundaries, the technological systems (TS) approach is more technology and industry specific. The TS research theme led by Bo Carlsson was developed under a five-year research programme on Sweden's Technological Systems and Future Development Potential. The programme includes theoretical studies of technological systems as well as empirical studies of factory automation (Carlsson, 1995), electronics and computers, pharmaceuticals and powder technology (Carlsson, 1997).

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[20] Carlsson and Stankiewicz (1995) believe that the term was first used by Thomas Hughes (1983) and refer to "Bijker, Hughes and Pinch (1987) and Mayntz and Hughes (1988) for a variety of essays on technological systems". However Edquist (1997, p. 4) states that Hughes "means something different from Carlsson and Stankiewicz" and does not consider Hughes's perspective to be a variant on the systems of innovation approach.

Carlsson describes four basic assumptions underlying the TS approach (Carlsson, 1997, p. 4):

i. the system as a whole is the basic unit of analysis, not its components;
ii. system configuration changes over time;
iii. global technological opportunities are practically unlimited; but
iv. there is bounded rationality[21]

All of these fall comfortably under the evolutionary and systems approaches to innovation. Technological systems are seen as involving interactions in three types of network: buyer-supplier (input/output) relationships, problem-solving networks, and informal networks. Since the focus is on technology and innovation it is the problem-solving network that defines the nature and boundaries of the system. The system exists to enable players to capture and enhance technological spillovers and create favourable conditions for market exchange.

The study of biotechnology described in chapters 4 and 5 requires a multi-sectoral approach since its techniques are used in a number of different "biotechnology-based sectors"(Saviotti, 1998, p. 19). As such, Carlsson and Stankiewicz's notion of a technological system (TS) is well suited to modelling the interaction of the various actors. This is underlined by Carlsson's description of a TS as: "a network of agents interacting in a specific *technology* under a particular *institutional infrastructure* or set of infrastructures and involved in the generation, diffusion, and utilization of technology" (Carlsson et al., 1999, p. 12).

2.6.4.3 Sectoral Innovation Systems

Sectoral innovation systems are based on the idea that different sectors or industries operate under different technological regimes and have distinctive sectoral characteristics (Carlsson et al., 1999, p.8). Pavitt's (1984) paper on sectoral patterns of technical change was an important precursor to this approach. He used a database on about 2000 significant innovations in Britain since 1945 to describe sectoral patterns of technical change based on a three part taxonomy of

[21] limited knowledge and information processing capability; the competence of various entities is differentiated but fairly stable and path dependent; and the search for new knowledge is local.

firms as: supplier dominated, production intensive or science based. Existence of these different categories was explained, based on sources of technology, requirements of users, and possibilities for appropriation. So, for example, instrument engineering firms are generally small and specialised while chemicals firms are relatively big and tend to develop innovations "over a wide range of specific product groups within their principal sector".

Malerba and Orsenigo wrote a series of papers looking at technological regimes[22] and sectoral patterns of technological change e.g. (Malerba & Orsenigo, 1995) but the formal appearance of the Sectoral Innovation System (SIS) approach is generally traced back to Breschi and Malerba. They defined it as:

> that system (group) of firms active in developing and making a sector's products and in generating and utilizing a sector's technologies. Such a system of firms is related … through processes of interaction and cooperation in artefact-technology development and through processes of competition and selection in innovative and market activities" (1997, p. 131).

The SIS approach is distinguished by the fact that the central actors are private firms and by its focus on competitive relationships among firms (the selection environment) rather than the TS notion of a network of vertically and horizontally connected agents and organisations. Breschi and Malerba follow a similar approach to Pavitt and identify five types of SIS based on number of innovators, geographic dispersion and knowledge boundaries see Table 2.3.

Table 2.3 Types of Sectoral Innovation System

Sector	**Number of Innovators**	**Geographic Dispersion**	**Knowledge Boundaries**
Traditional e.g. *agriculture, textiles, shoes*	Many	Dispersed	None
Mechanical Industries and the Industrial District	Many	Concentrated	Local
Auto Industry	Few	Concentrated	Local
Computer Mainframe Industry	Few	Concentrated	Local
Software Industry and Silicon Valley	Many	Concentrated	Internal and global

Source: (Breschi & Malerba, 1997)

[22] a description of the technological environment in terms of opportunity and appropriability conditions see for example: Nelson and Winter (1982) and Malerba and Orsenigo (1995)

They conclude that "technological regimes are a major structuring factor of the Schumpeterian dynamics of innovators, the geographical distribution of innovators and the knowledge spatial boundaries of innovative activities in SIS" (1997, p. 152).

Metcalfe takes a similar approach and explains the concept of sectoral innovation systems:

> as a convenient middle ground which recognises that not all the influences on technical progress lie within the firm, and that an economy wide, aggregate, approach can make little sense of the diverse conditions in which different kinds of knowledge are accumulated (1998, p. 2).

He suggests that "the fundamental source of growth is innovation at the level of the firm and that it is this which underpins structural change within and between economic sectors". He argues that there are major differences in the technological regimes[23] of different sectors that shape the overall pattern of growth. As a result the principal focus of empirical investigation should be at the sectoral level.

2.6.5 Empirical Evidence for Systems of Innovation

The systems of innovation (SI) literature started with Freeman's (1987) suggestion that Japanese technological progress could be attributed to major changes in what he termed the national system of innovation. This was followed in 1993 by Nelson's comparative analysis of national innovation systems in fifteen countries. Evidence for the existence of national innovation systems ranges from the descriptive case study approach pioneered by Freeman and Nelson to more formal proofs such as those provided by Malerba and Orsenigo (1995).

The first objective of Nelson's comparative analysis of national innovation systems was to "describe, to compare, and to try to understand the similarities and differences across countries in their innovation systems" (1993a, p. 505). The second major objective was to investigate what made an innovation system effective. The researchers "were bothered by the tendency of various analysts to argue on the basis of very little evidence or analysis that this feature or that one

[23] Metcalfe uses the term 'technical progress function' which would appear to be a very similar concept.

was a major factor behind country performance differences… [and hoped to] constrain such practice".

Overall, Nelson's fifteen case studies make a convincing case for the existence of national systems of innovation. Strong national differences were found which reflect differences in economic and political circumstances (e.g. size and resource endowments). Systems were also found to reflect conscious decisions to develop and sustain economic strength in certain areas. Nelson comments "in all these cases, a distinctive national character pervades the firms, the educational system, the law, the politics and the government, all of which have been shaped by a shared historical experience and culture" (1993a, p. 518).

Nelson's study contributed to a wave of activity aimed at describing and comparing national innovation systems including the OECD's National Innovation Systems project (OECD, 1997a) and the Innovation Systems and European Integration (ISE) Research Project, funded by the European Commission (Edquist, 1998). As a result there is now a large body of empirical literature aiming to describe and assess systems of innovation; see Table 2.4.

Malerba and Orsenigo used patent data from four countries to look at patterns of innovative activities across different technological classes. They found that "patterns of innovative activities differ systematically across technological classes, while remarkable similarities emerge across countries in the patterns of innovative activities for each technological class"(1995). Their results suggest that technology specific factors play a major role in determining the patterns of innovative activities. This provides support for the notion of technological systems or sectoral systems of innovation although the existence of "remarkable similarities across countries" might be interpreted as implying that national systems are of lesser importance.

Table 2.4 A Bibliography of Country Studies

Australia	Gregory (1993), Martin and Johnston (1999), Wells (1997), Bryant et al. (1996), Australian Bureau of Statistics (1996-97).
Austria	Schibany (1998), Hutschenreiter et al. (1996).
Argentina	Correa (1998), Katz and Bercovich (1993).
Belgium	Capron and Cincera (1997).
Brazil	Dahlman and Frischtak (1993).
Britain	Walker (1993), Vithlani (1997), Drejer (1999).
Canada	McFetridge (1993).
Denmark	Laursen and Christensen (1996), Edquist and Lundvall (1993), Lundvall and Christensen (1999).
France	Chesnais (1993).
Germany	Keck (1993), Drejer (1999), Beise and Stahl (1999).
Israel	Teubal (1993), Vekstein (1999).
Italy	Malerba (1993).
Japan	Freeman (1988), Odagiri and Goto (1993), Drejer (1999), Goto (2000).
Korea	Kim (1993), Wong (1999).
Netherlands	den Hertog et al. (1995).
New Zealand	Engelbrecht and Darrich (1999), Darroch (1998), Foundation For Research Science and Technology (1998), Frater et al. (1995), Martin and Johnston (1999), Parish (1998), Mills and Langdon (1997), Williams et al. (2001).
Singapore	Wong (1999).
Sweden	Edquist (1993), Carlsson and Jacobsson (1997).
Switzerland	Hotz-Hart (1996).
Taiwan	Hou and Gee (1993), Wong (1999).
USA	Alic (1994), Mowery and Ziedonis (1998), Mowery (1998), Mowery and Rosenberg (1993), Bozeman et al. (1999), Drejer (1999), Popper and Wagner (2001).
Multi-Country	Nelson (1992), Nelson (1993b), Soete (1994), Khan (1998), Edquist et al. (1998), Drejer (1999), Cappelen et al. (1999).
Developing Countries	Cassiolato (1999), Arocena (1999) .

Source: Marsh (1999)

John McCallum (1995) provides evidence from Canada on the continued importance of national systems. He found that Canadian provinces traded twenty times as intensely with each other as with US states of comparable size and distance. Helliwell's explanation for this finding ties in well with the SI approach:

> to deal with those you know and trust, under shared and well-understood rules and institutions, can mean lower costs and lower risks for all participants….To the extent that national boundaries enclose communities that have common institutions and shared views, local businesses are likely to be able to meet local market needs at lower cost than are their foreign or global competitors (Helliwell, 1999, p. 11).

A review of 42 articles belonging to the SI literature (Marsh, 1999) found that around 60% had at least some empirical content, the remainder being theoretical, methodological or review articles. Most of the empirical articles were classified as having a low or medium content of data and evidence. One of the most common subjects was the description of a national or regional system of innovation. Empirical articles that used formal econometric tests or modelling were rare; only four of the above 42 articles fell into this category. Two of these were based on analysis of patent data, one used computer simulations and one analysed national statistics to investigate regional convergence.

Janszen and Deganaars (Janszen & Deganaars, 1998) used semi-structured interviews with experts from more than 80 organisations to provide the empirical basis for a simple computer model. They used computer simulations to test various hypotheses but found it hard to obtain enough data to calibrate the system. As a result they restricted their objective to obtaining qualitative insight into "the dynamic relations between structure and process in innovation systems".

Gassler, Frölich, and Kopcsa (1996) used patent data to describe the Austrian national innovation system in terms of its technological specialisation profile, while Malerba, Breschi and Lissoni (1998) used patent data to analyse patterns of entry and exit by firms into different technological fields. Use of patent data in these two papers builds on the vast body of literature that already exists in this field and provides one practical method of quantifying aspects of the innovation systems. However it could be argued that these empirical papers are only SI 'in name' because their attempt to combine the patent and SI research fields does not provide many additional insights.

2.6.5.1 Measuring the Performance of Systems of Innovation

If we are to move beyond case studies and descriptive comparisons then we must develop ways of measuring the performance of systems of innovation. Patel and Pavitt outlined a list of indicators that might be used to measure the "change-generating activities of the major institutions in national systems of innovation" (1994, p. 81).

These were:

i. For business firms;
   - R&D activities performed.
   - Patents granted in the USA.

ii. For universities and related institutions;
   - R&D inputs
   - Number of papers published and citations.

iii. For educational institutions
   - Qualifications of the population
   - International comparisons of educational attainment.

Use of indicators has been by far the most common method by which systems of innovation have been described and compared. Typically this is achieved through use of secondary statistics often supplemented by a survey of firms. The innovation system is then described by reference to a series of indicators such as % of GDP spent on R&D or number of scientists per 1000 workers. For example Engelbrecht and Darroch (1999) based their assessment of the New Zealand system of innovation on indicators intended to measure New Zealand's potential to produce knowledge, inflows of technology, absorptive capacity and whether diffusion was taking place (see Table 2.5).

Various attempts have been made to refine and standardise this approach, for example Boyer (1997) used system characteristics to classify twelve national systems of innovation according to indicators of:

i. scientific specialisation
ii. technological specialisation
iii. implementation of new production model
iv. labour market flexibility

v. skill level

vi. education achievements

vii. costs of capital

viii. sophistication of capital market

ix. macroeconomic performance

Table 2.5 Performance Indicators for New Zealand's NIS

Potential to produce knowledge	Gross domestic expenditure on R&D (GERD) as % of GDP Government expenditure on R&D as % of GDP Percentage of GERD financed by industry Number of researchers per 10,000 workers in labour force Contribution made by industrial sector to GDP
Inflows of technology	Technology payments divided by technology receipts FDI inflows as % of GDP Imports of manufactured products as % of total imports
Absorptive capacity	University graduates as % of total population Science graduates as % of university graduates
Evidence of diffusion taking place	Percentage of production accounted for by high and medium technology products Exports of manufactured goods as % of total exports Growth of manufactured exports (average annual 1986-1996 growth rate) Economic growth rate (average annual 1985-1995 growth rate)

Source: Engelbrecht and Darroch (1999)

The problem with the indicator approach is that it tends to evaluate the performance of different players as single entities whereas an evaluation of system performance should try to measure the output of the system as a whole (Carlsson et al., 1999, p. 23). However in practice it is difficult, if not impossible, to find practical measures of overall system performance, although Carlsson (1999) provides a useful discussion of how this might be attempted.

2.7 Discussion

2.7.1 Criticism of Neo-Classical Approaches

The central concern of mainstream neo-classical economics is the interaction of self-interested, intelligent, individuals. Most neo-classical theory further assumes that "agents are not only intelligent, they maximize… And when they interact they achieve an equilibrium in which each individual is doing the best he can given what all others are doing" (Krugman, 1996, p. 2).

Individuals who were not willing to proceed within the constraints of these core assumptions have developed alternative approaches, criticism being focussed particularly on the ideas of maximization and equilibrium. Evolutionary theorists aim to drop the assumption that individuals maximize. They try instead to represent decision making as a process of groping through alternatives in which it may take a long time to get to a maximum and where the maximum reached may well be local rather than global. They also try to get away from the assumption of equilibrium, to an approach where the economy is always evolving. Some of these criticisms have been fleshed out by Metcalfe: "the [neo-classical] framework is lifeless, which makes it hard to incorporate innovation as the driving dynamic force in the competitive process" (1995a, p. 446); and the assumption of symmetric behaviour by identical firms is perceived to be unacceptable because: "…innovation and information asymmetries are inseparable and thus innovation and Pareto optimality are fundamentally incompatible" (1995b, p. 413).

However acceptance of the absolute truth of these neo-classical assumptions is certainly not a pre-requisite for those who choose to work within that tradition; for example Kenneth Arrow pointed out problems with the assumption that all individuals have the same utility function; "People just do not maximize on a selfish basis every minute. In fact, the system would not work if they did" (1987, p. 233). While Paul Krugman explained that his research has taken him to the edge of the neo-classical paradigm:

> When you are concerned, as I have been, with situations in which increasing returns are crucial; you must drop the assumption of perfect competition; you are also forced to abandon the belief that market outcomes are necessarily optimal, or indeed that the market can be said to maximize anything. You can still believe in maximizing individuals and

> some kinds of equilibrium, but the complexity of situations in which your imaginary agents find themselves often obliges you - and presumably them – to represent their behavior by some kind of ad hoc rule rather than as the outcome of a carefully specified maximum problem. And you are often driven by sheer force of modeling necessity to think of the economy as having at least vaguely "evolutionary" dynamics, in which initial conditions and accidents along the way may determine where you end up (Krugman, 1996, p. 1).

Seen in this light, economists in the neo-classical tradition are those who *prefer* to make sense of the world using models based on the simplifying assumptions of maximization and equilibrium. Those who believe that knowledge can be advanced further outside these constraints use alternative traditions such as the evolutionary approach.

> Neoclassical economists see individual and organizational action as largely the consequence of optimizing choices. Institutional and evolutionary economists see action as largely the consequence of following habits or customs…, or rules of thumb …, or routines … appropriate to the particular decision context (Nelson, 1994, p. 249).

A central criticism of the neo-classical growth models of the 1950s and 1960s (section 2.3.1) is the assumption that technological progress occurs in an unexplained (exogenous) manner. Solow's model cannot be used to determine the causes of technical change because it is treated as being exogenous. It is therefore of little use in studying policy issues such as whether market allocation of resources to R&D is optimal, or the more fundamental question of what explains long-run growth:

> the long-run per capita growth rate is determined entirely by an element – the rate of technological progress - that comes from outside the model… Thus we end up with a model that explains everything but long-run growth, obviously an unsatisfactory situation (Barro, 1997, p. 4).

Dissatisfaction with this exogenous treatment of technological change led to the development of alternative approaches; endogenous and new growth theories (that sought to endogenise technical change within the neo-classical paradigm); and evolutionary and institutional approaches.

Another problem with early neo-classical approaches was that R&D is not a profitable activity in a world where knowledge is a pure public good and where perfect competition prevents firms that invest in R&D from extracting any extra profit. In order to make R&D profitable new growth theory assumes that at least a

portion of benefits are appropriable and markets are imperfectly competitive to allow for profit from innovation.

However Nelson (1997) questioned the newness of new growth theory suggesting that all of these 'new' assumptions had been well documented in the empirical literature for some years and were included in a review article by Abramovitz (1952). Nelson went on to ask why some findings from the empirical literature were included in the new models while others that are equally important were ignored. He was particularly concerned with the unsatisfactory treatment of uncertainty and institutions:

> …virtually all detailed empirical inquiry into major technological advance has highlighted the inability of the actors involved to foresee the path of development, even in broad outline, or the major surprises that occurred along the path. In contrast the new models assume perfect foresight or if they admit less than that, that uncertainty about the future can be treated in terms of a well and correctly specified probability distribution of possible future events (1997, p. 31).

> The new neo-classical growth models treat firms in a highly simplified way and barely address institutions aside from the "competitive" (or monopolistically competitive market (p. 32).

Systems approaches respond directly to Nelson's concerns. The 'state of the art' in this field of research is discussed in the next section, followed by some conclusions regarding the theoretical approach adopted in this thesis.

2.7.2 Systems of Innovation; the 'State of the Art'

Studies of national and sectoral systems of innovation have yielded many valuable insights. It is undoubtedly true that innovation typically involves interactions with a range of actors and that it is affected by institutional and organisational settings. Studies using the systems perspective have greatly increased our understanding of the similarities and differences across countries in their innovation systems and have contributed significantly to policy making. But their findings are often country or sector specific and subject to change over time. It may also be asked whether the systems approach was always necessary for achievement of those

insights except in so far as they employ historical, holistic and interdisciplinary perspectives[24].

The difficulty with the national innovation system (NIS) concept as a theoretical framework seems to lie in its generality and inclusiveness. Few would argue with the proposition that innovation is affected by "the links and relationships among industry, government and academia in the development of science and technology" (OECD, 1997b p. 11). But there seems to have been little progress in developing a set of general principles relating innovation to a set of specific characteristics of institutions and their links. Nor has much progress been made in the development of general methods for measuring and analysing systems of innovation (SI), or in the synthesis of general conclusions about national systems of innovation.

The literature often seems to be stuck 'at first base'; still grappling with basic issues of definition and measurement. Karaömerlioglu (1998) and Carlsson et al (1999) amongst others have made practical suggestions on how systems of innovation should be defined but this has not led to the development of a more standardised SI methodology. Patel and Pavitt's (1994) list of indicators (section 2.6.5.1) has been widely used, but the literature to date has contained little explicit discussion of the function of each system, or of what constitutes system inputs and outputs. As a result little progress has been made in measurement of the performance of the total system, which should be the main focus (Carlsson et al., 1999).

Radosevic suggests that SI research has entered a temporary phase of diminishing returns where "empirical research has not resulted in added theoretical insights and theoretical research seems to have been incorporated into the broad concept of institutions" (1998, p. 76). He suggests that institutional diversity and lack of a common conceptual framework are part of the problem, with the result that presentations of systems of innovation are never exhaustive and directly

[24] These are two of the nine characteristics of the SI approach identified by Edquist and Hommen (1999, p. 65).

comparable. Further comment on the current state of SI work is provided by Cooke:

> given the demands of testing [the talisman concept of NIS] from an interactive rather than a linear perspective, it is perhaps not surprising that the main international study reported by Nelson (1993b) is weak on generalisable findings, whereas the main theoretical study edited by Lundvall (1992b) is almost entirely lacking in empirical content (Cooke et al., 1998).

Various authors have made suggestions on how to break the impasse. Bell and Albu (1999) and Lundvall and Christensen (1999, p. 2) agree that research should shift from studying production systems to knowledge systems. This would bring empirical research more into line with systems theory but will tend to make quantification more difficult since knowledge systems are much harder to measure than production systems.

An alternative way forward has been to break national systems down into more manageable proportions. This approach has had some success and Cooke et al. (1998, p. 1565) comment that "where theoretical and empirical work are well integrated the focus tends to be sectoral". Work by Carlsson (1997; 1991; 1995) is extensively cited and highly praised, but is not immune from many of the problems which have been associated with the national SI approach.

Zysman believes the answer comes from quite a different quarter: "… the answer does not come from within economics, but rather from historical and institutionally oriented political science" (1996, p. 662). Zysman explains economic and technological development through a painstaking study of the historical, political and institutional developments in each country. He criticises the narrow SI concentration on elements of science and technology influence, although his arguments may be seen as consistent with a broad SI definition.[25] Unfortunately "historical institutional analysis has low predictive power and it is difficult to generate much theoretical insight from it"(Radosevic, 1998, p. 79) because of the specificity of particular historical conditions.

[25] e.g. Lundvall's (1992a) definition; see Table 2.2.

While a set of general principles may, in fact never be developed Metcalfe suggests that the institutional approach will continue to provide essential insights which are different to the market failure approach to technology policy. "Fundamentally, the effective operation of an evolutionary innovation system depends on the effective coupling between firms with other knowledge-based institutions to jointly enhance processes of learning and creativity" (1995a, p. 497).

Krugman and Romer respond that evolutionary theorists must try to formalise their understanding into simple models. If they do not, then they run the risk of being bypassed. Krugman draws a parallel with the 'high development theorists'[26] of the 1950s; rather than compromise their insights so that they could be put into the available simple models, the high development theorists explicitly rejected the tendency in the profession towards rigor and formal modelling (Romer, 1993, p. 552). "Along with some others, notably Myrdal, Hirschman didn't wait for intellectual exile: he proudly gathered up his followers and led them into the wilderness himself. Unfortunately, they perished there" (Krugman, 1994).

2.8 Conclusions

In the preceding sections of this chapter, the main theoretical approaches to the economics of innovation have been described and reviewed. Each of these approaches has its advantages and its faults. The approach taken in this thesis does not fall under any single framework since, as Stoneman has pointed out: "the choice of framework is [often] a matter of 'horses for courses' and the most appropriate framework depends crucially on the questions being asked" (1995, p. 9).

Overall, the approach draws strongly on the evolutionary school – as summarised by Giovanni Dosi in his 1988 review in the Journal of Economic Literature[27]:

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[26] "…high development theory can be described as the view that development is a virtuous circle driven by external economies -- that is, that modernization breeds modernization. Some countries … remain underdeveloped because they have failed to get this virtuous circle going. (Krugman, 1994)

[27] See appendix 2 for an explanation of Dosi's terminology.

> In the new view, appropriability, partial tacitness; uncertainty; variety of knowledge bases; search procedures, and opportunities; cumulativeness and irreversibility … have been recognised as general features of technological progress. Relatedly, the endogenous nature of market structures associated with the dynamics of innovation, the asymmetries among firms in technological capabilities, various phenomena of nonconvexity, history of dependence, dynamic increasing returns, and the evolutionary nature of innovation/diffusion processes are some of the main elements of technological change (Dosi, 1988, p. 1164).

Theorists operating outside the mainstream have produced a wealth of appreciative theory[28] and qualitative description; work that has the distinct advantage that it has the ring of truth to it. However the disadvantages of departure from the neo-classical paradigm are well recognised. Evolutionary and SI theorists have not been able to distil their understanding into simple models and even though they have a framework that denies the assumptions of maximization and equilibrium often make use of these assumptions as modelling devices that allow them to cut through complexity[29]. Work in the evolutionary tradition differs from mainstream analysis because it places ideas or discoveries at the centre of the framework. The difficulty with this approach is that ideas have not proved susceptible to mathematical description; indeed as Metcalfe noted "the idea of a production function for knowledge is not going to be very useful because ideas are not commensurable" (2000).

Acceptance of the simplifying assumptions of the neo classical framework does not imply that they are wholly (or even partially) correct just that this is a useful way of simplifying the complex world and moving forward. The neo-classical framework is most developed and has the advantage of general principles e.g. Pareto criteria which are not available under the evolutionary approach. However there are occasions where research questions can best be framed within an evolutionary framework; particularly those that relate to systems of innovation.

The SI approach provides a more holistic way of looking at the world than the traditional neo-classical approach. While progress has been slow in developing

[28] "Nelson and Winter introduced the term appreciative theory to describe theory that is less abstract, more descriptive and closer to practice and the real world context". (Romer, 1993, p. 554)

ways of measuring and comparing systems this does not cast doubt on the validity of the concept. What seems to be required is more integration between the systems approach and other research into the economics of innovation. The SI concept and evolutionary theory on which it is based are useful supplements to neo-classical theory. They provide an alternative framework for thinking about innovation and encompass many of the features that seem to be essential to a full explanation of the economics of innovation. For these reasons the empirical research described in this thesis has been conducted mostly within the neo-classical framework but draws freely on the knowledge gained through other traditions whenever this is appropriate.

[29] Krugman (1996) comments that "those who try to do economics without these organizing devices have a propensity to produce sheer nonsense".

Chapter 3 The Determinants of Innovation

3.1 Introduction

This chapter starts with a review of alternative measures of innovation output and innovation rate. This is followed by a description of the hypotheses tested in the empirical section of this paper, alongside a discussion of their background in the innovation literature. The chapter concludes by setting out a framework describing the determinants of innovation.

3.2 Measures of Innovation Output and Rate

Any investigation into the determinants of innovation must first answer two questions; 'what is innovation?' and 'how can we measure it?' Innovation, in the economic sense, is accomplished with the first commercial transaction involving a new product or process[1]. A more precise operational definition is provided by the OECD (1997b, p. 47):

> Technological product and process (TPP) innovations comprise implemented technologically new products and processes and significant technological improvements in products and processes. A TPP innovation has been implemented if it has been introduced on the market (product innovation) or used within a production process (process innovation).

In practice, innovation is often used more loosely, to refer to the whole process of technological change (including invention and diffusion) and some 'measures of innovation' are in fact measures of invention or diffusion.

As noted by Hansen

> it has been recognised for some time that the optimal approach to assessing the level of industrial innovation is to collect a variety of pieces of information, none of which actually measures innovation, but all of which provide indicators of the level of innovation (Hansen, 1992, p. 38).

Various possible measures of innovation 'output' can be derived directly from the narrow and broad definitions of innovation (above):

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[1] This analysis concentrates on product and process innovation. Other innovation types have been defined and investigated for example service innovation (generally process innovation) and organizational and managerial innovations.

i. Presence or absence of innovation

The enterprise has or has not 'implemented TPP innovations' in the period under review. The OECD (OECD, 1997b) defines such enterprises as TPP innovating firms. Tether (2001, p. 29) breaks these down into four categories:

True innovators	Technological innovation is at the core of their activities.
Imitators.	Enterprises that *develop technologies* for their own new products, processes and services, but are essentially imitators rather than true innovators.
Active Technology Adopters	Enterprises that use technologies developed by others, in novel or creative ways.
Passive Technology Adopters	Enterprises that use technologies developed by others, but in standard rather than in novel or creative ways.

ii. Innovation counts e.g. number of new and significantly improved products and/or processes implemented. Count data are sometimes broken down according to the degree of novelty of the new or improved product or process (as in i. above).

iii. Proportion of sales due to new or technologically improved products introduced over a specified period. This provides a measure of the impact of innovation on enterprise performance. As an indicator of innovative output it has the advantage of providing a monetary value thus adjusting for the quality or impact of different innovations.

iv. Number of patents applications. Data on patent applications (rather than patents granted) are usually used because of the lag between application date and grant date, which can be up to ten years. Patents are an indicator of *invention* – not necessarily leading to innovation – but are also useful indicators of a broad definition of innovative output.

v. Bibliometrics (the generic term for data on publications). Bibliometric analysis uses publications data sets to measure the output of individuals, institutions and countries, to identify networks and to map the development

of new fields. Useful findings have emerged although this form of analysis does have a number of drawbacks; propensity to publish varies between scientific fields and databases are biased towards articles in English which may affect international comparisons (OECD, 2002b, p. 204.)

vi. R&D expenditure provides an indicator of the level of innovation inputs.

The above indicators of innovative output can usefully be modified to provide measures of innovation rate; where innovation rate is estimated from innovative output divided by some measure of firm size or innovative effort. Some of the empirical results for innovative output may be viewed as unsurprising; we would expect, after all, that the innovative output of large enterprises would be greater than that of smaller ones. What is often of more interest is whether any systematic pattern of variation in innovation rate can be identified. For example, are some firms more innovative (per unit of effort) than other firms, if so what are the reasons for this?

Investigations into the determinants of innovative activity have often been based on single indicators; often R&D expenditure or patents. The potential weaknesses of such an approach are well summarised by Arvanitis and Hollenstein (1996) who point out that the complexity of the innovation process means that a methodology based on a single measure may leave out important relationships and produce results that are not robust. In an attempt to overcome such problems they describe the use of a composite innovation indicator constructed using factor analysis from a broad set of variables describing patents, new products and processes, degree of novelty etc. Their 1994 paper investigating the relative strength of demand pull vs. technology push in 914 Swiss manufacturing firms, pointed to dominance of supply-oriented factors (e.g. appropriability and technological opportunity) as against the impact of demand and market conditions.

Hansen (1992) used indicators to assess the degree to which the level of innovation in manufacturing firms is influenced by firm size and firm age. The number of new products introduced as a function of firm sales and the proportion

of firm sales obtained from products first introduced in the previous five years were used as indicators of innovative output. The results indicated that it was possible to separate the effects of age and size; both being inversely related to innovative output.

A similar approach was taken by Mairesse and Mohnen (Mairesse & Mohnen, 2001, 2002), in their analysis of data from the European Community Innovation Surveys. They compared innovation across seven European countries using 'share of innovative sales' as an indicator of innovative output. This was defined as "the sales due to new or improved products for the firm (but not necessarily for the market) in the last three years". The advantage of this indicator, compared to R&D expenditure or counts of new products, processes or patents, is that it provides a direct measurement of innovative output. Ten explanatory variables were investigated including industry classification, number of employees, strength of competition, proximity to basic research, existence of cooperation in innovation and R&D intensity.

Zucker and Darby conducted some of the earliest research into biotech productivity, beginning their study of 'star' scientists and biotech firms in 1988. Their 1994 paper is an example of their considerable research output in this area; it examines the effects of university-based star scientists on three different measures of firm performance (number of products the firm has in development, number of products on the market and net change in employment over five years). Another rapidly growing biotech research area is based on analysis of patents. Recent examples have looked at factors affecting university ag-biotech patent production (Foltz, Barham, & Kim, 2000) and business performance in the Canadian biotechnology industry (Hall & Bagchi-Sen, 2002).

Empirically based analyses have contributed greatly to our understanding of the link between innovative output and a broad range of explanatory variables. Unfortunately there has been less progress in achieving comprehensive measurement and linkage of innovative inputs to innovation outputs and in exploring whether innovative effort has a measurable impact on firm performance (Hoffman, Parejo, Bessant, & Perren, 1998). Useful new indicators have been developed and tested empirically but data quality remains a real problem. Several of the most commonly used indicator variables seem to be open to varying interpretations depending on the organisational type, sector, country etc in which the data are collected (Mairesse & Mohnen, 2001; Mohnen & Dagenais, 2002; Tether, 2001). For example how new or improved or significant does a product have to be before it is reported?

Empirical work described in this thesis is based on a combination of the innovation indicators outlined above: innovation counts, patent applications and sales of new products/processes. Alternative indicators of innovative output were tested based on the number of new products and/or processes introduced and the number of patents applied for. Combining these three gives a much improved measure since different organisations exhibit innovative output in different ways. Patents are a better indicator for enterprises that concentrate on the creation (and protection) of intellectual property, while the number of new products and/or processes introduced is a better indicator for more production-oriented enterprises (many of which have applied for few if any patents).

Sections 3.3 to 3.10 of this chapter are devoted to presentation of a series of hypotheses regarding the determinants of innovation, alongside a brief review of their place in the innovation literature. Hypotheses are included:

i. if they are well supported in the theoretical literature;
ii. if they have significant empirical support, or have been the subject of extensive empirical investigation; and/or
iii. if they appear in multiple strands of the literature.

3.3 Stock of Ideas

The stock of ideas is given a central position in a group of endogenous growth models[2] that started with Romer's (1990) article (see section 2.4). The concept is similar to the concept of human capital[3] used in growth accounting applications. In Romer's model, growth is driven by the firm's desire to innovate through the accumulation of knowledge. They are able to profit from their innovations since monopolistic competition (through the patent system) makes knowledge a partially excludable input. Romer demonstrates that firms cannot survive under conditions of perfect competition if they are dependent to some degree on non-rival inputs (e.g. freely available knowledge). Romer's model specifies that knowledge is non-rival and that the rate of growth in the economy as a whole benefits from knowledge spillovers (i.e. other firms are able to make use of increases in the total stock of knowledge, to commercially exploit new products or processes thus leading to economic growth).

Hypothesis 1

Rate of new ideas production increases with the stock of ideas.

3.4 Demand Pull versus Technology Push

The relative significance of 'demand-pull' versus 'science and technology push' was debated for much of the last century, particularly amongst scholars of industrial organisation (section 2.3.2). In the 1960s and 1970s demand led theories of innovation had considerable influence. An empirical survey of over 500 innovations by Myers and Marquis (1969) appeared to support the demand-pull approach while Schmookler (1966, p. 207) provided a detailed historical justification through detailed analysis of US patent statistics. He found that the peaks and troughs of inventive activity usually lagged behind similar movements in investment activity and concluded that the main stimulus to innovation came from the changing pattern of demand: "…inventions are usually made because men want to solve economic problems or capitalize on economic opportunities".

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[2] Other important models in this area are detailed in Aghion (1992), Grossman (1991) and Jones (2000).

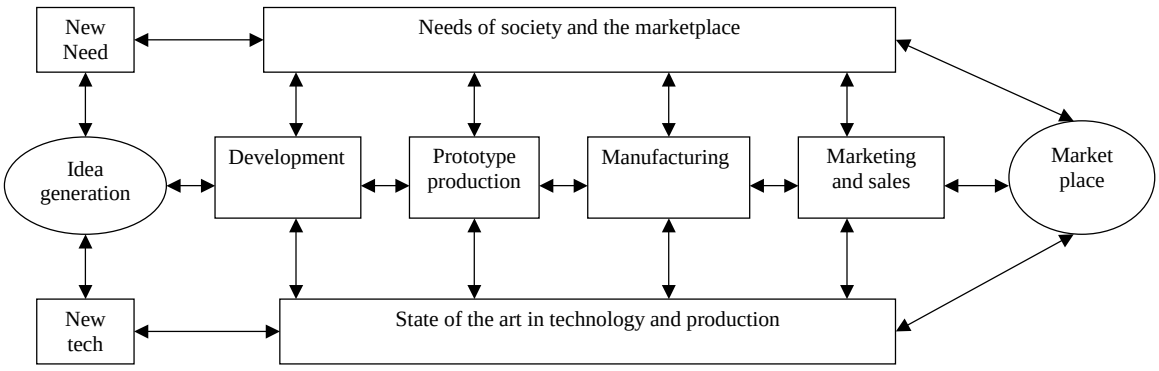
[3] Generally measured as years of education or training.

Various authors retested Schmookler's data and found a weaker relationship than he had claimed e.g. Scherer (1982a) and Mowery and Rosenberg (1979). It has also been demonstrated that technology push is likely to be strong, particularly in the early stages of radical innovations. For example Katz and Phillips (1982) showed that technology push dominated in the early days of the development of the computer, with several influential industrialists predicting that there would be no demand for the technology. More recent empirical work has tended to support the view that both factors are important although their relative significance varies across different stages of the industry cycle (Rothwell, 1992). This balanced view had been summarised earlier by Rosenberg (1974, p. 103):

> … the allocation of inventive resources has in the past been determined jointly by demand forces which have broadly shaped the shifting payoffs to successful invention, together with supply side forces which have determined both the probability of success within any particular time frame as well as the prospective cost of producing a successful invention.

Rothwell and Zegveld's interactive model (1985) usefully illustrates the balanced approach. In this model "the process of innovation represents the confluence of technological capabilities and market needs within the framework of the innovating firm", see Figure 3.1.

Figure 3.1 The Interactive Model of Innovation



Source Rothwell (1992, p. 222)

Although it is now widely accepted that different industries are faced with different technological opportunities there is no general agreement on how these opportunities should be measured. One approach is to treat technological opportunity as the elasticity of unit cost with respect to R&D spending (Dasgupta

& Stiglitz, 1980) but adequate data are rarely available to estimate technological opportunity in this way. Most other attempts are based on classification of industry into scientific or technological fields. While this can be effective in explaining variation in innovative activity such as patenting, this may be due to the effect of unspecified industry practices or demand effects rather than variation in technological opportunity (Cohen & Levin, 1989, p. 1084).

Hypothesis 2

Investment in innovation is determined jointly by technological opportunity and market demand.

3.5 Technological Certainty

R&D is an uncertain process at all stages from invention through to conversion of new knowledge and innovation into economic benefits. In general, the level of uncertainty is highest for more basic, long-term research and lower for more applied, short term research. Much of the early work on the effect of uncertainty on R&D and innovation was carried out by researchers within the field of industrial organisation (section 2.3.2). Although Nelson (1997) takes a rather different approach arguing that most empirical work on technological change has highlighted "the inability of the actors to foresee the path of development, even in broad outline, or the major surprises that occurred along the path". As an illustration of the uncertain returns to academic research, David (1995) reported on a study of over 2000 patents licensed by Stanford University's Office of Technology Licensing during the period 1970-1992; only 17% of patents produced any financial returns; 80% of revenue came from less than one per cent of patents; 46% of revenue came from one patent alone. However the risks of applied industrial R&D "are less formidable than corporate publicists and proponents of the hero theory of innovation would have us believe"[4] (Scherer,

[4] Scherer (1980, p. 416) quotes work by Mansfield and Brandenburg who analysed 70 projects carried out in the central R&D laboratory of a leading electrical equipment company and found that "in more than three-fourths of the cases, the ex ante probability of success had been estimated at 0.80 or higher"

1980, p. 416). This is explained by the fact that businesses do not usually begin new product or process development until the principal technical uncertainties have been removed through less expensive research conducted either in-house or elsewhere.

None of this alters the main conclusions that can be drawn from this area of the literature; namely that investment in risky activities such as R&D (and particularly basic research) is expected to be sub-optimal in the absence of market intervention.

Hypothesis 3
Increased technological certainty encourages innovative activity.

3.6 Market Structure and Firm Size

Much of the early innovation literature concentrates on the links between innovation, market structure and firm size[5]. Schumpeter (1942) brought this research area to prominence by stressing the importance of large oligopolistic firms in innovation. His positive view of monopolies diverged from orthodox theory and policy making, thus generating a controversy on innovation, size of firm and market structure that continued for decades[6].

Scherer (1980, p. 423-430) provides a useful description of the reasons why monopolists might be expected to innovate more. Most notably firms may invest in new products and processes because they expect this will allow them to achieve a monopoly and supra-normal profits. At the same time enterprises that have achieved monopoly power are more likely to be able to use resources in discretionary ways including investment in R&D. This leads to the suggestion that barriers to entry, higher profit levels, and economies of scale in R&D generally increase the level of R&D undertaken leading to persistence of innovation. On the

[5] While Schumpeter was an evolutionary economist (see 2.5), much of this work falls under the industrial organisation heading (see 2.3.2) e.g. Scherer (1980) above.

[6] See Freeman (1994, p. 467) for another review of this literature.

other hand these conditions may encourage firms to become complacent and disinterested in change.

Hypothesis 4

Barriers to entry, higher profit levels, and economies of scale in R&D generally increase the level of R&D undertaken leading to persistence of innovation.

Schumpeter seems to have been "primarily impressed by the qualitative differences between the innovative activities of small entrepreneurial enterprises and those of large modern corporations with R&D laboratories. Nonetheless the empirical literature interpreted Schumpeter's argument as a proposition that "there exists a continuous positive relationship between firm size and innovation" (Cohen & Levin, 1989, p. 1067). Levin et al (1987) document two common rationales for the hypothesis that R&D intensity and innovation rates are significantly influenced by industrial concentration:

> One common rationale for this hypothesis is that industry concentration enhances the potential for appropriation of R&D returns. A different view is that in the long run, concentration tends to be a consequence of industry evolution in a regime of abundant technological opportunity and a high degree of uncertainty associated with investment in R&D (Levin et al., 1987, p. 813).

The main reasons[7] that have been put forward to explain why larger firms may spend proportionately more on R&D are:

i. the costs of innovation are so great that they can only be borne by large corporations; large firms with a balanced portfolio can balance successes and failures;
ii. R&D projects are risky – small firms place themselves in a dangerous position when they invest all their resources in a single innovative project;
iii. there may be economies of scale in R&D e.g. a big laboratory can justify purchasing all sorts of specialised equipment;
iv. R&D projects may benefit from scale economies realised in other parts of the large firm's operations;

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[7] based largely on Scherer (1980, p. 413).

v. large producers have an advantage in making process innovations.

However an extensive empirical literature does not provide universal support for these ideas. Cohen and Klepper (1992; 1996) have written extensively on the relationship between firm size, R&D and technological progress. Summarising the literature they find that "among R&D performing firms, the number of patents and innovations per dollar of R&D decreases with firm size and/or the level of R&D, and among all firms, smaller firms account for a disproportionately large number of patents and innovations relative to size". They propose and test a simple model based on the idea of R&D cost spreading[8], to explain their findings about the R&D firm size relationship.

Scherer (1980, p. 414) summarises some possible disadvantages of size:

i. decisions to bear the risks of R&D are made by individual managers not impersonal organisations so the argument on risk spreading may not hold water;
ii. large firms are biased against really imaginative innovations;
iii. inability to get ideas approved by management drives away the most creative individuals; and
iv. research in large laboratories becomes over-organised.

There is further support for this view in the literature on the economics of biotechnology, where it is argued that small firms have advantages in the development of areas of new knowledge and are able to commercialise radical innovations more quickly than larger established organisations (McKelvey, 2001).

More recently Romer (1990) extended arguments first proposed by Schumpeter and in the industrial organisation literature by suggesting that the rate of new ideas production depends on 'the stock of ideas and effort.' This is a related idea since indicators of innovative effort are likely to be closely related to indicators of firm size. Innovative effort is most commonly measured as 'number of ideas workers'.

[8] In their model "size conditions the returns to R&D by spreading the costs of R&D over the output of a given product" (Cohen & Klepper, 1996).

It may well be the case that no single firm size is uniquely conducive to technological progress (Scherer, 1980, p. 418). In this case innovative output may be maximized by a diversity of sizes, each with its own special advantages and disadvantages. A particular focus of this paper is to investigate the effect of enterprise size since on innovative output in the New Zealand biotech sector hence we test the following hypothesis.

Hypothesis 5

Innovation *output* and innovation *rate* increase with enterprise size and the number of ideas workers.

3.7 Firm Type

Innovation depends on characteristics that are often associated with different firm or organisational types, for example industry sector, profit or not profit, research intensity etc. Research in this area has been carried out using a variety of different approaches. Scherer exemplifies the industrial organisation approach while Pavitt and McKelvey are from the evolutionary school (see 2.5).

Scherer (1982a) showed that classification of industries into a small number of technology groups explained a substantial fraction of variance in patenting activity. While his intention was to

> capture inter-industry differences in the vigour of advance of underlying scientific and technological knowledge, he recognised that statistical results obtained with the use of such crudely defined categorical variables might also reflect the influence of unspecified industry practices or demand effects not captured by the regressors (Cohen & Levin, 1989, p. 1084).

Pavitt's landmark (1984) paper describes the differences between firms in diverse industrial sectors. He found the "original neo-classical formulation [that] technology diffuses instantly across total capital"(Nelson, 1981), unhelpful and aimed to contribute to a body of knowledge that "encompasses the production of technology and reflects sectoral diversity" (p. 344). He found that technological knowledge was specific to firms and applications and varied amongst sectors in

source and direction. For example “innovating firms principally in electronics and chemicals, are relatively big, and they develop innovations over a wide range of specific product groups within their principal sector, but relatively few outside. Firms principally in mechanical and instrument engineering are relatively small and specialised”. Pavitt classified these characteristics and variations using a three part taxonomy of firms as supplier dominated, production intensive or science based. Similarly it may be argued that particular types of firms may be more innovative than others because “firms have different capabilities and perceptions that lead them to pursue different sets of approaches to innovation” (Cohen & Klepper, 1992, p. 2).

Another strand of the economics literature focuses on Dedicated Biotechnology Firms (DBFs) that can be viewed as a special type of science-based firm. DBFs are totally dedicated to biotech knowledge production with much interest being centred on the relative importance of DBFs and incumbents (for whom biotech activity may be a small percentage of total activity) and the linkages between them (McKelvey, 2001). On the other hand diversified firms may be better able to produce and market unanticipated inventions:

> research, and especially basic research is a venture into the world of uncertainty, yielding inventions and discoveries in unexpected areas. The company with interests in a diversity of fields generally will be able to produce and market a higher proportion of these unanticipated inventions than will an enterprise whose product line is narrow (Nelson, 1959).

Firms that conduct R&D are expected to have a higher innovative output than those that do not, although it is important to note that innovation can also result from other activities such as imitation, and technology adoption (Tether, 2001, p. 29).

The reason why there is so much interest in modern biotechnology is because of the idea that it may be a generic technology of the kind that has so deeply transformed industrial economies in the past; by implication firms that are involved in modern biotechnology are expected to have a higher innovative output than those using traditional processes. The empirical section of this thesis (chapter 6) addresses the importance of specialisation in biotech as well as whether firms

conduct R&D or not and whether they are involved in modern or traditional biotechnology.

Hypothesis 6

Innovation *output* and innovation *rate* vary with firm or organisational type.[9]

3.8 Appropriability

When new knowledge is transmitted easily from creators to competitors and particularly when it is embodied in new products or processes that can be copied at relatively low cost, appropriable rewards may be insufficient to justify innovative effort. This idea that the free market may not provide sufficient incentive for inventive activity has been around for hundreds of years and gave rise to the Statute of Monopolies passed by the English Parliament in 1623 (Cohen & Levin, 1989, p. 1091). Arrow (1962b, p. 619) provides a detailed examination of the issue concluding that:

> a free enterprise economy will under invest in invention and research (as compared with an ideal) because it is risky, because the product can be appropriated only to a limited extent, and because of increasing returns in use. This under investment will be greater for more basic research. Further, to the extent that a firm succeeds in engrossing the economic value of its inventive activity, there will be an under utilization of that information compared with an ideal allocation.

In theory patents provide a solution to the problem of imperfect appropriability. Society grants exclusive rights to inventors thus ensuring that society benefits from technological change by providing incentives to invest in R&D. However, even when patents protect the inventor from imitation, the patent holder's monopoly profit is less than the full social benefit (unless the patent holder can price discriminate). Thus although patents may encourage additional research, they may induce less than the optimal level (Carlton & Perloff, 2000, p. 511).

[9] Firm type refers to several different dimensions:- industry sector or technological field (e.g. modern or traditional biotechnology), involved in R&D or not, specialised versus more general, high or low absorptive capacity (Scherer, 1980, p. 432) etc.

In practice a strong body of evidence suggests that patents are perceived to be ineffective in most industries and are not the most common method by which firms appropriate R&D returns.

> In many industries, however, firms find other means of appropriation to be quite satisfactory. In some instances, imitation is costly despite the absence of strong patent protection. In others, investment in complementary assets such as marketing, sales efforts and customer service can facilitate appropriation when neither strong patent protection nor technical barriers to imitation are present (Cohen & Levin, 1989, p. 1091).

Hypothesis 7

R&D spending (and hence innovation)[10] increases as the degree of appropriability of R&D outputs increases (and more R&D spending leads to more innovation).

3.9 Spillovers, Clustering and Alliances

Technological change is driven in part by knowledge spillovers, where new knowledge produced by individuals, firms and research organisations becomes available for use by others. Knowledge spillovers are a form of externality in that the knowledge producer does not obtain any direct benefit for outward flows of knowledge that are not paid for. They provide theoretical support for many of the empirical findings on the benefits of clusters and alliances. The basic proposition that the quantity and quality of interaction between organisations is an important determinant of innovation finds support in several strands of the literature; most notably in the literatures on externalities, knowledge spillovers, clusters and Systems of Innovation (SI).

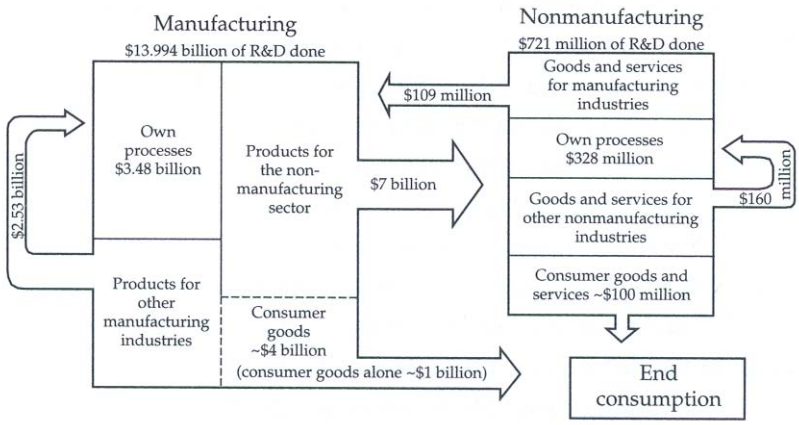
The idea that externalities can be a source of increasing returns and productivity growth has a long history dating back to Edgeworth[11] and before (Griliches, 1992, p. S34). More recently Griliches (1958) highlighted the issue of knowledge spillovers in his study of the social rate of return to research into hybrid corn;

[10] at the level of the enterprise or individual

[11] Francis Edgeworth (1845-1926) held the Chair of Political Economy at Oxford University from 1891-1926.

while Scherer (1982b) constructed a detailed matrix showing how new technology flowed through the U.S. economy from the firms carrying out R&D in 1974 to businesses, government agencies and consumers, see **Error! Reference source not found.**

Figure 3.2 Technology Flows in the U.S. Economy 1974



Source: Scherer (1982b)

A further resurgence of interest in spillovers was set off by Romer's (1990) model of endogenous technical change[12]. This led Scherer (1999, p. 35) to comment that inspired by Romer "economists began looking under every lamp-post for empirical evidence of knowledge spillover effects". Good evidence of substantial spillovers has been found, both between firms and between industries, leading to productivity gains and even to changes in the structure of production. There is also evidence that spillovers have an important effect on innovative activity itself. These effects vary according to R&D intensity in both firms and industries (Baptista, 1998, p. 37).

The literature on spillovers overlaps with the recent upsurge in research into clustering, although the idea that businesses can receive major benefits from being located in what are now called clusters is not at all new. The great British economist Alfred Marshall wrote in 1920 that:

> When an industry has chosen a locality for itself it is likely to stay there long: so great are the advantages which people following the same skilled

[12] driven in part by knowledge spillovers

> trade get from neighbourhood to one another … And presently subsidiary trade grows up in the neighbourhood (Marshall, 1920, p. 271-2).

Since then the arguments underpinning the location of production and innovation activities have been developed in several different streams of literature (urban and regional economics, geography, history, evolutionary economics and new growth theory); see Baptista (1998, p. 14).

Stern et al. (2000, p. 8) provide a useful summary of some of the main benefits of clusters. They note that innovation rate (in a cluster) is increased by the presence of related industries (and increases with the degree and strength of interconnection since the presence of related industries generates positive externalities both from knowledge spillovers and cluster-level scale economies, especially when clusters are concentrated geographically[13]. Andersen (1992, p. 90) summarising some of the findings of a research programme conducted using SI approaches concludes that "production and linkage patterns are important determinants of learning and innovation". Later he pointed out the need to identify the consequences of different sets of linkage pattern:

> What are the properties of the connecting flows… Does interaction change the way organizations search for new knowledge, does it lead them to abandon some lines in favour of others? Does it lead to measurable changes in R&D programmes? Does it lead to explicit forms of co-ordination in the generation of new knowledge (Andersen, Metcalfe, & Tether, 1999, p. 36).

Arora and Gambardella (1990) reporting on the results of an early empirical investigation into the use of external linkages by large biotech firms found that large firms "were no longer the sole focus of innovative activity. The locus of innovation should be thought of as a 'network' of inter-organizational relations". Since then biotechnology alliances have been the subject of intense investigation (Deeds & Hill, 1996; Mytelka, 1999; Orsenigo, Pammolli, & Riccaboni, 2001; Prevezer & Toker, 1996; van Geenhuizen, 1999).

[13] Stern describes three other determinants of innovation rates in a cluster; the number of trained scientists and engineers, and whether R&D personnel are specialised in disciplines congruent with emerging opportunities; the extent of local rivalry and openness to international competition; and the numbers of sophisticated, quality sensitive local customers. Henderson (1986) and Porter (1998) provide other lists of the benefits of clusters.

Andersen (1992, p. 85) suggests that "intranational relationships are normally better than international relationships as a means of transferring semi-formal and informal information" and that "the creation of new channels of the innovative type is easiest between members of a national production system", based partly on his investigations into Scandinavian socio-economic evolution. However international linkages are of particular significance for a small geographically isolated country such as New Zealand. For example, recent research on networks in biotechnology found that "while the importance of physical distance has been decreasing, the importance of communication links to the centre have been increasing … fewer and fewer inventors exist in isolation from research centres as connections drive more and more research activity" (Johnson & Mareva, 2002, p. 28). Furthermore, recent work has shown that international (not domestic) technology diffusion is the major source of technical change leading to productivity growth in OECD countries (Keller, 2001).

The extent of the literature on spillovers, clustering and alliances is reflected in the effort put into testing these effects. Analysis reported in chapter 6 tests the importance of interactions between organisations and specifically investigates the relative importance of international and domestic linkages, with a variety of indicators being used to try and describe quality of interaction.

Hypotheses 8 and 8a

Innovation *output* and innovation *rate* increase with the quantity and quality of interaction between organisations making up the innovation system.

International linkages have a stronger positive effect than domestic linkages.

3.10 Institutional Factors

The importance of institutional factors in explaining innovative output has been emphasised in several areas of the literature. In recent years economists working within the evolutionary and systems approaches have been particularly prominent in stressing the role of institutions; so for example Nelson (1997, pp. 50-52)

details the most important propositions which are present in the systems of innovation approach (but absent in the formal neo-classical models) as:

i. "technological advances today are significantly shaped by what has (and has not) been achieved earlier"
ii. "issues of firm organization and strategy are at least as important to technical advance as the quantity of their investment in research and development"
iii. "national institutions are important for supporting the technological and organizational capabilities of business firms."

Andersen (1992, pp. 78-91) produced a complementary synthesis of SI propositions on factors affecting national innovative performance:

> a) The specialisation pattern of a nation is relatively stable, but occasionally relatively rapid change takes place.
>
> d) Learning and innovation pattern effects of different specialisation patterns are important determinants of the overall competitiveness of nations.
>
> j) Differences with respect to the character and amount of national linkages between producers and lead users lead to differences in the overall competitiveness of nations

A variety of different institutional factors have been shown to have significant effects on innovative output; examples include:

i. science and technology institutions
ii. economic, financial and educational settings
iii. rules and regulations
iv. national specialisation pattern
v. firm organisation and strategy
vi. social and cultural factors
vii. distinct, institutionally rooted, historically created paths of growth

---

Hypothesis 9

Institutional factors are important determinants of innovative output.

3.11 Alternative Approaches to Investigating the Determinants of Innovation

The overall aim of this thesis is to investigate the determinants of innovation through empirical testing of an innovation framework constructed from nine key hypotheses (section 3.12). Within the discipline of economics the main alternatives for conducting such an investigation are:-

i. theoretical approaches
ii. qualitative and case study approaches
iii. modelling and simulation approaches; and
iv. econometric approaches

Theoretical approaches provide an essential foundation for empirical studies but cannot, by themselves allow us to answer empirical questions. Qualitative and case study approaches can be particularly useful in providing in-depth understanding of particular cases and complex systems. This approach was used in this thesis to develop an initial understanding of the New Zealand biotech sector and to investigate the effect of institutional factors. Modelling approaches are best suited to predicting the effect on such a system of change in the underlying variables. To be useful they must be well calibrated and based on a detailed empirical understanding of the relationship between key system variables.

Janszen and Deganaars (1998) provide an example of a recent attempt to model a national innovation system for biotechnology. They used interviews with experts from more than 80 organisations to provide the empirical basis for their model and tested various hypotheses using computer simulations. However they found it hard to obtain enough data to calibrate the system and so restricted their objective to obtaining qualitative insight into “the dynamic relations between structure and process in innovation systems”. The small size and diversity of the New Zealand biotech sector might be expected to lead to similar difficulties with system calibration and the production of reliable output. Modelling approaches have been productively used to address other biotech research questions in New Zealand – notably work by Saunders and Cagatay (2003) to assess the impact on producer returns of commercial release of genetically modified food products.

Ramanathan (2002) defines econometrics as being "concerned with i) estimating economic relationships, ii) confronting economic theory with facts and testing hypotheses involving economic behavior, and iii) forecasting the behaviour of economic variables". It is thus ideally suited to investigating the determinants of innovation in biotechnology by testing the hypotheses that comprise the innovation framework described in the following section (3.12).

The recent economic literature includes various alternative frameworks and models that attempt to explain the determinants of technological change and innovation. Many have substantial limitations in their application to empirical research. Mainstream neo-classical models tend to achieve simplicity at the expense of realism, while systems approaches tend to lose analytical tractability in their attempts to achieve realism. A framework will be presented in the next section (3.12) that expands the usefulness of conventional analytical techniques by using insights from both neo-classical and systems approaches.

Important recent examples of neo-classical models relating private R&D activity to economic growth and innovation, include Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992). In these models the developer of new ideas (the innovator) is usually assumed to have exclusive control over use of the idea and to license its use to the producers of final goods. The innovator can charge others for the use of the idea depending on the usefulness of the idea in production. The amount of effort put into R&D is modelled as resulting from the profit received by using the new idea in production[14].

Romer (1990, p. S89) solves his model to specify the relationship between output (Y), physical labour (L), human capital devoted to final output (H_Y), total capital (K) and the stock of designs (A) as:

$$Y(H_A, L, x) = (H_Y A)^{\alpha} (LA)^{\beta} (K)^{1-\alpha-\beta_\eta \alpha+\beta-1}$$

[14] This description draws on Romer (1996, p. 113).

He specifies that the aggregate stock of designs evolves according to $\dot{A} = \delta \mathrm{H}_A A$ in other words output of new designs (or innovative output) depends on total human capital engaged in research (H_A) and the aggregate stock of designs.

Romer's formulation is simple and elegant but leaves out several factors that are known to affect innovative output. Lack of a single satisfactory model, may have led some authors to concentrate on hypothesis testing, without reference to an overall model e.g. Hansen (1992) and Zucker and Derby (1994). Others such as Arvanitis and Hollenstein, and Crépon et al. have developed alternative models and frameworks.

Arvanitis and Hollenstein (1994, p. 18) specify a causal relationship between innovation output x and several explanatory factors.

$$x = f(s, e, 1/n, 1-\lambda, b, a, r, v)$$

where

s	=	shift parameter of the firms demand schedule (representing income effects and demand influences);
e	=	price elasticity of a firm's demand;
1/n	=	inverse number of firms in the market (market concentration);
$1-\lambda$	=	degree of appropriability of a firm's own knowledge;
b	=	shift parameter of the knowledge production function (cost and quality shifts);
a	=	elasticity of costs (demand) with respect to innovation output;
r	=	elasticity of knowledge production function with respect to extramural knowledge inputs; and
v	=	unit costs of innovation

They used data from a survey of innovative activity in Swiss Manufacturing conducted in 1990 with most of the above explanatory variables reflecting assessments by the surveyed firms based on a five point scale. The main the variables specified by Arvanitis and Hollenstein are also included in the framework adopted in this thesis (see section **Error! Reference source not found.** below). An example of a more recent attempt to investigate the determinants of innovative output is provided by Mairesse and Mohnen (2002). They base their analysis on a model first described in Crépon, Duguet and Mairesse (1998). The model consists of "four equations, two for research, one for innovation and one for productivity" (p.118). It includes three relationships: "the research equation - linking research to its determinants, the innovation equation -

relating research to innovation output measures, and the productivity equation - relating output to productivity" (p. 116). The explanatory variables in their research equation include: size, market share, diversification, demand conditions and technological opportunities[15].

When innovation output (IO) is proxied by number of patents they specify that the expected output of patents n_i^* is given by:

$$n_i^* = E\left(n_i \middle| k_i^*, x_{2i}, u_{2i}; \alpha_k, b_2\right) = \exp\left(\alpha_k k_i^* + x_{2i} b_2 + u_{2i}\right)$$

where k_i^* is their latent research variable (specifying research intensity), x_{2i} is a vector of other explanatory variables (supposedly exogenous) and u_{2i} is the error term.

3.12 A Framework Describing the Determinants of Innovation

The innovation framework developed in this thesis draws on the models of the determinants of innovative output described above. It is also based on a synthesis of hypotheses drawn from four strands of the innovation literature: mainstream neo-classical and industrial organisation (Scherer, 1980), endogenous growth theory (Romer, 1990), theories of innovation at the level of the network, cluster or technological system e.g. (Carlsson & Stankiewicz, 1991; Freeman, 1991; Porter, 1990), and the literature on national systems of innovation (Freeman, 1987; Lundvall, 1992b; Nelson, 1993b). The approach taken in developing this framework may be regarded as somewhat eclectic, but Paul Samuelson, in a recent speech to the International Schumpeter Society[16], showed that eclecticism has at least one famous supporter. Samuelson said that he has been "as eclectic as the parent empirical data require", ever since a conversation with his first economics professor. Other supporters of an eclectic approach include Furman,

[15] They state that the explanatory variables that they are able to measure "are most of the ones usually considered in the literature on R&D determinants (in the 'Schumpeterian tradition') (Crépon et al., 1998, p. 120).

[16] Samuelson (2002) 9th Conference of the International Schumpeter Society, Gainesville, Florida, USA.

Porter and Stern (2002); their paper on the determinants of national innovative capacity uses a framework that

> draws on three distinct areas of prior research: ideas-driven endogenous growth theory (Romer, 1990), the cluster-based theory of national industrial competitive advantage (Porter, 1990) and research on national innovation systems (Nelson, 1993b).

The innovation framework used in this thesis regards innovation as a deliberate activity that is usually undertaken to solve economic problems or capitalize on economic opportunities. Innovation results from research and development and various other kinds of learning activity that are usually undertaken in the expectation of gaining economic benefits. The level of innovation can be directly related to the amount of effort put into R&D, the existing stock of ideas (Romer, 1990), firm level factors and to supply side forces that determine the probability of success e.g. technological opportunity and the cost of producing a successful invention (Rosenberg, 1974, p. 103). Innovative output is also affected by market structure (e.g. numbers of buyers and sellers, barriers to entry) and the extent to which firms can appropriate the economic benefits of their innovations. R&D spending has spillover effects both between enterprises and internationally. This increases the rate of technological change but means that the level of private R&D spending is generally sub-optimal.

There has been a particular focus in recent years on the role of various kinds of linkage between the different players in clusters or systems of innovation. The quality and quantity of these links are an important determinant of innovative output. The Evolutionary approach includes important propositions which are largely absent in neo-classical models. These propositions are included under a global heading of ‘institutional factors’ in a diagrammatic representation of the main features of the framework presented as Figure 3.3.

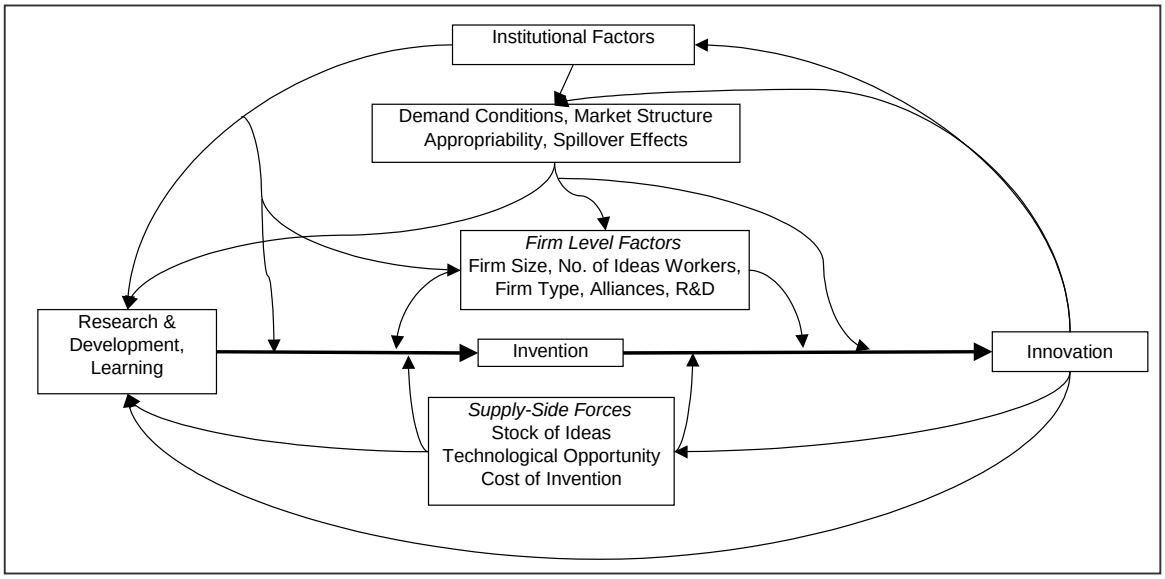
A series of *key innovation hypotheses* emerging from the different strands of the literature were identified in sections 3.3 to 3.10 of this chapter. These hypotheses are included in the framework based on theoretical and empirical criteria. Hypotheses are included:

i. if they are well supported in the theoretical literature e.g. hypothesis 1 on the stock of ideas; and/or

ii. if they have significant empirical support, or have been the subject of extensive empirical investigation e.g. hypothesis 5 on firm size; and/or

iii. if they appear in multiple strands of the literature e.g. hypothesis 8 on spillovers.

Figure 3.3 A Framework Describing the Determinants of Innovation



Source: (Marsh & Oxley, 2002)

The key hypotheses are summarised in Table 3.1. This Table also indicates the literature strand from which each hypothesis originates, together with an indication (number of asterisks) of the relative importance of each origin. In chapter 6 variables are defined corresponding to each hypothesis. Results are then reported for the hypothesis that innovative output (Y) depends on a vector of variables (X)[17].

[17] These variables are defined in more detail in Tables 6.2 and 6.3.

$$Y = f(i, d, o, m, s, t, a, all, ins)$$

where i = stock of ideas
d = market demand for new product/process
o = technological opportunity
m = market structure
s = firm size
t = firm type/characteristics
a = appropriability of new product/process
all = quantity and quality of interaction between organisations making up the innovation system
ins = institutional factors

Table 3.1 Key Innovation Hypotheses

Subject		**Hypothesis (Explanatory Variable)**	Origin IO	CL	EN	SI
Stock of ideas	1	Rate of new ideas production increases with the stock of ideas		*	**	*
Demand pull vs. Technology push	2	Investment in innovation is determined jointly by technological opportunity and market demand	**	*		*
Technological certainty	3	Increased technological certainty encourages innovative activity	**			
Market structure	4	Barriers to entry, higher profit levels, and economies of scale in R&D generally increase the level of R&D undertaken leading to persistence of innovation	**	*	*	
Firm size	5	Innovation output and innovation rate increase with enterprise size and the number of ideas workers	**		*	*
Firm type	6	Innovation output and innovation rate vary with firm or organisational type	*			*
Appropriability	7	R&D spending (and hence innovation) increases as the degree of appropriability of R&D outputs increases	**			*
Spillovers, clustering and alliances	8	Innovation increases with the quantity and quality of the interaction between the organisations making up the innovation system[18]		**	*	**
	8a	International linkages have a stronger positive effect than domestic linkages		**		**
Institutions	9	Institutional factors are important determinants of innovative output		*		**

IO Industrial Organisation and mainstream neo-classical, CL Clustering, EN: Endogenous Growth Theory, SI Systems of Innovation and Evolutionary Approaches. Number of asterisks (*) used to indicate relative importance of origin.

[18] Coombs (2000, p. 6) attributes this partly to the fact that increasing benefits can be derived from combining diverse technologies (e.g. biotechnology and robotics).

Chapter 4 Biotechnology in New Zealand

4.1 Introduction

This chapter provides a description of the New Zealand biotechnology sector based on analysis carried out by Marsh (2001b; Marsh, 2002) and a review of secondary sources. This description is intended to set the scene and provide context for the study of the determinants of innovation described in Chapters 5 and 6.

Despite the small size of its economy and of its science base New Zealand has had a significant role in the development of modern biotechnology. Indeed a New Zealand born biophysicist, Dr Maurice Wilkins assisted at the birth of modern biotechnology through the first description of the structure of DNA. Wilkins was later jointly awarded the Nobel Prize for this work together with Crick and Watson.

Much of New Zealand's work builds on national strengths in agricultural and primary industry production and research. But there are also a number of new enterprises at the forefront of research in health and in intellectual property. Recent examples cited by the industry organisation BIOTENZ (1998) include: breeding of transgenic crops; clonal afforestation; genetic manipulation of flower colour; the world's first enteric bacteria-based bio insecticide; a project to map the sheep genome; the world's first sheep genetically engineered for increased wool production; and the world's first recombinant livestock vaccine to combat sheep measles. More recently the report of the biotechnology taskforce noted that:

> New Zealand has significant strengths in large animal biology (in particular being world leading in overall knowledge of the sheep and dairy cow), as well as having world-class research teams in a number of areas of biomedical science and bioengineering. More recently New Zealand has also emerged as world leading in some areas of enabling technology, which is technology that allows both novel and intensive data collection (Biotechnology Taskforce, 2003, p. 23).

Most modern biotechnology activities in New Zealand are concentrated in universities and Crown Research Institutes (CRI) and a small number of private sector companies e.g. Genesis, Virionyx, ViaLactia. The government has been

estimated to spend around NZ$127m per year on biotechnology-related research (Ogilvie, 2003), ranging from genomics to processing of natural products including about NZ$18 million on research involving genetic modification (Wright, 2000, p.7). Biotechnology-related research comprises around 19% of total government R&D spending ($677 million in 2002/2003[1]), making New Zealand one of three OECD countries with a share above 10% (OECD, 2003a). Genesis has invested over NZ$80 million in research since its inception in 1994 while CRIs and companies such as Auckland UniServices have also been successful in generating research revenue from outside the government sector. Nonetheless it must be recognised that New Zealand's total expenditure on biotechnology research is very small by global standards.

Few innovations or processes in *modern* biotechnology have reached the stage of being commercialised. Genesis Research and Development is perhaps one of the closest to achieving income from a new biotechnology product; it initiated additional US phase II clinical trials of its PVAC Psoriasis treatment in June 2002; one of over 300 biotech products now in phase II or phase III trials[2] (Ernst & Young, 1999b, p. 35).

Over the last few years there has been an explosion of interest in biotechnology in New Zealand. Politicians and policy makers have become increasingly interested in the role that biotech might play in the 'new economy'; and aware of the policy initiatives in support of biotech which have been implemented by many of our competitors. The biotech industry has begun to achieve critical mass and has been increasingly effective in lobbying for policy changes that would make New Zealand more supportive of biotech R&D and innovation. At the same time,

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[1] See Ministry of Research Science and Technology. (2002). *Briefing to the Incoming Minister of Research, Science and Technology*.

[2] Clinical trials in the United States are conducted in phases. In Phase II trials, the study drug or treatment is given to a group of 100-300 people to see if it is effective and to further evaluate its safety. In Phase III trials, the study drug or treatment is given to large groups of people (1,000-3,000) to confirm its effectiveness, monitor side effects, compare it to commonly used treatments, and collect information that will allow the drug or treatment to be used safely. Source http://clinicaltrials.gov/ct/

increasing levels of popular concern over the safety of some modern biotechnologies culminated in the setting up of the Royal Commission on Genetic Modification that spent over $6 million and 14 months listening to all sides of the debate. In October 2001 the government announced its response to the Royal Commission report, including permission for field trials to restart and a two-year ban on commercial release of genetically modified products[3].

In early 2002 the Government released its Growth and Innovation Framework (GIF), which aims to return New Zealand to the top half of the OECD in terms of GDP per capita. The GIF identified three potential growth areas that were worthy of special attention and government effort. These were information and communications technology, creative industries and biotechnology. Task forces were established in all three areas to agree priorities and develop action plans to stimulate growth and develop international competitiveness. The Biotechnology Task Force report was published in May 2003 and focuses on "three essential areas":

a) the need to build critical mass;

b) the introduction of a package of regulatory reform to create a competitive environment for growth; and

c) the establishment of a robust international network through which to stimulate the flow of international investment" (Biotechnology Taskforce, 2003, p. 3).

In the same month, the government published the New Zealand Biotechnology Strategy. The strategy aims to promote growth in biotechnology and draws on the work of the biotechnology taskforce. The strategy document includes the vision statement that:

> New Zealand responsibly develops and applies our world-class biological knowledge, skills, innovation and technologies to benefit the wealth, health and environment of New Zealanders, now and in the future (Ministry of Research Science and Technology, 2003a, p. 3).

It goes on to define three goals that support the Government vision for biotechnology:

[3] This was lifted, amidst much vocal opposition and lobbying, in October 2003.

1. Build understanding about biotechnology and constructive engagement between people in the community and the biotechnology sector.

2. Grow New Zealand's biotechnology sector to enhance economic and community benefits.

3. Manage the development and introduction of new biotechnologies with a regulatory system that provides robust safeguards and allows innovation.

4.2 Data Sources and Sector Size

Research into the potential impact of modern biotechnology on New Zealand dates back to a 1983 discussion paper published by the Department of Scientific and Industrial Research (DSIR). The authors aimed to assess the significance for New Zealand industry of new developments in biotechnology and also made suggestions "on aspects of research and development which require emphasis if the perceived industrial opportunities are to be realised" (Hunt et al., 1983). This was followed in 1988 by a Department of Trade and Industry (DTI) study that aimed "to identify the impediments affecting the growth and development of biotechnology in New Zealand and to recommend any action the Government and/or department could take to overcome these impediments" (this has many parallels with the task assigned to the Biotechnology Task Force in 2003). DSIR and DTI did not attempt to quantify biotech activity in New Zealand but did identify 40-50 separate organisations working in the biotech sector.

Kennedy and Davis (1994) assessed the impact of biotechnology on New Zealand industry over the period 1984-94 identifying around 50[4] separate organisations that were making direct use of biotechnology. They did not attempt an "all inclusive review of New Zealand Biotechnology because of the difficulties with the definition of the term biotechnology, and the difficulty in obtaining commercial and confidential information" (Kennedy & Davies, 1994, p. 2).

4.2.1 Estimates by Tradenz

An early attempt to put a monetary value on New Zealand biotech activity was conducted by Tradenz, based on a series of interviews with representatives from

[4] The precise number varies depending on definition of a separate organisation, and approach taken to subsequent mergers and other organisational changes.

"companies, universities, research and development organisations and professional advisors" (Tradenz, 1994, p. 44). The authors classified the biotech industry into three groups using a broad definition of biotechnology and made estimates of turnover and foreign exchange revenue in each group, see Table 4.1.

Table 4.1 Tradenz Estimates of Biotech Turnover and Foreign Exchange Earnings in 1994

Group	Description	Members	Turnover $ million	Forex $ million
1	Companies and organisations of a research and development nature which are primarily concerned with the creation of intellectual property in the medical and veterinary field, and to a limited extent its commercialisation	Universities, Crown research institutes Technology development companies	100	10
2	Companies processing and marketing biologically active products - mainly meat, dairy and marine	Processing and marketing Companies (includes nutraceuticals)	150	120
3	Companies manufacturing and marketing generic pharmaceuticals	Pharmaceutical Companies	80	7
All Groups			330	137

Source: Tradenz (1994, p. 44)

Tradenz concluded that total turnover was around NZ$330 million with foreign exchange receipts of around NZ$137 million (around 0.7% of total merchandise exports). Industry estimates of growth rates for different categories of firm ranged from 16 to 25% per annum. These figures exclude traditional areas such as dairy and other food production e.g. New Zealand Dairy Exports of NZ$4.6 billion in 1998/9. By including biotechnology in traditional food applications (Cheese, yoghurt, beer) and natural health products including deer velvet, BIOTENZ (1998) predicted that the industry could have a turnover of NZ$7-11 billion in 2010.

4.2.2 The 1998/99 Biotechnology Survey

The most comprehensive attempt to quantify biotech activity in New Zealand was commissioned by the Ministry of Research Science and Technology (MORST) in 1999. The main purpose was to "produce statistics concerning the present position of this industry in New Zealand" in order to "take stock of the current situation for planning purposes"(Statistics New Zealand, 2000b, p. 1). The survey was intended to focus only on modern biotechnology since it was thought that "the contribution to future economic development resulting from modern biotechnology is likely to be much greater than the potential contribution by its traditional counterpart". The objectives[5] of the survey were:

i. To understand the present status, the structure and the future progression of the biotechnology industry in New Zealand
ii. To assess the present status of strategic alliances, the links with the public / private research system and the potential for cluster development for the biotechnology industry
iii. To provide a baseline on the utilisation of resources including the knowledge in the biotechnology industry against which progress could be compared at a future date
iv. To identify the enabling factors and constraints facing the biotechnology industry in New Zealand

The 1998/99 survey of modern biotechnology activity in New Zealand was conducted by Statistics New Zealand in 2000 with the results being published in April 2001[6]. Questionnaires[7] were sent out to 426 enterprises that had been identified as possible users of modern biotechnology processes. The survey achieved a 98% response rate with 180 enterprises being identified as users of at least one biotechnology process. The high response rate and wide ranging processes used to identify possible users of modern biotechnology suggest that the

[5] Source: Ministry of Research, Science and Technology (2000) *Draft Objectives for the Biotechnology Survey*.

[6] Statistics New Zealand. (2001). *Modern Biotechnology Activity in New Zealand.* Wellington.

[7] The questionnaire for this survey is included as Appendix 5.

survey is likely to have captured almost all significant users of *modern* biotech in New Zealand over the survey period (1998/99).

The survey also included enterprises that use *traditional* biotech processes (TBU). Estimates on the size of the traditional biotech 'sector' cannot be regarded as being complete since a significant numbers of other users of such processes were not included in the survey, or reported that they did not use modern biotech and so did not fill in the questionnaire. For example 33 'local authority' enterprises reported use of biotech processes – primarily for treatment of sewage and wastewater but around 20 reported no involvement.

Marsh (2001b) extensively re-analysed the SNZ dataset[8]. He reported that around 80 biotech respondents conducted R&D; 57 of these conducted R&D into modern processes. Marsh also applied the Statistics Canada definition of a biotech enterprise to the SNZ data set ((Marsh, 2001b, p. 26). Based on this definition, the New Zealand biotech sector consisted in 1998/99 of 39 biotech enterprises with income from biotech of $205 million.

4.2.3 The 2002 Biotechnology Survey

In 2002 Marsh (2002) designed and implemented a survey of all enterprises in New Zealand that used modern biotech processes and/or all enterprises that conducted R&D using biotech processes (modern or traditional), see Appendix 3. Data from this survey are used in this chapter to describe biotechnology in New Zealand and are used to test a series of key hypotheses about the determinants of innovation (see chapter 6).

[8] This included preparation of additional tables and cross tabulations; presentation and analysis of the data in alternative formats; and breakdowns based on four new respondent categories (see Figure 4.1 on page 99). Some of his results presented here may appear to conflict with those published by Statistics New Zealand. This is mainly explained by different treatment of multiple responses from single enterprises.

The 2002 survey was conducted by the author, in order to address research questions not covered in the 1998/99 biotech survey. The questionnaire was designed and drafted based on an iterative process involving consideration of:

i. the data that should ideally be used to test the hypotheses;
ii. the data or indicators that have been used in previous studies;
iii. the outcome of those studies; and
iv. the data or indicators that New Zealand respondents were likely to be willing and able to provide.

International experience in the practice of surveys of innovation and biotechnology was reviewed; particularly Community Innovation Surveys conducted in the EU e.g. (Muzart, 1998) etc, OECD innovation surveys (OECD, 2002a), OECD studies of biotechnology e.g. (van Beuzekom, 2001) and Statistics Canada biotechnology surveys e.g. (McNiven, 2001a; Pattinson, Van Beuzekom, & Wyckoff, 2001). An extended email discussion was also held with staff at Statistics Canada; the first national statistical organisation to implement a comprehensive biotechnology survey.

Survey design took account of New Zealand experience with studies of innovation and biotechnology; most notably lessons learned in the conduct and analysis of the 1998/99 survey of modern biotechnology; see (Marsh, 2001c), R&D expenditure surveys e.g. (Ministry of Research Science and Technology, 2002) and business practices surveys; see (Statistics New Zealand, 2002). Survey design was also discussed with government (MoRST and SNZ) and representatives of the biotechnology industry. A detailed research proposal was written up and circulated for comment. Ethical approval was secured from the Waikato Management School ethics committee.

The study population was defined as 'all enterprises using modern[9] biotech processes and/or all enterprises conducting R&D using biotech processes (modern or traditional)'. Inclusion of enterprises that conduct R&D using modern *and* traditional processes allowed investigation into the differences between these

[9] List based definition see Appendix 2.

organisations. Enterprises that use traditional processes only and do *not* carry out R&D were excluded for both practical and theoretical reasons. In practice, they are not well suited to a study of innovation as they tend to exhibit low innovation rates and an unwillingness to participate in voluntary innovation surveys. From a theoretical perspective these enterprises are of less interest since the hypotheses tested focus on factors affecting innovative output and innovation rate – rather than why enterprises are, or are not innovative. It should also be noted that these enterprises would not normally[10] be regarded as being part of the biotech 'sector'.

Enterprises contacted were identified from a database of all biotech enterprises in New Zealand built up over three-year period 1999-2002. Entries in the data base are based on data from a variety of sources including:

i. the NZBA web directory;
ii. firms and organisations attending NZBA conferences;
iii. the BIOTENZ website;
iv. A'Courts and other commercial directories;
v. internet searches;
vi. print media articles (internet searches based on key words such as biotech, gene etc);
vii. the website of the Royal Commission on Genetic Modification;
viii. the FRST website; and
ix. published sources e.g. Kennedy & Davies (1994) and Packer, Robertson, & Wansbrough (1998).

A total of 146 questionnaires were sent out in April 2002. Responses were received from 93 enterprises indicating a 'crude' response rate of 64%. The sample frame was adjusted to 138 enterprise units by subtracting enterprises that reported that they were not involved in biotech. Sixty one usable responses were received indicating a 'usable' response rate of 44%. Further details of the 2002 survey are included in Appendix 3.

[10] In the economic literature and in international statistics.

4.2.4 Overview of Sector Size Estimates

Recent attempts to quantify New Zealand biotech activity are summarised in Table 4.2. It may be seen that different interpretations of the terms biotechnology and biotechnology sector continue to hinder attempts to measure biotech activity in a way that is comparable over time and across nations.

Ernst and Young publish annual reports on the state of the biotech industry in various countries (Ernst & Young, 1999a, 1999b); in their survey of the Australian industry they identified 120 core biotechnology companies. They excluded not-for-profit enterprises and traditional biotechnology operations and defined 'core biotechnology' companies as "those whose business is entirely or substantially biotechnology related and that have a significant commitment to technological innovation". Based on this definition there were around 30 core biotech enterprises in New Zealand in 1998/99[11].

Estimates of the size of the New Zealand biotech sector range from 30 core biotech companies with annual income of the order of $200 million, to the Biotechnology Taskforce (350 organisations in the 'biotech community') to BIOTENZ income estimates of several billion dollars (including traditional food applications such as cheese, yoghurt and beer).

These alternative estimates serve different purposes and are not mutually exclusive. Authors aiming to take a comprehensive approach that promotes all New Zealand organisations that use biotech tend to include both traditional and modern applications. On the other hand international statistics and the economic literature since the mid 1980s has generally concentrated on modern biotechnology and the biotech sector is often taken internationally to refer to the population of 'core' private sector enterprises that conduct R&D into *modern* biotechnology.

[11] own calculations

Table 4.2 Size of the New Zealand Biotech Sector

Source	Year	No. of Enter-prises	No. of Empl-oyees	Biotech Income $ million	Remarks
BIOTENZ Capability Survey (Cooper, 2003)	2003	258 42 *core*	4000		Comprehensive survey of the biotech community including core biotech firms, natural products and suppliers.
Biotechnology Taskforce (2003)	2003	350 40 *core*	3900		350 organisations in the "biotech community" includes natural product manufacturers, importers, lawyers, consultants, equipment suppliers, government agencies etc
Hopper and Thorburn (2003)	2002	60 *core* 70-80 *other*	1200		60 "dedicated, core biotech firms …70-80 involved in biotech in a more minor way"
Statistics New Zealand (2001)	1998 /99	180	2727[12]	475	Includes most enterprises that use modern biotech and some that use traditional biotech processes
Marsh (2001b)	1998 /99	57	1667[13]	236	Includes only enterprises that use modern processes and conduct R&D
Marsh (2001b)	1998 /99	39	1708[14]	205	Based on Statistics Canada definition of a biotech enterprise[15]
Marsh (2001b)	1998 /99	27			No. of Dedicated Biotech Enterprises (DBF)[16]
Kennedy (1994)	1993	50[17]			Broad definition of biotech
Tradenz (1994)	1994			330 *turnover*	Broad definition of biotech

Source: various sources collated by the author

Marsh (2001b) divided users of biotech processes into four categories (see Figure 4.1) based on whether they used modern or traditional processes and whether they were creators (engaged in R&D) or simply users of biotechnology processes. The

[12] Head count of employees associated with biotechnology

[13] Full-time equivalents (year to 30 June '99)

[14] Head count

[15] conduct R&D, have a minimum of five biotech employees and biotech expenditure of at least NZ$150,000

[16] DBFs defined as enterprises that received 100% of their income from biotech. A further nine received 75-100% of their income from biotech.

[17] The precise number varies depending on definition of a separate organisation, and approach taken to subsequent mergers and other organisational changes.

term Modern Biotech Enterprise (MBE) is used to describe respondents that are engaged in R&D into at least one modern biotech process.

Figure 4.1 Classification of Biotech Respondents

	Modern ! ! ! ! ! Traditional	
Creators ↓ ↓	Modern Biotech Enterprises (MBEs)	Traditional Biotech Enterprises (TBEs)
↓ ↓ **Users**	Modern Biotech Users (MBUs)	Traditional Biotech Users (TBUs)

Source: Marsh (2003)

Based on this definition, New Zealand's modern biotech 'sector' consisted in 1998/99 of approximately 57 enterprises (15 primary product and manufacturing firms, 24 research organisations and 6 universities) employing around 1700 people. Enterprises were split fairly evenly between the private sector (30) and the public sector (27). They reported expenditure on biotech of NZ$202 million and income from biotech of NZ$236 million. This compares to enterprise income from all sources of NZ$2.1 billion, i.e. biotech provided around 11% of income for the 57 enterprises. Twelve enterprises reported that they received all of their income from biotech and so might be referred to as dedicated biotech firms. A selection of key indicators of biotech activity based on analysis in Marsh (2001b) is provided as Table 4.3.

Table 4.3 Key Indicators of Biotech Activity in New Zealand 1998/99

	Modern Biotech Enterprises	Traditional Biotech Enterprises	Modern Biotech Users	Traditional Biotech Users	All Biotech Respondents
No. of Respondents and Processes					
No. of Respondents	57	24	36	63	**180**
No. in Private Sector	30	21	21	30	**102**
Biotech Processes per enterprise	19	3	8	4	**9**
No. Involved in DNA Based Processes	42	0	9	0	**51**
Innovation Indicators					
No. New Products last 3 yrs	114	18	27	18	**180**
No. New Processes last 3 yrs	105	21	45	9	**177**
New Products & Processes per Enterprise	3.8	1.8	2.0	0.4	**2.0**
No. Processes New to the World last 3 yrs	30	6	3	0	**39**
No. New Products Planned Next 3 years	207	24	42	21	**298**
No. New Processes Planned Next 3 years	219	12	24	30	**288**
New Products & Processes per Enterprise	7.5	1.5	1.8	0.8	**3.3**
No. of Patents Applications Last 5 Yrs	147	6	3	0	**156**
Patents Applications per Enterprise	2.6	0.3	0.1	0	**0.9**
Biotech Income and Exports					
Total Income ($ million)	2,124	1,008	1,647	2,475	**7,254**
Biotech Income ($ million)	236	68	112	59	**475**
Biotech as % of Total Income	11%	7%	7%	2%	**7%**
Biotech Income per Enterprise ($ million)	4.1	2.8	3.1	0.9	**2.6**
Biotech Exports ($ million)	60	*c*[1]	40	*c*	**170**
Biotech Employment					
Full-time Equivalents (yr to 30 June '99)	1,667	218	944	155	**2,984**
PhDs	667	*c*	*c*	*c*	**703**
Graduates	1,512				**1,824**
Graduates per Enterprise	27				**10**
Biotech Alliances					
% Reporting Biotech Alliances	90%	50%	42%	24%	**53%**
% Reporting Alliance with CRI	68%	25%	17%	14%	**32%**
% Reporting Alliance with Business	47%	13%	17%	10%	**22%**

Source: Marsh (2001b).

Note: *c* indicates cell 'confidentialised' to give effect to the confidentiality provisions of the Statistics Act 1975.

A further 36 enterprises *used* modern biotech processes (but were not engaged in R&D) and employed around 950 people in 'biotech based activities', which provided income of NZ$112 million. Twenty four enterprises, employing around 220 people conducted R&D using *traditional* biotech processes but were not involved in *modern* biotechnology.

4.2.5 International Comparisons

The OECD has taken the lead in attempting to develop internationally comparable statistics on biotechnology. It held the first ad hoc meeting on Biotechnology Statistics in March 2000 and decided to address the lack of biotechnology statistics in OECD member and observer countries by preparing a compendium of biotechnology statistics (van Beuzekom, 2001). The compendium provides an invaluable source of information on biotech in the OECD, although the variety of definitions and data collection methods make the production of reliable comparisons pretty well impossible. Selected data from Van Beuzekom and a recent update by Devlin (2003) are summarised in Table 4.4.

Table 4.4 Biotechnology in Numbers

	Data Year	Total Number of Companies Involved in Biotech	Number of 'Core'[1] Biotech Companies	Total Number of Biotech Employees	'Core' Biotech Companies per million inhabitants, 2000[7]
Australia	'99		120	3801	
Belgium	'97	52		4471	5.3
Canada	'99		358	7695	12.2
Denmark	'98		74	34116	9.6
Europe	'99		1351	53511	
Finland	'99		110	8200	10.4
France	'99		380	11000[2]	5.8
Germany	'99	709	279	228845[3]	5.9
Ireland	'99	140	50		11.2
Israel	'99		135	3800	
Italy	'99		45		1.1
Japan	'99	1000	394	29358[4]	
Netherlands	'99	300	55		5.0
Norway	'00		44	10154	8.3
New Zealand[5]	'00	250-350	40	2727	10.4
Spain	'99	200	22	90000	0.8
Sweden	'99		144	2998	26.0
Switzerland	'99	233	117	7000	12.6
UK	'99		275	13780[6]	7.6
USA	'99		1273	162000	

Source: van Beuzekom (2001, p. 42) and Devlin (2003, p. 11)
Notes: 1. 'Core' biotech firms have their main activities in biotechnology although they can be active in other fields. 2. Only covers 255 companies. 3. Covers all 709 companies. 4. Only covers 210 companies. 5. Data inserted based on Table 4.2.
6. Based on 221 companies and 1997 data. 7. Data from Devlin (2003, p. 11)

The 2001 edition of OECD's STI Scoreboard (2001) included data on public funding of biotechnology R&D and patents, for the first time, see Table 4.5. Data for New Zealand have been inserted based on Rolleston (1999, p. 46) who reported that the government spent an estimated NZ$100m a year[18] on biotechnology-related research ranging from genomics to processing of natural products and Wright, (2000, p. 7) who reported that around NZ$18 million is spent on research involving genetic modification (Wright, 2000, p.7).

Table 4.5 Government Funded Biotechnology R&D 1997& 2000

	1997 Biotechnology R&D, 1997 $ million PPP	1997 GBAORD[1] $ million PPP	1997 Biotech R&D as % of GBAORD	2000[2] Biotech R&D as % of GBAORD
Australia ('98)	196.3	2533	7.8	8.0
Austria	16.8	1147	1.5	
Belgium	181.7	1314	13.8	
Canada	261.4	2581	10.1	10.6
Czech Republic ('99)	7.8	749	1.0	
Denmark	45.2	946	4.8	10.4
Finland	94.5	1165	8.1	9.0
France	560.0	12683	4.4	
Germany	1048.2	15596	6.7	3.1
Greece	6.5	431	1.5	8.3
Iceland	0.9	69	1.3	
Ireland	15.0	230	6.5	0.6
Italy	32.1	7330	0.4	0.7
Netherlands	78.0	3070	2.5	
New Zealand[3]	12.3–68.0	400	3-17	14.6
Norway[4]	26.8-32.2	880	3-3.7	3.7
Portugal	19.2	782	2.5	
Spain	15.5	3203	0.5	3.2
Sweden[5]	65.6	1795	3.7	
Switzerland[5]	16.4	1380	1.2	
United Kingdom	705.1	9056	7.8	2.6

Notes: Sources (OECD, 2001, 2003a) and authors estimates.

1. GBAORD; Total Government Budget Appropriations or Outlays for R&D.
2. 2000 or nearest year available, Eurostat National Sources May 2003.
3. Author's estimates based on published data.
4. National estimates.
5. GBAORD has been estimated.

[18] Consistent with estimated spending of $127 million in 2002/3, (Ogilvie, 2003).

Based on Wright's narrower definition, New Zealand is spending around 3% of GBAORD[19] on biotech R&D – giving it a middle ranking amongst the OECD members reported above. Probably a rather wider definition should be adopted suggesting that New Zealand's proportional effort on biotech R&D is comparable with the leaders e.g. Canada, Australia Belgium, UK. This approach was taken by the OECD (2003a) which reported that New Zealand put the highest proportional effort into biotech R&D[20]. Not surprisingly, a rather different picture emerges in absolute terms with New Zealand's total biotech GBAORD being the third smallest of the 21 countries listed.

Some more accurate international comparisons can be made based on data from the Statistics New Zealand biotech survey, since this was closely modelled on surveys carried out by Statistics Canada. However there are some important differences; the New Zealand definition of biotech included several additional processes and so was somewhat wider than that used in Canada; the number of biotech firms is also not directly comparable since the Canadian survey excluded firms that had less than five employees and less than C$100,000 R&D expenditure.

An approximate comparison between the two data sets is included as Table 4.6. It is based on application of the Statistics Canada definition of a biotech enterprise to the New Zealand data set; namely enterprises which conduct R&D, have a minimum of five employees and biotech expenditure of at least NZ$150,000. Data for Australia are also included although based on a narrower definition (see 4.2).

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[19] Government Budget Appropriations or Outlays on R&D

[20] Major differences in biotech R&D as a percentage of GBAORD between 1997 and 2000 (see Table 4.5) are probably caused by changes in definition. R&D definitions for the 2000 data vary across countries, especially with respect to inclusion or exclusion of biotechnology R&D performed by the higher education sector. The data are based on: government budget appropriations or outlays for R&D (GBAORD) for Australia, Canada, Germany, Greece, Ireland, Italy, Korea, Spain and the United Kingdom; government-financed gross domestic expenditure on R&D (GERD) for Norway; and the sum of R&D performed by the government, higher education and private non-profit sectors for Denmark, Finland and New Zealand (OECD, 2003a).

Table 4.6 Comparison of Biotech in New Zealand, Canada and Australia

	Canada 1999	Australia 1998/99	NZ 1998/99
Population (1997)	30.3	18.5	3.8
No. of biotech enterprises	358	120	39
Total biotech revenue (NZ$ m)	2850	1077	205
Biotech revenue per million population (NZ$ m)	94	58	54
Revenue per firm (NZ$ m)	8.0	9.0	5.3
Biotech related employees (Headcount)	7695	3801	1708
Biotech related employees per million population	254	205	449
% of products and processes in R&D stage	49%	47%	72%

Sources: NZ - Marsh (2003), Canada - McNiven (2001a), Australia - Ernst & Young (1999a).

New Zealand's biotech revenue per million population (NZ$54 million) is rather lower than Canada's (NZ$94 million), but the difference is fairly small considering Canada's higher per capita income and proximity to the United States. New Zealand has a rather lower mean revenue per biotech firm (NZ$5.3m vs. NZ$8.0m); consistent with the predominance of small firms in the New Zealand economy. New Zealand appears to have a significantly higher rate of biotech employment. There is some evidence that use of biotech processes in New Zealand is at an earlier stage with 72% being at the R&D stage against 49% in Canada.

4.3 Enterprise Types in the NZ Biotech Sector

4.3.1 Classification by Industry Group

Users of modern and traditional biotech processes are spread fairly evenly over five main industrial groups: food and non-food manufacturers, scientific research, and local government and health services. The proportion of New Zealand enterprises that make use of biotech is very low; fewer than half of one per cent of enterprises in the above industrial groupings. Most modern biotech R&D is conducted within research organisations, universities and a small number of private companies. Table 4.7 summarises data from Statistics New Zealand (2001) and Marsh (2001b; 2002) on the number of enterprises involved in biotech, by industrial group.

Biotech respondents were concentrated in a small number of industrial groups; 120 of the SNZ's 180 respondents falling under 8 ANZSIC categories (at the 5 digit level), see Table 4.8.

Around 60% of SNZ's biotech respondents were from the private sector (including manufacturers, research enterprises and laboratories), the remainder being mainly comprised of local and regional authorities, universities, crown research institutes and health providers[21]. The smaller number of enterprises responding to the 2000/01 survey reflects a change in the survey population and a lower response rate – not a fall in the number of enterprises (see section 4.2).

Table 4.7 No. of Enterprises Responding to Biotech Surveys, by Industrial Grouping, 1998/9 and 2002

Industrial Group	No. Enterprises Involved in Biotech Activity 1998/99	No. Modern Biotech Enterprises 1998/99	No. MBE Respondents 2001/02	No. All Enterprises in each Industrial Group 1998/99
Primary Products	6	3	5	8,122
Food Manufacturing	33	3	4	1,268
Non-Food Manufacturing	24	9	8	591
Scientific Research	36	24	10	5,404
Local Government Administration	33	6	Not sampled	201
Tertiary Education	9	6	6	76
Health Services	24	9	1	3,536
Other	12			25,036
Total	180	57	34	44,234

Note: Other includes water supply, sewerage and drainage services, veterinary services, parks and gardens.
Sources: Statistics New Zealand (2001) and Marsh (2001b; 2002).

[21] Formerly known as Crown Health Enterprises

Table 4.8 Number of Biotech Enterprises Responding to Biotech Surveys, by ANZSIC Category

	1998/99	2000/01
Dairy Product Manufacturing	6	0
Wine Manufacturing	9	0
Medicinal and Pharmaceutical Product	15	10
Manufacturing Scientific Research	24	13
Technical Services nec	6	1
Local Government Administration	33	0
Higher Education	12	12
Hospitals (except psychiatric)	15	1
Total No of Respondent in above categories	*120*	*37*
Other ANZSIC Categories	*60*	*24*

Sources: Marsh (2001b; 2002).

4.3.2 Classification by Product End-Use

Modern biotechnology is used in a number of different economic sectors ranging from food and non-food manufacturing through various primary industries to health, diagnostic and environmental applications, see Table 4.9.

Table 4.9 Classification by End-Use Sector

End-Use Sector	SNZ 1998/99 All Respondents	SNZ 1998/99 MBEs	Hopper and Thorburn 2002[22]	
			NZ	Australia
Human Health	30%	53%	29%	40%
Food Processing	33%	42%	10%	2%
Mining/Energy etc	4%	5%	8%	11%
Environment	35%	37%		
Agbiotech	32%	63%		
Forest Products	8%	21%	25%	19%
Aquaculture	13%	37%		
Genomics	12%	42%	13%	22%
Custom Synthesis	8%	21%	*including diagnostics*	*including diagnostics*
Other	13%	21%		
Multiple Sector	na	na	13%	4%

Sources: Marsh (2001b), Hopper & Thorburn (2003).

Modern Biotech Enterprises reported that they were researching and developing products, processes and services for use in the ag-bio and human health sectors,

[22] Data adjusted by removing biotech suppliers.

followed by food processing, genomics/molecular modelling, aquaculture and the environment. Food manufacturers were generally classified as MBEs because of their use of non-DNA based processes e.g. peptide sequencing, immune stimulants, antigens and antibodies etc.

Other biotech categories exhibit a similar pattern while being influenced by the industry group of some respondents; so for example the environment industry sector was reported most frequently by Traditional Biotech Users, reflecting the waste treatment activities of local authorities, while Modern Biotech Users most reported sector was human health – reflecting the activities of health services respondents.

A similar pattern emerges when 'end use sector' is tabulated against industry group see Marsh (2001b, p. 34). The main end use sector is in many cases 'self defined':

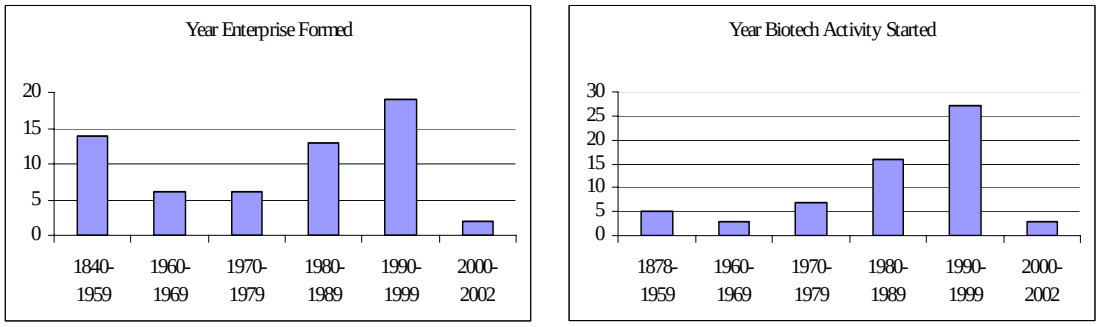
i. Food manufacturers reported food processing as the main end use sector;
ii. Non-food manufacturers were mainly involved in ag-bio, human health and food processing ;
iii. Scientific research organisations were involved in most sectors, ag-bio being the most common;
iv. Local government was mainly involved in environmental processes (water and waste treatment)
v. The university and polytechnic group were involved in all areas; human health being the most common;
vi. Health services organisations were all involved in human health and have some involvement in ag-bio and the environment.

Classification according to end-use may allow better international comparisons but has the disadvantage that many enterprises are involved in multiple sectors. This may explain the lack of correspondence between the end-use sectors reported by Hopper and Thorburn (2003), in which most enterprises were assigned a single end-use sector, and Marsh (2001b) where each enterprise can select several sectors.

4.3.3 Year of Formation and First Biotech Activity

Enterprises responding to the 2001/02 survey were formed as early as 1840, although 35% had been formed since 1990. Biotech activity was reported to have started as early as 1878 but in most cases had started much more recently; 49% had started since 1990 and 85% since 1970, see Figure 4.2.

Figure 4.2 Year of Enterprise Formation and First Biotech Activity



Source: Marsh (2002).

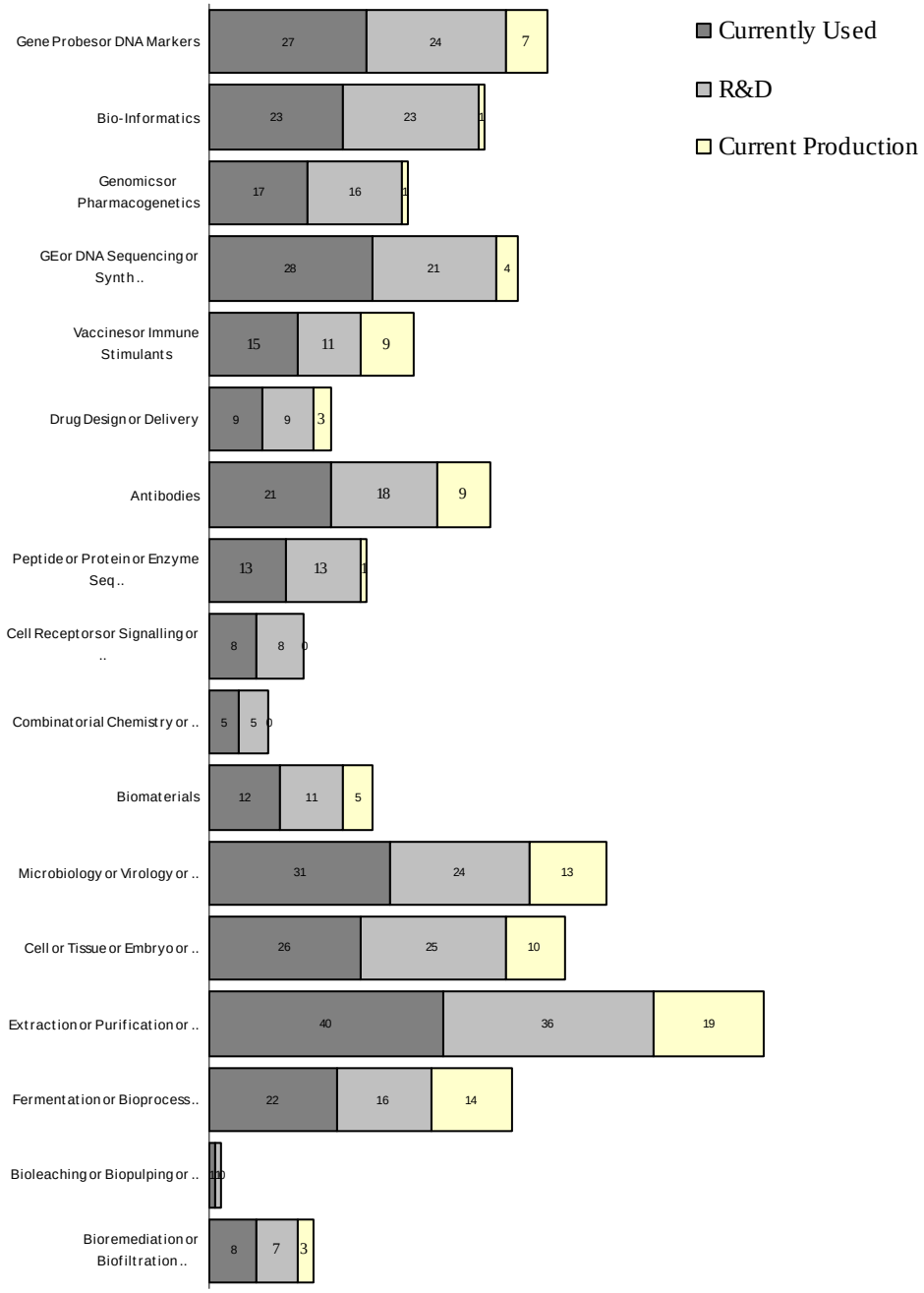
4.3.4 Biotech Processes Used

Biotech enterprises in New Zealand may also be described by reference to the types of biotech process that they use and whether these processes are used for R&D or for production. Respondents to the 2002 survey were asked to review a list of 17 groups of biotech processes and indicate whether each process/group was currently used for R&D or for current production, see Figure 4.3[23].

It may be seen that the most commonly used process group was 'extraction, purification etc' followed by 'microbiology or virology etc' and 'gene probes or DNA markers'. The way in which process groups are used varies considerably, so for example bio-informatics and GE or DNA sequencing are used almost exclusively for R&D, while 'fermentation or bioprocessing' is generally used for current production.

[23] This Figure provides data on respondents to the 2002 survey of organisations conducting biotech R&D. For data on *all* biotech users see Marsh (2001b, p. 11).

Figure 4.3 No. of Respondents Using Biotech Processes in R&D and for Current Production in 2002



Source: Marsh (2002).
Note: 'Currently Used' denotes total number of users including those who use biotech processes for R&D and for 'Current Production'.

Use of modern biotech in New Zealand is at an early stage of development with many enterprises being involved primarily in R&D. Overall 92% of biotech respondents (2002 Survey) used at least one biotech process for R&D or process development, see Table 4.10.

66% reported use of biotech processes for current production. There is significant variation between the different biotech areas, for example:

i. 90% of enterprises using DNA based processes conducted R&D in this area while only 30% used these processes for current production;
ii. 87% of enterprises using biochemistry based processes conducted R&D in this area while 47% used these processes for current production;
iii. Enterprises using bioprocessing based processes were most likely to use them for current production (63%).

Table 4.10 Percentage of Enterprises Involved in Different Biotech Areas by Stage in 2002

Biotech Area	No. of Enterprises Involved at any stage	% Using Processes in R&D 2000/01	*% Using Processes in R&D 1998/99*	% Using Processes for Current Production 2000/01	*% Using Processes for Current Production 1998/99*
DNA Based Processes	30	90%	*76%*	30%	*24%*
Biochemistry Based	45	87%	*57%*	47%	*43%*
Bioprocessing Based	51	90%	*37%*	63%	*37%*
Environmental Biotech	8	88%	*54%*	38%	*19%*
Enterprises Involved in each Stage	61	92%	*53%*	66%	*45%*

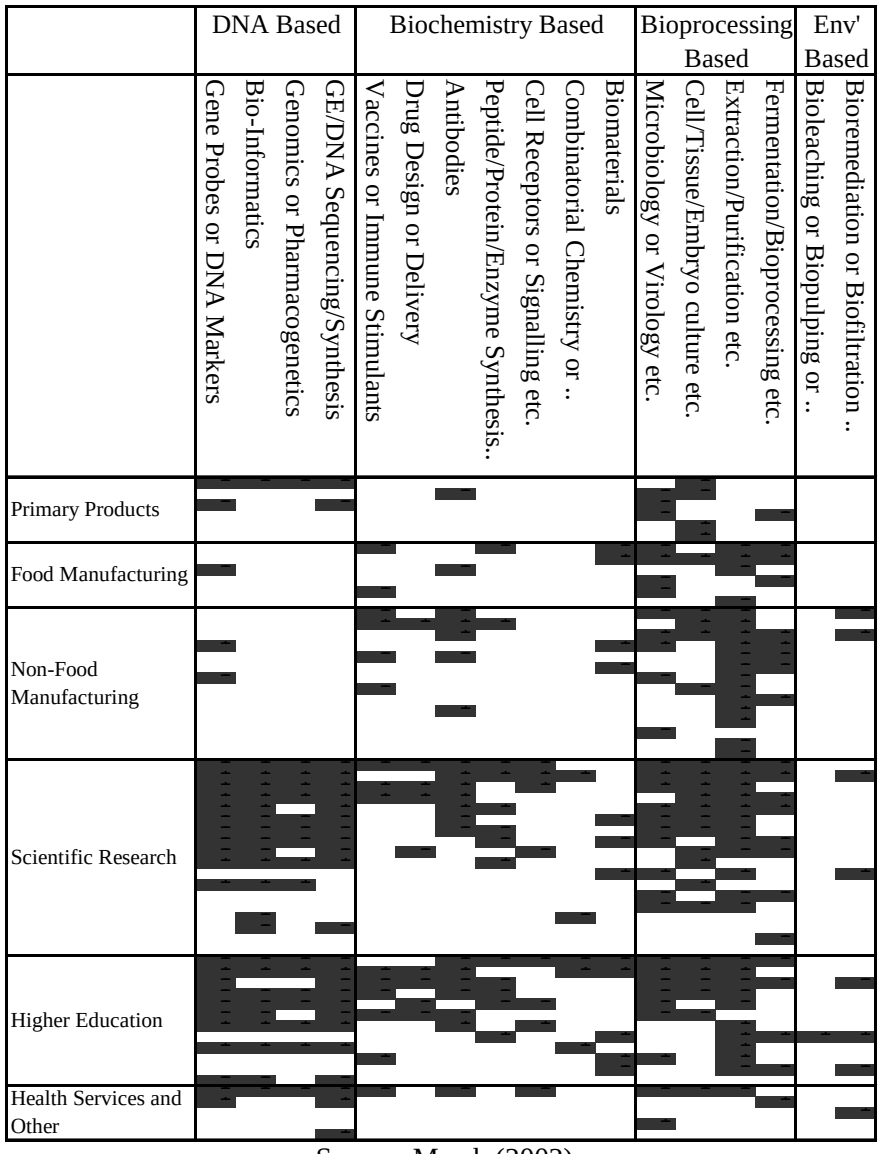
Note: Percentages are expressed as a proportion of the number of enterprises involved in each area e.g. '90% of the 30 enterprises that used DNA based processes used DNA based processes for R&D'. Enterprises may use the same process in more than one stage.
Sources: Marsh (2001b; 2002).

4.3.4.1 Number of Processes Used

Figure 4.4 provides a pictorial representation of biotech process use in the different industrial groups. It illustrates the number of processes used in different biotech areas. Each black rectangle indicates use of one process group by one respondent. It can be seen that respondents in scientific research and higher education use the most processes; including most in the DNA, biochemistry and

bioprocessing based areas, while manufacturers mainly use bioprocessing based processes. Private sector organisations (primary, food and non-food industrial groups) were involved in fewer process categories – an average of 2.5 to 3.2 per respondent than public sector organisations.

Figure 4.4 Process Use by Industrial Group



Source: Marsh (2002)

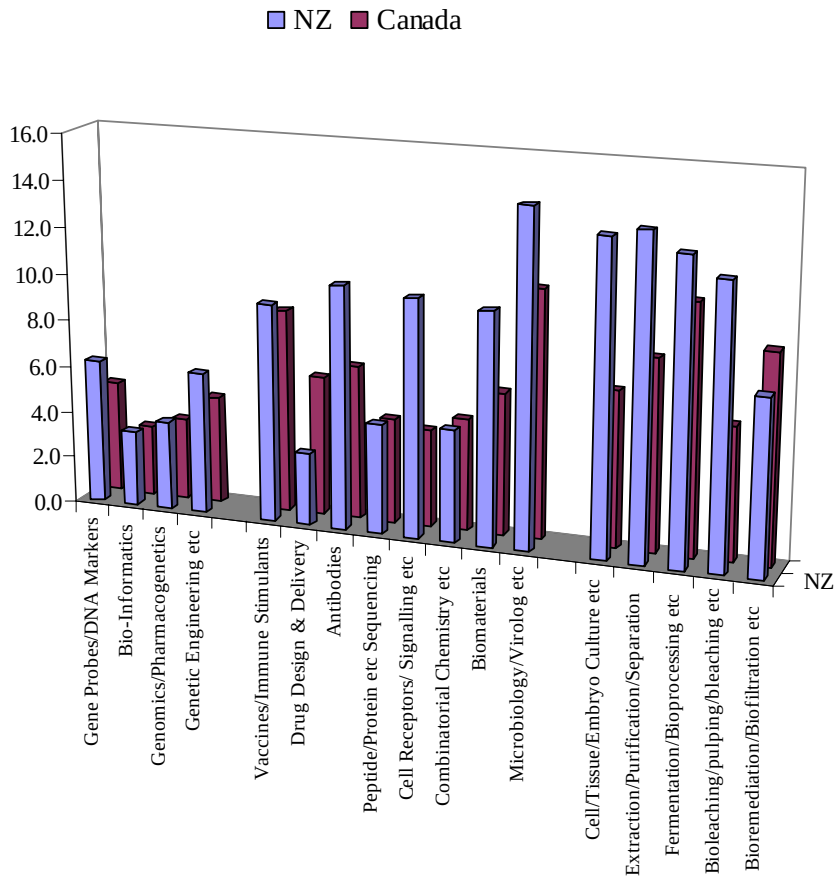
4.3.4.2 Age distribution of processes

Data on the age distribution of biotech processes provides useful information on the development of the biotech industry over time and may also be compared with similar data from overseas. Average age in use in New Zealand is longer than in

Canada for all but two process categories (see Figure 4.5), possibly because of the lower number of new entrants in New Zealand.

There are distinct differences between modern and older biotechnology processes. Genomics exhibits a typical age structure for a recent process; 56% have used this process for 5 years or less, 83% have used it for 10 years or less. Extraction/purification/separation is typical of a more mature technology; 24% started using this process within the last 5 years (often these are new enterprises). A further 24% have been using this process for at least 20 years. See Figure 4.6 and Figure 4.7.

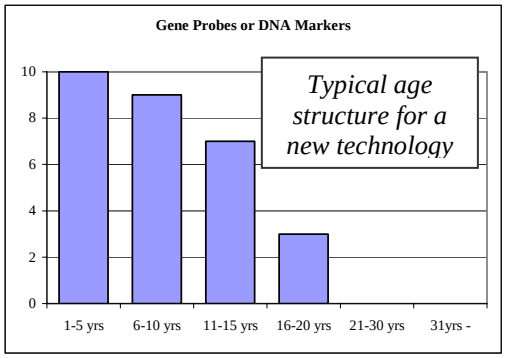
Figure 4.5 Number of Years Biotechnologies Used in Canada and New Zealand

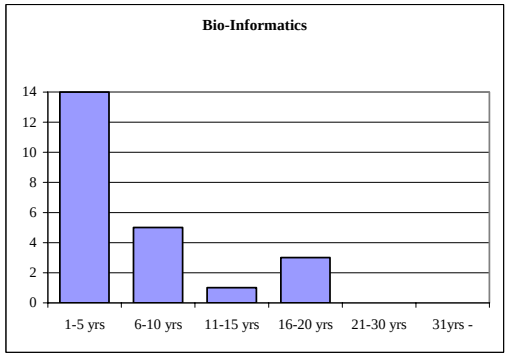


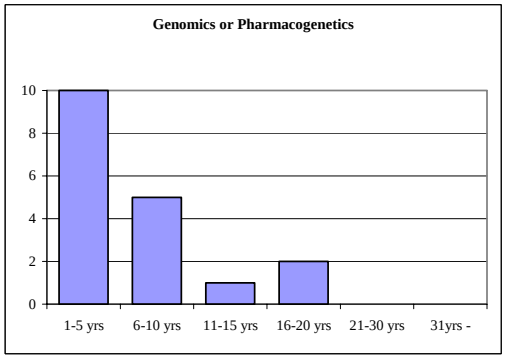
Source: Marsh (2002), McNiven (2001b, p. 11).
Note: Data for New Zealand is drawn from the 2000/01 survey; adjusted for survey year.

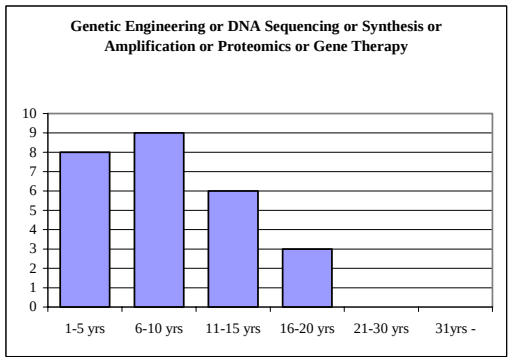
Figure 4.6 Age Distributions for Selected Biotech Processes[24]

DNA based processes

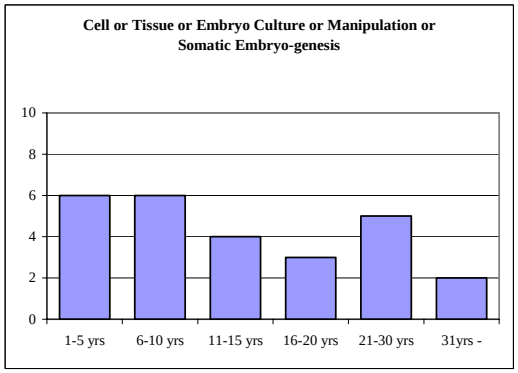


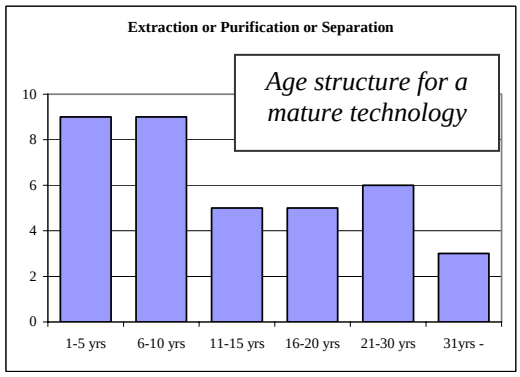


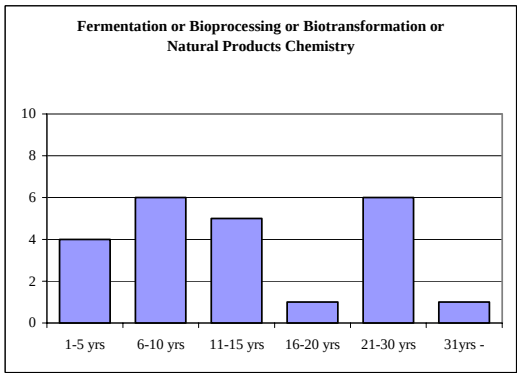




Bioprocessing based processes



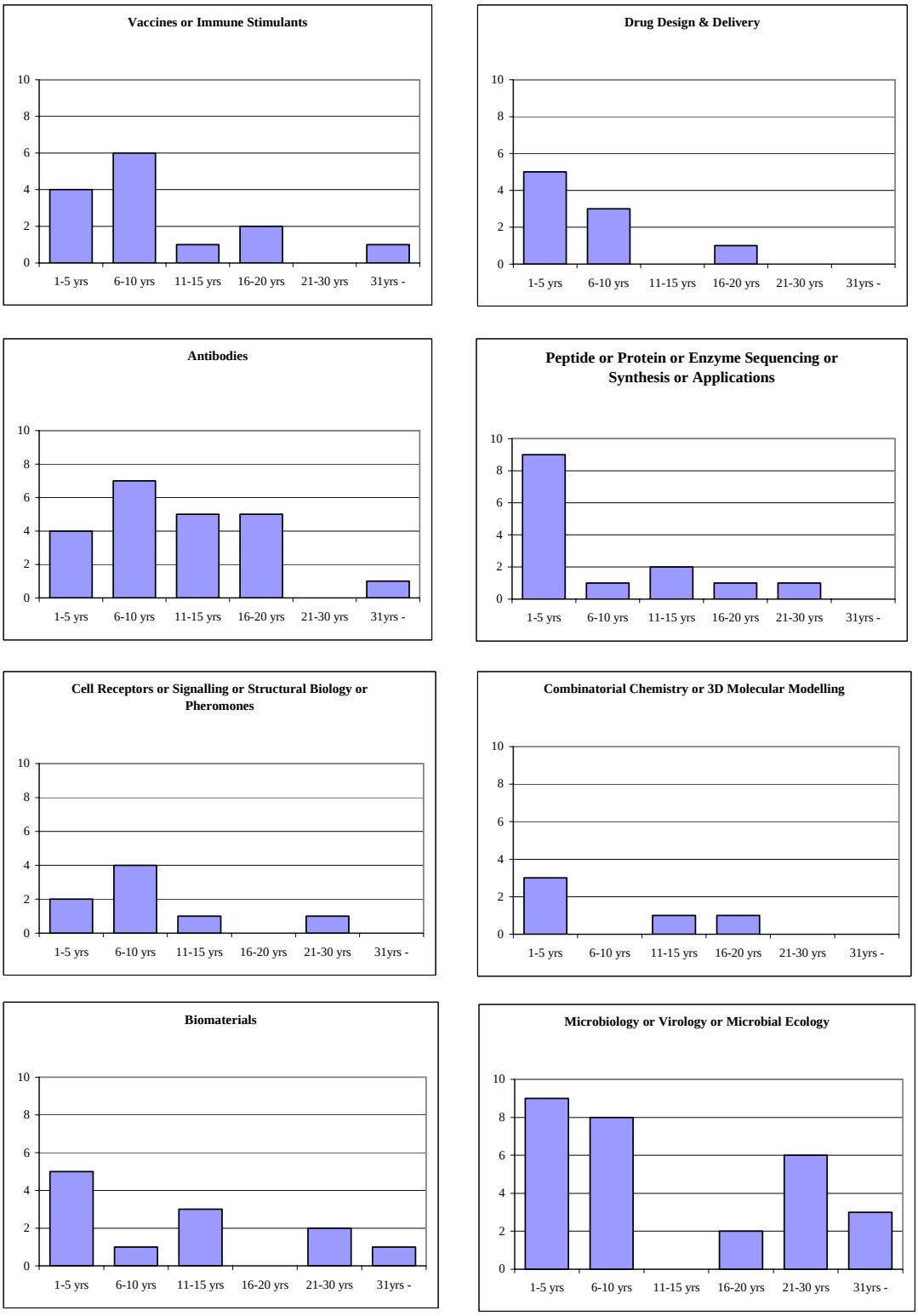




[24] Source: Marsh (2002)

Figure 4.7 Age Distributions for Selected Biotech Processes[25]

Biochemistry/Immunochemistry based processes



[25] Source: Marsh (2002)

4.4 Enterprise Size

4.4.1 Expenditure data

4.4.1.1 Data from the 1998/99 Survey

Respondents to the 1998/99 survey estimated that income of $475 million was attributable to 'biotechnology activity', in the year ended June 1999 - $326 million from private sector respondents, $149 million from the public sector. This compares to respondents' income from all sources of $7.25 billion i.e. overall biotech provided around 7% of income for the 180 biotech using enterprises[26].

Various difficulties associated with the data on income and expenditure mean that these estimates should be treated with caution. Enterprises were asked to estimate the proportion of their total income and expenditure that could be attributed to biotechnology. Such an instruction is open to widely varying interpretations[27], so for example dairy product manufacturers' estimates varied between zero and 100% of their income.

Fifteen percent of enterprises which use biotech processes reported that they received no income attributable to biotechnology. Seventy three percent received less than 50% of their income from biotech, while 15% attributed *all* of their income to biotech. Within the MBE group 53% received 0 > 25% of their income from biotech, while 15% (around 9 enterprises) received *all* of their income from biotech – such firms are commonly termed Dedicated Biotechnology Firms (DBF) in the international literature, see Table 4.11 below.

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[26] Expenditure of $405 million was attributable to biotech activity; 6% of total expenditure ($6312 million).

[27] depending on interpretation of 'attributable' and whether the respondent concentrated only on *modern* biotech. Based on a broad interpretation it could be said that *all* dairy manufacturing income is attributable to biotech. Separation of the proportion of this attributable to *modern* biotech would be very difficult. These issues are also discussed in Statistics New Zealand (2001) and Marsh (2001c).

Table 4.11 Biotech Income as a Percentage of Total Income (1998/9)

Percentage of Income from Biotech	All Groups	Modern Biotech Enterprises
0	15%	5%
0 > 25%	47%	53%
25 > 75%	17%	16%
75 > 100%	5%	11%
100%	15%	16%

Source: Marsh (2001b, p. 22)

4.4.1.2 *Data from the 2001/02 Survey*

The 2001/02 survey, conducted by the author (Marsh, 2002), was addressed to organisations thought to be conducting R&D using modern or traditional biotech processes; a different survey population to the 1998/99 survey. It provides data on some expenditure variables not included in the 1998/99 survey e.g. R&D expenditure, biotech R&D expenditure and revenue from new biotech products/processes. Estimates in Table 4.12 and Table 4.13 have been obtained by adjusting category totals based on the response rate in each category[28]. These estimates are subject to wide confidence limits and so should be used with caution.

Table 4.12 Expenditure and Revenue Estimates 2001/2 ($ millions)

Industrial Group	Expenditure 2000/01	Revenue/ Sales 2000/01	R&D Expenditure 2000/01	% Expenditure on R&D
Primary Products	27	33	3	13%
Food Manufacturing	4,566	5,384	70	2%
Non-Food Manufacturing	103	179	14	14%
Scientific Research	668	553	478	72%
Tertiary Education	101	61	45	45%
Health Services & Other	619	623	3	1%
Total	6,085	6,833	616	10%

Source: Marsh (2002)
Note: These are population estimates for all biotech enterprises conducting R&D. Estimates for scientific research and tertiary education are based on responses for sub-units and so refer only to the parts of those organisations engaged in biotech research.

[28] For example response rate in the non-food manufacturer's category was 67%. Total R&D expenditure for all respondents was $9.7 million. Estimated R&D expenditure for all non-food manufacturers (that conduct biotech R&D) is $9.7m/0.67=$14.47m

Respondents indicated that R&D constituted around 10% of total expenditure; the proportion varying from a high of 72% in the scientific research group to a low of 1-2% for food-manufacturers, health services and other. Respondents spend far more on R&D than the industry average; the dairy industry is reported to spend around 1% of turnover on R&D[29], while R&D expenditure as a proportion of value added of manufactured products was 1.3 percent in 1999/2000 (Ministry of Research Science and Technology, 2002, p. 17).

Table 4.13 Biotech R&D Expenditure Estimates 2001/2

Industrial Group	Biotech Expenditure 2000/01	Biotech Expenditure as % of Total Expenditure	Biotech R&D expenditure 2000/01	Biotech 'New Revenue'[30]
Primary Products	4	16%	2	12
Food Manufacturing	20	0%	14	56
Non-Food Manufacturing	69	67%	13	13
Scientific Research	268	40%	266	8
Tertiary Education	20	20%	16	0
Health Services & Other	9	1%	3	1
Total	390	6%	313	91

Source: Marsh (2002)
Note: These are population estimates for all biotech enterprises conducting R&D.

Biotech expenditure in 2000/01 was estimated to be around $390 million; this can be compared with an estimate of $260 million for 1998/99[31]. These estimates are consistent with the sector growth rate of around 20% per annum reported by some industry observers[32] (Ernst & Young, 2003). Expenditure on biotech R&D ($313 million) comprised around 80% of all biotech expenditures.

[29] The dairy industry (dominated by Fonterra) is reported to spend "in excess of 1% of it's annual turnover on R&D; in excess of $100million per year" Marshall (2001).

[30] From biotech products/processes introduced in the last 3 years

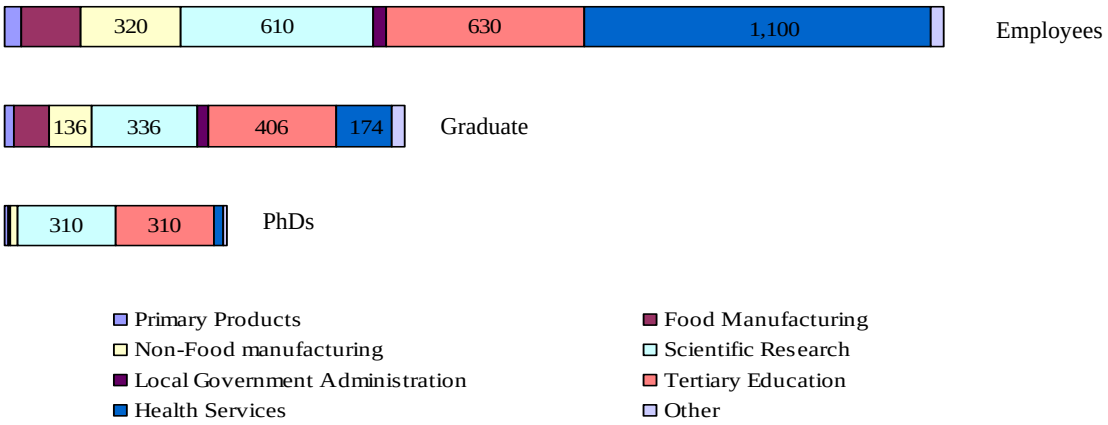
[31] Biotech expenditure by all respondents in MBE and TBE groups – Marsh (2001) Unpublished Results from Further Analysis of the 1998/99 Survey data.

[32] Growth from $260m in 1998/99 to $390m in 200/01 indicates a growth rate of 22.5% per annum.

4.4.2 Human Resources data

Respondents to the 1998/9 survey were asked to provide data on their employees 'supporting biotech activity'. They were specifically asked *not* to include staff performing indirect support to biotech activities e.g. central finance or personnel or other similar centralised support services.

Figure 4.8 Number of Biotech Employees by Qualification and Industrial Group



Source: Marsh (2002)

Survey respondents reported that a total of 3057 (or 2984 full time equivalent) staff supported biotech activity. Around 67% were graduates and 26% had PhDs. The largest employee group came from the health services industrial group, followed by the tertiary education and research groups (see Figure 4.8).

Most graduates were employed by the tertiary education and research groups (most health services biotech employees are not graduates). The concentration of qualified staff is most marked for staff with PhDs – 88% of these were employed within these two groups. MBEs employed 1667 biotech staff (FTE) – 56% of the total for all respondents. Employment of qualified staff was heavily concentrated in MBEs; they employed 83% of biotech graduates and 95% of PhDs.

The 20002 survey provides data on the number of employees engaged in biotech R&D; this variable was not included in the 1998/99 survey. Estimates in Table 4.14 and Table 4.15 have been obtained by adjusting category totals based on the

response rate in each category[33]. These estimates are subject to wide confidence limits and so should be used with caution.

Table 4.14 No. of Employees (2002)

Industrial Group	All Employees	Biotech Employees						
		PhD	MSc or MPhil	BSc or BTech	Diploma or Cert	Other Qual	No Qual	Total Biotech Staff
Primary Products	624	27	24	68	14	11	97	241
Food Manufacturing	21,568	26	21	174	205	16	211	653
Non-Food Manufacturing	639	33	21	185	60	7	115	421
Scientific Research	5,022	527	129	517	85	22	32	1,298
Tertiary Education	1,502	243	107	227	21	20	14	632
Health Services & Other	11,863	37	7	26	2	2	-	74
Total	41,218	893	309	1,196	387	78	469	3,318

Source: Marsh (2002)
Note: These are population estimates for all biotech enterprises conducting R&D

The 2002 estimate of 3,318 biotech staff may be compared with a head count of 2053 reported for June 1999[34]. These estimates are also consistent with the high sector growth rate mentioned in section 4.4.1.2 above.[35].

Table 4.15 No. of Employees Engaged in Biotech R&D 1999 and 2002

Industrial Group	1999	2002
Primary Products	95	116
Food Manufacturing	42	68
Non-Food Manufacturing	51	75
Scientific Research	978	1,227
Tertiary Education	463	527
Health Services & Other	33	30
Total	1,661	2,044

Source: Marsh (2002).
Note: These are population estimates for all biotech enterprises conducting R&D

Respondents to the 2002 survey indicated that around 60% of all 'biotech staff' were engaged in R&D. The number of staff engaged in R&D increased from around 1660 in 1999 to 2044 in 2002, indicating growth of around 7% per annum.

[33] See footnote 28 for estimation method.

[34] Headcount at June 1999 for all respondents in MBE and TBE groups – Marsh (2001) Unpublished Results from Further Analysis of the 1998/99 Survey data.

[35] Growth from 2053 in 1999 to 3318 in 2002 indicates a growth rate of 17% per annum.

4.5 Innovation Output

4.5.1 Product and Process Development

One indication of the rate of innovation by biotech respondents is provided by questions such as: "In the last 3 years, how many new or significantly improved products or processes has this business introduced on to the market?"

Overall, 51% of respondents to the 2002 survey reported implementation of a new *product* with the innovation rate being lowest for food manufacturers (33%) and highest for non-food manufacturers (79%). Process innovation rates were much lower with only 21% reporting implementation of a new *process* in the last 3 years; this is notably different to the 98/99 survey when 33%[36] of enterprises reported introduction of new products and the same percentage reported introduction of new processes[37]. Enterprises were also asked about products and processes under development. Innovation rates were rather higher for this question with 79% of respondents reporting that they had products or processes under development, see Table 4.16.

Respondents were asked whether new products/processes were new to their business, new to New Zealand or new to the world. This question aims to elicit an indication of the degree of novelty of the new product/process[38]. Out of 80 new products introduced in the last 3 years, 91% (73) were reported to be new to New Zealand and 66% (53) new to the world, see Table 4.17. The proportion reported to be new to New Zealand or to the world is surprisingly high[39]. One possible explanation is that respondents under reported products that were new to their business only.

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[36] The higher innovation rate reported in the 2002 survey (51%) is expected since it was targeted at enterprises that conduct R&D.

[37] Future work is required to better understand the way in which New Zealand enterprises respond to questions on the number of new products and new processes.

[38] 'New to the world' products/processes are assumed to be most novel.

[39] No data is available from the 1998/99 survey on products new to business, NZ, world. Process data was collected but was processed inconsistently and so is of little use.

The distribution of the new product/process variables is very skewed; for example the top 3% introduced 20% of all new products while the bottom 74% introduced only 19%, see Table 4.18.

Table 4.16 Innovative Output of Biotech Respondents (2002)

Industrial Group	No. of Biotech Respondents	% Reporting Any R&D	% Implementing New Product Last 3 Yrs	% Implementing New Process Last 3 Yrs	% with products or processes under development
Primary Products	6	83%	67%	17%	67%
Food Manufacturing	6	83%	33%	17%	67%
Non-Food Manufacturing	14	100%	79%	43%	93%
Scientific Research	18	94%	39%	6%	89%
Tertiary Education	12	100%	42%	17%	75%
Health Services and Other	5	40%	40%	40%	40%
Total	61	90%	51%	21%	79%

Note: percentages should be interpreted with caution because of small cell numbers.
Source: Marsh (2002).

Table 4.17 Number of New Products and Processes in Last 3 years (2002)

	Number of New Products			Number of New Processes		
Industrial Group	New to the Business[40]	New to New Zealand	New to the World	New to the Business	New to New Zealand	New to the World
Primary Products	21	20	14	1	0	1
Food Manufacturing	2	1	1	4	4	0
Non-Food Manufacturing	34	30	19	9	2	2
Scientific Research	12	11	11	1	0	1
Tertiary Education	8	8	7	2	2	2
Health Services and Other	3	3	1	2	0	0
Total	80	73	53	19	8	6

Source: Marsh (2002).

[40] This is also the 'total' number of new products introduced. Products that are 'new to the world' are also recorded as being 'new to NZ' and 'new to the business'.

Table 4.18 Frequency Distribution for Number of New Products and Processes 2002

Number of Products/ Processes Planned	New Product Last 3 Yrs		New to New Zealand	New to World	New Process Last 3 Yrs	
0	30	49%	33	52	48	79%
1	15	25%	13	6	10	16%
2-5	11	18%	10	1	3	5%
More than 5	5	8%	5	2	0	

Source: Marsh (2002).

4.5.2 International Comparisons

Innovation rate data have been collected in EU and OECD member states since 1992[41] but was not systematically collected in New Zealand until 2001. Some data are available from an innovation survey commissioned by MORST in 1994. Respondents were asked: "how many completely new product lines have you introduced in the last 5 years?" It was found that the average company had introduced 16 completely new products over that period (Frater et al., 1995, p. 74). This is a significantly higher level than reported by biotech respondents, (averaging one new product per enterprise over the last three years) although this may be partly attributable to differences in the survey populations, question formats and timeframe.

In June 2001, Statistics New Zealand conducted the first economy wide Business Practices Survey (BPS). The BPS collected information on three aspects of business activity: use of information technology, innovation and management practices (Statistics New Zealand, 2002). Key findings included:

> Sixty-eight percent of New Zealand private sector enterprises introduced an innovation in the three years ended June 2001. Forty-two percent of firms introduced both product and process innovations, while a smaller proportion introduced product-only innovations (19 percent), and process-only innovations (7 percent).
>
> The proportion of New Zealand firms that introduced an innovation increased with business size. Eighty percent of large firms (those with 50 or more full-time employees) introduced an innovation, compared with 66 percent of small firms (those with 6 to 19.5 full-time employees).

[41] The European Community Innovation Surveys (CIS) began in 1992 and were repeated in 1996 and 2001(Archibugi, Cohendet, Kristensen, & Schaffer, 1994; Eurostat, 2001), for details of OECD innovation surveys see Muzart (1998).

> The manufacturing sector had the highest rate of innovation in the economy (79 percent of firms). In particular, 87 percent of firms in the petroleum, coal and chemical manufacturing industry introduced an innovation. Fifty-six percent of firms in the primary sector introduced an innovation, and 67 percent of firms in the services sector introduced an innovation.

The OECD has used 'the share of firms introducing at least one new or improved product or process onto the market over a given period' to compare the innovative output of firms in different member countries. The OECD average proportion of manufacturing firms that introduced a new product or process in 1994-96 was 56% (data from 21 OECD members). For firms with 20-49 employees the share was significantly lower, averaging 41% of firms (OECD, 2001, p. 174). Statistics New Zealand (2002) reports that:

> the level of innovative activity carried out by New Zealand enterprises is at least equal, if not higher, than that indicated in a survey of European Union (EU) countries. The level of innovation in the New Zealand manufacturing and services sectors (the EU survey excluded the primary sector) was higher than that of all EU countries.

Review of the innovation literature suggests that Statistics New Zealand should be cautious of claiming that "the level of innovation in the New Zealand manufacturing and services sectors …was higher than that of all EU countries" on the basis of one set of survey results. For example Tether (2001, p. 17) reports that comparisons between sectors and between countries are problematic:

> For although the aim of CIS is to provide comparable statistics (between countries and sectors), there are doubts as to whether the findings are comparable. Are services really less likely to be (technological) innovators than manufacturers? – perhaps they are merely less likely to recognize themselves as innovators. Statements about the proportion of innovators also say nothing about the intensity of innovation activities, which tend to be unevenly distributed among firms and groups of firms. Meanwhile the threshold of what is considered an 'innovation' may vary between sectors and countries. A small change may not qualify as an innovation in a sector where change is routine or continuous, but may be considered an innovation where change is rare.

New Zealand government, business and the media have been heavily preoccupied with the word innovation over the last few years. The word tends to be used in a loose sense and it is reasonable to assume that many respondents will have been predisposed to regard quite small changes to their business as 'innovations'. A detailed investigation into the kinds of activities that respondents in New Zealand and other countries regard as being innovations is required before definite

conclusions can be reached on the relative innovative output of New Zealand firms.

The mean innovation rate for a group of small OECD countries that New Zealand might wish to emulate[42] was 62% for all firms and 50% for small firms. The 1998/99 biotech survey found that 45% of respondents had introduced an innovation in the previous 3 years, while the 2002 survey found that 54% were innovators. The low level of reported innovation, relative to the BPS may, in part, be explained by the nature of the sector where a high proportion of enterprises[43] are engaged in scientific research or higher education where the main outputs may be intellectual property in the form of journal publications and patent applications. It is also possible that enterprises in a research-intensive sector such as biotech are less likely to classify changes as innovations, compared to less research-intensive sectors.

Further work is required before definite conclusions can be reached on the relative innovative output of New Zealand biotech firms – although the evidence reviewed above suggests that New Zealand biotech firms do not have a particularly high rate of new product or process development relative to other New Zealand sectors or to other countries.

4.6 Patenting and the Stock of Ideas

The use of patents as economic indicators has been well established for many years[44]. Ideally we might hope that patents would provide an indication of the rate at which the production possibilities frontier is shifted outward (Griliches, 1990, p. 1699). In practice they are most commonly used as indicators of innovative activity, although more strictly defined they are indicators of *invention* not necessarily leading to innovation.

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[42] Austria, Belgium, Denmark, Finland, Ireland, Netherlands, Portugal, Sweden, Switzerland

[43] 38% of institutions responding to the 2002 survey fell into these two groups (25% for the 1998/9 survey).

[44] See Griliches (1990) for a comprehensive survey.

Patent statistics have also been used to test Romer's (1990) model of endogenous technological change. In this model productivity growth is driven by allocation of resources to an ideas-producing sector and ideas sector productivity must increase proportionately with the stock of ideas already discovered. Patent statistics have been used as an indicator of the stock of ideas by Porter and Stern (2000), among others. There is also a rapidly increasing literature in the biotechnology area based on analysis of patents (Foltz et al., 2000; Joly & de Looze, 1996; Malo & Geuna, 1999; McMillan, Narin, & Deeds, 2000).

Analysis of New Zealand patenting activity in biotechnology was carried out by the author, using international applications published in the Patent Cooperation Treaty (PCT) Electronic Gazette. The PCT provides for the filing of an international application to have the same effect as a national application in each of the contracted states designated in the application (OECD, 1994, p. 19); it thus provides a useful measure of international patenting activity. Use of applications data provide a more immediate picture, since it can take up to five years from the first application for a patent to be granted.

Methodology based on Engelbrecht and Darroch (1999) was used to compare New Zealand's rate of patenting with G7 and a reference group of small high-income OECD countries (see Table 4.19 and Figure 4.10). For the purposes of this analysis the International Patent Class C12N is assumed to provide a good indication of the level of modern biotech activity.

Table 4.19 New Zealand and OECD Patenting Rates in Biotechnology

	1997-99	2000-02	% Change 97/99-00/02	1998-2002
OECD (18 Countries)	3.9	5.9	51%	5.3
G7	3.9	5.9	52%	5.3
Small Countries[45]	4.4	6.1	40%	5.5
Australia	3.5	4.7	34%	4.1
New Zealand	2.0	4.8	145%	3.7

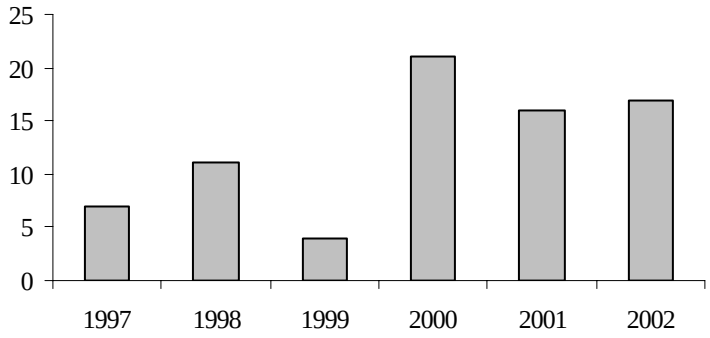
Source: Original analysis of PCT database by the author.
Notes: Patenting rates are for class C12N per million population per year.

[45] Australia, Belgium, Denmark, Finland, Ireland, Netherlands, NZ, Norway, Sweden, Switzerland

New Zealand's rate of modern biotech patent applications over the five years to the end of 2002 was 3.7 per million of population, per year. This is below the average for the G7 (5.3) and for a reference group of small, developed OECD economies (5.5). Patent application rates range from a high of 15.2 for Denmark to a low of 0.5 for Italy. Overall New Zealand ranks eleventh out of 18 with a patenting rate above that found in France and Japan. However New Zealand's performance is disappointing compared to other small countries with strong primary industries that it might hope to emulate e.g. Denmark (15.2), Switzerland (10.9), Netherlands (5.5), Australia (4.1).

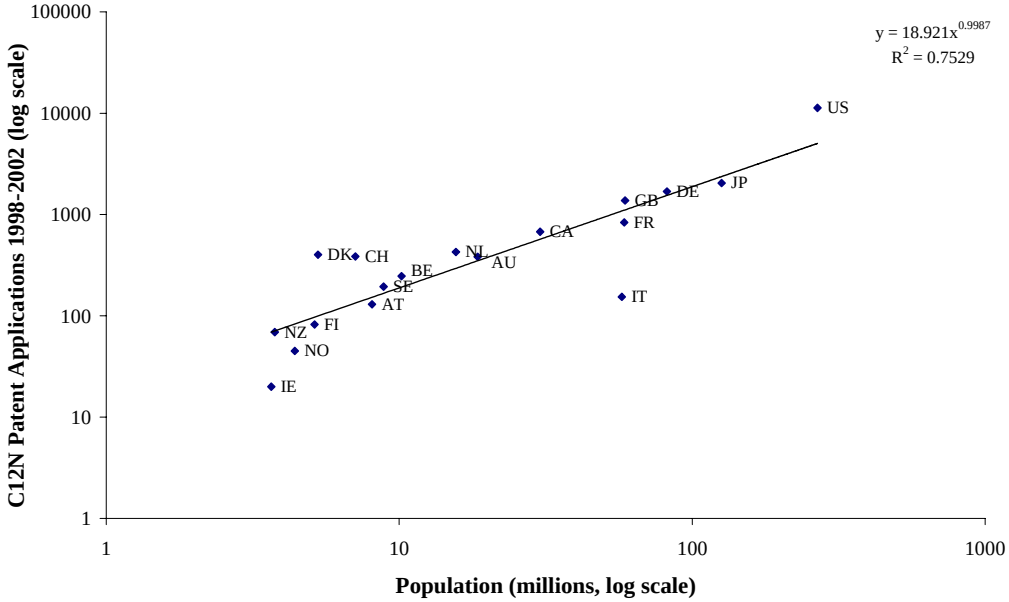
Comparison of the three-year periods 1997-99 and 2000-02 reveals an average increase in patenting rates of 51%. Patent application rates increased in all countries, with the rate of increase varying from 18% in the Netherlands to 145% in New Zealand (see Figure 4.9). New Zealand has increased its performance relative to the OECD and Australia; although the rapid change in patent application rates may, in part reflect an increased propensity to patent caused by institutional change in the science system (see section 1.3.2).

Figure 4.9 New Zealand C12N Patent Applications



Source: Original analysis of PCT database by the author.

Figure 4.10 Comparison of International Biotech Patent Application Rates



Country Codes (in patent rate order): Denmark (DK), Switzerland (CH), United States (US), Netherlands (NL), Belgium (BE), United Kingdom (GB), Canada (CA), Sweden (SE), Australia (AU), Germany (DE), New Zealand (NZ), Japan (JP), Austria (AT), Finland (FI), France (FR), Norway (NO), Ireland (IE), Italy (IT).

Source: Original analysis of PCT database by the author.

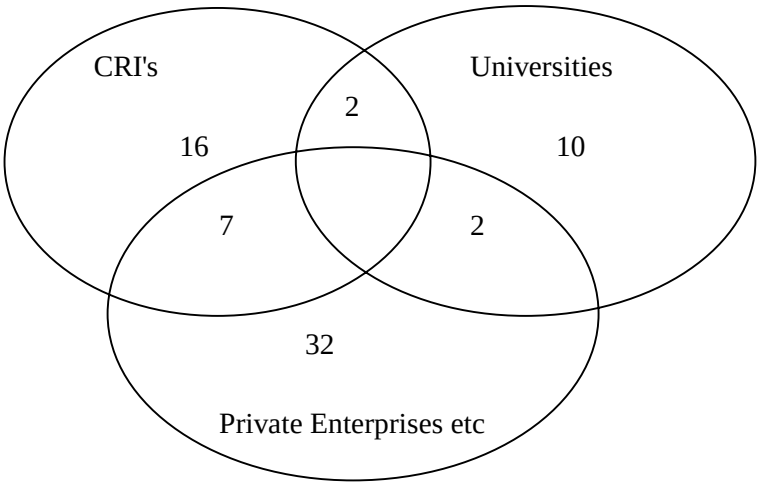
Figure 4.1 uses log scales to compare international C12N patenting rates, adjusted for the population of each country. It can be seen that this produces a surprisingly good fit with 75% of the variation in applications being explained by population size. Based on this analysis New Zealand is very close to the trend line; its C12N patent rate is close to the expected value, after adjusting for population size. There are few real outliers, although Denmark and Switzerland have a rather higher patenting rate than expected, while the rate for Italy and Ireland is lower than expected.

A breakdown of New Zealand patent applications by organisational type indicates that C12N patenting activity is heavily concentrated in a small number of organisations. Five organisations[46]; a private company (Genesis), two CRIs (AgResearch and HortResearch) and two universities (Auckland and Otago)

[46] Either individually or in partnership with others.

accounted for 75% of patenting activity over the five years to the end of 2002. Figure 4.11 illustrates the distribution of patenting activity across the main organisational types. It can be seen that joint patents accounted for 16% of the total, with collaborations between CRIs and private enterprises being most common.

Figure 4.11 No. of Patent Applications 1998-2002, by Organisational Type



Source: Original analysis of PCT database by the author.
Notes: Joint patent applications were also observed within organisational types e.g. between universities and between different private enterprises.

Organisations participating in the 1998/99 and 2002 biotech survey were asked whether they had made 'biotech related patent applications' and so reported on a wider range of patents falling under C12N and several other patent classes. As would be expected from the data presented above, patenting activity was concentrated in a relatively small number of organisations, see Table 4.20.

Table 4.20 Patent Applications

	1998/99	2002
No. of Respondents	180	61
No. respondents making patent applications in last year	21	22
Total No. of patent applications	56	69

Sources: Marsh (2001b; 2002).

4.7 Partnerships and Alliances

4.7.1 Data from the 1998/99 Survey

Respondents to the 1998/99 biotech survey were asked[47] about partnerships and alliances for biotechnology activity over the last 3 years. Further questions focussed on the purpose of any alliances and the types of New Zealand and overseas organisations involved.

52% of biotech respondents reported a partnership/alliance with a total of 303[48] different organisation types; this suggests that the 93 respondents that had alliances had an average of at least three partners each.

The proportion of respondents reporting a biotech alliance varied markedly between industry groups from 100% in tertiary education to a low of 18% for local government. Overall 48% reported at least one New Zealand alliance while 30% reported an overseas alliance. Overseas alliances were most common in the tertiary education, non-food manufacturing and scientific research groups, see Figure 4.12. A breakdown of alliance frequency by biotech category reveals that 90% of MBEs reported alliances falling to 42% for MBUs and 24% for TBUs.

The most commonly reported alliance purposes were product or process development; reported by 81% of respondents who had an alliance and clinical/field trials (48%). 13% reported alliances for the purpose of undertaking basic research[49], see Figure 4.13.

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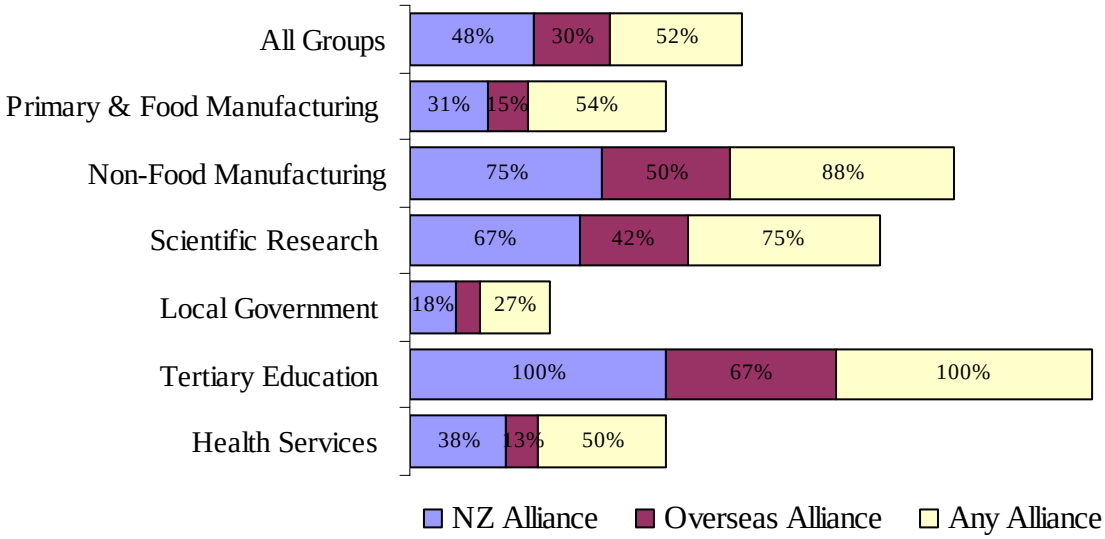
[47] "In the last 3 years did this business have any partnership/alliance for undertaking biotechnology activity (research or production)?"

[48] Respondents were not asked how many different organisations they had partnerships with. Data was collected on the different *types* of organisations with which they formed alliances e.g. CRIs businesses, universities etc both in NZ and overseas.

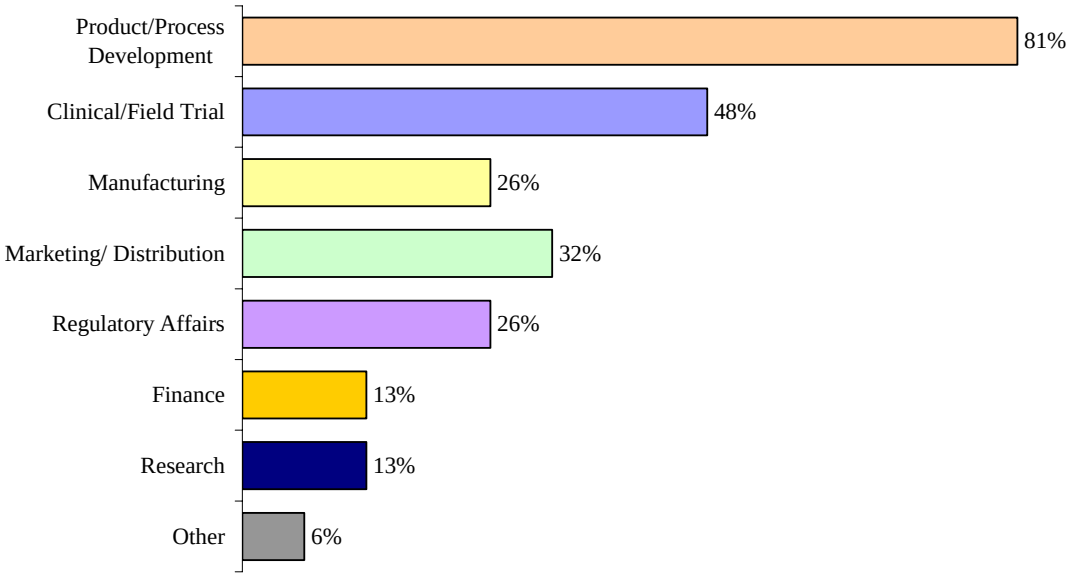
[49] Based on answers in the 'other' category - this may be an underestimate since the questionnaire did not include a basic research option.

Figure 4.12 Percentage of Respondents Reporting Biotech Alliances (1998/99)



Source: Marsh (2001b, p. 17)

Figure 4.13 Purpose of Biotech Alliances (1998/99)



Source: Marsh (2001b, p. 18)

4.7.2 Data from the 2001/02 Survey

84% of respondents to the 2001/02 survey reported a biotech partnership or alliance with a total of 406 different organisations. The higher incidence of alliances compared to the 1998/99 survey was expected, given the different characteristics of the survey population. While most enterprises (88%) reported up to 10 alliances; two organisations reported 90 and 50 different alliances respectively[50], see Table 4.21.`

Table 4.21 Frequency Distribution for No. of Alliances

Number of Alliances	
1-3	51%
4-10	37%
10+	12%

Source: Marsh (2002).

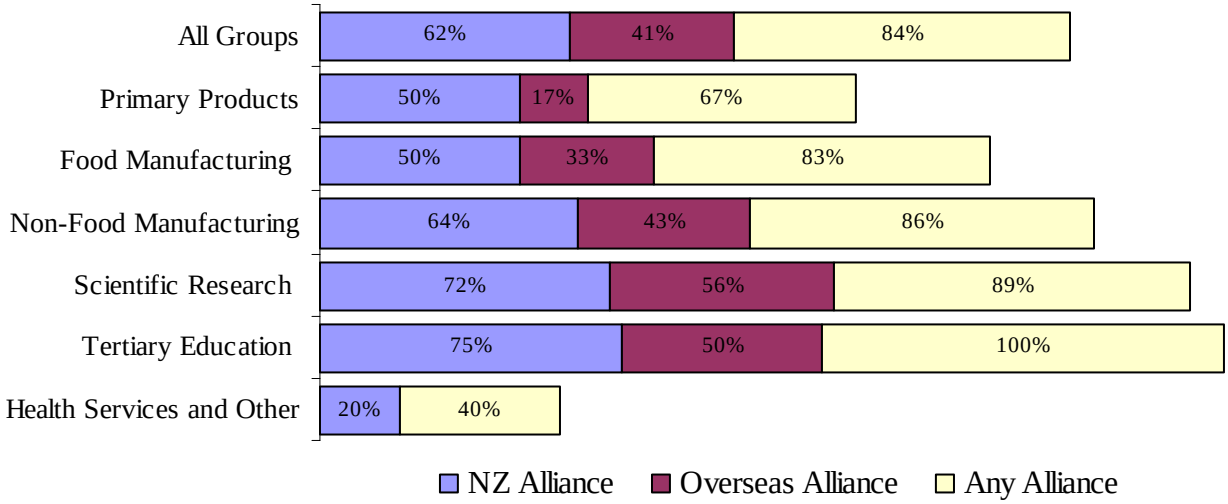
The proportion of respondents reporting a biotech alliance was high in all industry groups, varying from 100% in the tertiary education group to 40% for 'health services and other' (a small group including some enterprises that did not conduct significant R&D).

Overall 62% reported at least one New Zealand alliance while 41% reported an overseas alliance. Overseas alliances were most common in the tertiary education, and scientific research groups, see Figure 4.14.

The most commonly reported alliance purposes were product/process development – reported by 82% of respondents who had an alliance and basic research (74%), see Figure 4.15. A higher proportion of alliance partners were engaged in basic research than reported in the 1998/99 survey. This can be explained by differences in the survey population and the lack of a specific question about basic research in the earlier survey.

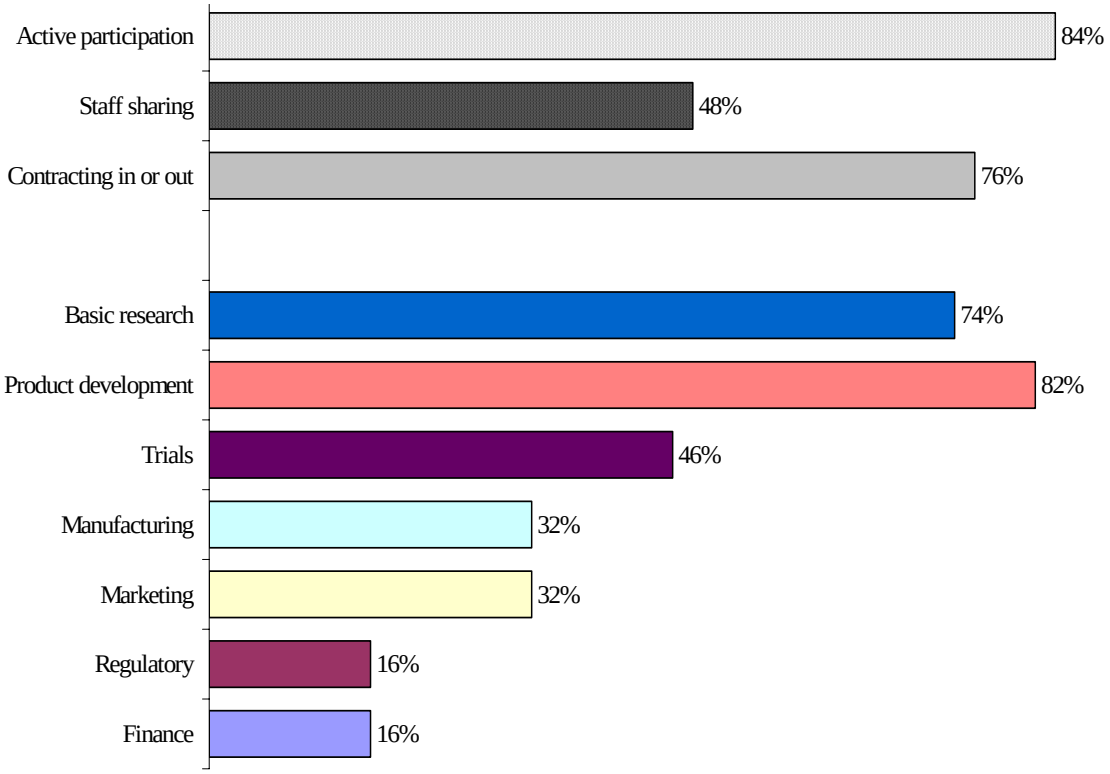
[50] A university 'sub-unit' with around 100 staff conducting R&D reported 90 different 'partnerships or alliances'; many of these are 'academic collaborations'.

Figure 4.14 Percentage of Respondents Reporting Biotech Alliances (2002)



Source: Marsh (2002)

Figure 4.15 Alliance Type and Purpose

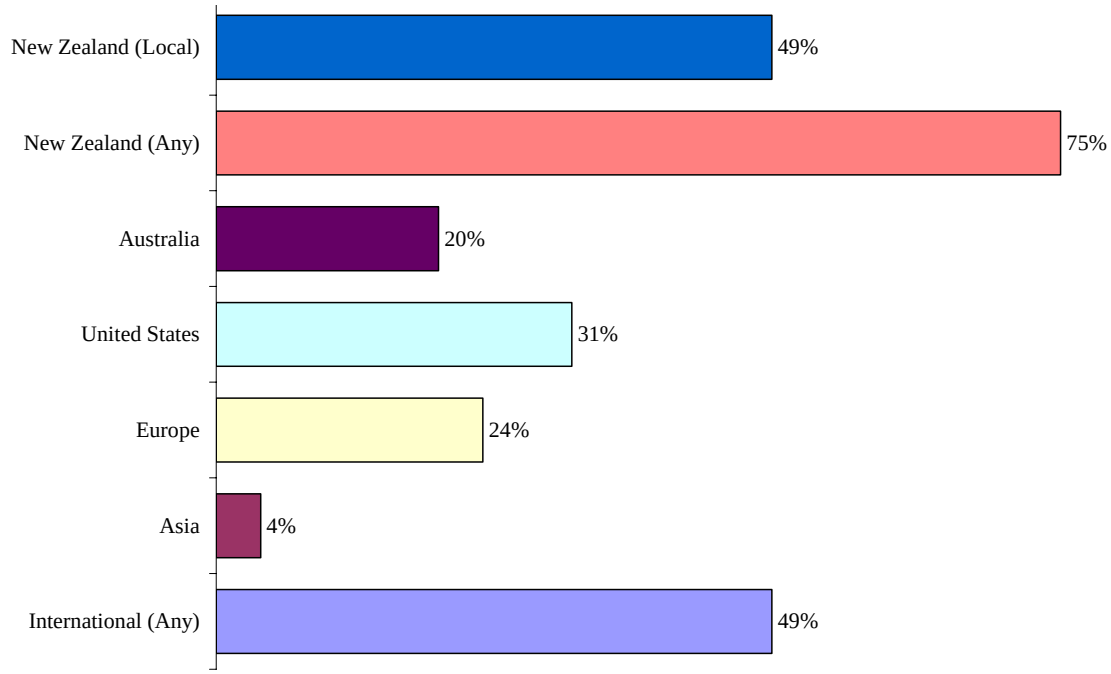


Source: Marsh (2002).
Note: Percentages expressed as % of number of enterprises with an alliances.

A high proportion of alliances had characteristics that would indicate active and substantive partnerships. 84% of respondents (with alliances) reported that at least one alliance involved 'active participation by both parties', 76% had alliances involving 'contracting in or out' and 48% had alliances involving 'staff working or training at partner locations', see Figure 4.15.

Respondents were asked to report on the key characteristics of their three most important partnerships; 55% of these involved New Zealand partners, followed by 19% USA, 14% Europe, 9% Australia[51]. Figure 4.16 summarises data on the percentage of respondents with at least one alliance in different countries.

Figure 4.16 Percentage of Respondents with Alliance Partners, by Country



Source: Marsh (2002). Notes: Percentages expressed as % of number of enterprises with an alliance. International (Any) excludes Australia.

Most alliance partners were universities/polytechnics (32%), larger firms (27%), smaller firms (17%) or CRIs (16%)[52].

[51] Based on data for 117 different partnerships/ alliances, from 50 respondents with partnerships/ alliances.

[52] See footnote 51.

Partnerships were established between 1956 and 2001. 54% of partnerships had been established in the last 3 years; providing some support for the observation that partnership activity has increased in recent years[53].

Respondents were asked to rate 'partnership outcomes to date'; 50% were described as 'very productive' and 44% as 'somewhat productive'. Only 6% were reported to be 'not very/not at all productive', see Table 4.22. The relationship between perceived alliance productivity and other variables is explored in Chapter 6.

Table 4.22 Alliance Outcomes

Industrial Group	Very Productive	Somewhat Productive	Not Very Productive	Not at all Productive	No. of Alliances
Primary products	60%	40%	0%	0%	5
Food manufacturing	56%	33%	0%	11%	9
Non-food manufacturing	52%	41%	7%	0%	27
Scientific research	52%	43%	2%	2%	44
Tertiary education	48%	45%	7%	0%	29
Health services & other	0%	100%	0%	0%	3
Total	50%	44%	4%	2%	117

Source: Marsh (2002).
Note: Based on up to three of 'the most important partnerships' per respondent.

[53] This result is based on a subset of the data; respondents reported year of formation for only 50 out of 117 of the 'three most important partnerships/alliances'.

4.8 Information Sources

One of the more detailed investigations into information sources for technological learning in New Zealand was carried out by the Foundation for Research Science and Technology (FRST) in 1996/97[54]. The review sought to identify ways in which government could accelerate and enhance technological learning. It was based on 500 personal interviews and 666 mail survey responses. The review highlighted widespread concerns about the availability of science and technology information to users:

> Many concerns about access to information relate to the behaviour of science providers (especially CRIs), often in relation to their intellectual property, commercial confidentiality and charging policies…The Review identifies a wide and pervasive trend among user and other stakeholder groups to be more restrictive and less willing to share information. This trend is occurring even in sectors such as agriculture and horticulture with long traditions of open and free exchanges of information and new ideas…There is a view that CRIs (or at least some CRIs) are ignoring small companies in favour of building more commercially profitable relationships with larger businesses (Hodgson et al., 1998, p. 23-4).

The review report describes sources and forms of technological learning and 'learning concerns' separately for 233 'technological learning groups[55]'. The review could usefully have identified a smaller number of broad categories based on key characteristics of technological learning. Such categories might then have been related to industrial groups, learning concerns and other variables.

Unfortunately very little aggregate analysis was ever reported[56]. Qualitative data from selected technological learning groups associated with biotechnology have been used to create Table 4.23. Unfortunately the qualitative approach adopted in the report does not allow any conclusions to be drawn on the relative importance

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[54] Reported in Hodgson, P., Howe, J., Saunders, R., & Winsley, P. (1998).

[55] "The taxonomy of 233 technological learning groups was developed over time … with this taxonomy being "grounded" in the experiences and perceptions of research end users, rather than being determined *a priori*"(Hodgson et al., 1998, p. 9).

[56] The decision not to aggregate was defended by the authors; "the level of detail achieved in producing the 233 technological learning group summaries at an end user organisational level means it is more appropriate to present the complete material in Annex 6 rather than attempt to generalise the results of the Review in a way that would mask the differentiated nature of learning and diminish the usefulness of the review"(Hodgson et al., 1998, p. 6).

of different information sources. Furthermore data source coverage in different technological groups appears to be patchy; for example private laboratories might be expected to make some use of trade literature and equipment suppliers. This patchiness may perhaps be a consequence of the qualitative methods used in the survey.

Table 4.23 Technological Learning Sources 1997

Technological Learning Source	Animal Vaccines and Remedies	Drugs and Medicine Manu-facturers	Dairy Food Product Companies	Private Lab-oratories	Private R&D Companies
Customers	✓		✓	✓	✓
R&D Staff	✓	✓	✓	✓	✓
Senior Management	✓		✓	✓	✓
Journals	✓	✓		✓	✓
Trade Literature	✓	✓	✓		
CRIs	✓	✓			✓
Universities	✓		✓	✓	✓
Overseas research institutes		✓			
Overseas Licences		✓			
Suppliers (raw materials)		✓	✓		
Suppliers (equipment)		✓	✓		✓
Research Associations		✓	✓		
Competitors			✓	✓	
Conferences and Trade Fairs			✓		

Source: Hodgson et al., (1998).

Statistics New Zealand's 2001 Business Practices Survey provides some useful information on the sources of ideas and information used in innovation. One question related to whether innovations relied on internal or external information sources, or both;

> product innovations relied more on external resources than process innovations. Twenty-one percent of product innovators relied on external resources compared with 8 percent of process innovators. Process innovators relied mainly on internal resources (55 percent), while the proportion of product and process innovators relying on a combination of internal and external resources was about the same (just under a third).

The BPS also provides data on the percentage of innovators making use of different information sources, see Figure 4.1. It can be seen that the most used

sources were ‘competitors’, ‘books, trade journals and conferences’ and ‘industry associations’.

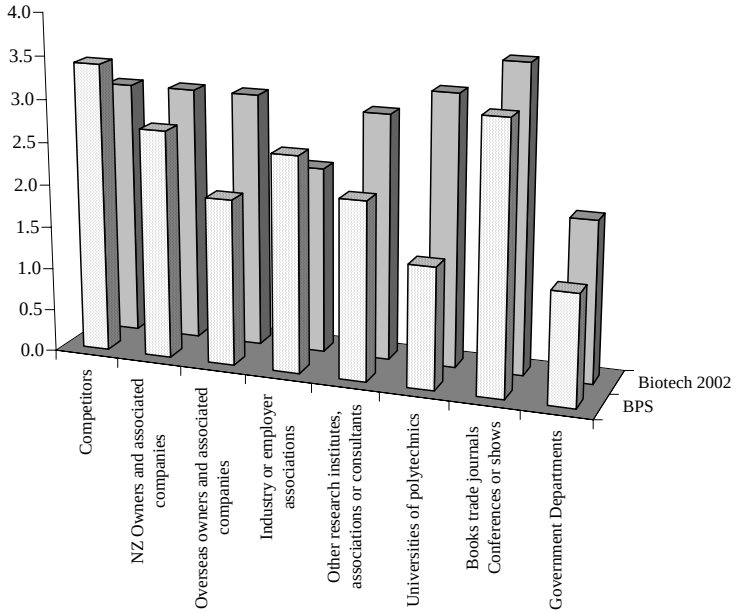
Figure 4.17 Sources of Information for Innovative Business

Source: Statistics New Zealand (2002, p. 23)

Data on the relative importance of these different sources in all New Zealand firms can be compared with the 2002 Biotech Survey[57], see Figure 4.18. Biotech respondents ranked the research institutions, universities/polytechnics and ‘books, trade journals and conferences’ more highly than the average for BPS respondents, while BPS respondents ranked industry or employer associations more highly.

[57] Mean scores were created based on Statistics New Zealand category ‘very important’=5, ‘somewhat important’=3, ‘not important’=1. Category descriptions across the two surveys do not exactly match.

Figure 4.18 Comparison of Information Sources, BPS and Biotech Survey 2002



Sources: Marsh (2002) and Statistics New Zealand (2002).

Table 4.24 Information Sources, Biotech Survey 2002

	Low				High	*Not Applicable*	Mean Score
	1	2	3	4	5		
Own staff or staff in parent/subsidiary	0	2	10	16	27	*5*	4.2**
Hiring new staff with required 'know-how'	3	7	12	15	10	*11*	3.5*
Personal contacts with others	2	2	8	19	26	*2*	4.1**
Conferences/workshops/trade shows	3	7	13	25	11	*0*	3.6*
Other Firms	8	7	19	13	4	*7*	3.0
Crown Research Institutes	13	11	16	8	7	*4*	2.7
Other Research Organisations	5	10	23	11	6	*4*	3.1
Universities, Polytechs, research networks	6	9	18	13	10	*3*	3.2
Hospitals	23	9	7	2	1	*17*	1.8
Government departments/agencies	24	11	13	2	1	*8*	1.9
Professional/industry associations	15	16	14	3	2	*6*	2.2
Other organisations			1			*5*	3.0
Academic journals and trade publications	0	3	10	22	25	*0*	4.2**
Library/literature search	2	5	8	24	20	*0*	3.9*
Database retrieval services	5	7	11	15	19	*3*	3.6*
Patent disclosures	15	9	7	9	11	*8*	2.8

Notes: The symbols ** mark sources ranked first to third, * marks sources ranked 4th to 7th. Modal scores for each source are shaded.

Source: Marsh (2002).

4.9 Other Factors Affecting Innovative Performance

The 2001 survey asked respondents to rank a list of factors "that may affect the amount of innovation produced by your business", see Table 4.25. Many of the results are unsurprising; for example 'quantity of funds available for R&D' is ranked most highly, followed by 'number and quality of R&D staff' and 'appropriability (ability to profit from the innovation)'.

These mean scores hide some important patterns in the way that respondents answered this question. The most controversial question relates to the impact of 'one or a few star scientists'; 18 respondents regarded this as being highly important (score 5), while 14 clearly disagreed giving this item a score of 1.

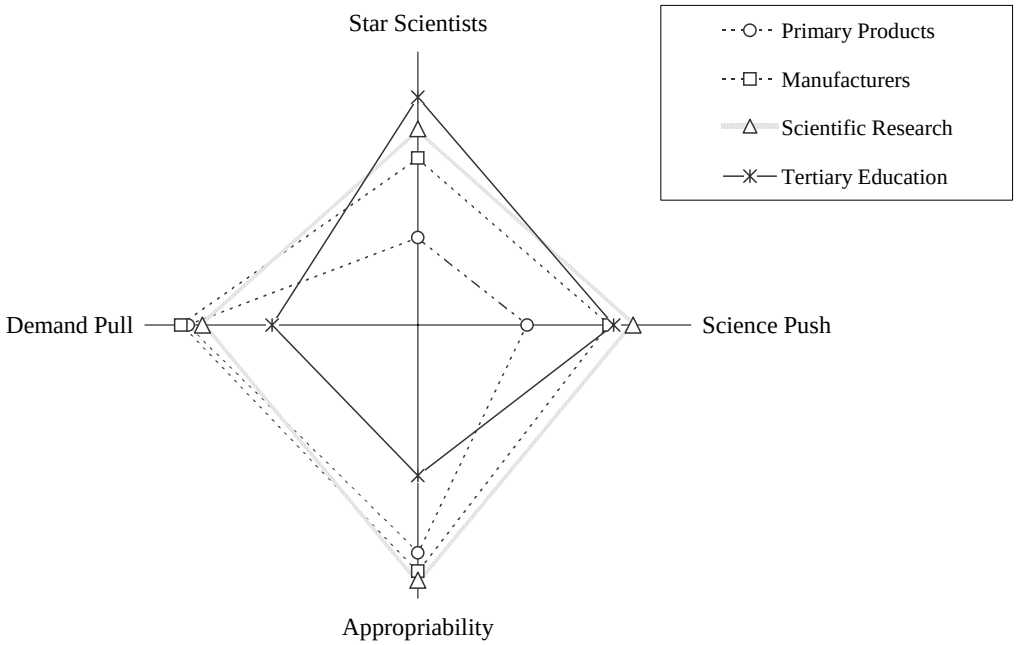
Table 4.25 Factors Affecting Business Performance 2002

	Low				High	Mean Score
	1	2	3	4	5	
Conditions in your business						
Quantity of funds available for R&D	1	2	9	16	31	4.3**
Quality of the R&D environment	4	2	9	19	25	4.0
Number and quality of R&D staff	3	3	5	18	28	4.1**
One (or a few) 'Star Scientists'	14	4	8	12	18	3.3
'Science push' or technological opportunity	5	4	16	20	10	3.5
Quality of links with other organisations *in New Zealand*	4	8	23	17	7	3.3
Quality of links with *overseas* organisations	4	5	11	21	16	3.7
Ownership of intellectual property	10	8	9	12	19	3.4
Appropriability (ability to profit from the innovation)	3	5	4	15	31	4.1**
Links with purchasers or consumers e.g. 'demand pull'	6	7	4	18	21	3.7
Conditions in New Zealand						
Quality/quantity of Basic Science carried out	6	6	13	20	12	3.5
Quality/quantity of Applied Science carried out	5	6	11	23	12	3.5
R&D environment e.g. regulations, incentives, attitudes etc	5	5	13	13	20	3.7

Notes: The symbols ** mark sources ranked first to third,
Modal scores for each source are shaded.
Source: Marsh (2002).

Figure 4.19 illustrates some of the differences between industrial groups in the perceived importance of different factors. Enterprises in tertiary education place greater weight on ‘star scientists’ and ‘science push’ and regard ‘appropriability’ and ‘demand-pull’ as less important. By contrast, primary product enterprises rank ‘demand-pull’ and appropriability as being more important. Mean scores for manufacturers and scientific research organisations were similar for these four factors; perhaps reflecting the importance of commercial incentives for organisations in the scientific research category.

Figure 4.19 Mean Factor Scores by Industrial Group



Source: Marsh (2002).

4.10 Summary and Conclusions

4.10.1 Sector Size and Definition

Different interpretations of the terms biotechnology and biotechnology sector hinder attempts to measure biotech activity in a way that is comparable over time and across nations. Size estimates for the New Zealand biotech sector range from 30 core biotech companies with annual income of the order of $200 million, to many thousands of companies having annual production worth several billion dollars, when traditional food applications such as cheese, yoghurt and beer are included.

The economic literature since the mid 1980s has generally concentrated on modern biotechnology and the biotech sector is often taken internationally to refer to the population of 'core' private sector enterprises that conduct R&D into *modern* biotechnology. In this thesis the modern biotech 'sector' is defined as the population of private and public sector enterprises that carry out modern biotech R&D. Based on this definition, New Zealand's modern biotech 'sector' consisted in 1998/99 of approximately 57 enterprises, employing around 1700 people. Most activity was concentrated in universities, Crown Research Institutes (CRI) and a small number of private sector companies e.g. Genesis, Virionyx, ViaLactia.

4.10.2 International Comparisons

The OECD has taken the lead in attempting to develop internationally comparable statistics on biotechnology. Data on public funding of biotechnology and patents were included in its Science, Technology and Industry Scoreboards for 2001 and 2003 (OECD, 2001, 2003a) but the variety of definitions and data collection methods make reliable comparisons almost impossible. In the 2003 scoreboard New Zealand is reported to put the highest proportional effort into biotech R&D (biotech R&D as a proportion of total R&D). This results both from New Zealand's R&D specialisation in the primary sector and from use of a broad definition of what constitutes biotech R&D. Not surprisingly, a rather different picture emerges in absolute terms with New Zealand's total biotech GBAORD being the third smallest of the 21 countries listed (see section 4.2.5)

A more accurate international comparison can be made with Canada, based on data from the Statistics New Zealand biotech survey, since this was closely modelled on surveys carried out by Statistics Canada. New Zealand's biotech revenue per million population (NZ$54 million) is rather lower than Canada's (NZ$94 million), but the difference is fairly small considering Canada's higher per capita income and proximity to the United States. New Zealand has a rather lower mean revenue per biotech firm (NZ$5.3m vs. NZ$8.0m); consistent with the predominance of small firms in the New Zealand economy. New Zealand appears to have a significantly higher rate of biotech employment. There is some evidence that use of biotech processes in New Zealand is at an earlier stage with 72% being at the R&D stage against 49% in Canada.

4.10.3 Sector Characteristics

Enterprises in the modern biotech sector are split fairly evenly between the private sector and the public sector. They reported expenditure on biotech of NZ$202 million and income from biotech of NZ$236 million for 1998/99. This compares to enterprise income from all sources of NZ$2.1 billion i.e. biotech provided around 11% of income for the 57 enterprises. More recent data indicates that annual growth in expenditure may be as much as 20%.

Respondents to the 2002 biotech survey indicated that R&D constituted around 10% of total expenditure while expenditure on biotech R&D comprised around 80% of all biotech expenditures. Around 60% of all 'biotech staff' were engaged in R&D. Respondents spent far more on R&D than the industry average. For example the dairy industry is reported to spend around 1% of turnover on R&D, while R&D expenditure as a proportion of value added of manufactured products was 1.3 percent in 1999/2000 (see section 4.4.1.2).

The government has been estimated to spend around NZ$127m a year on all biotechnology-related research, ranging from genomics to processing of natural products. Biotechnology-related research comprised around 15% of total government R&D spending in 2000.

Data on the age distribution of biotech processes provides useful information on the development of the biotech industry over time and may also be compared with similar data from overseas. Average age in use in New Zealand is longer than in Canada for all but two process categories, possibly because of the lower number of new entrants in New Zealand. There are distinct differences between modern and older biotechnology processes. Genomics exhibits a typical age structure for a recent process; 56% have used this process for 5 years or less, 83% have used it for 10 years or less. Extraction/purification/separation is typical of a more mature technology; 24% started using this process within the last 5 years (often these are new enterprises). A further 24% have been using this process for at least 20 years (see section 4.3.3)

4.10.4 Innovative Output

In June 2001 Statistics New Zealand conducted the first economy wide Business Practices Survey (BPS). The BPS collected information on three aspects of business activity: use of information technology, innovation and management practices (Statistics New Zealand, 2002). Statistics New Zealand (2002) reports that: “the level of innovative activity carried out by New Zealand enterprises is at least equal, if not higher, than that indicated in a survey of European Union (EU) countries”. Review of the innovation literature suggests that Statistics New Zealand should be cautious of making such claims on the basis of one set of survey results. For example Tether (2001, p. 17) reports that comparisons between sectors and between countries are problematic for a number of reasons (section 4.5.2).

One indication of the rate of innovation by biotech respondents is provided by questions such as: “In the last 3 years, how many new or significantly improved products or processes has this business introduced on to the market?” Overall, 51% of respondents to the 2002 biotech survey reported implementation of a new *product* with the innovation rate being lowest for food manufacturers (33%) and highest for non-food manufacturers (79%). Process innovation rates were much lower with only 21% reporting implementation of a new process in the last 3 years; this is notably different to the 1998/99 survey when 33% of enterprises

reported introduction of new products and the same percentage reported introduction of new processes.

Further work is required before definite conclusions can be reached on the relative innovative output of New Zealand biotech firms, although the evidence reviewed in section 4.5.2 suggests that New Zealand biotech firms do not have a particularly high rate of new product or process development relative to other New Zealand sectors or to other countries.

4.10.5 Data on Patenting

New Zealand's rate of modern biotech patent applications over the five years to the end of 2002 was 3.7 per million of population, per year. This is below the average for the G7 (5.3) and for a reference group of small, developed OECD economies (5.5). Patent application rates range from a high of 15.2 for Denmark to a low of 0.5 for Italy. Overall New Zealand ranks eleventh out of 18 with a patenting rate above that found in France and Japan. However New Zealand's performance is disappointing compared to other small countries with strong primary industries that it might hope to emulate e.g. Denmark (15.2), Switzerland (10.9), Netherlands (5.5), Australia (4.1).

Comparison of the three-year periods 1997-99 and 2000-02 reveals an average increase in patenting rates of 51%. New Zealand has increased its performance relative to the OECD and Australia; although the rapid change in patent application rates may, in part reflect an increased propensity to patent in universities and Crown Research Institutes.

Regressing C12N patenting rates against population produces a surprisingly good fit with 75% of the variation in applications being explained by population size. Based on this analysis New Zealand is very close to the trend line; its C12N patent rate is close to the expected value, after adjusting for population size. There are few real outliers, although Denmark and Switzerland have a rather higher patenting rate than expected, while the rate for Italy and Ireland is lower than expected (see section 4.6).

4.10.6 Biotech Alliances and Other Factors

Most enterprises (84%) responding to the 2002 biotech survey had at least one alliance involving biotech activity, 62% reported at least one New Zealand alliance while 41% reported an overseas alliance. Overseas alliances were most common in the tertiary education, and scientific research groups. The most commonly reported alliance purposes were product/process development; reported by 82% of respondents who had an alliance and basic research. Respondents were asked to rate 'partnership outcomes to date'; 50% were described as 'very productive' and 44% as 'somewhat productive'. Only 6% were reported to be 'not very/not at all productive'. Further details of biotech alliances are reported in section 4.7.

Section 4.8 provides data on the main sources of information used by enterprises in the biotech sector while section 4.9 focuses on a range of other factors that affect innovative performance. There are some significant differences between industrial groups in the perceived importance of different factors. Enterprises in tertiary education place greater weight on 'star scientists' and 'science push' and regard 'appropriability' and 'demand-pull' as less important. By contrast, primary product enterprises rank 'demand-pull' and appropriability as being more important.

This chapter has provided a detailed description of the New Zealand biotech sector based on data collection and analysis carried out by Marsh (2001b; 2002) and a review of secondary sources. This description sets the scene and provides context for the study of the determinants of innovation described in Chapters 5 and 6. Prior to this analysis our knowledge of most sector parameters was very limited or completely lacking. There is a need for policy makers to make more use of the available data, rather than continuing to use less reliable estimates produced by organisations that have a vested interest in exaggerating the size of the sector.

Chapter 5 Analysis of the Institutional Setting for Biotechnology in New Zealand

5.1 Introduction

This chapter makes use of a combination of secondary sources and data from interviews to analyse the institutional setting for biotechnology in New Zealand. The innovation framework adopted in this thesis suggests that institutional factors are important determinants of innovative output (hypothesis 9, see 3.10). The qualitative approach pioneered by Nelson and (1993b) is used in order to describe the institutional setting and test this hypothesis.

Following Nelson the analysis uses systems of innovation (SI) methodology and starts with an assessment of New Zealand's innovation system for biotechnology[1]. Such a system can usefully be defined as "a network of agents interacting in a specific technology under a particular infrastructure … and involved in the generation, diffusion and utilization of technology" (Carlsson et al., 1999, p. 12). Central to the innovation systems approach is the idea that the existence of a well functioning system fosters innovation and economic growth. The analysis also makes use of the conceptual framework from the OECD's Oslo Manual on the measurement of scientific and technological activities, to analyse the institutional factors that affect the innovative output of the New Zealand biotechnology sector, and the effectiveness of New Zealand's innovation system for biotechnology.

The Oslo Manual (1997b, p. 31) conceptual framework organises factors that may affect innovation into four main categories:

i. the *framework conditions* of national institutional and structural factors
   e.g. economic, financial and educational setting and the rules and range of opportunities for innovation

ii. the *science and engineering base*

[1] An earlier version of this chapter was published as: Marsh, D. (2003). *Does New Zealand Have an Innovation System for Biotechnology?* Technovation, 23(2) February, 103-112.

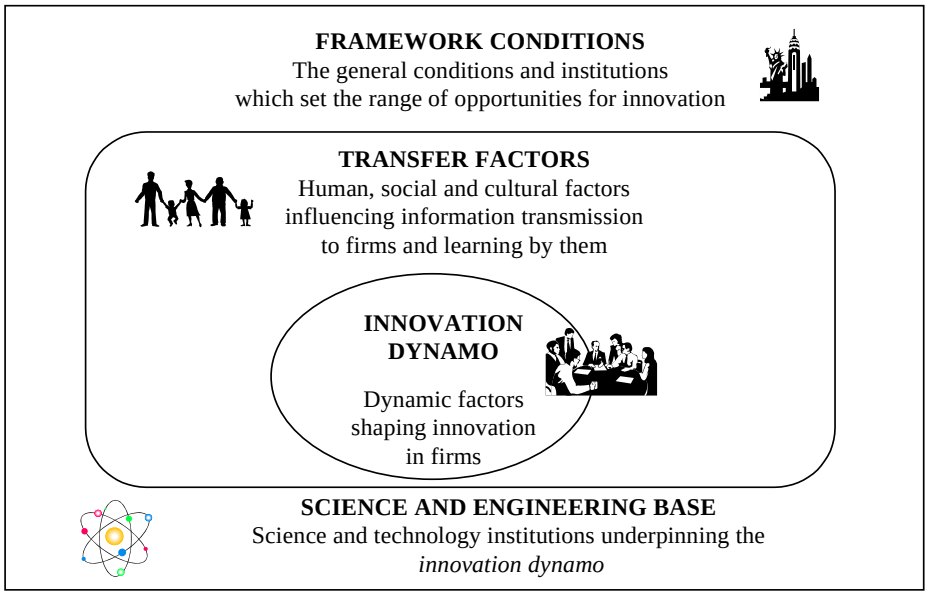
the accumulated knowledge and the science and technology institutions which underpin innovation

iii. *transfer factors*
which strongly influence linkages and flows of information etc which are essential to innovation

iv. the *innovation dynamo*
dynamic factors shaping innovation at the level of the firm.

These four categories can be presented as a map; the innovation policy terrain (Figure 5.1) that highlights the main categories of factors affecting innovation and points to areas that need to be taken account of when formulating policies relating to innovation.

Figure 5.1 The Innovation Policy Terrain



Note: Adapted by the author based on OECD(1997b)

Previous chapters have described and analysed different parts of the innovation policy terrain. Framework conditions for innovation and the science and engineering base were introduced in chapter 1, while chapters 4 and 6 present detailed analysis of the innovation dynamo (factors shaping innovation in firms) and transfer factors. This chapter brings these different strands together, and

presents some additional information on framework conditions in order to assess the effect of institutional factors on innovation in New Zealand's biotech sector.

The Oslo manual framework follows the Systems of Innovation (SI) approach (Freeman, 1987; Lundvall, 1992b; Nelson, 1993b). Central to this concept is the idea that the overall innovation performance of an economy depends not so much on how specific organisations perform but on how well they interact with each other. Systems of innovation have been analysed at several levels ranging from sectoral and enterprise specific innovation systems, to local, national, regional and global systems of innovation.

Bartholomew (1997) was perhaps the first author to refer to a *national system of biotechnology innovation* which she defined as "the specific institutional arrangements within a country which affect the generation of scientific knowledge relevant to biotechnology, and the diffusion of that knowledge throughout industry".

Country specific factors in the development of the biotechnology industry have been extensively investigated often within an SI framework e.g. in Canada, Japan and Germany (Arundel & Rose, 1999; Fransman & Tanaka, 1995; Momma & Sharp, 1999). Less work has been published on smaller or less developed economies with the exception of Fontes and Novais (1998) on Portugal, Rickne (2002) on Sweden and various authors (Janszen & Deganaars, 1998; van Geenhuizen, 1999) on the Netherlands.

This chapter makes use of interviews conducted in 2000 as part of a scoping study into the New Zealand biotech sector. The scoping study aimed to achieve an improved understanding of the New Zealand biotechnology sector with a particular focus on issues affecting innovation. Data collected in the study are reported directly in this chapter[2], and were also used to facilitate design of the larger scale questionnaire survey conducted in 2002 (see chapter 6 and appendix 3). Senior members of ten leading firms and other organisations were

[2] and in other publications e.g. Marsh (2000; 2001a; 2003)

interviewed using a semi-structured method that included a core list of standard questions and also addressed other issues of interest as they arose. All interviews were taped and fully transcribed. Quotations in this chapter refer to these transcripts and are referenced as interviews A-H in order to preserve the anonymity of the interviewees.

5.2 New Zealand's Innovation System for Biotechnology

New Zealand's innovation system for biotechnology is dominated by Crown Research Institutes and universities which rely on the government for the majority of their funding. Research and teaching in biotechnology is carried out in seven of New Zealand's eight universities. Biotechnology research is also carried out at eight of the country's nine Crown Research Institutes. Indeed this spread of activity has been argued to be a serious waste of resources by some who believe that it would be more efficient to concentrate biotech research into a smaller number of sites[3].

Data from interviews with biotech industry representatives carried out as part of this study provide little evidence for the existence of a well functioning innovation system for biotechnology. Private firms did not place high importance on strong linkages with CRIs and universities. Universities and CRIs do not generally have particularly strong linkages; indeed the relationship is often more one of competition for scarce research funding. Nor is their much movement of staff between CRIs, universities and the private sector. Turnover at the CRI HortResearch was reported to be 3-5% per annum "there were limited cross-CRI transfers and just a few people moving on to universities or polytechnics" (Clark et al., 1999, p. 6).

[3] Such views led the government to provide special funding of $10-$13 million per year for 'Centres of Research Excellence'. The first seven centres were selected in 2002. Four work mainly within the field of biotechnology, a fifth (the New Zealand Institute of Mathematics and its Applications) has applications for biotech e.g. bio-engineering and bio-informatics (Royal Society of New Zealand, 2002) and http://www.rsnz.org/funding/core/.

Some private firms placed little emphasis on linkages in development of biotechnology innovation; others found few organisations worth linking with (perhaps because the use of modern biotechnology in New Zealand is so limited) and so concentrated on developing strategic alliances and joint ventures with overseas partners. Others felt that CRIs and universities have little to offer them: "they operate on a completely different time horizon … the difference between commercial reality and university and government research is so wide that most people cannot understand that what they are doing never actually achieves a desired outcome" (interview C).

This view is supported by another biotech CEO quoted in Mazoyer (1999): "NZ does not have a broad range of public research agencies that are well inter-linked. There may not be much cross-over into industry – in fact the public research system seems to operate in a sector of its own". Opinion is divided as to whether it is the public research agencies which don't meet the needs of the private sector or the private sector which has a limited ability to apply the results of publicly funded R&D or to evaluate opportunities (Winsley, Couchman, & Gilbertson, 1998, p. 61). It is not surprising then, that Mazoyer goes on to conclude that "commercialisation is sometimes hindered by a lack of interaction between the science sector and manufacturers … [and that] more effective learning interactions and networking between scientists, public and private investors and users needs to be encouraged" (1999, pp. 6-7).

Modern biotechnology activity in New Zealand may perhaps be better described through the idea of 'islands of excellence'. Leading edge work is carried out in a number of areas; but these islands of excellence tend to collaborate strongly with a small number of other organisations rather than being strongly connected to any wider innovation system. A good example is provided by the forestry industry where a small number of leading companies collaborated with the Forest Research Institute to promote research into forest biotechnology. A New Zealand company was able to develop the ability to genetically transform pine trees using a company scientist, a recent graduate with an MSc in biotechnology and email contact with a colleague in Canada (interview D). This is now an area where New Zealand based firms and scientists are at the forefront of technology. Arborgen,

one of the world's leading forestry biotechnology companies is a joint venture between two huge US companies (International Paper and Westvaco Corporation) and three New Zealand companies (Fletcher Challenge Forests, Genesis and Carter Holt Harvey).

While New Zealand's position in forestry genetics owes much to 'industry pull' the drivers of innovation in other areas are quite different. Scientists at AgResearch and the University of Otago perform world leading research in the field of sheep genetics where they are reported to have acquired "a very good base for driving forward in biotechnology [that was] … totally driven by scientists … irrespective of what the industry thought they needed" (interview F). A different model again is provided by Genesis, where research excellence at the University of Auckland Medical School seems to have played a key role. Jim Watson was head of the Department of Molecular Medicine before he used his understanding of signalling molecules to found Genesis Research and Development (interview B). Genesis has strong partnerships with three CRIs, Fonterra and six overseas companies[4], however during its start-up phase, it could best be characterised as being part of the international innovation system for biotechnology rather than having particularly strong links with many New Zealand based institutions.

5.3 Framework Conditions for Innovation

Many of those interviewed for this study had serious concerns about New Zealand's framework conditions for innovation. They focussed particularly on the lack of a pro-business environment, national attitudes to entrepreneurs and risk takers and the regulatory framework which has made New Zealand an expensive country in which to do business. One interviewee cited the increase in the top rate of income tax as an example of negative attitudes to business that has harmed their ability to recruit scientists internationally. He also expressed the opinion that "we don't like people being enterprising, we don't admire people being rich [and]… if we don't have an admiration for people taking risks and being successful then we won't have innovation in biotechnology".

[4] See http://www.genesis.co.nz/partnerships.asp

Increasing levels of popular concern over the safety of some modern biotechnologies culminated in the setting up of the Royal Commission on Genetic Modification to inquire "into and report on the strategic options available to enable New Zealand to address genetic information now and in the future" (Royal Society of New Zealand, 2000). The Commission spent over NZ$6 million and 14 months listening to all sides of the debate before concluding "that New Zealand should keep its options open. It would be unwise to turn our back on the potential advantages on offer, but we should proceed carefully, minimising and managing risks" (Royal Commission on Genetic Modification, 2001, p. 2). In October 2001 the government announced its response to the Royal Commission report, including permission for field trials to restart and a two-year ban on commercial release of genetically modified products. In October 2003 the ban was lifted amidst much vocal public opposition from 'GE Free' lobby groups[5].

Work on genetically modified and new organisms in New Zealand is controlled by the Hazardous Substances and New Organisms (HSNO) Act 1996 which aims to "protect the environment, and the health and safety of people and communities, by preventing or managing the adverse effects of hazardous substances and new organisms" (Environmental Risk Management Authority, 1999). Serious concerns have been expressed both about the degree of control and the associated delays: "it can take 18 months to get approval from ERMA to do a piece of research … by the time you get approval to do it, it is a whole new world, literally"(interview A). The University of Otago recently fell foul of ERMA regulations on "a very low risk project that in any other country would not require the approval of a regulatory authority" (Cassie, 2000). There are concerns that implementation of recommendations from the Royal Commission will make New Zealand's regulatory regime even tighter.

On the positive side, research costs are estimated to be 40% below international levels (New Zealand Trade Development Board, 2000, p. 4). This and New Zealand's rigorous border controls and relatively disease free status have been

[5] This refers to groups who believe that New Zealand should be kept 'free' of all genetically modified organisms.

pushed heavily by BIOTENZ and the New Zealand Trade Development Board in an attempt to increase overseas funding of biotechnology activities in New Zealand.

Unfortunately these low research costs are a double-edged sword when it comes to attracting overseas talent and retaining top New Zealand scientists as illustrated by the following quote from a CRI manager: "We were recruiting a plant breeder. We had a very good candidate from the US who we brought out here. We paid for him to come out. We said we don't want you to come just for an interview, come for a week. You need to find out about us and we need to find out about you. He was our preferred candidate. We offered him between $5,000 - $10,000 more per annum starting salary. So we really wanted this person. But he converted his dollars back and said 'No'" (Clark et al., 1999, p. 5).

5.4 Government Policy

Over the six years from 1984 to 1991 New Zealand engaged in "one of the most radical market liberalisation programmes initiated anywhere in the world" (Massey, 1995, p. xii), "transforming New Zealand from the most to the least regulated economy in the OECD" (Hazeldine, 1998, p. 1). These non-interventionist, free market policies continued to dominate the New Zealand political scene until the election of a new Labour government in 1999. There have been neither large-scale policy interventions designed to increase R&D spending nor major funding initiatives to promote biotechnology[6]. Indeed government and industry only seem to have started taking a close interest in biotechnology in the last four to five years (interview F). However, the present government is taking a more interventionist approach to science policy through the Growth and Innovation Framework (GIF) and the creation of task forces and sectoral strategies (see section 4.1).

[6] The current Labour Government has increased R&D spending in some areas and is promoting biotech through the New Zealand Biotechnology Strategy (Ministry of Research Science and Technology, 2003a), however neither of these initiatives are 'large-policy interventions' comparable to developments in many of New Zealand's competitors.

New Zealand's approach has until recently, contrasted strongly with some of its regional trading partners. In Australia, the federal government established two new agencies "to ensure Australia realises the potential gains being offered by biotechnology" (Biotechnology Australia, 2000). The Singapore Government has a strategy 'to position Singapore as the strategic hub for the pharmaceutical, biotechnology and health care industry in Asia' while Taiwan aims to develop into 'an Asia-Pacific R&D Center' and 'an Asia-Pacific Manufacturing Center for high-tech products'. Taiwan currently spends NZ$200 million per year on biotech and is increasing its technology budget by 10-15% per year (Rolleston, 1999, p. 43).

There is a significant level of dissatisfaction with government policy towards research, science and technology in New Zealand. Indeed Sommer (2001, p. 7) found that the 1996 and 2000 surveys of New Zealand scientists and technologists "indicate a stunning level of dissonance over New Zealand science and technology policy reforms". The statement "The management systems now in place are appropriate for the effective advancement of research," evoked 69.8% disagreement in 1996 and 70.9% in 2000. Similarly, the statement "The changes in the organization of New Zealand science over the past four years have enhanced my situation/conditions for performing innovative research," was disagreed with by 70% of panellists in 2000.

More specific criticisms are that "the science reforms produced an over-emphasis on incremental innovation or technology and undermined the science base, leaving less time for research from which big new ideas could emerge" (quoted in Mazoyer, 1999, p. 9); and a "focus on small projects focussed on individuals has taken away the ability of CRIs to build future science capabilities"(interview A). This is supported by Petersen (1998, p. 10) who suggests "there must be some mechanism that allows scientist to be kept on the payroll while alternative funding routes are worked out". There is a serious brain drain of students completing PhD's "because they are not prepared to spend the rest of their lives living from hand to mouth on short-term contracts".

On a more positive note some interviewees found that government programmes to encourage technology transfer were useful. They attributed low uptake of these programmes to company culture and short termism. Others said accountability requirements were excessive (Mazoyer, 1999, p. 10).

5.5 R&D Funding

It has been known for some years that New Zealand's expenditure on R&D is low relative to other OECD members. In 1996 New Zealand's gross expenditure on R&D (GERD) was 0.98% compared to 2% or over for G7 and a group of small OECD countries (Engelbrecht & Darroch, 1999). Spending by New Zealand industry, as a % of GDP was 0.26% in 1995, far below the OECD average of 1.46% (OECD, 1999, p. 131).

Data from the R&D surveys conducted in 2000 and 2002 (Ministry of Research Science and Technology, 2002, 2003b) show some significant increases, leading some to hope that a long awaited shift in attitudes towards R&D is finally taking place[7]. Figures released by Statistics New Zealand indicate a 30% increase in private sector spending on R&D[8], while GERD increased by 20% to 1.06% of GDP. However business expenditure on R&D (BERD) has been increasing in most OECD countries so a sustained period of above average growth in BERD will be required for New Zealand spending to reach the OECD average. While no comprehensive data are available on R&D expenditure on biotechnology[9], it may be logical to assume that "if New Zealand is bad at doing R&D generally it would [expect to be] a whole lot worse in the biotech area" (interview B).

One factor that would be expected to affect the level of R&D expenditure by industry is the tax and incentive regime. In a recent review of the evidence on the effects of fiscal incentives for R&D, Hall and Van Reenen (2000, p. 449)

[7] See '2002 R&D Stats Commentary' at http://www.morst.govt.nz

[8] Business expenditure on R&D (BERD) was 0.31%, 0.34% and 0.42% of GDP in 1998, 2000 and 2002.

[9] See chapter 4 for a discussion of available data on biotech expenditure in New Zealand.

concluded that "in the current (imperfect) state of knowledge … a dollar in tax credit for R&D stimulates a dollar of additional R&D".

All OECD countries except New Zealand have special tax schemes for R&D expenditures such as immediate write-off and various types of tax credit; indeed New Zealand came bottom of an OECD league table of the amount of tax subsidy for R&D (OECD, 1999, p. 135). In New Zealand, private sector expenditure of one dollar cost companies $1.13 after tax and compliance were included. This compared to 89 cents in Australia, 83 cents in Canada and 69 cents in Spain.

It has also been suggested that differences in national tax regimes may significantly bias reported levels of R&D expenditure. The negative treatment of such expenditures in New Zealand encourages under-reporting while the favourable treatment in other countries encourages widespread over-reporting.

Industry views appear to be somewhat polarised on whether the tax treatment of R&D spending has had a major effect on the level of expenditure in the private sector. Some large players saw this as a key influence: "the 150% tax rebate meant that you could do research for free in Australia and make money out of it … it was a pretty favourable regime – nothing like that here" (interview B). Others were more sceptical: "I have not seen results that suggest support of R&D delivers real commercial benefits" (interview C).

Difficulties in obtaining venture capital may also constrain start-up or expanding biotech firms in New Zealand, although some suggest "the lack of entrepreneurs who can build companies, rather than a shortage of money, is curtailing the development of new companies" (Springall, 2000). Until recently no venture capital appeared to be available for biotechnology and companies relied on traditional methods of funding. However there has recently been a marked increase in private sector funding. At a 1999 venture capital conference in Auckland one speaker concluded "New Zealand does not yet have a venture capital market. But we do have up to NZ$800 million in venture capital available for high-tech firms and another NZ$900 million already committed by 30 venture capital companies (Caragata, 2000)". Overall venture capital investment in

Australia and New Zealand combined has increased sharply over the last three years with the health/bioscience category showing a huge increase from A$7.9 million in 1998 to A$81 million in 1999 (Australian Venture Capital Journal, 2000).

5.6 Conclusions

New Zealand has some 'islands of excellence' where world-leading biotechnology R&D is carried out. While most biotech activities build on existing strengths in primary industry (e.g. forestry, deer and sheep) there are also examples of innovative research in health and the creation of intellectual property. The factors that seem to have encouraged the emergence of world-leading research are diverse, ranging from strong basic science in medical research, and science push in sheep genomics, to industry pull in the case of forest biotechnology. Growth in these and other biotech-based sectors may be constrained by the poor performance of New Zealand's National System of Innovation. The system is dominated by Crown Research Institutes and universities which rely on government for the majority of their funding. Leading edge work is carried out in certain areas, but this tends to involve links with a small number of organisations rather than strong connections to any wider system of innovation. There have been major changes to research, science and technology policy since the late 1980s, but it remains to be seen whether these will result in improved performance.

The New Zealand Government has only recently taken leadership in fostering innovation in modern biotechnology. Indeed government and industry only seem to have taken a close interest in biotechnology in the last four to five years. New Zealand has not made the kinds of large investment seen in Australia and some of its regional trading partners. Instead it has concentrated on science sector reforms and a free market oriented approach. New Zealand has the potential to demonstrate a new model for the development of a biotech industry based on comparative advantage in primary industry and some other niche areas. The jury is still out on whether New Zealand's innovation environment will allow that potential to be achieved.

Chapter 6 Analysis of Factors Affecting Innovation

6.1 Introduction

This chapter analyses the factors that affect the innovative output (IO) and innovation rate (IR) of enterprises in the New Zealand biotechnology sector. The analysis is based on the innovation framework described in chapter 3 which suggests that innovative output (Y) depends on a vector of variables (X).

$$Y = f(i, d, o, m, s, t, a, all, ins)$$

where
- i = stock of ideas
- d = market demand for new product/process
- o = technological opportunity
- m = market structure
- s = firm size
- t = firm type/characteristics
- a = appropriability of new product/process
- all = quantity and quality of interaction between organisations making up the innovation system
- ins = institutional factors

Table 6.1 provides a summary of the hypotheses addressed in this thesis and notes the section in this chapter where each is discussed while the variables tested are defined in more detail in Tables 6.2 and 6.3 (starting on page 170).

Sections 6.2 and 6.3 explain the regression models used in this analysis and the interpretation of model results. Section 6.3 presents results for a general model of innovation along with sample statistics and results for innovation rate and zero-inflated and simplified models. Sections 6.4 to 6.8 describe and discuss model results for the effect of firm size, firm type, alliances, information sources and other factors on IO and IR.

The analysis makes use of data from a re-analysis of the 1998/99 biotech survey and from an original survey conducted by the author in 2002. The 1998/99 survey of modern biotechnology in New Zealand was conducted by Statistics New Zealand in 2000. Questionnaires were sent to 426 enterprises that had been

identified as users of at least one biotechnology process. The survey achieved a 98% response rate with 180 enterprises being identified as users of at least one biotechnology process, see (see sections 4.2.2 and Marsh (2001b) for further details).

A total of 146 questionnaires were sent out in the 2002 survey. The study population was defined as 'all enterprises using modern[1] biotech processes and/or all enterprises conducting R&D using biotech processes (modern or traditional). Sixty one usable responses were received indicating a 'usable' response rate of 44%[2] (see section 4.2.3 and Appendix 3 for further details).

[1] List based definition see Appendix 2.

[2] The sample frame was adjusted to 138 enterprises by subtracting enterprises that reported that they were not involved in biotech.

Table 6.1 Hypotheses Tested in the Empirical Analysis

No.	Hypothesis	Section
1	*Stock of ideas* Rate of new ideas production increases with the stock of ideas	NT
2	*Demand pull vs. Technology push* Investment in innovation is determined jointly by technological opportunity and market demand	6.8
3	*Technological certainty* Increased technological certainty encourages innovative activity	NT
4	*Market structure* Barriers to entry, higher profit levels, and economies of scale in R&D generally increase the level of R&D undertaken leading to persistence of innovation	NT
5	*Firm Size* 5a Innovation output increase with enterprise size and the number of ideas workers 5b Innovation rate increase with enterprise size and the number of ideas workers	0
6	*Firm type* Innovation output and innovation rate vary with firm or organisational type 6a IO and IR vary with industry group 6b Enterprises that conduct R&D have a higher IO and IR than those that do not 6c Enterprises that use modern biotech processes have a higher IO and IR than those that do not 6d Enterprises that specialise in biotech have a higher IO and IR than those that do not	6.5
7	*Appropriability* R&D spending (and hence innovation) increases as the degree of appropriability of R&D outputs increases	6.8
8	*Spillovers, clustering and alliances* Innovation increases with the quantity and quality of the interaction between the organisations making up the innovation system 8a International linkages have a stronger positive effect than domestic linkages 8b Links with purchasers have a positive effect on IO 8c Links with firms have a positive effect on IO	6.6 & 6.7 6.7 6.8 6.6
9	*Institutions* Institutional factors are important determinants of innovative output	NT

Notes: 1. NT – not tested.
2. See Chapter 3 for a detailed introduction to these hypotheses.

6.1.1 Analysis Scope

The scope of the analysis is shaped by the variables covered by the 1998/99 and 2002 biotechnology surveys. In order to maximise the response rate, the 2002 questionnaire was kept short and was limited to questions that could be answered easily by most respondents. For these reasons hypotheses 1, 3, 4 and 9 on the stock of ideas, technological certainty, the role of institutions and market structure (e.g. barriers to entry, profit levels, economies of scale in R&D) are not tested (see Table 6.1). Patent stocks and the number and qualifications of R&D staff can provide an indication of the stock of ideas (hypothesis 1). However patents are also used as an indicator of innovative output, while number of R&D staff is also a size variable, so no separate testing of the effect of stock of ideas was possible. Hypotheses 2 and 7 are not tested directly but are investigated using data on respondent perceptions of the importance of demand-pull vs. technology-push and appropriability.

6.1.2 Innovation Indicators and Dummy Variables

The analysis is based on several different indicators of innovation output including the number of new products and/or processes introduced to the market, the number of products/processes undergoing trials or R&D and the number of patent applications. Combining product and/or process introductions and patent applications provides a better overall measure since different organisations exhibit innovative output in different ways. Patents are a better indicator for enterprises that concentrate on the creation (and protection) of intellectual property, while the number of new products and/or processes introduced is a better indicator for more production-oriented enterprises (many of which have applied for few if any patents). A possible refinement would be to include data on the number of articles published in top-ranking refereed journals - possibly one of the best indicators of innovative output for universities and organisations conducting basic research[3].

[3] Data for this indicator were not included in the 1998/9 or 2002 biotechnology surveys.

In the 2002 survey (Marsh, 2002), data were collected on the percentage of revenue or sales attributable to biotech products or processes introduced in the last three years. This innovation metric has been widely used particularly in the Community Innovation Surveys (CIS)[4]. It has the advantage that it provides a measure of the impact of innovation on innovators, whereas new product, process and patent counts do not distinguish between trivial innovations and those that have greater significance. Unfortunately this indicator has only limited application in the New Zealand biotech sector where much innovative activity is concentrated in R&D and has not reached the market (see 6.5 for analysis results).

The effect of firm size (innovative effort) was unclear when specified as continuous variables. Creation of a series of dummy variables for total expenditure, biotech expenditure and alternative indicators for 'number of ideas workers', enabled significant size effects to be identified and allowed the effect of different size categories to be identified. In each case the sample was divided into quartiles. Three dummy variables were used to define membership of quartiles two to four with the first quartile being the constant. Food manufacturers were selected as the constant for industry group; being a reasonably large group expected to have significantly different characteristics to groups such as research organisations and universities.

6.2 Regression Models

The innovative output indicators outlined above are count variables[5] that do not have normal distributions so use of the linear regression model could result in inefficient, inconsistent and biased estimates (Long & Freese, 2001, p. 223). Fortunately methodology for analysing count variables is well developed; see Cameron and Trivedi (1986) for a comprehensive review. The Poisson Regression Model (PRM) is the count data model that was developed first. It is generally used to model the number of occurrences of an event as a function of some independent variable. Poisson distributions have three distinguishing characteristics. "First the

[4] A series of innovation surveys carried out in the European Community, see Muzart (1998) and Tether (2001).

[5] with the exception of percentage of revenue or sales attributable to biotech products or processes introduced in the last few years.

Poisson distribution is skewed; traditional regression assumes a symmetric distribution of errors. Second, the Poisson distribution is non-negative; traditional regression might sometimes produce predicted values that are negative. Finally the variance of a Poisson distribution increases as the mean increases; traditional regression assumes a constant variance."(Simon, n.d.).

The Poisson Regression Model accounts for observed differences among sample members by specifying the count variable as a function of observed independent variables.

> In practice the PRM rarely fits due to *overdispersion.* That is the model underestimates the amount of dispersion in the outcome. The Negative Binomial Regression model (NBRM) addresses the failure of the PRM by adding a parameter α that reflects *unobserved* heterogeneity among observations…
>
> …the PRM and the NBRM have the same mean structure. That is if the assumptions of the NBRM are correct, the expected rate for a given level of the independent variable will be the same in both models. However, the standard errors in the PRM will be biased downward, resulting in spuriously large *z*-values and spuriously small *p*-values (Long & Freese, 2001, p. 243)

Lambert (1992) introduced zero-inflated count models as an alternative means of dealing with overdispersion. In these models the mean structure is adjusted to allow zeros to be generated by two separate processes. Zero-inflated models assume that there are two unobserved groups; an 'always-zero group' where individuals have an outcome of zero with a probability of one and a 'not always-zero group' where individuals may have a zero count, but there is a non-zero probability that they have a positive count (Long & Freese, 2001, p. 251).

Use of the Zero-Inflated Negative Binomial Regression Model (ZINB) for the innovation data reported in this chapter implies that there is a group of enterprises that innovate and a group that do not. ZINB enables separate estimation of:

i. the probability that an individual will be in the 'no innovation group' given certain characteristics; and
ii. the effect of certain characteristics on innovative output, among the 'innovators group'.

This form of analysis is well suited to analysis of the 1998/99 dataset where around 50% of the sample did not introduce new products or processes or make patent applications.

Stata[6] estimates the deviance (D) goodness of fit statistic to enable assessment of whether use of the PRM is optimal, it is given by:

$$\chi^2_D = -2\{L(\beta) - L_{\max}\}$$

In this equation the likelihood (L) for a particular β is compared with $L_{\max}$, where

$$L_{\max} = \sum_{i=1}^{n}\left[-w_i y_i \{\ln(y_i) - 1\} - w_i \ln(y_i!)\right]$$

Testing the general model for 1998/99 data gives the following result:

χ_D^2	=	583.3615
Prob > χ^2	=	0.0000

Based on this test the PRM does not fit the data at all well; the goodness of fit χ^2 tells us that, given the model, we can reject the hypothesis that these data are Poisson distributed at the 0.01% significance level.

Since the NBRM reduces to the PRM when $\alpha = 0$, the presence of overdispersion can also be investigated by testing $H_0 : \alpha = 0$. Long and Freese (2001) describe this test, pointing out that the Negative Binomial Regression:

> …estimates $\ln(\alpha)$ rather than α … A test of $H_0 : \ln\alpha = 0$ corresponds to testing $H_0 : \alpha = 1$…Since α must be greater than or equal to 0, the asymptotic distribution of $\hat{\alpha}$ when $\alpha = 0$ is only half a normal distribution. That is all values less than 0 have a probability of 0. This requires an adjustment to the usual significance level of the test. (Long & Freese, 2001, p. 246)

To test the $H_0 : \ln\alpha = 0$ Stata (Stata Corporation, 2003) provides a likelihood ratio test. The test is computed by comparing the log likelihoods:

$$LR = 2\ln L(M_{full}) - 2\ln(M_{\text{int}ercept})$$

[6] Stata Corporation (Stata Corporation, 2003). Stata is a statistical package for analysing data. Details available at http://www.stata.com

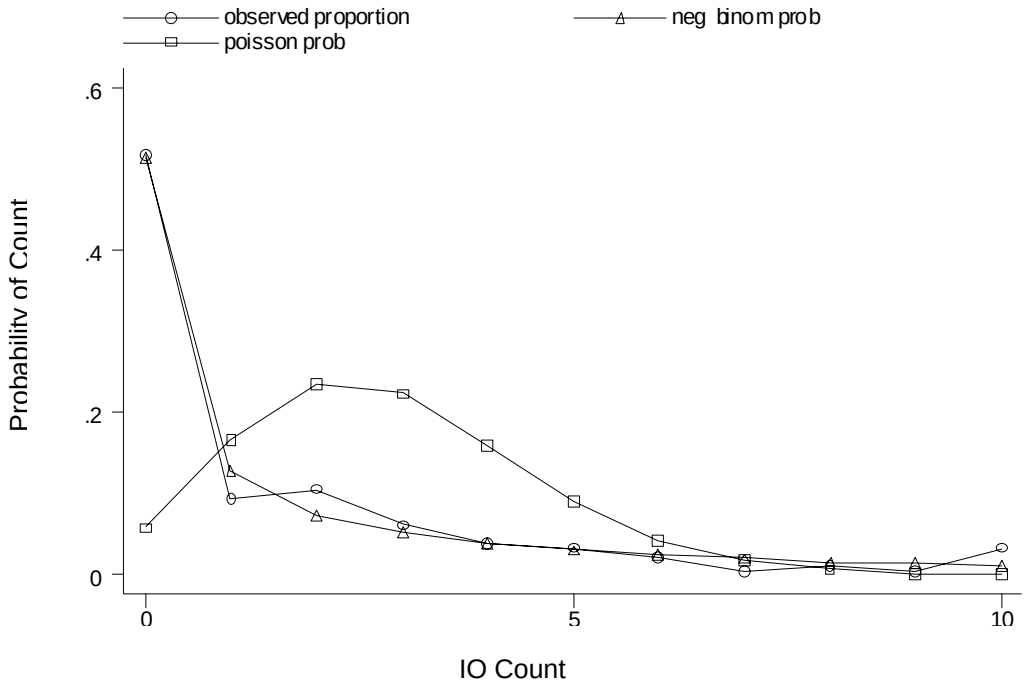
This statistic is sometimes designated as G^2 (Long & Freese, 2001, p. 83). Test results for the model are:

Likelihood-ratio test of ln alpha=0: $\overline{\chi^2}$ = 249.45
Prob> $\overline{\chi^2}$ = 0.000

Since there is significant evidence of overdispersion (G^2=249.45, p< 0.01), the Negative Binomial Regression Model is preferred to the Poisson Regression Model.

The superior performance of the NBRM can be illustrated by plotting the observed frequencies of different counts of innovative output (IO) against levels predicted by the Poisson and Negative Binomial Regression Models, see Figure 6.1. It can be seen that the PRM under predicts the frequency of IO counts of zero and over predicts IO counts of 1-6. By contrast the NBRM predicts the observed proportion of counts very accurately; particularly for count levels three or more.

Figure 6.1 Observed vs. Predicted Level of Innovative Output

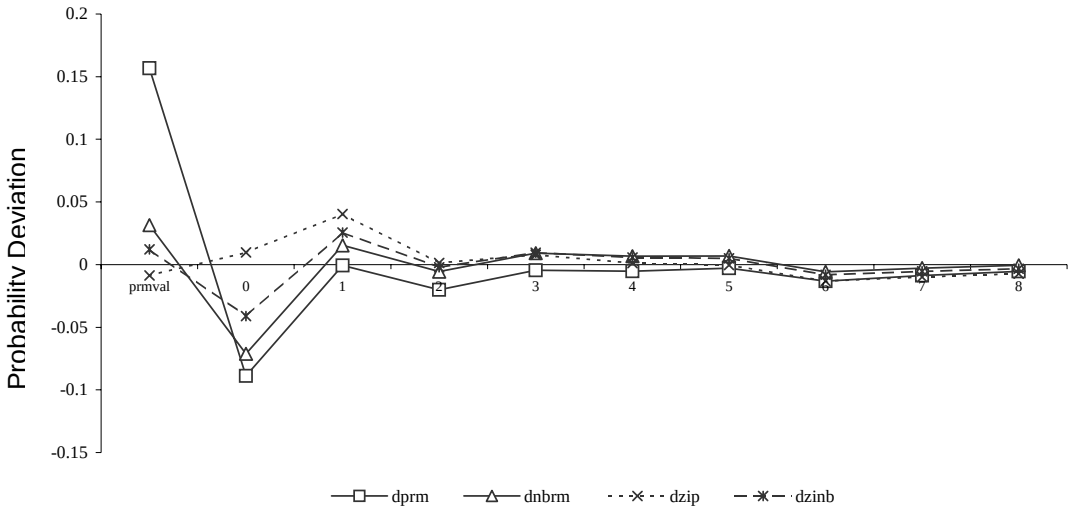


Source: Original Analysis by the author.

Figure 6.2 illustrates model deviations from observed probability levels using four different regression models (Poisson, Negative Binomial, Zero-Inflated Negative Binomial and Zero-Inflated Poisson). It can be seen that NBRM, ZINB and ZIP all produce similar results and are all superior to the PRM. The NBRM is used for most analysis in this chapter, since it is simpler than ZINB and ZIP while providing similar goodness-of-fit.

The Zero-Inflated Model provides a useful supplement for analysis of the 1998/99 data and can be theoretically justified since there are some enterprises within the New Zealand 'biotech sector[7]' that for structural reasons[8] do not innovate. For other enterprises the failure to innovate in a given time period is a matter of chance; this is the basis for zero-inflated models. The Negative Binomial version of the model (ZINB) is preferable to the Poisson version (ZIP) since there seem to be unobserved sources of heterogeneity that differentiate enterprises.

Figure 6.2 Comparison of Model Deviations from Observed Levels of IO



Source: Original Analysis by the author.

[7] As defined by Statistics New Zealand for the purposes of the 1998/99 survey, see Marsh (2001b) for a detailed discussion.

[8] For example research by university departments often focuses on peer reviewed publications rather than bringing innovations to the market.

6.3 Model Estimates and Interpretation

A variety of regression models are presented in order to test the hypothesis that innovative output (Y) depends on a vector of firm level factors (X) as detailed in Table 6.2 and Table 6.3.

$$Y = \exp(\beta' X) + \upsilon$$

A general model that includes most variables[9] included in the theoretical framework is supplemented by a number of alternative models used to investigate particular issues e.g. the effect of alternative measures of firm size, R&D expenditure and alliance characteristics.

The general model relates innovative output to enterprise size (using dummies for biotech expenditure), industry group, existence of biotech alliances, whether modern biotech processes used and the presence and strength of R&D activity[10]. OLS regression results are included as a benchmark for comparison with the count data models that are used for most of the analysis. Using OLS, only strength of R&D activity has significant explanatory power; see Table 6.4. It has already been noted (section 6.2) that use of OLS for analysis of count variables may result in estimates that are inefficient, inconsistent and biased. In contrast the innovative output count variable has been shown to be well predicted by the Negative Binomial Regression Model.

The negative binomial regressions reported in Table 6.5 use the same variables as the OLS regression but many of the independent variables are highly significant. Model testing using data from the 2002 survey produces similar results although fewer of the independent variables are significant; perhaps because of the smaller number of observations (61 instead of 180).

The general model is expected to generate positive coefficients for most independent variables, indicating that innovative output increases with biotech expenditure, research intensity, strength of strategic alliance etc. Coefficients for

[9] All variables in the theoretical model are included, except for variables where data were not available (see discussion in 6.1).

[10] Variables dum_rd, rdtot_no and pct_tota; see Table 6.2 for definitions.

industrial group indicate innovative output relative to food manufacturers (the constant). It should be noted that coefficients in count regression models cannot be used to make *direct* estimates of the change in IO so factor and percentage change in rates are presented using the method described by Long and Freese (2001, p. 232):

> If we define E (y | x, x_k) as the expected count for a given x where we explicitly note the value of x_k and define E (y | x, x_k +δ) as the expected count after increasing x_k by δ units, then
>
> $$\frac{E(y \mid x, x_k + \delta)}{E(y \mid x, x_k)} = e^{\beta_k \delta} \qquad (5.1)$$
>
> Therefore the parameters can be interpreted as
>
> > For a change of δ in x_k, the expected count increases by a factor of exp(β_k x δ) holding all other variables constant…
>
> Alternatively, the percentage change in the expected count for a δ unit change in x_k holding other variables constant, can be computed as
>
> $$100 \times \frac{E(y \mid x, x_k + \delta) - E(y \mid x, x_k)}{E(y \mid x, x_k)} = 100 \times \left[\exp\left(\beta_k \times \delta\right) - 1\right]$$
>
> ... In some discussions of count models, μ is referred to as the *incidence rate* and Equation 5.1 for δ = 1 is called the *incidence rate ratio*…
>
> (Long & Freese, 2001, p. 232)

Model results presented in this chapter include values for percentage change in the expected count, so for example in Table 6.5 the value 59% reported for the independent variable strategic alliance, should be interpreted as 'having a strategic alliance increases the expected value of innovative output by 59%, holding all other variables constant'.

Incidence rate ratios are used in sections 6.4 to 6.6, to investigate hypotheses relating to innovation rate (IR). Table 6.8 provides incidence rate ratios for a model that relates innovative output, weighted by biotech expenditure (the exposure variable) to the independent variables in the model. Incidence rate ratios can be interpreted as the difference in innovation rate[11], holding other variables constant. For example the value 6.4 reported for the independent variable

[11] Innovation rate is defined in this case as innovative output weighted by biotech expenditure.

scientific research, should be interpreted as: ‘being in the scientific research industrial group increases the expected value of innovation rate by a factor of 6.4, holding all other variables constant’.

Table 6.2 Variable Description and Sample Statistics (1998/9 Survey)

Variable	Abbrev'	Details		Mean	SD	No. > 0[1]
Innovative output	innout2	No. of new products and processes introduced in last 3 yrs plus No. of patents applied for in last 5 yrs		2.85	5.79	87
Dummies for	Constant	Biotech expenditure $0-0.05m	Total expenditure year ended 30 June 1999 multiplied by			45
biotech expenditure	d_bex1	$0.05-0.38m	'% biotechnology'. Constant is first quartile	0.25	0.43	45
	d_bex2	$0.38-1.98m		0.25	0.43	45
	d_bex3	$1.98m+		0.25	0.43	45
Dummies for	Constant	Total Expenditure $0-0.8m	Total expenditure year ended 30 June 1999.			45
total expenditure	d_tex1	$0.8-5.6m	Dummies based on quartiles. Constant is lowest quartile.	0.25	0.43	45
	d_tex2	$5.6-24m		0.25	0.43	45
	d_tex3	$24m+		0.25	0.43	45
Dummies for No. of	Constant	Number of biotech graduates: 0	No. of biotech staff members with graduate qualification at			49
biotech graduates	d_grad1	1 or 2 biotech graduates	30 June 1999. Constant is zero graduates.	0.31	0.46	56
	d_grad2	3,4,5 or 6 biotech graduates		0.16	0.37	29
	d_grad3	7+ biotech graduates		0.26	0.44	46
Dummies for No. of	Constant	Number of biotech employees: 0	No. of full time equivalent biotech staff members at 30			62
biotech employees	d_bfte1	1 or 2 biotech employees	June 1999. Constant is zero biotech FTE's.	0.15	0.36	27
	d_bfte2	3 – 10.75 biotech employees		0.26	0.44	46
	d_bfte3	10.75+ biotech employees		0.25	0.43	45
Dummies for total No.	Constant	Number of employees: 0 – 23.5	Total No. of full time equivalent staff members			44
of employees	d_tfte1	23.5 – 114 employees		0.26	0.44	46
	d_tfte2	114 - 553.5 employees		0.25	0.43	45
	d_tfte3	553.5+ employees		0.25	0.43	45
Strategic alliance	strategi	Enterprise did/did not have a biotech strategic alliance		0.53	0.50	95
New Zealand alliance	d_allnz	Did/did not have biotech strategic alliance with NZ enterprise		0.47	0.50	85
Overseas alliance	d_allov	Did/did not have biotech strategic alliance with overseas enterprise		0.31	0.31	55

Note: Total number of respondents is 180

[1] Number of occurrences where variable value greater than zero e.g. 45 respondents had biotech expenditure of $0 to $0.8 million.

Table 6.2 (continued)

Variable	Abbrev'	Details		Mean	SD	No. > 0
	Constant	Food manufacturing	Dummies for 7 of the 8 industrial groups: Primary, Food			33
Primary industry	d_prim	Dummies for Industrial Group	and Non-Food Manufacturers, Scientific Research, Local	0.03	0.17	6
Non-food manufacturers	d_nonfd		Government Administration, Tertiary education, Health	0.14	0.35	24
Scientific research	d_resear		Services, Other	0.21	0.41	36
Local government	d_locala		*Food Manufacturers Group is the Constant*	0.18	0.38	33
Tertiary education	d_univ			0.06	0.23	9
Health services	d_health			0.14	0.35	24
Other	d_other			0.06	0.24	12
Modern biotech	narrow	Dummy for use of modern biotech processes	Modern biotech processes defined using a list based definition, see Appendix 2.	0.53	0.50	95
R&D	dum_rd	Dummy for R&D	Enterprises considered to undertake R&D if they reported use of at least one biotech process (modern or traditional) for R&D and had at least one biotech graduate.	0.47	0.50	84
Biotech percentage	pct_tota	Biotech percentage	Biotech as a percentage of total income. Indicates importance of biotech relative to other enterprise activities. Dedicated Biotech Firms report pct_tota = 100.	30.5	37.5	151
No. of R&D processes	rdtot_no	No. of biotech R&D processes	Number of biotech processes used by the enterprise for R&D. Together with biotech expenditure, this provide an indication of the amount and breadth of resources invested in biotech R&D.	5.9	10.6	98

Note: Total number of respondents is 180

Table 6.3 Variable Description and Sample Statistics (2002 Survey)

Variable	Abbrev'	Details		Mean	SD	No. > 0
New Products/Processes	Prd_all	Number of products and processes at R&D or trials stage or on the market		13.03	17.47	53
New Products	prd3tot	Number of new products introduced on to the market in the last 3 yrs		1.31	2.06	31
Patent Applications	pat3totx	Number of patents[2] applied for in last 3 yrs		1.97	4.66	28
Innovative Output	innout1	No. of new products and processes introduced in last 3 yrs plus + No of patents applied for in last 3 yrs		3.59	4.85	46
New Product Revenue	fdbiotnr	Sales/revenue from biotech products or processes introduced in the last 3 years ($ millions)		0.49	1.21	28
Dummies for	Constant	Biotech expenditure $0-0.125m	Total expenditure year ended 30 June 2001 multiplied by			15
Biotech expenditure	d_bex1	$0.125-0.675m	'% biotechnology'. Constant is first quartile	0.26	0.44	16
	d_bex2	$0.675-2.470m		0.25	0.43	15
	d_bex3	$2.470m+		0.25	0.43	15
Biotech R&D expend	fdbirdex	Biotech R&D expenditure 2000/01 ($ '000s)	Biotech R&D expenditure 2000/01 ($ millions)	2.16	5.51	56
Biotech R&D Employees	biotrd	Biotech R&D employees, headcount (2002)	Biotech R&D employees, headcount (mid 2002)	15.5	25	55
Dummies for Industrial	Constant	Food manufacturing	Dummies for 7 of the 8 industrial groups: Primary, Food			6
Group	d_prim	Primary industry	and Non-Food Manufacturers, Scientific Research, Local	0.10	0.30	6
	d_nonfd	Non-food manufacturing	Government Administration, Tertiary education, Health	0.23	0.42	14
	d_resear	Scientific research	Services&Other	0.30	0.46	18
	d_univ	Tertiary education	*Food Manufacturers Group is the Constant*	0.20	0.40	12
	d_hlthot	Health services and other		0.08	0.28	5
Modern biotech	narrow	Dummy for use of modern biotech processes. Modern biotech processes defined using a list based definition, see Appendix 2.		0.74	0.44	45
R&D	dum_rd	Dummy for R&D. Enterprises considered to undertake R&D if they reported use 1of at least one biotech process (modern or traditional) for R&D and had at least one biotech graduate.		0.90	0.30	55
Biotech Percentage	fdexbpc	Biotech Percentage	Biotech as a percentage of total expenditure.	47.21	41.47	56
No. of R&D Processes	prno_rd	No. of Biotech R&D Processes	Number of biotech processes used by the enterprise for R&D. (Process definitions different to 1998/99)	4.48	3.87	56

Note: Total number of respondents is 61.

[2] Pat3totx is the maximum number of patent applications in any jurisdiction. This definition aims to avoid double counting since the same invention is often covered by a number of different patent applications in different jurisdictions.

Table 6.3 (continued)

Variable	Abbrev'	Details	Mean	SD	No. > 0
Alliance outcome	apoinv	Alliance/Partnership outcome to date. Score 1 (Unproductive) to 5 (Very productive). Long data set[1].	4.43	0.66	117
Strategic alliance	allany	Enterprise did/did not have a biotech strategic alliance	0.84	0.37	51
New Zealand alliance	aplnzlx	Did/did not have biotech strategic alliance with NZ enterprise	0.41	0.50	25
Overseas alliance	aplintx	Did/did not have biotech strategic alliance with overseas enterprise	0.41	0.50	25
Alliance with international partner	riad	As above, but Australia not included in 'international'. Long data set.	0.57	0.50	100
Alliance with a firm	pcfmd	Did/did not have alliance with a firm. Long data set.	0.28	0.45	51
Staff work of train at partner location	apssw	Indicators of degree of active participation in alliance/partnership. Score	0.20	0.40	34
Work contracted out to/from other party	apswc	1 (low) to 5 (high).	0.43	0.50	78
Active participation by both parties	apsap		0.56	0.50	101
Own staff	isownst	Rate the importance of each information source. Score 1 (low) to 5	4.24	0.88	55
Hiring new staff	isnewst	(high) or "not applicable".	3.47	1.18	47
Personal contacts	ispers		4.14	1.03	57
Conferences	isconf	No.>0 varies because respondents indicated that some information	3.58	1.09	59
Other firms	isfirm	sources were not applicable.	2.96	1.17	51
CRIs	iscri		2.73	1.33	55
Other Research Organisations	isres		3.05	1.10	55
Universities and Polytechnics	isuniv		3.21	1.23	56
Government Departments	isgovt		1.92	1.04	51
Professional/Industry Organisations	isprof		2.22	1.07	50
Academic journals and trade publications	isjourn		4.15	0.88	60
Library/Literature search	islit		3.93	1.06	59
Database retrieval	isdata		3.63	1.30	57
Patent disclosures	ispat		2.84	1.55	51
Domestic vs international links	domint	What is the relative importance of domestic vs international information sources? (NZ more imp't=1, about same=2, international more imp't=3)	2.34	0.71	58

Notes: Total number of respondents is 61.
1. Long dataset created from three most important alliances for each respondent, see section 6.6.

Table 6.3 (continued)

Variable	Abbrev'	Details	Mean	SD	No. > 0
Conditions in your business					
Quantity of funds available for R&D	bpfund	How important are the following factors	4.25	0.96	59
Quality of the R&D environment	bprdenv	that may affect the amount of innovation	4.00	1.16	59
Number and quality of R&D staff	bprdstaff	produced by your business?	4.14	1.13	57
One or a few star scientists	bpstars		3.29	1.59	56
'Science push' or technological opportunity	bppush	Use a scale where 1 is low importance and	3.47	1.15	55
Quality of links with org's in New Zealand	bpnzlink	5 is high importance.	3.25	1.06	59
Quality of links with overseas organisations	bpovlink		3.70	1.18	57
Ownership of intellectual property	bpip		3.38	1.50	58
Appropriability	bpapprop		4.14	1.19	58
Links with purchasers	bpprlink		3.73	1.37	56
Conditions in New Zealand					
Quality/quantity of basic science	bpsci		3.46	1.24	57
Quality/quantity of applied science	bpapsci		3.54	1.20	57
R&D environment in New Zealand	bpregs		3.68	1.29	56

Note: Total number of respondents is 61.

Table 6.4 OLS Estimates for the General Model; 1998/99 and 2002 Data

Variable	Coefficient Std Error	Coefficient Std Error
	1998/99	2002
Constant	-0.903	-1.885
	(1.105)	(3.174)
Dummy 1 for biotech expenditure	-0.482	0.632
	(1.090)	(1.907)
Dummy 2 for biotech expenditure	0.753	0.253
	(1.104)	(2.242)
Dummy 3 for biotech expenditure	3.237	2.790
	(1.213)***	(2.573)
Primary industry	3.968	3.035
	(2.394)*	(2.813)
Non-food manufacturers	1.922	1.049
	(1.445)	(2.506)
Scientific research	1.579	1.431
	(1.303)	(2.541)
Local government	0.980	*na*
	(1.261)	
Tertiary education	0.487	-1.314
	(2.140)	(2.858)
Health services	1.706	*na*
	(1.500)	
Other industrial group	2.190	0.491
	(1.737)	(3.163)
Strategic alliance	-0.713	2.368
	(0.912)	(2.017)
Modern biotech	0.339	-0.338
	(1.020)	(1.797)
R&D	0.262	0.505
	(1.072)	(2.718)
No. of R&D processes	0.237	0.266
	(0.057)***	(0.277)
Biotech percentage	0.009	0.009
	(0.115)	(0.017)
Number of observations	180	61
R^2	0.3511	0.2609

Notes:
1. * significant at 10%; ** significant at 5%; *** significant at 1%
2. *na* denotes no data available for this variable.
3. This analysis uses the Ordinary Least Squares (OLS) regression model.
4. Dependent variable is innovative output (innout1 & innout2)
5. Data are from the 1998/99 and 2002 Biotech Surveys.

Table 6.5 NBRM Estimates for the General Model; 1998/99 and 2002 Data

Variable	Coefficient (Std Error)	%	Coefficient (Std Error)	%
	1998/99		2002	
Constant	-2.272		-1.902	
	(0.499)***		(0.986)*	
Dummy 1 for biotech expenditure	0.439	55.1	0.546	72.7
	(0.399)		(0.460)	
Dummy 2 for biotech expenditure	0.978	166.0	0.520	68.3
	(0.397)**		(0.481)	
Dummy 3 for biotech expenditure	1.348	284.9	1.023	178.2
	(0.409)***		(0.571)*	
Primary industry	1.823	519.3	1.314	272.1
	(0.691)***		(0.636)**	
Non-food manufacturers	1.391	302.0	0.627	87.2
	(0.471)***		(0.571)	
Scientific research	1.385	299.5	0.467	59.6
	(0.474)***		(0.602)	
Local government	0.447	56.3	*na*	
	(0.552)			
Tertiary education	0.510	66.6	-0.175	-16.1
	(0.765)		(0.652)	
Health services	2.000	638.9	*na*	
	(0.554)***			
Other industrial group	1.418	312.9	0.426	53.2
	(0.557)**		(0.889)	
Strategic alliance	0.464	59.0	1.303	267.9
	(0.275)*		(0.516)**	
Modern biotech	0.034	3.5	0.151	16.3
	(0.344)		(0.390)	
R&D	0.479	61.4	0.523	68.8
	(0.382)		(0.697)	
No. of R&D processes	0.042	4.3	0.042	4.3
	(0.018)**		(0.053)	
Biotech percentage	0.002	0.2	0.002	0.2
	(0.003)		(0.004)	
Number of observations	180		61	
Pseudo R^2	0.1400		0.1041	

Notes:
1. * significant at 10%; ** significant at 5%; *** significant at 1%
2. % denotes percent change in expected count for unit increase in X
3. *na* denotes no data available for this variable.
4. This analysis uses the Negative Binomial Regression Model (NBRM).
5. Dependent variable is innovative output (innout1 & innout2)
6. Data are from the 1998/99 and 2002 Biotech Surveys.

Table 6.6 Zero Inflated Estimates for the General Model; 1998/99 Data

	Coefficient (Std Error) 'Innovators Group'	%	Coefficient (Std Error) 'No Innovation Group'	%
Constant	-2.189 (0.463)***		-4.082 (2.210)*	
Dummy 1 for biotech expenditure	0.425 (0.360)	52.9		
Dummy 2 for biotech expenditure	1.012 (0.355)***	175		
Dummy 3 for biotech expenditure	1.340 (0.345)***	281.9		
Primary industry	1.930 (0.538)***	589.2	-23.428 (534,503)	-100
Non-food manufacturers	1.226 (0.396)***	240.7	-12.289 (581.389)	-100
Scientific research	1.569 (0.422)***	380.0	1.682 (1.812)	437.7
Local government	1.066 (0.642)*	190.3	4.183 (2.357)*	6453.0
Tertiary education	1.282 (0.653)**	260.2	5.645 (3.784) [w]	28194.4
Health services	2.875 (0.511)***	1672.3	5.784 (2.714)**	32397.7
Other industrial group	2.568 (0.584)***	1203.4	5.278 (2.316)**	19493.9
Strategic alliance	0.039 (0.258)	3.9	-1.786 (0.927)*	-83.2
Modern biotech	-0.299 (0.304)	-25.8	-2.016 (1.229) [w]	-86.7
R&D	1.185 (0.349)***	227.1	4.369 (1.875)**	7796.9
No. of R&D processes	0.025 (0.014)*	2.5	-0.166 (0.116) [w]	-15.3
Biotech percentage	0.003 (0.003)	0.3	0.002 (0.011)	0.2
Observations	180		180	

Notes:

1. This analysis uses the zero inflated negative binomial regression model
2. Dependent variable is innovative output (innout2)
3. Data are from the 1998/99 Biotech Survey.
4. Aid to Interpretation:
   a. Enterprises engaged in R&D had IO 227% higher than those not engaged (*Innovators group*).
   b. Enterprises engaged in modern biotech had a 77% *lower* chance of being in the '*no innovation group*' - i.e. a 77% *higher* chance of innovating.

The Zero-Inflated Negative Binomial Regression Model (Table 6.6 above) provides additional insights into the 1998/99 data set since it provides separate estimates of the probability that an individual will be in the 'no innovation group'; and the effect of characteristics on innovative output, among the 'innovators group'.

The 2002 survey provides data on biotech R&D effort and revenue from sales of new products and processes that were not included in the earlier survey. Table 6.7 provides estimates for two models that make use of this additional data to relate innovative output to biotech R&D effort (expenditure or number of staff engaged in biotech R&D) and the strategic alliance dummy variable. Data on new product and process revenue are analysed in Table 6.10 on page 185.

Table 6.7 Estimates for Two Models based on Biotech R&D Effort

Variable	Coefficient (Std Error)	%	Coefficient (Std Error)	%
Constant	-0.003		-0.020	
	(0.394)		(0.399)	
Biotech R&D expenditure	0.000	0.0		
	(0.000)***			
No. Biotech R&D staff			0.015	1.5
			(0.004)***	
Strategic alliance or not	1.094	198.7	1.038	182.2
	(0.419)***		(0.429)**	
No. observations	61		61	
Pseudo R^2	0.0799		0.0734	

Notes:
1. This analysis uses the Negative Binomial Regression Model (NBRM).
2. Dependent variable is innovative output (innout1 & innout2).
3. Data are from the 2002 Biotech Survey.
4. Results for the full model (including non-significant variables) are included in Appendix 6.

Hypotheses about innovation rate (IR) have been investigated using incidence rate ratios where IR is estimated from innovative output divided by biotech expenditure[1] (as a measure of firm size or innovative effort), see Table 6.8 and the discussion in sections 6.3 and 6.4.

[1] Incidence rate ratios weighted by number of biotech graduates are not reported because of the high proportion of enterprises without any graduates.

Table 6.8 Incidence Rate Ratios; 1998/99 and 2002 Data

Variable	IRR (Std Error) 1998/99	IRR (Std Error) 2002
Dummy 1 for biotech expenditure	0.138	1.134
	(0.060)***	(0.988)
Dummy 2 for biotech expenditure	0.562	0.208
	(0.024) ***	(0.189) *
Dummy 3 for biotech expenditure	.0141	0.102
	(0.006) ***	(0.101) **
Primary industry	5.204	63.964
	(4.075) **	(75.621) ***
Non-food manufacturers	7.037	2.909
	(3.605) ***	(2.858)
Scientific research	6.409	1.233
	(3.270) ***	(1.294)
Local authorities	2.209	na
	(1.292)	
Tertiary education	3.691	1.643
	(3.126)	(1.946)
Health services	10.689	na
	(6.434) ***	
Other industrial group	8.370	17.244
	(4.904) ***	(35.283)
Strategic alliance	1.551	1.490
	(0.478)	(1.262)
Modern biotech	0.922	0.902
	(0.348)	(0.608)
R&D	1.62	0.117
	(0.693)	(0.204)
No. of R&D processes	1.038	0.885
	(0.021) *	(0.082)
Biotech percentage	0.998	0.990
	(0.004)	(0.007)
No. of observations	180	61
Pseudo R^2	0.1391	0.2155

Notes

1. This analysis uses the Negative Binomial Regression Model, weighted by the exposure variable $ million biotech expenditure (1998/99)[2] and $ million biotech R&D expenditure (2002).
2. Dependent variable is innovative output (innout1 & innout2).

[2] Zero values were replaced by $0.02 million. This is the median value for non-negative values in the first quartile. A similar result was obtained when the 21 zero cases were dropped from the analysis.

New product revenue is a continuous variable making use of Poisson or Negative Binomial Regression Models inappropriate. The Tobit model is used in section 6.5 to investigate the determinants of new product revenue because the distribution is skewed towards zero but has no negative values.

6.4 Firm Size

The relationship between innovation, market structure and firm size has been extensively investigated since it was first brought to prominence by Schumpeter (1942). The material presented in this section focuses on the links between innovation output, innovation rate and enterprise size. Model estimates from the general model Table 6.5 confirm the expected result that firms that spend more money on biotechnology have a larger innovative output. More specifically: enterprises in the top two quartiles for biotech expenditure have a significantly higher innovative output compared to those in the lowest quartile and Hypothesis 5a should not be rejected. Enterprises in quartile three have innovative output 166% higher than those in quartile one, while the output of those in quartile four is 285% higher.

This finding may be considered unsurprising; we would expect after all, that the innovative output of large enterprises would be greater than that of smaller ones. What is of much more interest is whether any systematic pattern of variation in innovation rate can be identified, where innovation rate is estimated from innovative output divided by some measure of firm size or innovative effort.

	Hypotheses about Firm Size and Stock of Ideas
1	Rate of new ideas production increases with the stock of ideas (not tested).
5a	Innovation output increases with enterprise size and the number of ideas workers.
5b	Innovation rate increases with enterprise size and the number of ideas workers.

The coefficients for the biotech expenditure dummy variables in Table 6.5 are positive and increasing but the rate of increase is much lower than the difference

in biotech expenditure underlying these dummy variables[3]. This is highlighted by the fall in incidence rate ratios for biotech expenditure dummies as biotech expenditure increases (Table 6.8). This result clearly suggests that higher levels of biotech expenditure produce diminishing returns in terms of innovative output. In other words, smaller enterprises tend to have a higher innovation rate and Hypothesis 5b should be rejected.

An important aspect of enterprise size is the number of 'ideas workers'. Data on the number and qualifications of employees (total or engaged in biotech) may provide useful indicators for this variable. All indicators show similar results to biotech expenditure; see for example the results for biotech full time employees in Table 6.9. The innovative output of enterprises in the top two quartiles (for number of biotech employees or biotech graduates) is significantly higher than the constant group. Similarly the coefficients for the biotech employee dummy variables are positive and increasing, but the rate of increase is much lower than the difference in number of biotech employees underlying these dummy variables. Increasing the number of biotech employees produces diminishing returns in terms of innovative output so that smaller enterprises (whether measured by number of ideas workers or biotech expenditure) tend to have a higher innovation rate. Overall therefore, Hypothesis 5b is not supported.

It may also be noted that larger enterprises are expected to be more innovative, in part because of their larger 'stock of ideas' (Hypothesis 1). The impact of stock of ideas is, however, hard to test empirically. Stock of patents and number and quality of staff might be used as proxies except that use of staff numbers would not allow separation of the firm size and stock of ideas effects, while patent stock is only a useful proxy for the small number of respondents that make extensive use of patenting.

[3] See Table 6.2. For example mean expenditure by quartile four is 40 times higher than that of quartile one, but mean IO is only 285% higher.

Table 6.9 Estimates for the General Model (Number of Ideas Workers, 1998/9 Survey)

Variable	Coefficient	Std. Error	%
Constant	-1.979	(0.445)***	
Dummy 1 for No. biotech employees	0.193	(0.416)	21.3
Dummy 2 for No. biotech employees	0.856	(0.360)**	135.3
Dummy 3 for No. biotech employees	1.059	(0.405)***	188.2
Primary Industry	2.008	(0.710)***	644.8
Non Food Manufacturers	1.243	(0.485)**	246.7
Scientific Research	1.149	(0.472)**	215.5
Local Government	0.342	(0.550)	40.7
Tertiary Education	0.220	(0.791)	24.6
Health Services	1.927	(0.574)***	586.6
Other Industrial Group	1.567	(0.564)***	379.2
Strategic Alliance	0.419	(0.275)	52.1
Modern biotech	-0.080	(0.354)	-7.7
R&D	0.580	(0.386)	78.7
No. of R&D processes	0.045	(0.019)**	4.6
Biotech percentage	0.003	(0.004)	0.3
No. of Observations	180		
Pseudo R^2	0.1348		

Notes:
1. This analysis uses the Negative Binomial Regression Model (NBRM).
2. Dependent variable is innovative output (innout2).
3. Data are from the 1998/99 Biotech Survey.

Results from the 1998/99 dataset for variables describing number of staff show some inconsistency in the coefficients. This is probably a data quality issue since there were measurement problems in deciding who was a biotech staff member and no question was asked about how many of these worked on biotech R&D (Marsh, 2001c). A number of organisations with large numbers of biotech staff had a low innovative output and put little effort into R&D while several small organisations were engaged almost exclusively in R&D.

Using the 2002 survey, number of staff engaged in biotech R&D is found to be highly significant, see Table 6.7; for example an extra 25 biotech R&D staff would increase innovative output by 38% (holding all other variables constant).

6.5 Firm Type

Innovation depends on characteristics that are often associated with different firm or organisational types for example industry sector or research intensity.

	Firm Type Hypotheses
6a	Innovation output and innovation rate vary with industry group.
6b	Enterprises that conduct R&D have a higher IO and IR than those that do not.
6c	Enterprises that use modern biotech processes have a higher IO and IR than those that do not.
6d	Enterprises that specialise in biotech processes have a higher IO and IR than those that do not.

The general and zero inflated models (Table 6.5 and Table 6.6) presented in section 6.3 suggest that none of the hypotheses relating to firm type should be rejected. There are significant differences in innovative output between industry groups; the output of most groups being significantly higher than that of food manufacturers. The primary industry and health services groups had the highest innovative output followed by research organisations, non-food manufacturers, 'other' and universities. The innovative output of New Zealand universities is not captured very well by the indicator based on new products/processes and patents, thus providing a possible explanation for their relatively low output. This may change if New Zealand follows US trends in the commercialisation of university-based research. Comparison of incidence rate ratios (Table 6.8) suggests that firm type also has a strong effect on innovation rate. The health services and other industry groups had the highest innovation rate (IR) per unit of biotech expenditure with the lowest IR being reported by local authorities.

The Zero Inflated Model (Table 6.6) provides separate estimates for enterprises that innovate and those that do not. Among enterprises that innovate, alternative indicators of the presence and strength of R&D have a positive effect on innovative output (IO). Conducting R&D and using more biotech processes for

R&D[4] increase the expected level of innovative output. Enterprises engaged in R&D had IO more than triple[5] the IO of those that did not while enterprises using an additional biotech process for R&D had an IO expected to be 2.5% higher; so for example use of twelve[6] processes suggests additional IO around 30%. Use of modern (as opposed to traditional) biotechnology reduces the expected level of IO[7]; although this is not a significant effect[8].

Several factors were found to significantly affect the probability that enterprises innovate. Having an alliance, using modern biotechnology and conducting R&D using more biotech processes all increase the chance of innovating. Conducting R&D[9] significantly reduces the chance of innovating; this counter-intuitive result may be caused by universities and research organisations that conducted R&D but did not innovate in the form of patent applications or new products or processes. In the general model (Table 6.5) fewer significant effects were detected although use of more biotech R&D processes was found to increase the expected level of innovative output.

Table 6.10 provides estimates for a Tobit model of the determinants of new product/process revenue. In the first stage of the analysis all variables from the general model were included, but the final specification includes only those variables that appear to have some significant effect.

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[4] Number of different biotech process categories used for R&D. See Appendix 2 for category dtails. This is an alternative indicator of the breadth and strength of R&D activity.

[5] 227% higher - all results for firm type are based on the 1998/99 dataset; see % column in Table 6.5 and Table 6.6.

[6] This is the mean number of biotech processes used for R&D by all scientific research enterprises.

[7] This may be because much modern biotech is undertaken in universities and research organisations whose innovative output is not well captured by the IO indicator.

[8] The effect of two age variables was also tested; year biotech activity started (yrbiot) and year enterprise formed (yrform) neither had a significant effect on IO.

[9] Two variables describe R&D activity; the R&D dummy indicates whether R&D is conducted (at all) while 'No. of R&D processes' gives an indication of the breadth of R&D activity.

Surprisingly, R&D expenditure and number of R&D staff appear to be almost totally unrelated to the level of new product revenue. This may perhaps be explained in part, by the small sample size.

Table 6.10 Estimates for Tobit Model based on New Product Revenue; 2002 Data ($ '000s)

Variables	Coefficients	Standard Error
Constant	-184.117	(1203.194)
New Products	355.908	(138.109)**
Primary industry	-3257.313	(1128.085)***
Non-food manufacturers	-2783.850	(859.867)***
Scientific research	-3261.412	(836.576)***
Tertiary education	-3990.937	(926.8595)***
Health services and other	-2611.226	(1119.927)**
R&D	2558.012	(1269.751)**
Observations	57	
Pseudo R^2	0.0538	

Notes:
1. 29 left-censored observations at 'new product revenue'= 0
   28 uncensored observations
2. Dependent variable is fdbbiotnr - sales/revenue from biotech products or processes introduced in the last 3 years ($ million).
3. Data are from the 2002 Biotech Survey.
4. Results for the full model (including non-significant variables) are included in Appendix 6.

The level of new product/process revenue was found to have a strong relationship with firm type, number of new products introduced onto the market, and the dummy variable for R&D. Interestingly new revenue was not related to available indicators of R&D effort (biotech R&D expenditure and R&D employees) or even to the level of total revenue or biotech revenue. New revenue for food manufacturers (the control group) was significantly greater than that of all other industry groups. The next highest level of new revenue was reported by non-food manufacturers and health services/other followed by primary industry, scientific research and tertiary education. The relatively low level of revenue reported by these latter two groups is as expected, given their focus on research rather than product or process commercialisation.

Taking all of these effects together the Hypothesis 6 that innovation output varies with enterprise type is not rejected. Specialisation, R&D and use of more biotech processes for R&D all tend to increase innovative output; so for example, a

dedicated biotech firm, engaged in biotech R&D using twelve processes would have additional IO of 284% compared to a non-specialised biotech firm not engaged in R&D.

6.6 Alliances

There is theoretical and empirical support for the proposition that technological change is encouraged by knowledge spillovers; where new knowledge diffuses outward from the original inventor or innovator (section 3.9). These spillovers explain the importance of the quantity and quality of interaction between organisations in determining the innovative output of individual firms or an innovation system. Inter-firm linkages have been found to be particularly significant in the biotechnology industry[10], where the locus of innovation has been described as "a network of inter-organizational relations" (Arora & Gambardella, 1990).

The research described below focuses on the effect of alliances or partnerships[11] on innovative output and innovation rate. Results are presented based on both of the available data sets. The 1998/99 data set is larger and more comprehensive, but contains only limited information on the number and quality of biotech alliances. The 2002 survey addressed these gaps by collecting more detailed information on the number and quality of alliances entered into by biotech enterprises. The following discussion addresses the overall effect of alliances on IO and IR before considering the effect of alliances with different characteristics. Results are also presented on the relationship between the characteristics of particular alliances and respondent perceptions of the productivity of that alliance.

[10] See chapter 3 for a more detailed discussion.

[11] Respondents were asked about 'partnerships or alliances for undertaking biotech activities (research or production)'. The terms 'alliance' and 'partnership' are used interchangeably in this chapter.

	Alliance Hypotheses
8	Innovation increases with the quantity and quality of the interaction between the organisations making up the innovation system
8a	International linkages have a stronger positive effect than domestic linkages
8b	Links with purchasers have a positive effect on IO (see 6.8)

6.6.1 Results from 1989/99 Dataset

Initial analysis using the 1998/99 dataset (see Table 6.5) suggested that presence of a biotech alliance has a positive effect on innovative output; enterprises with a strategic alliance have an expected IO 59% higher than those that do not[12]. Using the Zero Inflated Model (Table 6.6) having an alliance is found to increase the probability of innovating by 83%. Both findings suggest that hypothesis 8 should not be rejected.

However the strategic alliance variable simply records presence or absence of a biotech alliance and is unlikely to adequately reflect the quantity and quality of interaction through alliances. Attempts were made to determine whether an indicator of biotech alliance strength could explain variation in innovative output. Analysis was hampered by absence of a satisfactory indicator. The survey dataset includes the different types of organisations with which respondents formed alliances e.g. Crown Research Institutes, businesses, universities etc, but unfortunately respondents were not asked how many different organisations they had alliances with. An alliance strength indicator was tested based on the number of different alliance purposes and partner organization types[13]. Negative binomial regression produced a positive coefficient with a p value of 0.28 providing some limited support for the notion that 'more and better alliances' increase innovative output.

[12] Using the 2002 data set presence of an alliance increases expected IO by 268% but enterprises with no alliance are probably not representative of the relevant population.

[13] Number of alliance purposes plus number of NZ organization types plus number of overseas organization types. These variables are not necessarily correlated either with the total number of alliances formed, or with the strength and importance of those alliances.

6.6.2 Results from 2002 Dataset

The 2002 survey aimed to provide more comprehensive data on the number and quality of alliances entered into by biotech enterprises. Each enterprise was asked to provide details of "the three most important alliances". The 51 respondents that reported an alliance provided usable data on 117 separate alliances. This allowed creation of a reshaped dataset providing 117 observations of alliance characteristics, alongside variables describing enterprise characteristics.

For each of the three most important alliances/partnerships respondents were asked to provide information on:

i. Year alliance started
ii. Alliance characteristics, namely whether or not:
    a. there was active participation by both parties;
    b. staff work/train at partner location (or vice versa);
    c. work contracted out to/from other party
iii. Purpose of the alliance (basic research, product/process development, clinical/field trials, manufacturing, regulatory affairs, finance, other)
iv. Partner location (New Zealand; local or not, Australia, USA, Europe, Asia, other)
v. Partner category (small firm, larger firm, CRI, other research organisation, university/polytech, research network, hospital, government, other)
vi. Alliance outcome to date (score of 1 to 5 denoting unproductive to very productive).

In most cases alliance characteristics were found *not* to have a significant effect either on alliance outcome or on innovative output. Alliance age, purpose, location and category did not have a significant effect on the alliance outcome reported by respondents, although there was limited support for the proposition that alliances with international partners lead to more successful outcomes[14]. The count variable 'number of biotech alliances' was also quite unrelated to innovative output.

[14] Ordered probit of alliance outcome against dummy for partner location =international (excluding Australia) approaches significance at 16%.

This failure to find significant associations between alliance characteristics and outcomes may have been caused in part by limited spread in the alliance outcomes variable with 94% of alliances reported to be 'very productive' or 'somewhat productive'. Either enterprises that have alliances are generally happy with them, or the variable suffers from 'grade inflation' with respondents being reluctant to give alliances a low outcome score.

A strong association was found between reported alliance outcome and the extent to which the alliance involved active participation, see Table 6.11. Alliances that were reported to include any of three participation indicators had higher alliance outcome scores. The 'catch-all' indicator 'active participation by both parties' has the strongest effect followed by work contracted in or out.

Table 6.11 Estimates for Model of Alliance Outcome and Alliance Characteristics (Ordered Probit)

	Coefficient	Standard Error
Staff work or train at partner location	0.609	0.267**
Work contracted out to/from other party	0.934	0.251***
Active participation by both parties	1.533	0.328***
Number of observations	117	
Pseudo R^2	0.1709	

Notes:
1. * significant at 10%; ** significant at 5%; *** significant at 1%.
2. This analysis uses the ordered probit model.
3. Dependent variable is alliance outcome; see Table 6.3.
4. Data are from the 2002 Biotech Survey.

Although most alliance characteristics did not have a significant effect on IO and IR, some significant effects were detected, see Table 6.12. Enterprises that report alliances involving active participation and alliances with firms have IO more than double[15] those that do not while those that have alliances with international partners[16] have IO 39% higher. International linkages are of particular significance for a small geographically isolated country such as New Zealand as confirmed in recent work by Keller (2001) who demonstrated that international

[15] 100.2% higher for active participation, 102.6% higher for alliances with firms, see Table 6.12.

[16] International partners *excluding* Australia.

(not domestic) technology diffusion is the major source of technical change leading to productivity growth in OECD countries.

Table 6.12 Negative Binomial Estimates of the Model of Alliance Characteristics vs. Innovative Output

	Coefficient	Standard Error	%
Constant	0.604	.615	
Alliance outcome	-0.0752	.170	-7.2
Staff work or train at partner location	-0.1030	.201	-9.8
Work contracted out to/from other party	0.149	.202	16.1
Active participation by both parties	0.694	.315**	100.2
Alliance with international partner	0.331	.186*	39.2
Alliance with a firm	0.706	.182***	102.6
Number of observations	117		
Pseudo R^2	0.0451		

Notes:
1. * significant at 10%; ** significant at 5%; *** significant at 1%.
2. This analysis uses the Negative Binomial Regression Model (NBRM).
3. Dependent variable is innovative output (innout1).
4. Data are from the 2002 Biotech Survey.

It can be concluded from Table 6.12 that alliance characteristics such as partner type and location and degree of active participation influence the expected level of IO, however reported alliance outcome does not have a *separate* effect on IO after accounting for these alliance characteristics.

The estimation results reported above provide some evidence in support of hypotheses 8 and 8a (see p.186). International linkages were found to have a stronger positive effect than domestic linkages so hypothesis 8a should not be rejected. Enterprises that have a biotech alliance have a higher IO than those that do not, suggesting that hypothesis 8[17]should also not be rejected. Some indicators of alliance quality also have a positive effect on innovative output; in particular, active participation improves alliance outcome and innovative output and enterprises with alliances with firms have a higher IO. While the 2002 data set includes a detailed description of biotech alliances this has not enabled a comprehensive unravelling of the links between alliance characteristics and

[17] Innovation increases with the quantity and quality of the interaction between the organisations making up the innovation system.

alliance outcomes. The small size of the data set and the limited spread in the alliance outcome variable may have contributed to the lack of significance attached to most alliance characteristics. It may also be suggested that alliance 'quality' will be hard to quantify even in large datasets, since it depends on a wide range of factors, some of which may be specific to individual alliances[18].

6.7 Information Sources

Respondents to the 2002 survey were asked to rate the importance of various information sources on biotechnology used by their business. Each source was assigned a score ranging from 1 – 'low importance' to 5 – 'high importance'; see Table 6.3. This topic is closely related to the previous section on partnerships and alliances, since knowledge sharing and acquisition, in the broadest sense, are often primary reasons for alliance formation. Data on information sources describe a particular aspect of interaction between enterprises and so enables further investigation of Hypothesis 8[19]. The data are also used to investigate whether the use of different types of information source is associated with different levels of innovative output. Factor scores were tested against different indicators of IO. Model results are detailed in Table 6.13 and summarised in Table 6.14.

[18] for example a productive working relationship between two individuals.

[19] Innovation increases with the quantity and quality of the interaction between the organisations making up the innovation system.

Table 6.13 Innovative Output vs Information Sources; 2002 Data

	No. of Products and Processes		Patent Applications	
	Coefficient (Std Error)	%	Coefficient (Std Error)	%
Constant	5.619 (1.317)***		-1.537 (2.135)	
Biotech R&D Expenditure	0.000 (0.000)	0.0	0.000 (0.000)***	0.0
Own staff	-0.348 (0.212)*	-29.4	-0.078 (0.287)	-7.5
Hiring new staff	0.023 (0.122)	2.4	-0.014 (0.159)	-1.4
Personal contacts	-0.388 (0.152)**	-32.2	0.464 (0.255)*	59.0
Conferences	-0.200 (0.167)	-18.1	0.096 (0.212)	10.0
Other firms	-0.256 (0.143)*	-22.6	-0.026 (0.182)	-2.6
CRIs	-0.100 (0.114)	-9.6	-0.089 (0.181)	-8.5
Other Research Organisations	0.371 (0.148)**	44.9	-0.200 (0.212)	-18.1
Universities and Polytechnics	0.127 (0.137)	13.5	0.105 (0.189)	11.1
Goverment Departments	-0.098 (0.159)	-9.3	0.186 (0.232)	20.4
Professional/ Industry Organisations	0.005 (0.137)	0.5	-0.431 (0.224)*	-35.0
Academic Journals	-0.603 (0.273)**	-45.3	-0.249 (0.413)	-22.1
Library/ Literature search	0.186 (0.246)	20.4	0.437 (0.314)	54.8
Database retrieval	0.137 (0.166)	14.7	0.201 (0.224)	22.2
Patent disclosures	0.009 (0.113)	0.9	0.052 (0.137)	5.4
International vs Domestic links	0.573 (0.309)*	77.3	-0.317 (0.407)	-27.2
Number of observations	50		50	
Pseudo R^2	0.0690		0.1072	

Notes:

1. * significant at 10%; ** significant at 5%; *** significant at 1%
2. This analysis uses the Negative Binomial Regression Model.
3. Dependent variables prd_all (No. of products or processes in R&D, trials or on the market), pat3totx (number of patents applied for in last 3 years), (see Table 6.3).
4. Data are from the 2002 Biotech Survey.

Enterprises that consider international sources (in general) and research organisations (other than CRIs) to be important information sources had higher product and process IO while those that believed personal contacts, conferences, other firms and academic journals to be important tended to have a *lower* innovative output.

Table 6.14 Information Sources vs. Innovative Output: Summary of Results from Table 6.13

	Dependent Variable	
	No. of Products and Processes	*Patent Applications*
Positive Effects	Other Research Organisations** International sources*	Personal contacts*
Negative Effects	Own staff* Personal contacts** Other firms* Academic Journals**	Professional/Industry Organisations*

Note: * significant at 10%; ** significant at 5%.

Significantly different results are estimated for a model with patent applications as the dependent variable. In this model, organisations that consider personal contacts and library/literature search to be important sources of information have a *higher* innovative output in terms of patent applications, while professional/industry organisations have a negative effect.

It should be stressed that the associations reported above are between innovative output and respondent *perceptions* of the importance of different information sources. Nonetheless there does appear to be a significant difference between enterprises where innovative output is revealed through products and processes and those where it is revealed through patents. This effect is partly explained by differences between enterprises in different industry sectors; for example the variable for importance of personal contacts is positively correlated with research organisations and universities, but negatively correlated with other industry sectors. Based on the above, respondents that think that personal contacts are important tend to come from enterprises that have *lower* product and process innovation, but *higher* levels of patent innovation and are often from research organisations or universities.

6.8 Other Factors

Material presented in this section describes the relationship between respondent *perceptions* of factors affecting the amount of innovation produced by organisations and *actual* innovative output, see Table 6.15.

Respondents were asked to assign a score to a list of factors that might affect the amount of innovation produced by their business. Factor scores were tested against different indicators of innovative output with the model based on the number of patent applications producing the best fit. The list of factors was based on the innovation literature and discussions with members of the New Zealand biotech industry reported in Marsh (2003). Model results are summarised in Table 6.16.

These results may be used to investigate hypotheses on demand-pull vs. science push and appropriability.

	Hypotheses (Other Factors)
2	Demand pull vs. Technology push Investment in innovation is determined jointly by technological opportunity and market demand.
7	Appropriability R&D spending (and hence innovation) increases as the degree of appropriability of R&D outputs increases.
8b	Alliances Links with purchasers have a positive effect on IO.

Table 6.15 Respondent Perceptions of Factors Affecting Innovative Output vs. Reported Innovative Output; 2002 Data

	No. of Products and Processes		Patent Applications	
	Coefficient (Std Error)	%	Coefficient (Std Error)	%
Constant	2.429 (1.195)**		-7.172 (1.773)***	
Biotech R&D expenditure	0.000 (0.000)	0.0	0.000 (0.000)***	0.0
Conditions in your business				
Quantity of funds available for R&D	-0.000 (0.208)	-0.0	-0.015 (0.267)	-1.5
Quality of the R&D environment	-0.240 (0.259)	-21.3	1.114 (0.400)***	204.6
Number and quality of R&D staff	0.199 (0.247)	22.1	0.844 (0.336)**	132.5
One or a few star scientists	0.189 (0.156)	20.8	0.015 (0.127)	1.5
'Science push' or technological opportunity	-0.320 (0.204)	-27.4	-0.112 (0.188)	-10.6
Quality of links with org's in New Zealand	-0.183 (0.235)	-16.7	0.387 (0.216)*	47.3
Quality of links with overseas organisations	0.180 (0.179)	19.8	-0.157 (0.183)	-14.6
Ownership of intellectual property	0.033 (0.172)	3.3	-0.011 (0.181)	-1.1
Appropriability	-0.164 (0.224)	-15.1	-0.376 (0.260)	-31.3
Links with purchasers	0.383 (0.194)**	46.7	0.186 (0.157)	20.5
Conditions in New Zealand				
Quality/quantity of basic science	-0.092 (0.151)	-8.8	-0.019 (0.127)	-1.9
Quality/quantity of applied science	-0.345 (0.222)	-29.2	-0.248 (0.177)	-22.0
R&D environment in New Zealand	0.296 (0.148)**	34.4	-0.023 (0.115)	-2.3
Number of observations	47		47	
Pseudo R^2	0.0525		0.2720	

Notes:
1. * significant at 10%; ** significant at 5%; *** significant at 1%
2. This analysis uses the Negative Binomial Regression Model.
3. Dependent variables prd_all (No. of products or processes in R&D, trials or on the market), pat3totx (number of patents applied for in last 3 years), (see Table 6.3).
4. Data are from the 2002 Biotech Survey.

Table 6.16 Factors Affecting Innovative Output: Summary of Results from Table 6.15

	Dependent Variable	
	No. of Products and Processes	*Patent Applications*
Positive Effects	Links with purchasers** R&D environment in New Zealand (regulations, incentives etc)**	R&D environment in business*** Number and quality of R&D staff** Quality of links with org's in NZ*
Negative Effects	'Science push'[12%] Quality/quantity of applied science in New Zealand[12%]	Appropriability[15%] Quality/quantity of applied science in New Zealand[16%]

Note: * significant at 10%; ** significant at 5%; *** significant at 1%, superscript percentages denote lower levels of significance.

The regression results reported above can be interpreted as follows: enterprises that consider links with purchasers and overseas organisations, star scientists and the R&D environment in New Zealand to be important, tend to have more products and processes on the market (or under development). Those that consider 'science push' and the quality/quantity of basic and applied science in New Zealand to be important tend to have a *lower* innovative output.

Using patent applications as the dependent variable produces a similar result in terms of links with purchasers (positive effect) and applied science (negative effect). Enterprises that consider quality of links with New Zealand organisations to be important tend to make more patent applications, while organisations that consider appropriability to be important make fewer patent applications.

The positive coefficient 'links with purchasers' and negative coefficient for 'science push' suggests that market demand is a more important determinant of innovative output than 'science-push'; at least as measured by the indicators used in this study. These results lend some partial support to hypothesis 2. Enterprises engaged in 'science-push' tend to conduct basic research where outputs are mainly in the form of articles in scientific journals rather than new products, processes or patent applications[20]. Enterprises with strong links with purchasers are more likely to conduct applied research and to commercialise their innovative

[20] Although Griliches (1986) and Mansfield (1980) present evidence that basic research has a stronger effect on firm productivity than applied research.

output in the form of new products and processes or patent applications (Porter, 1998; Stern et al., 2000). Hypothesis 8b that purchaser links have a strong positive effect on innovation rate is also supported by the survey respondents.

Ownership of intellectual property and ability to profit from innovation are expected to be positively associated with innovation output (Hypothesis 7). Enterprises perceptions that ownership of IP was important did not have a significant effect on expected IO however enterprises that considered appropriability to be important were associated with *fewer* patent applications. This may be a consequence of commercial firms (that tend to make fewer patent applications) giving a higher score to this factor. Overall, enterprises that considered ownership of IP and appropriability to be important were not associated with higher levels innovative output. The survey data provide no evidence in support of Hypothesis 7, nor any direct evidence that would suggest that the hypothesis should be rejected.

Respondents that believed number and quality of R&D staff and the R&D environment in their enterprise to be important had a higher than expected number of patents than those that gave this factor a lower score, this is supported by the model results reported in section 6.4. For product and process innovators importance of 'star scientists' had a positive coefficient. Responses to this question were highly polarised; while many enterprises clearly felt that 'star scientists' did not affect their innovative output, enterprises that considered 'star scientists' to be important had a higher IO.

Respondent perceptions in this area are also well supported by the literature; for example Vanevar Bush, one of the major figures in the development of modern science policies pointed out in 1945 that:

> the responsibility for the creation of new scientific knowledge – and for most of its application – rests on that small body of men and women who understand the fundamental laws of nature and are skilled in the techniques of scientific research (1945, p. 7)

Evidence from enterprise perceptions of the New Zealand R&D environment is rather mixed. Those that are highly concerned with the quantity and quality of applied science carried out nationally, tend to have a *lower* product and process

IO; perhaps respondents with these concerns tend to carry out more basic research and so have lower product/process IO. By contrast enterprises that are concerned with the overall R&D environment in New Zealand (e.g. regulations and incentives etc) have a higher product and process IO. This provides some support for the empirical observation that leading biotech enterprises have strong concerns that government regulations are restricting the growth of the New Zealand biotech industry.

6.9 Summary and Discussion

This chapter has presented the results of data analysis based on the 1998/99 and 2002 biotechnology surveys that aimed to identify and quantify the factors affecting innovation in the New Zealand biotechnology sector.

The 2002 survey addressed many of the limitations encountered in analysing the 1998/99 dataset. In particular, collection of additional data on new products, processes and patents allowed creation of improved measures of innovative output. The survey also provided more precise data on innovative input; particularly human resources and expenditure devoted to biotech R&D and a more precise description of the number, characteristics and outcomes of biotech alliances.

The hypotheses outlined in the theoretical section of this paper can now be revisited in the light of the empirical work presented above, see Table 6.17. These results are novel internationally, both in their use of an innovation framework that combines knowledge from four strands of the innovation literature and in application of this framework to the biotechnology sector. Within New Zealand very little quantitative analysis of the determinants of innovation has been carried out and there is no prior work on the biotechnology sector.

Table 6.17 Summary of Results from 1998/99 and 2002 Surveys

No.	Hypothesis	
2	*Demand pull vs. Technology push* Investment in innovation is determined jointly by technological opportunity and market demand	Enterprises that report that links with purchasers are important have higher IO**. Enterprises that consider science-push to be an important determinant of IO have lower IO**.**
5	*Firm Size*	Innovation Output increases with biotech expenditure***.
5a	Innovation output increase with enterprise size and the number of ideas workers.	Innovation Output increases with number of ideas workers*** (biotech graduates or biotech employees) **.**
5b	Innovation rate increase with enterprise size and the number of ideas workers	Innovation Rate per unit expenditure falls as biotech expenditure increases. Innovation Rate per employee falls as number of biotech employees increases.
6	*Firm type* Innovation output and innovation rate vary with firm or organisational type	See 6a to 6d below**.**
6a	IO and IR vary with industry group	Innovation Output (IO) of most industry groups significantly greater than IO for food manufacturers***. Innovation Rate (IR) of most industry groups significantly higher than IR for food manufacturers***.**
6b	Enterprises that conduct R&D have a higher IO and IR than those that do not	Enterprises that conduct R&D have a higher IO*** **.** Enterprises that use more biotech processes for R&D have a higher IO**.
6c	Enterprises that use modern biotech processes have a higher IO and IR than those that do not	Not supported**.**
6d	Enterprises that specialise in biotech have a higher IO than those that do not.	Not supported.
7	*Appropriability* R&D spending (and hence innovation) increases as the degree of appropriability of R&D outputs increases	Enterprises that consider appropriability to be an important determinant of IO had lower IO. (Patent applications indicator).
8	*Spillovers and alliances* Innovation increases with the quantity and quality of the interaction between the organisations making up the innovation system	Alliances with a strategic alliance have higher IO*.** Active participation improves alliance outcome and IO***.** Enterprises that consider international sources and other research organisations to be important information sources have higher product and process IO***.
8a	International linkages have a stronger positive effect than domestic linkages.	Enterprises with strategic alliance with international partners have a higher IO*. Enterprises with alliances with international partners report better alliance outcomes (p=0.16) **.**
8b	Links with purchasers have a positive effect on IO	Enterprises that report that links with purchasers are important have higher IO**.
8c	Links with firms have a positive effect on IO	Enterprises with alliances with firms have a higher IO***.

Note: * significant at 10%; ** significant at 5%; *** significant at 1%,

It has been shown that enterprises that report that links with purchasers are important have a higher innovative output while those that consider science-push to be important tend to have lower innovative output (section 6.8). It will be

recalled (section 3.4) that the relative importance of 'demand pull' versus 'science and technology push' was debated for much of the last century. Recent empirical work has tended to support the view that both factors are important although their relative significance varies across different stages of the industry life cycle (Rosenberg, 1974; Rothwell et al., 1974). Previous empirical work, for example Katz and Phillips (1982), showed that technology push dominated in the early days of the development of the computer. Based on this result, it might be expected that 'technology' push would be similarly dominant in the development of modern biotechnology.

However, it should be remembered that the result reported above is based on respondent *perceptions*, rather than any objective measure of the relative importance of 'demand pull' or 'science push'. It should also be noted that our measure of innovative output only counts inventions that have been commercially exploited and patent applications. Allocation of resources toward such activities is expected to be more strongly influenced by 'demand pull' and links with purchasers. Overall, hypothesis 2 is not rejected. We conclude that enterprises that report that links with purchasers and 'demand pull' are important tend to have a higher innovative output (as measured by our indicators), while those that consider science-push to be important tend to have lower innovative output.

Romer (1990) formalised the hypothesis that the rate of new ideas production increases with the number of ideas workers and the stock of ideas, while alternative literature strands e.g. Scherer (1980) provide other models suggesting that innovation rate is driven by market structure (large firms, monopoly power, economies of scale, barriers to entry etc); so large firms should have a higher innovative output. On the other hand extensive empirical research by Cohen and Klepper (1992; 1996) and work focussing on the biotech sector by McKelvey (2001) finds that *smaller* firms have a higher innovation rate.

The expected positive relationship between innovative effort and innovative output has been confirmed and some significant differences between the innovative outputs and innovation rates of different organisational types have been identified. But this thesis finds that innovation rate *falls* with biotech

expenditure and with the number of biotech graduates. In other words smaller enterprises with lower levels of biotech expenditure and fewer biotech graduates generally have a higher innovation rate (per graduate or per unit of biotech expenditure) than larger enterprises and Hypothesis 5b should be rejected.

This finding is supported by other studies reported in the literature; for example Cohen & Klepper (1996) found that "the number of patents and innovations per dollar of R&D decreases with firm size and/or the level of R&D". They explain the lower innovation rate of smaller firms through the mechanism of cost spreading; namely that "the larger the firm then the greater the level of output over which it can average the cost of R&D". In their model, this results in the average project pursued by larger firms having a lower return, in terms of numbers of patents or innovations, than smaller firms (p. 933).

There is further support for this view within the biotechnology industry, where it is argued that small firms are able to develop of areas of new knowledge and commercialise radical innovations, more quickly than larger established organisations (McKelvey, 2001).

Arvanitis and Holenstein (1996, p. 51) also find no evidence for increasing returns to scale but distinguish two types of innovating firms:

> on the one hand, small firms operating in relatively well protected market niches and generating continuous small improvements of products and processes by using extramural knowledge, and protecting themselves against imitation by secrecy as well as by time leads on competitors. On the other hand, large firms creating new products and introducing new processes in an environment of strong, international, primarily non-price competition. They rely more strongly on their own innovative knowledge which is stimulated by basic research done at universities and laboratories.

This typology has much relevance to the New Zealand biotech sector where most players are small by international standards. Those that are successful often match the characteristics described above and often have an innovation rate above that of larger firms that engage directly in international competition.

The analysis reported in this chapter has also demonstrated significant differences between different enterprise types and industrial groups thus supporting

hypothesis 6. It has been shown that biotech enterprises engaged in R&D generally have a higher innovative output compared to those that do not. Use of more different types of biotech process for R&D (an alternative indicator of R&D activity) also tends to increase innovative output. Findings on the importance of enterprise type are supported by Scherer (1982a) and Pavitt (1984), see section 3.7. R&D is expected to increase innovation output in Romer's (1990) model and this result is also supported by a wealth of empirical research[21].

The idea that the overall innovation performance of an economy depends not so much on how specific organisations perform, but on how well they interact with each other, is central to the Systems of Innovation approach (hypothesis 8). The quantitative analysis reported in this thesis finds that enterprises with strategic alliances have a higher innovative output compared to those that do not. Data from the 2002 survey enabled conclusions to be drawn about some of the other alliances characteristics that are associated with increased innovative output. Enterprises that had alliances with international partners reported better alliance outcomes and had higher innovative output than those that did not. Similarly, enterprises that had links with firms (rather than other types of organisation) and those that considered links with purchasers to be important also had higher innovative output. Alliances involving active participation were also reported to lead to more productive alliance outcomes.

These results on the role of alliances are in line with theoretical models and empirical work on spillovers, clustering and alliances (see section 3.9d to more productive alliance outcomes.

These results on the role of alliances are in line with theoretical models and empirical work on spillovers, clustering and alliances (see section 3.9). Arora and Gambardella (1990) reporting on the use of external linkages by large biotech firms found that "the locus of innovation should be thought of as a 'network' of

[21] See Hinloopen (2003), Crépon, Duguet and Mairesse (1998), Hansen (1992) and many others. It should be noted that innovation can also result from imitation and from other types of learning processes, see Tether (2001, p. 29).

inter-organizational relations". More recent research on networks in biotechnology found that "the importance of communication links to the centre have been increasing … fewer and fewer inventors exist in isolation from research centres as connections drive more and more research activity" (Johnson & Mareva, 2002, p. 28). Furthermore, Keller (2001) found that international (not domestic) technology diffusion is the major source of technical change leading to productivity growth in OECD countries.

A framework describing the determinants of innovation was first presented in chapter 3. The framework is based on a synthesis of nine key innovation hypotheses drawn from four strands of the innovation literature. The analysis reported in this chapter has enabled empirical testing of five of these hypotheses. The analysis has confirmed the importance of most[22] of the innovation determinants included in the framework and has provided specific results based on application of the framework to the New Zealand biotechnology sector.

[22] Five determinants were tested; demand pull vs. technology push, firm size, firm type, appropriability and alliances. Significant results were obtained for all of these factors *except* appropriability.

Chapter 7 Conclusions

This thesis has described the determinants of innovation in the New Zealand biotechnology sector. Until the 1950s most economists were content to regard innovation as a 'black box' and research into the mechanism inside the box was largely overlooked. But in the last 15 years, innovation has assumed centre stage in debates conducted by economists, geographers, urban planners and policy makers. So much so, that innovation is now widely held to be the central driver of successful national and regional economies" (Berry, 2003, p. 9). There has also been an explosion of interest in biotechnology, as economists, policy makers and politicians have become increasingly interested in the role that it might play in the 'new economy' and aware of the policy initiatives that have been implemented by many of New Zealand's competitors.

One of the reasons why economists are so interested in modern biotechnology is because of the idea that it may be a generic technology with pervasive effects throughout the economic system. The development of modern biotechnology in the 1970s created enormous excitement in the scientific research community and was fuelled by a great upsurge in private venture capital funding. To date, it has led to profitable innovations in only a relatively small number of applications and has not had the pervasive and widespread effects that we would expect of a generic technology. However Diebold (1952) suggested that the effective diffusion of revolutionary technologies usually takes decades rather than years or months, as has proved to be the case with computing and information technologies. Modern biotechnology may prove to be a generic technology, but its full impact will not be felt until well into the twenty first century[1].

Alfred Marshall, in one of the most brilliant introductions to the nature and scope of economics defined it as "a study … of the material requisites of wellbeing" (1920, p. 1). It is concerned ultimately with just two goals; economic growth, and an acceptable distribution of income and wealth. Economic growth can be

[1] Arundel (2003) provides an up to date discussion of the possible impact of biotechnology.

generated through use of larger quantities of production inputs (labour, natural resources and capital), and through innovation. While economic growth based on use of increasing quantities of inputs must ultimately be constrained by global resource availability, growth based on innovation is in principle limitless, because it improves the productivity of existing inputs. This fact, combined with increased concern over the sustainability of global resource use explains why governments around the world have become so interested in innovation and the development of policies that will help transform economies into 'knowledge societies'[2].

The vast majority of innovation studies are based on large industrialised countries such as the United States. The research described in this thesis has two distinguishing features. First, it relates to a small country where innovation has, until recently, been little studied. Second, it focuses on biotechnology in New Zealand, a topic that has not been the subject of previous economic research.

The New Zealand biotechnology sector is of interest for several reasons. Firstly, there is a large and growing international literature on economic aspects of biotechnology innovation (e.g. work by Carlsson, McKelvey, Orsenigo, Zucker and Darby) but these studies concentrate on the United States and Europe. Secondly, the New Zealand biotechnology sector may be expected to develop along a different trajectory as a consequence of a markedly different set of initial and framework conditions. Thirdly, New Zealand has a small open economy, which has been modified by an extensive set of institutional and economic reforms including transformation of the national science and technology system towards a more market driven model. Government has indicated a strong interest in fostering innovation and aims to concentrate on selected areas where New Zealand may be able to develop a new comparative advantage. One such area is biotechnology, which would build on New Zealand's existing comparative advantage in the primary sector.

[2] See Drucker (1993, p. 8) "the basic economic resources…is (sic) no longer capital, nor natural resources … nor labour. It is and will be knowledge".

Recent science sector reforms aim to foster networks and increase the flow of knowledge between researchers, industry and business. An extensive foresight process was intended to focus science spending on specific science outcomes and other initiatives have been announced to support innovative New Zealanders. Yet our empirical knowledge of innovation processes and knowledge flows in New Zealand was, until recently, very limited.

This thesis contributes to the literature on the economics of innovation in four ways:

i. the different strands of the literature on the economics of innovation are reviewed and synthesised in order to extract a series of key hypotheses regarding the determinants of innovation (chapters 2 and 3);
ii. the New Zealand biotech sector is described in order to provide context for the study of the determinants of innovation in this sector. This description is considerably more accurate and detailed than previous accounts. It makes use of original analysis by the author, using two surveys of the New Zealand biotech sector (Marsh, 2001b, 2002) as well as a comprehensive review of secondary sources (chapter 4);
iii. New Zealand's innovation system for biotechnology is assessed based on a review of secondary sources and interviews with senior members of ten leading firms and organisations, see chapter 5 and Marsh (2003); and
iv. two original datasets are used to test a set of key hypotheses relating to the determinants of innovation in the New Zealand biotechnology sector. This is the first time that this set of hypotheses has been tested in New Zealand and represents one of the first detailed investigations into the determinants of innovation in New Zealand.

Innovation is now widely studied and written about both in academia and in books, newspapers, policy documents and other non-academic publications. Within the economic literature, individuals who are not willing to proceed within the core assumptions of neo-classical economics have developed alternative evolutionary and systems approaches. Evolutionary theorists aim to drop the assumption that individuals maximize. They try instead to represent decision making as a process of groping through alternatives in which it may take a long

time to get to a maximum and where the maximum reached may well be local rather than global. They avoid the assumption of equilibrium and pursue an approach where the economy is always evolving. Systems theorists focus on “the network of institutions in the public and private sector whose activities and interactions initiate, import, modify and diffuse new technologies (Freeman, 1987, p. 1)”. They believe that interactions between these institutions are important determinants of the innovative performance of firms and of nations.

However, acceptance of the absolute truth of neo-classical assumptions is certainly not a pre-requisite for those who choose to work within that tradition. Rather, economists in the neo-classical tradition are those who prefer to make sense of the world using models based on the simplifying assumptions of maximization and equilibrium. Those who believe that knowledge can be advanced further, outside these constraints use alternative traditions such as the evolutionary approach. The approach taken in this thesis draws on both the neo-classical and the evolutionary literature. The neo-classical framework is most developed and has the advantage of general principles which are not available under the evolutionary approach. However, systems concepts and evolutionary theory provide useful supplements to neo-classical theory. They provide an alternative framework for thinking about innovation and encompass many of the features that seem to be essential to a full explanation of the economics of innovation. For these reasons the empirical research described in this thesis has been conducted mostly within the neo-classical framework but draws freely on the knowledge gained through other traditions whenever this is appropriate.

In this thesis, innovation is held to be a deliberate activity that is usually undertaken to solve economic problems or capitalize on economic opportunities. Innovation results from research and development and various other kinds of learning activity that are usually undertaken in the expectation of gaining economic benefits. The level of innovation can be directly related to the amount of effort put into R&D, the existing stock of ideas (Romer, 1990), firm level factors and to supply side forces that determine the probability of success e.g. technological opportunity and the cost of producing a successful invention (Rosenberg, 1974, p. 103). Innovative output is also affected by market structure

(e.g. numbers of buyers and sellers, barriers to entry) and the extent to which firms can appropriate the economic benefits of their innovations. R&D spending has spillover effects both between enterprises and internationally. This increases the rate of technological change but means that the level of private R&D spending is generally sub-optimal. There has been a particular focus in recent years on the role of various kinds of linkage between the different players in clusters or systems of innovation. The quality and quantity of these links are an important determinant of innovative output.

Evolutionary perspectives add to our understanding of innovation particularly in describing dynamic processes and the path dependent nature of innovation systems. For example Berry (2003, p. 117) describes innovation as occurring:

> within a socio-technical matrix or 'milieu' that is spatially focussed in particular regional economies, linked by flows – of capital, labour, trade and information. Successful regional economies are those that capture and keep assets (skilled workers, patient investors, cultural and leisure resources, good governance and the rule of law, smart infrastructure and creative people) that enhance innovation processes and outcomes.

Evolutionary and systems approaches have made valuable contributions but it is important not to neglect the key relationships first described by economists such as Marshall, Schumpeter and Scherer. For example, innovative effort, firm size and firm type explain much of the variation in innovative output, both internationally and within the particular circumstances of the New Zealand biotech sector.

This thesis provides a detailed description of the New Zealand biotech sector based on analysis carried out by Marsh (2001b; 2001c; 2002) and a review of secondary sources. This description sets the scene and provides context for the study of the determinants of innovation described in Chapters 5 and 6. Prior to this analysis our knowledge of most sector parameters was very limited or completely lacking. There is a need for policy makers to make more use of the available data, rather than continuing to use less reliable estimates produced by organisations that have a vested interest in describing the sector in way that suits their particular purpose.

Different interpretations of the terms biotechnology and biotechnology sector hinder attempts to measure biotech activity in a way that is comparable over time and across nations. Size estimates for the New Zealand biotech sector range from 30 core biotech companies with annual income of the order of $200 million, to many thousands of companies having annual production worth several billion dollars, when traditional food applications such as cheese, yoghurt and beer are included.

Marsh (2001b) divided the biotech sector into four categories based on whether enterprises used modern or traditional biotech processes and whether they were creators (engaged in R&D) or simply users of biotechnology processes. By this method, the modern biotech sector can be defined as the population of private and public sector enterprises that carry out modern biotech R&D. Based on this definition, New Zealand's modern biotech sector consisted in 1998/99 of approximately 57 enterprises, employing around 1700 people. Most activity is concentrated in universities, Crown Research Institutes and a small number of private sector companies.

Enterprises in the modern biotech sector are split fairly evenly between the private and public sector. They reported expenditure on biotech of NZ$202 million and income from biotech of NZ$236 million for 1998/99. This compares to enterprise income from all sources of NZ$2.1 billion i.e. biotech provided around 11% of income for the 57 enterprises. More recent data indicate that annual growth in expenditure may be as much as 20%.

Respondents to the 2002 biotech survey indicated that R&D constituted around 10% of total expenditure while expenditure on biotech R&D comprised around 80% of all biotech expenditures. Around 60% of all 'biotech staff' were engaged in R&D. Respondents spent far more on R&D than the industry average. For example the dairy industry is reported to spend around 1% of turnover on R&D, while R&D expenditure as a proportion of value added of manufactured products was 1.3 percent in 1999/2000.

According to the OECD (2003a) New Zealand put the highest proportional effort into biotech R&D. This results both from New Zealand's R&D specialisation in the primary sector and from use of a broad definition of what constitutes biotech R&D. Not surprisingly, a rather different picture emerges in absolute terms with New Zealand's total expenditure on biotech R&D being the third smallest of the 21 countries listed.

Further work is required before definite conclusions can be reached on the relative innovative output of New Zealand biotech firms, although available evidence suggests that New Zealand biotech firms do not have a particularly high rate of new product or process development relative to other New Zealand sectors or to other countries. New Zealand's rate of modern biotech patent applications over the five years to the end of 2002 was below the average for the G7 and for a reference group of small, developed OECD economies. New Zealand's performance is disappointing compared to other small countries with strong primary industries that it might hope to emulate e.g. Denmark, Switzerland, Netherlands and Australia (Marsh, 2003).

Chapter 5 makes use of a combination of secondary sources and data from interviews to assess the effect of institutional factors on biotech innovation in New Zealand. It follows the systems approach[3] in assessing the extent to which these factors combine to create an effective innovation system for biotechnology. It concludes that the system, if it exists, performs poorly and is dominated by Crown Research Institutes and universities which rely on the government for the majority of their funding. World-leading biotechnology R&D is carried out in some fields, but this tends to involve links with a small number of organisations. These examples are better described by the term 'islands of excellence' rather than being part of a wider, strongly connected system of innovation.

The factors that seem to have encouraged the emergence of world-leading research are diverse, ranging from strong basic science in medical research and science push in sheep genomics, to industry pull in the case of forest

[3] The NIS approach to describing innovation systems is exemplified by Nelson (Nelson, 1993b).

biotechnology. Growth in these and other biotech-based sectors may be constrained by the poor performance of New Zealand's National System of Innovation. There have been major changes to research, science and technology policy since the late '80s, but it remains to be seen whether these will result in a sustained improvement in performance.

The New Zealand Government has only recently taken leadership in fostering innovation in modern biotechnology. Indeed government and industry only seem to have taken a close interest in biotechnology in the last four to five years. New Zealand has not made the kinds of large investment seen in Australia and some of its regional trading partners. Instead it has concentrated on science sector reforms and a free market oriented approach. New Zealand has the potential to demonstrate a new model for the development of a biotech industry based on comparative advantage in primary industry and some other niche areas. The jury is still out on whether New Zealand's innovation environment will allow that potential to be achieved.

The factors that affect the innovative output and innovation rate of enterprises in the New Zealand biotechnology sector are analysed in chapter 6, based on the theoretical framework and innovation framework laid out earlier in this thesis. Innovation output is investigated using several different count variables including the number of new products and/or processes introduced to the market, the number of products and/or processes undergoing trials or R&D and the number of patent applications. Combining product and/or process introductions and patent applications provides a better overall measure since different organisations exhibit innovative output in different ways. Patents are a better indicator for enterprises that concentrate on the creation (and protection) of intellectual property, while the number of new products and/or processes introduced is a better indicator for more production-oriented enterprises (many of which have applied for few if any patents).

In the 2002 survey, data were collected on the percentage of revenue or sales attributable to biotech products or processes introduced in the last three years. This innovation metric has been widely used, particularly in the Community

Innovation Surveys (CIS). It has the advantage that it provides a measure of the impact of innovation on enterprise performance, whereas innovation counts do not distinguish between trivial innovations and those that have greater significance. Unfortunately this indicator has only limited application in the New Zealand biotech sector where much innovative activity is concentrated in R&D and has not reached the market.

This thesis describes the measurement of innovation inputs and innovation outputs and details the relationship between them. Useful new indicators are developed and tested empirically but data quality remains a real problem. Several of the most commonly used indicator variables remain open to varying interpretations depending on the organisational type, sector, country etc in which the data are collected (Mairesse & Mohnen, 2001; Mohnen & Dagenais, 2002; Tether, 2001). For example how new or improved or significant does a product have to be before it is reported?

Econometric analysis of count data requires careful selection of the appropriate regression model. The Poisson Regression Model rarely fits the data due to underestimation of the amount of dispersion in the count variable. The Negative Binomial Regression Model (NBRM) addresses the failure of the PRM by adding a parameter that reflects unobserved heterogeneity among observations. The superior performance of the NBRM for the count variables analysed in this thesis is illustrated by plotting the observed frequencies of different counts of innovative output against levels predicted by the Poisson and Negative Binomial Regression Models. The PRM under predicts the frequency of innovative output counts of zero and over predicts counts of one to six. By contrast the NBRM predicts the observed proportion of counts very accurately; particularly for count levels three or more. For these reasons, the econometric analysis reported in this thesis is based mainly on the NBRM. Some use is also made of zero-inflated negative, binomial regression and the Tobit model.

The factors affecting the innovative output of enterprises in the New Zealand biotech sector can now be summarised based on the analysis reported in chapters 5 and 6. Innovation increases with innovative effort, whether measured by R&D

expenditure or by the number of staff devoted to biotech activity. However innovation rate (per unit of expenditure or per employee) falls as innovative effort increases. In other words smaller enterprises with lower levels of biotech expenditure and fewer biotech graduates generally have a higher innovation rate than larger enterprises. Not withstanding this result, it may well be the case that no single firm size is uniquely conducive to technological progress (Scherer, 1980, p. 418). In this case innovative output may be maximized by a diversity of sizes, each with its own special advantages and disadvantages. The higher innovation rate of some small biotech firms in New Zealand may be directly related to their ability to share knowledge with larger enterprises, while others may be recent start-ups that capitalise on the R&D efforts of their larger 'parents'.

Enterprise characteristics are significant determinants of innovative output and rate so, for example, enterprises that conduct R&D have a significantly higher IO and IR than those that do not. There are also differences depending on firm type. The primary industry and health services group had the highest innovative output followed by research organisations, non-food manufacturers, other and universities. However, as noted by Tether (2001), varying interpretations of the meaning of innovation, across sectors make such comparisons problematic. This is an area where further research would assist our understanding of New Zealand innovation statistics. A useful first stage would be a follow up survey to interview a sample of enterprises included in the Business Practices Survey and/or the 1998/99 Biotech Survey (Statistics New Zealand, 2001, 2002). Such a survey would list and describe the innovations identified by respondents and explore whether other innovative activities might have been missed. The aim of the research would be to make a qualitative description and assessment of respondent's interpretation and reporting of innovative activity.

Evidence on the role of alliances in the New Zealand biotech sector is somewhat mixed. Some private firms place little emphasis on linkages in the development of new products and processes; others consider that there are few organisations that are worth linking with and so concentrate on developing strategic alliances and joint ventures with overseas partners. There is a broad consensus that more effective interaction between the different players in the biotech sector needs to be

encouraged, both in research and in new product development. Government and industry groups have sought to encourage such interaction for several years and there is some evidence of success, both in the formation of more alliances and in the outcome of such alliances. The quantitative analysis reported in this thesis provides support for such policies. Enterprises that have biotech alliances tend to be more innovative than those that do not, particularly when the alliance is with an international partner or firm. Other characteristics that have a positive effect include alliances that involve 'active participation' and 'strong links with purchasers'. International linkages are clearly of crucial importance yet small enterprises often face barriers in establishing these linkages. Government funded agencies and research organisations can usefully provide a co-ordination and dissemination role in facilitating such linkages, while remembering that international partners will be most interested in forming alliances with partners of 'international quality'.

There are interactions between some of the findings reported above, for example, smaller enterprises may be more efficient than larger enterprises in certain kinds of activities *provided* that they have strong domestic and international links. Such a conclusion might provide support for policies designed to increase the rate of spin-offs from CRIs, from universities and from other research organisations in order to create a larger cohort of small, highly innovative firms with strong links to other players in the innovation system for biotechnology.

Martin and Salter (1996) found that there is great heterogeneity in the relationship between basic research and innovation since the relative importance of different forms of research benefit varies with scientific field, technology and industry. As a consequence, they concluded that "no simple model of the nature of the economic benefits from basic research is possible" (p. 59). They went on to conclude that the main empirical requirement was for case studies and surveys that systematically analyse the relationship between research and technology.

Analysis of the mechanisms underlying innovation has been a complex task. Much progress has been made in identifying and describing the underlying relationships. It has been shown that there is considerable heterogeneity; for

example, the areas where New Zealand conducts world-leading research are diverse and cannot be reduced to a simple reproducible model. Progress in explaining innovation at this level requires use of a variety of models, capable of taking account of the considerable heterogeneity. Following the suggestion by Martin and Salter (1996), it has been shown that several different but complementary analytical tools can be used to enable description of the determinants of sectoral innovation[4].

This thesis has added to our understanding of innovation in biotechnology through collection and analysis of data from an original survey conducted by the author. Further progress can be made in two main areas. Firstly, through incorporation of some of the methods and indicator variables, developed in this thesis, into future innovation surveys, both in the biotech sector and in industry-wide studies. The analysis reported in this thesis has been governed by the variables included in the 1998/99 survey and by the number of enterprises that responded to the 2000/01 survey. There is therefore considerable scope to extract additional findings from future innovation surveys, provided appropriate variables are included.

Data from such surveys could build on the analysis reported in this thesis to explore additional issues such as the impact of innovative effort on firm performance (Hoffman et al., 1998), the reasons for the higher innovation rate of smaller enterprises and the optimal mix of large and small enterprises.

Case studies and other methods of qualitative assessment provide a second area where further research should be attempted. Mention has already been made of the need to increase our understanding of the meaning of innovation in New Zealand innovation surveys i.e. how do respondents decide on the number of innovation counts entered on survey forms? The research value mapping (RVM) approach developed by Barry Bozeman and his colleagues[5] would also provide an excellent

[4] Or, more precisely, the determinants of innovation in the *technological system,* see 2.6.4.2.

[5] Kingsley, Bozeman, & Coker (1996), Bozeman & Kingsley (1997) Bozeman & Klein (1999). The RVM research procedure has been summarized by Bozeman (1999) as involving the

base from which to develop our understanding of the links between research and innovation in New Zealand.

The most valuable contribution of this thesis has been the integration of insights from neo-classical and evolutionary approaches to test a comprehensive set of hypotheses about the determinants of innovation. Techniques for the measurement of innovation in biotechnology have been successfully developed in order to add significantly to our knowledge of the underlying relationships. Policy makers need more information on the extent to which the underlying conditions and factors driving innovation in successful regions, sectors and technologies can be applied elsewhere. This thesis should prove useful to those policy makers who seek to develop empirically based innovation policy.

development of “sequential, but nonlinear, branching model(s) of the flow of knowledge from research to exhaustive outcomes”. The method involves analysis of case study materials.

Appendix 1 Glossary, Abbreviations and Acronyms

ANZSIC	Australia New Zealand Standard Industrial Classification
BERD	Business Expenditure on Research and Development
Biotech	Short for and synonymous with biotechnology.
Biotechnology (Modern and Traditional)	"The application of Science & Technology to living organisms as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services" (OECD, 2003c, p. 4). This is the current OECD definition.
Biotech(nology) Industry	Modern biotechnology is used in a number of different economic sectors ranging from food and non-food manufacturing through various primary industries to health, diagnostic and environmental applications. The terms 'biotech industry' and 'biotech sector', although not strictly 'correct' are often used to denote the group of industries and sectors that use biotechnologies.
Biotech Respondent	Biotech respondents, for the purposes of the 1998/99 and 2000/01 biotech surveys are defined as any enterprise or enterprise sub unit that uses at least one biotech process (see Appendix 2). Biotech respondents are divided into four categories based on whether they use modern or traditional processes and whether they are creators (performing R&D) or are simply *users* of biotechnology processes. See terms MBE, MBU, TBE and TBU (below) and discussion in section 4.1.
Biotech(nology) Sector	See Biotech(nology) Industry
BIOTENZ	A group of leading New Zealand providers of biotechnology, natural products, pharmaceutical and biological products and services. http://www.biotenz.org.nz/home.asp
BPS	Business Practices Survey Survey conducted by Statistics New Zealand, see Statistics New Zealand (2002).
Cluster	"a cluster is a concentration of firms that prosper because of their interaction, whether it is through competition or cooperation, or by serving as suppliers or customers in the value-chain" Padmore & Gibson (1998, p. 627).
Core Biotech Firm	"Core biotech firms have their main activities in biotechnology, although they can be active in other fields" (Devlin, 2003, p. 11). This is the OECD definition.
CRI	Crown Research Institute

DBF	Dedicated Biotechnology Firm A firm that is totally dedicated to biotech knowledge production (see section 3.7) and McKelvey (2001).
Diffusion	"Occurs after the invention and innovation stages and refers to the process by which innovation spreads across the market" (Stoneman, 1983)
DNA	Deoxyribonucleic acid A molecule that carries genetic information.
DSIR	Department of Scientific and Industrial Research The former government department that was responsible for most government funded research carried out in New Zealand.
DTI	Department of Trade and Industry
Endogenous Growth Theory	A growth theory in which technological change is determined endogenously (i.e. within the system). Invention, innovation and diffusion are treated as deliberate activities (see section 2.4).
Enterprise	For the purposes of the 1998/99 and 2000/01 biotech surveys an enterprise is defined as 'any public or private sector, organisation or business'. The term thus includes firms, research organisations, universities, government departments etc.
EU	European Union
Evolutionary Economics	Richard Nelson uses "the term 'evolutionary' to define a class of theories, or models, or arguments that have the following characteristics. First, their purpose is to explain the movement of something over time … that is, the analysis is expressly dynamic. Second, the explanation involves both random elements which generate or renew some variation in the variables in question, and mechanisms that systematically winnow on extant variation. Third, there are inertial forces that provide continuity of what survives the winnowing" (Nelson, 1995, p. 56). See section 2.5.
FDI	Foreign Direct Investment
FRST	Foundation for Research Science and Technology. "The Foundation for Research, Science and Technology (FRST) invests in research, science and technology (RS&T) on behalf of Government to enhance the wealth and well-being of New Zealanders". http://www.frst.govt.nz/about/
FTE	Full Time Equivalent
GBAORD	Government Budget Appropriations or Outlays on R&D
GERD	Government Expenditure on R&D

GIF	Growth and Innovation Framework A framework for New Zealand government innovation policy. See Office of the Prime Minister (2002).
G7/G8	Group of Seven France, United States, Britain, Germany, Japan, Italy, Canada. G8 also includes Russia.
GERD	Government Expenditure on Research and Development
Innovation	"The economic application of a new idea. Product innovation involves a new or modified product; process innovation involves a new or modified way of making a product. Innovation sometimes consists of a new or modified method of business organization"(Black, 2002).
IO Innovation Output	A measure of the amount of innovation produced, based on an indicator such as number of new products, processes or patents see section 3.2.
IR Innovation Rate	Innovation output divided by innovative effort (e.g. R&D expenditure or number of employees engaged in R&D).
Invention	"The idea of a new product, or a new method of producing an existing product. This is distinguished from an innovation, which is the development of an invention to the stage where its use becomes economically viable" (Black, 2002).
ISI	Institute for Scientific Information
MBE Modern Biotech Enterprise	An enterprise that conducts R&D using modern biotech processes, it may also use modern biotech processes for production.
MBU Modern Biotech User	An enterprise that uses modern biotech processes, but does not conduct R&D using modern biotech processes.
MITI	The Ministry of Trade and Industry MITI defines long term strategies for the development of Japanese industry and the economy.
Modern Biotechnology	For the purposes of this thesis, *modern* biotechnology is defined as: (1) recombinant DNA technology, (2) use of antibodies (3) protein engineering (4) novel bioprocessing techniques (Eliasson & Eliasson, 1997, p. 145; U.S. Congress, 1991, p. 5). The term "modern" is used to distinguish processes that have been developed in the last 30 years or so, from traditional biotech areas such as fermentation and extraction.
Modern Biotech Process	See appendix 2 for a list of modern biotech processes.

MoRST	Ministry for Research Science and Technology "The Ministry of Research, Science & Technology (MoRST) is a New Zealand government department which develops research and innovation policies and manages the publicly funded part of the RS&T system on behalf of the Government". http://www.morst.govt.nz/
NBRM	Negative Binomial Regression Model
Nether Region	In order to distinguish between the two uses of the word 'regional' Freeman (1995, p. 21) defines "nether region" as much smaller sub-national 'regions' ... in contrast to 'regional trading blocs' eg NAFTA or the South-East Asian 'region' which he calls an "upper region".
New Growth Theory	New Growth Theory is distinguished by two principal characteristics: "there is continuing growth at endogenously determined rates, and the growth path is treated as a general equilibrium of a competitive market, but not necessarily a perfectly competitive market" (McKenzie, 1998, p. 9).
NIS	National Innovation System Synonymous with NSI. "the network of institutions in the public and private sector whose activities and interactions initiate, import, modify and diffuse new technologies" (Freeman, 1987, p. 1). See section 2.6.1.
NSI	National System of Innovation Synonymous with NIS.
NZBA	New Zealand Biotechnology Association http://www.biotech.org.nz/
OECD	Organisation for Economic Co-operation and Development http://www.oecd.org/home/
OLS	Ordinary Least Squares
PCT	Patent Cooperation Treaty http://pctgazette.wipo.int/
PGSF	Public Good Science Fund See http://www.morst.govt.nz/
PRM	Poisson Regression Model
R&D	Research and Development
SCP	Structure – Conduct – Performance. See section 2.3.2.
SI	System(s) of Innovation See section 2.6.

SIS	Sectoral Innovation System; "that system (group) of firms active in developing and making a sector's products and in generating and utilizing a sector's technologies. Such a system of firms is related … through processes of interaction and cooperation in artefact-technology development and through processes of competition and selection in innovative and market activities" (Breschi & Malerba, 1997, p. 131).
SNZ	Statistics New Zealand
TBE Traditional Biotech Enterprise	An enterprise that conducts R&D using traditional biotech processes, it may also use traditional biotech processes for production.
TBU Traditional Biotech User	An enterprise that uses traditional biotech processes, but does not conduct R&D.
Technical Change	Change in technique. See technological change (below).
Technology	"In the broadest sense, the term technology refers to the method of carrying out any activity that incorporates recurring acts, as well as the use of tools or implements. In a narrower and more common context, technology refers to the method of pursuing activities on a given minimum level of mechanical, engineering, or scientific sophistication"(Suranyi-Unger Jr., 1994).
Technological Change	"The process by which economies change over time in respect of the products they produce and the processes used to produce them" (Stoneman, 1983, p. 3). Distinguished from *technical change*, which is change in *technique*. In practice the two concepts are often intermixed in the literature with the use of the term *technical change* being common among certain key authors who worked on the production function approach (Suranyi-Unger Jr., 1994). See also Hay and Morris: "we define *technology* as information: the specifications (in the engineering sense) for a product or a process. It must be more than just an idea: it must be something which, if built or produced according to specification will 'work'. The technology at any time is the 'book' of specifications or blueprints. If an invention has not reached the blueprint stage, then it is excluded from technology. It is the task of R&D to bring such ideas to the blueprint stage. A change in the 'book' of blueprints is *technological change* (Hay & Morris, 1991, p. 466).

Technological System	"A network of agents interacting in a specific technology under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilization of technology" (Carlsson, Jacobsson, Holmén, & Rickne, 1999, p. 12) .
Technological Paradigm	"A 'model' and a 'pattern' of solution of selected technological problems, based on selected principles derived from natural sciences and on selected material technologies (Dosi, 1982, p. 152). "Technological Paradigms have a powerful *exclusion effect*: the efforts of the technological imagination of engineers and of the organisations they are in are focussed in rather precise directions while they are so to speak 'blind' to other technological possibilities" (Dosi, 1982, p. 153). "A technological paradigm might be seen as a particular recipe book" (Zysman, 1996, p. 654).
Technological Trajectory	See technological paradigm (above).
TPP	Technological Product and Process (innovation). "Technological product and process (TPP) innovations comprise implemented technologically new products and processes and significant technological improvements in products and processes. A TPP innovation has been implemented if it has been introduced on the market (product innovation) or used within a production process (process innovation)" (OECD, 1997b, p. 47).
Tradenz	New Zealand Government agency concerned with trade promotion.
Upper Region	In order to distinguish between the two uses of the word regional Freeman (1995, p. 21) defines "nether region" as much smaller sub-national 'regions' ... in contrast to 'regional trading blocs' eg NAFTA or the South-East Asian 'region' which he calls an "upper region".
ZINB	Zero Inflated Negative Binomial Regression Model.
ZIP	Zero Inflated Poisson Regression Model.

Appendix 2 Definitions of Biotechnology

A2.1 Origin and OECD Definitions

Karl Ereky, a Hungarian agricultural economist introduced the term biotechnology in 1919. Since then "the word biotechnology has been re-developed at least four times and its definition changed on each occasion" (Kennedy, 1991, p. 218).

The OECD has played a leading role in attempting to develop internationally comparable statistics on biotechnology. One of the most widely used recent definitions originated in an OECD report authored by Bull, Holt and Lilley: "the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services" (Bull, Holt, & Lilly, 1982). More recently, the fourth annual meeting of experts from OECD member and observer countries (OECD, 2003b), resulted in agreement on the following statistical definition of biotechnology.

Table A2.1 OECD Statistical Definition of Biotechnology

The provisional single definition of biotechnology:

> The application of Science & Technology to living organisms as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services.

The (indicative, not exhaustive) list of biotechnologies as an interpretative guideline to this single definition is:

i. DNA (the coding): genomics, pharmaco-genetics, gene probes, DNA sequencing/synthesis/amplification, genetic engineering.
ii. Proteins and molecules (the functional blocks): protein/peptide sequencing/synthesis, lipid/protein glyco-engineering, proteomics, hormones, and growth factors, cell receptors/signalling/pheromones.
iii. Cell and tissue culture and engineering: cell/tissue culture, tissue engineering, hybridisation, cellular fusion, vaccine/immune stimulants, embryo manipulation.
iv. Process biotechnologies: bioreactors, fermentation, bioprocessing, bioleaching, bio-pulping, bio-bleaching, biodesulphurization, bioremediation, and biofiltration.
v. Sub-cellular organisms: gene therapy, viral vectors.
vi. Other (please specify).

Source: Devlin (2003, p. 7)

A2.2 Definition of Biotechnology in the 2002 Survey

For the purposes of the 2002 biotechnology survey and this thesis, *modern* biotechnology is defined as: (1) recombinant DNA technology, (2) use of antibodies (3) protein engineering (4) novel bioprocessing techniques (Eliasson & Eliasson, 1997, p. 145; U.S. Congress, 1991, p. 5). The term "modern" is used to distinguish processes that have been developed in the last 30 years or so, from traditional biotech areas such as fermentation and extraction.

A dual approach to the definition of biotechnology was adopted in the 2002 biotech survey. Respondents were provided with the OECD (1982) definition and the definition of modern biotechnology (above) and were then asked to review a list of biotechnology processes (Table A2.2) and indicate which if any were used by their business. The list was based on a list of technologies developed by Statistics Canada[1]. Use of this list was intended to facilitate international comparisons.

Table A2.2 List-Based Definition of Biotechnology (2002)

Main Category	Sub Categories
DNA Based Technology	*1. Gene Probes or DNA Markers* *2. Bio-Informatics* *3. Genomics or Pharmacogenetics* *4. Genetic Engineering or DNA Sequencing or Synthesis or Amplification or Proteomics or Gene Therapy*
Biochemistry or Immunochemistry based	*5. Vaccines or Immune Stimulants* *6. Drug Design & Delivery* *7. Antibodies* *8. Peptide or Protein or Enzyme Sequencing or Synthesis or Applications* *9. Cell Receptors or Signalling or Structural Biology or Pheromones* *10. Combinatorial Chemistry or 3D Molecular Modelling* 11. Biomaterials 12. Microbiology or Virology or Microbial Ecology
Bio Processing	*13. Cell or Tissue or Embryo Culture or Manipulation or Somatic Embryo-genesis* 14. Extraction or Purification or Separation 15. Fermentation or Bioprocessing or Biotransformation or Natural Products Chemistry
Environmental Biotechnology	16. Bioleaching or Biopulping or Biobleaching or Biodesulphurization 17. Bioremediation or Biofiltration or Phytoremediation

Note: For the purposes of this thesis, processes in italics are 'modern', other processes are 'traditional'.

[1] When the survey was being designed the OECD had not agreed on the standard list-based definition detailed in Table A2.1.

A2.3 Definition of Biotechnology in the 1998/99 Biotech Survey

The 1998/99 Statistics New Zealand survey adopted a dual approach to the definition of biotechnology. The stated purpose was to collect statistics on *modern* biotechnology and the second page of the questionnaire started with the New Zealand Biotechnology Association definition[2] of modern biotechnology:

> the application of scientific and engineering principles to the processing of material by biological agents and the processing of biological materials to improve the quality of life by isolating, modifying and synthesising the genetic instructions responsible for actual biological processes (Statistics New Zealand, 2000a, p. 2)

Respondents were then asked to review a list of biotechnology processes (see Table A2.3) and indicate which if any were used by their business. This was based on a list of technologies developed by Statistics Canada. An expert panel also added several processes in order to develop a definition appropriate to New Zealand.

While the stated intention of the survey was to focus on modern biotechnology it included a fairly wide list of processes, many of which have been around for quite some time. As a result many of the enterprises that reported use of biotech processes were involved in traditional rather than modern biotechnology.

In an attempt to extract more meaning from the survey data, Marsh (2001b) adopted specific rule based definitions of traditional and modern biotechnology (see above). The list of processes in Table A2.3 was divided into 'modern' (processes in italics) and 'traditional' processes with the aim of separating enterprises involved in processes that have been developed in the last 30 years or so, from those involved in traditional areas e.g. fermentation, extraction etc. Further details of the list based definition are provided in Table A2.4.

[2] This definition appears to be open to alternative interpretations depending on whether the reader considers that the specifications before and after the 'and' must both be fulfilled.

Table A2.3 1998/99 Biotech Survey List Based Definition

Main Category	Sub Categories
DNA Based Technology	*Genetic engineering, Gene Probes, Bio-informatics, Genomics, Pharmacogenetics, Gene Therapy, Rational Drug Design, DNA Sequencing, Synthesis, Amplification*
Biochemistry or Immunochemistry based	*Vaccines, Immune Stimulants, Drug Design and Delivery, Combinatorial Chemistry,* Diagnostic Tests, *Peptide/Protein Synthesis and Sequencing, Cell Receptors and Cell Signalling,* Bio-Sensing, Pheromones, *Molecular Modelling, Structural Biology, Antigens, Antibodies,* Microbiology, Biomaterials
Bio Processing	Cell, *Tissue and Embryo Culture, Cell, Tissue and Embryo Manipulation, Somatic Embryo genesis,* Fermentation, Bio processing, Bio transformation, Bio leaching, Bio pulping, Bio bleaching, Bio desulphurisation, Bio pesticide Manufacturing, Extraction, concentration, purification, separation, Natural Products Chemistry, Bio filtration, Bio indicators, *Micro-selected Breeding of Plants and Animals,* Microbio inoculants, Bio Sensing
Environmental Biotechnology	Bio augmentation, Bio reactors, Biological Gas Cleaning, Bio remediation, Phyto remediation

Source: Statistics New Zealand (2000a, p. 39) and analysis by author
Note: For the purposes of this thesis, processes in italics are 'modern', other processes are 'traditional'.

Table A2.4 Definition of 'Modern' and 'Traditional' Processes DNA Based

SNZ Q No.	Process	Definition in Biotechnology Survey 1998/99	Stat's Canada Categ'y
	DNA Based Processes: Technology using chemistry of DNA as a major component		
5.1	Genetic Engineering/Recombinant DNA	The manipulation of an organism's genetic material by introducing or eliminating specific genetic changes through modern molecular biology techniques.	1140
5.2	Gene Probes	A section of DNA or RNA of known structure or function which is marked with a radioactive isotope, dye or enzyme that can be used to detect the presence of a similar sequence from any biological material	1110
5.3	Bio Informatics	Computer-based analysis of biological information (bio-info), especially genomics and molecular modelling (eg DNA/RNA/ protein sequencing and databases for genes of humans, plants, animals and micro-organisms)	1120
5.4	Genomics	The use and organisation of information of biological interest, including the construction and analysis of genes that may be used to search for new genes of interest, matching existing genes etc.	1140
5.5	Pharmacogenetics	The study of the genetics of drug production, action or assimilation	1140
5.6	DNA Sequencing	A method to determine the order of nucleotides on a gene or DNA fragment	1140
5.7	DNA Synthesis	Design and synthesis of a DNA molecule from existing information of its constituent bases	1140
5.8	DNA Amplification	Process of increasing the number of copies of a particular gene of chromosomal sequence	1140
5.9	Gene Therapy	Replacement of a defective gene in an organism suffering from a genetic defect	*1140* *
5.10	Rational Drug Design	Analysis of the structures of active sites of enzymes and receptors in order to design pharmocologically active synthetic molecules	*1160*
5.11	Other DNA Based		

Notes:
1. 'Modern' biotech processes (for the purpose of this report) are represented in normal font, white background, 'Traditional' biotech processes in italic, grey background.
2. Statistics Canada categories refer to 1999 questionnaire in McNiven (2001).
3. * indicates Statistics Canada category may not fully correspond with SNZ category.

Table A2.4 (cont): Definition of 'Modern' and 'Traditional' Processes Biochemistry/Immunochemistry Based

SNZ Q No.	Process	Definition in Biotechnology Survey 1998/99	Stat's Canada Categ'y
	Biochemistry/Immunochemistry Based: Technology which utilises immunochemistry/antibodies or enzymes as a major component		
6.1	Vaccines	The agent containing antigens produced from killed, attenuated or live pathogenic micro-organisms or their genetic material used to stimulate the immune system to protect the host	1150
6.2	Immune Stimulants	Compounds that induce the immune system to produce antibodies or antibody containing lymphocytes	1150
6.3	Drug Design and Delivery	Development of drugs where the raw materials and/or processes involve the use of biotechnology	1160
6.4	Combinatorial Chemistry	An approach to chemical synthesis that enables the creation of large numbers of organic compounds by putting chemical building blocks together in every possible combination. It is used to synthesise novel compounds, which are screened, or tested, against biological targets as part of the drug discovery process	1200
6.5	*Diagnostic Tests*	A test used to determine the source of a problem or a method of determining the nature of a disease by analysing the symptoms	*1170*
6.6	Peptide/Protein Synthesis	Procedure to link two or more amino acids joined by a linkage called a peptide bond	1180
6.7	Peptide/Protein Sequencing	The process of determining the sequence of a polypeptide or cluster of polypeptides, or the process of creating a new substance from precursor molecules	1180
6.8	Cell Receptors	Functional proteinaceous structures found in the membrane (surface) of cells that tightly bind specific molecules (organic, protein or viruses).	1190
6.9	Cell Signalling	The mechanism used by cells to induce or trigger events at remote sites within cells	1190
6.10	*Bio-sensing*	Use of biological molecules (eg enzymes, antibodies) in conjunction with a transducer to low level detection of substances such as sugars and proteins in body fluids, pollutants in water etc.	*none*
6.11	*Pheromones*	Compounds emitted by insects and spread through the air for the purpose of attracting the opposite sex	*1190*
6.12	Three Dimensional Molecular Modelling	Description of the characteristics of molecules through a 3D spatial representation	1200
6.13	Structural Biology	The study of the three dimensional structures of biological molecules(such as proteins) and their mutual interactions as a means of understanding the functions of these molecules within the cell	1190
6.14	Antigens	A substance that stimulates the production of specific neutralizing antibodies in an immune response. Any chemical substance, usually protein that interacts with an antibody	*1170* *
6.15	Monoclonal Antibodies	A monoclonal antibody is a highly specific antibody which is derived from a line of specialised cells and which recognises only one specific complimentary antigen	1170
6.16	Antibodies	Proteins that circulate in the blood stream and bind to foreign invading substances (antigens eg bacteria, toxins, certain viruses) with a great deal of specificity	1170
6.17	*Microbiology/Microbial Ecology*	Study of organisms that are too small to be seen with the naked eye	*1220*
6.18	*Biomaterials*	Any biologically derived material which is used for its material properties rather than its biological properties	*none*
6.19	*Other Biochemistry*		

Notes:

1. 'Modern' biotech processes (for the purpose of this report) are represented in normal font, white background, 'Traditional' biotech processes in italic, grey background.
2. Statistics Canada categories refer to 1999 questionnaire in McNiven (2001).
3. * indicates Statistics Canada category may not fully correspond with SNZ category.

Table A2.4 (cont): Definition of 'Modern' and 'Traditional' Processes Environmental Biotechnologies

SNZ Q No.	Process	Definition in Biotechnology Survey 1998/99	Stat's Canada Categ'y
	Environmental Biotechnologies: Biotechnologies used for pollution control		
7.1	*Bioaugmentation*	The process of increasing the efficiency of the naturally occurring microbial population to concentrate or accumulate specific com-pounds. This is usually achieved by adding nutrients, oxygen or water	*none*
7.2	*Bio-reactors*	Enclosed containers in which micro-organisms are maintained under controlled conditions for the purpose of creating or destroying specific compounds	*none*
7.3	*Biological Gas Cleaning*	The use of micro-organisms to break down or degrade hazardous substances in a gas stream into less hazardous or non-toxic substances	*none*
7.4	*Bio-remediation*	The use of naturally occurring or genetically modified micro-organisms to breakdown or degrade hazardous substances into less hazardous or non-toxic substances	*1270*
7.5	*Phytoremediation*	The use of plants to treat or clean environmental pollution	*1270*
7.6	*Other Environmental*		

Notes:
1. 'Modern' biotech processes (for the purpose of this report) are represented in normal font, white background, 'Traditional' biotech processes in italic, grey background.
2. Statistics Canada categories refer to 1999 questionnaire in McNiven (2001).
3. * indicates Statistics Canada category may not fully correspond with SNZ category.

Table A2.4 (cont): Definition of 'Modern' and 'Traditional' Processes Bioprocessing Based

SNZ Q No.	Process	Definition in Biotechnology Survey 1998/99	Stat's Canada Categ'y
	Bioprocessing Based: Processing of any natural material of biological origin		
8.1	*Cell Culture*	A population of cells grown for microbiological testing, cell culture development or in fermenters to study their biology or to manufacture products	*1230*
8.2	Tissue Culture	A technique for growing cells from multi-cellular organisms in an artificial medium	1230
8.3	Embryo Culture	A technique for growing embryos from multi-embryo organisms in an artificial medium	1230
8.4	Cell Manipulation	Ability to grow and modify a range of cell types under laboratory conditions	1230
8.5	Tissue Manipulation	Ability to grow and modify a range of tissue types under laboratory conditions	1230
8.6	Embryo Manipulation	Ability to grow and modify a range of embryo types under laboratory conditions	1230
8.7	*Fermentation*	Micro-organic process in which the metabolism of sugars for energy is accompanied by the formation of alcohol and/or lactic acid and solvents. Include processes such as wine, cheese and yoghurt making, brewing, yeast production etc.	*1250*
8.8	*Bioprocessing*	Production stages that include fermentation, recovery and purification	*1250*
8.9	*Biotransformation*	Conversion of one chemical or material into another using a biological catalyst	*1250*
8.10	*Bio-leaching*	Use of micro-organisms to leach metals from ore	*1260*
8.11	*Bio-pulping*	The use of enzymes to degrade wood structures to produce pulp for paper-making purposes	*1260*
8.12	*Bio-bleaching*	The use of enzymes to bleach paper fibre	*1260*
8.13	*Bio-desulphurisation*	The removal of organic or inorganic sulphur from coal by bacterial or soil micro-organisms	*1260*
8.14	*Bio-pesticide manufacturing*	Biological pest control through the use of naturally occurring microbes or bacteria	*none*
8.15	*Extraction/Concentration/ Purification/Separation*	The retrieval of a compound of interest from a raw material	*1240*
8.16	*Biofiltration*	The treatment of sewage or industrial wastewaters using active biomass growing on a solid support	*none*
8.17	*Bioindicators*	The use of organisms to indicate the status of an environment	*none*
8.18	Micro Selected Breeding	Using modern biotechnological tools to accelerate selection	*none*
8.19	*Natural Products Chemistry*	The study of a biological material or a biologically-derived material using analytic methods, normally being the isolation and identification of the novel chemicals within a biological material	*1250*
8.20	*Microbio-inoculants*	Naturally occurring bacterial inoculates used to promote plant growth	*none*
8.21	Somatic Embryo-genesis	Propagation of genetically desirable plant and tree lineages by tissue culture methods	*1230* *
8.22	*Other Bioprocessing*		

Notes:

1. 'Modern' biotech processes (for the purpose of this report) are represented in normal font, white background, 'Traditional' biotech processes in italic, grey background.
2. Statistics Canada categories refer to 1999 questionnaire in McNiven (2001).
3. * indicates Statistics Canada category may not fully correspond with SNZ category.

A2.4 Other Definitions

United States Congress Definition of Modern Biotechnology

The influential Office of Technology Assessment Report *Biotechnology in a Global Economy* (U.S. Congress, 1991) provides two definitions of biotechnology.

> The first definition broad in scope described biotechnology as any technique that uses living organisms (or parts of organisms) to make or modify products, to improve plants or animals, or to develop micro-organisms for specific uses. This definition encompassed both new biological tools as well as ancient uses of selecting organisms for improving agriculture, animal husbandry, or brewing.
>
> A second, more narrow definition refers only to "new" biotechnology: the industrial use of rDNA, cell fusion, and novel bioprocessing techniques.

The Australian Biotechnology Report Definition

The following extracts detail the definition adopted by Ernst and Young (1999).

> "Biotechnology is defined for the purposes of this report as the application of science and engineering in the direct or indirect use of living organisms or parts of organisms in their natural or modified forms in an innovative manner in the production of goods and services or to improve existing processes…
>
> We *included* in our sample any company, public or privately held, which is developing or commercialising biotechnology related products, or who provided expertise and supplies to biotechnology companies as a significant component of their business…
>
> We *excluded* not-for-profit enterprises, research institutions and corporate structures which are established for the purposes of administering research grant funds but have no commercial intent.
>
> … we define 'core biotechnology' companies as those whose business is entirely or substantially biotechnology related and that have a significant commitment to technological innovation."

New Zealand Biotechnology Association Definition of Biotechnology

> The application of scientific and engineering principles to the processing of material by biological agents and the processing of biological materials to improve the quality of life.[3]

[3] Source: NZBA website http://www.biotech.org.nz/.

Appendix 3 2002 Biotechnology Survey: Survey Details

A3.1 Survey Design

This purpose of the 2002 biotech survey was to test a series of hypotheses about the factors affecting innovation in the biotech 'sector' in New Zealand. This required analysis of enterprise specific data that had never previously been collected and a sufficient number of observations to allow reliable conclusions to be drawn.

The most common survey instruments are mail, telephone, direct interview and internet/email. A telephone survey was rejected since a number of questions required respondents to refer to enterprise records. Direct face-to-face interviews can produce better quality data but would have required an excessive amount of time and resources. Internet or email based approaches are favoured by some respondents but others fill in parts of the survey in spare moments (on planes, at home etc) when they do not have easy and immediate access to the internet. A mail survey was selected since it gave the best balance between data quality and resource use. It was combined with use of email and publicity over the internet in order to increase response and completion[4] rates.

The questionnaire was designed and drafted based on an iterative process involving consideration of:

i. the data that should ideally be used to test the hypotheses;
ii. the data or indicators that have been used in previous studies;
iii. the outcome of those studies; and
iv. the data or indicators that New Zealand respondents were likely to be willing and able to provide.

International experience in the practice of surveys of innovation and biotechnology was reviewed; particularly Community Innovation Surveys

[4] The proportion of forms where all questions were answered.

conducted in the EU e.g. (Muzart, 1998) etc, OECD innovation surveys (OECD, 2002), OECD studies of biotechnology e.g. (van Beuzekom, 2001) and Statistics Canada biotechnology surveys e.g. (McNiven, 2001a; Pattinson, Van Beuzekom, & Wyckoff, 2001). An extended email discussion was also held with staff at Statistics Canada; the first national statistical organisation to implement a comprehensive biotechnology survey.

Survey design took account of New Zealand experience with studies of innovation and biotechnology; most notably lessons learned in the conduct and analysis of the 1998/99 survey of modern biotechnology; see (Marsh, 2001c), R&D expenditure surveys e.g. (Ministry of Research Science and Technology, 2002) and business practices surveys; see (Statistics New Zealand, 2002). Survey design was also discussed with government (MoRST and SNZ) and representatives of the biotechnology industry. A detailed research proposal was written up and circulated for comment. Ethical approval was secured from the Waikato Management School ethics committee.

In March 2002 a pre-test version of the questionnaire was circulated for comment[5] and sent to 11 enterprises. Two completed questionnaires were returned and meetings were held to discuss the questionnaire with a further two enterprises. Email and telephone were used to try to persuade the other enterprises to respond, but with no success. No major problems were identified at this stage although a number of improvements were made to questionnaire format and wording.

A3.2 The Study Population

The study population was defined as 'all enterprises using modern[6] biotech processes and/or all enterprises conducting R&D using biotech processes (modern or traditional)'. The definition follows directly from the research topic; innovation in enterprises that use biotechnology. Inclusion of enterprises that conduct R&D using modern *and* traditional processes allowed investigation into the differences

5 Circulated to PhD supervisors, biotech academics at the University of Waikato, NZBA, BIOTENZ and MoRST.

6 List based definition see Appendix 2.

between these organisations. Enterprises that use traditional processes only and do *not* carry out R&D were excluded for both practical and theoretical reasons. In practice, they are not well suited to a study of innovation as they tend to exhibit low innovation rates and an unwillingness to participate in voluntary innovation surveys. From a theoretical perspective these enterprises are of less interest since the hypotheses tested focus on factors affecting innovative output and innovation rate – rather than why enterprises are, or are not innovative. It should also be noted that these enterprises would not normally[7] be regarded as being part of the biotech 'sector'.

Some large organisations (e.g. universities) are generally unwilling to complete questionnaires for the *whole* organisation because this would require them to compile data from many different organisational units. In order to increase response rate and survey accuracy, enterprise sub units were contacted where appropriate; rather than asking enterprises to respond for the whole organisation.

Enterprises contacted were identified from a database of all biotech enterprises in New Zealand built up over three-year period 1999-2002. Entries in the data base are based on data from a variety of sources including:

i. the NZBA web directory;
ii. firms and organisations attending NZBA conferences;
iii. the BIOTENZ website;
iv. A'Courts and other commercial directories;
v. internet searches;
vi. print media articles (internet searches based on key words such as biotech, gene etc);
vii. the website of the Royal Commission on Genetic Modification;
viii. the FRST website; and
ix. published sources e.g. Kennedy & Davies (1994) and Packer, Robertson, & Wansbrough (1998).

[7] In the economic literature and in international statistics.

A3.3 Survey Implementation and Response Rate

A combined approach was used to try and ensure an adequate response rate including institutional support, publicity, research credentials, questionnaire design and follow-up. NZBA agreed to endorse the study; this was highlighted on the front page of the questionnaire and in the covering letter. Publicity included:

i. a Waikato Management School press release;
ii. an article in Waikato Times;
iii. an article in the UNILINK[8] newsletter;
iv. Biotenz News Update, 19 April 2002;
v. Royal Society Alert 221, 24 April 2002; and
vi. GM Discussion (email circular).

The media campaign was intended to persuade respondents that this was an important study being conducted by a researcher with good credentials and broad institutional support. To provide an extra incentive, all completed questionnaires were entered into a draw to win $200. Information provided to participants stressed confidentiality and the rights of participants and explained the purpose of the study and the way in which the data would be used. The survey form was formatted and printed to a professional standard and was designed to be as easy to fill in as possible.

A total of 146 questionnaires were sent out, most on the 17 April 2003. The rate of questionnaire returns peaked around two weeks later; boosted in part by follow-up emails sent on May 2 (see Figure A3.1).

All respondents were sent an immediate email thanking them for returning the questionnaire. Questionnaires were then checked and follow-up questions asked where necessary, either by email or by phone. A second batch of survey forms was despatched on 14 May to all enterprises that had not returned the survey in the first month of the survey. Table A3.5 provides details of survey response rate broken down by industry group.

[8] A publication on research funding activities produced by the University of Waikato

Figure A3.1 Survey Form Returns by Date

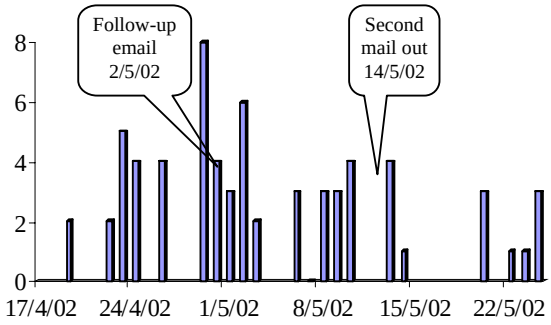

Table A3.5 Survey Response Rate

	Primary Products	Food Manu-facturing	Non-Food Manu-facturing	Scientific Research	Tertiary Edu-cation	Health Services & Other	Total	Remarks
Complete/mainly complete	7	4	14	15	15	6	61	
Very incomplete	1	2		2	4	2	11	
Not biotech	2	0	0	3	2	1	8	
Declined	0	5	2	4	1	1	13	
No reply	11	10	5	16	7	4	53	
Total sent out	21	21	21	40	29	14	146	
Crude Response Rate	*48%*	*52%*	*76%*	*60%*	*76%*	*71%*	*64%*	All responses/total sent out
Adjusted Total	19	21	21	37	27	13	138	subtract not biotech
Usable response rate	*37%*	*19%*	*67%*	*41%*	*56%*	*46%*	*44%*	usable/adj' total

Responses were received from 93 enterprises (including declines[9]) indicating a 'crude' response rate of 64%. The sample frame was adjusted to 138 enterprise units by subtracting enterprises that reported that they were not involved in biotech (including 53[10] that did not reply). 61 usable responses were received indicating a 'usable' response rate of 44%.

[9] Enterprise that replied that they would not be filling in the questionnaire.

[10] From 46 separate enterprises.

Questionnaires were sent to 112 separate enterprises[11], 108 of these were thought to be involved in biotech over the survey period. Complete or mainly complete responses were received from 53 separate enterprises indicating a 'usable' response rate at the enterprise level of 49%.

Enterprises providing usable responses to the 2000/01 survey are distributed across the main industrial groups as detailed in Tables 2. Response rates varied across industrial groups; four groups fell within the range 37-56%, food manufacturers are under-represented (19%) and a high response rate (67%) was achieved for the Non-food manufacturers group. These variations need to be adjusted for, in any attempt to scale up sample data to describe the biotech sector as a whole.

Table A3.36 Enterprises Involved in Biotechnology 1998/99 and 2000/01

Industrial Group	No. Enterprises Involved in Biotech Activity 1998/99	Adjusted[12] No. Enterprises Involved in Biotech Activity 1998/99	Adjusted Sample Frame 2000/01	No. Respondents Involved in Biotech Activity 2000/01	Usable Response Rate
Primary Products	6	3	19	6	37%
Food Manufacturing	33	18	21	6	19%
Non-Food Manufacturing	24	21	21	14	67%
Scientific Research	36	33	37	18 (15[13])	41%
Local Government Administration	33	0	Not surveyed	Not surveyed	
Tertiary Education	9	6	27	12 (7)	56%
Health Services and Other	36	30	13	5	46%
Total	180	111	138	61	44%

[11] See above. In universities and some research organisations multiple enterprise sub units were sent survey forms. In this count of 'separate enterprises' university commercialisation operations e.g. Auckland UniServices are classified as being part of the parent university.

[12] Enterprises that did not use modern biotech and did not carry out R&D have been excluded to allow comparison with the 2000/01 survey.

[13] Number in brackets denotes the number of enterprises responding.

Table A3.7 provides a breakdown of survey respondents based on use of modern vs. traditional biotech processes and whether or not they carry out R&D. Comparison with the 98/99 survey suggests that the 00/01 survey achieved a response rate of around 60% for MBEs with coverage being well above this in all groups except scientific research and health services.

Table A3.7 Respondent Category by Industrial Group 00/01

	Modern Biotech Enterprises (MBEs)	*MBEs 98/99*	Modern Biotech Users	Traditional Biotech Enterprises	Traditional Biotech Users	All Biotech Respondents
Primary Products	5	*3*			1	6
Food Manufacturing	4	*3*		1	1	6
Non-Food Manufacturing	8	*9*		6		14
Scientific Research	13 (10)	*24*	1	4		18
Tertiary Education	11 (6)	*6*		1		12
Health Services & Other	1	*9*	2	1	1	5
Total	42	57	3	13	3	61

Note: Parentheses denote number of enterprises rather than enterprise sub-units

Table A3.8 presents a more detailed comparison based on ANZSIC categories. The 2000/01 survey achieved good coverage in the medicinal and pharmaceutical product manufacturing, scientific research and higher education groups. Areas of low coverage may be explained by a variety of factors:

i. wine manufacturers and local government administration generally do not conduct R&D so were not sampled;

ii. a single combined response covering most dairy product manufacturing is classified under scientific research category

iii. the hospital category consists mainly of laboratories not engaged in significant biotech R&D, so it was not sampled.

Table A3.8 Number of Biotech Enterprises in Selected ANZSIC Categories

	1998/99	2000/01
Dairy Product Manufacturing	6	0
Wine Manufacturing	9	0
Medicinal and Pharmaceutical Product Manufacturing	15	10
Scientific Research	24	13
Technical Services nec	6	1
Local Government Administration	33	0
Higher Education	12	12
Hospitals (except psychiatric)	15	1
Total No of Respondent in above categories	*120*	*37*
Other ANZSIC Categories	*60*	*24*

Sixty four percent of biotech respondents were from the private sector (including manufacturers, research enterprises and laboratories), the remainder being mainly comprised of universities, Crown Research Institutes and health providers. This is a similar private/public sector split to the 98/99 survey where around 60% of respondents were from the private sector.

Appendix 4 2002 Biotechnology Survey: Questionnaire

The University of Waikato
Te Whare Wānanga o Waikato

Innovation in Biotechnology
A Nationwide Study

This study has been endorsed by the New Zealand Biotechnology Association Executive
Please start filling it in Today!

Win $200!
All completed questionnaires go in the draw to win $200.
All participants receive a summary of the main findings

Questionnaire to be filled in by:
Please correct any errors in this panel

WAIKATO MANAGEMENT SCHOOL
Te Raupapa

Biotechnology Survey 2002

Purpose

This questionnaire aims to collect information on innovative output (e.g. new products, processes and patents) and the factors that may affect this output. It is being sent to a sample of businesses that *may* be involved in biotechnology (based on tracking New Zealand biotech over the last 3 years).

The government is committed to "growing an innovative New Zealand" and is focussing on biotechnology. This study will attempt to fill some of the gaps in our knowledge of the factors affecting innovation. Improved understanding should prove invaluable in developing policy to help grow the New Zealand biotech sector. The Waikato Management School Ethics Committee has approved this study.

What are you being asked to do?

Please fill in this survey form and return it in the enclosed prepaid envelope (whether or not your firm/organisation is involved in biotechnology). If I do not hear from you, I will follow up by phone/email after **2 weeks**.

I would also like to visit a sample of firms/organisations in order to discuss questionnaire answers and other aspects of innovation in the biotech sector. There is space on the last page where you can indicate whether you are willing to participate in this part of the study. I expect each interview to take around one hour.

Who is the researcher?

Dan Marsh, a lecturer in the Department of Economics at the University of Waikato. I have been researching the New Zealand biotech sector since 1999. I can give you examples of my work on the biotech sector or you can download from http://ideas.uqam.ca/ideas/data/waieconwp.html
My research supervisor is Associate Professor Frank Scrimgeour scrim@waikato.ac.nz

My **contact details** are:

Phone 07-838-4950 (or 4045)
Fax 07-838-4331

Email dmarsh@waikato.ac.nz

Mail FREEPOST 472
Dan Marsh
Department of Economics
University of Waikato
Private Bag 3105
Hamilton.

What will happen to the data?

I will use the data and interview responses to analyse innovation processes in the biotechnology sector. This material will be written up in my PhD Thesis, in conference papers and in papers submitted for publication in journals. I will also write a summary including policy implications for distribution to survey participants, industry groups and government.

Confidentiality

Only my supervisors and I will have access to the questionnaires, data and notes (or tapes) of any discussions, which will be treated with the strictest confidentiality. Your information will be combined with similar information to prepare aggregate analyses and descriptions. Your name, or the name of your organisation will appear in research papers only if you have given express consent for disclosure.

What are your rights as participants?

Involvement in this study is purely voluntary. If you decide to take part, you have the right to refuse to answer any particular question; to withdraw from the study at any time; to ask any further questions about the study that occur to you during your participation and be given access to a summary of the findings of the study when it is completed.

Instructions and Definitions

All respondents are referred to as **'businesses'** this is intended to be a general term covering ALL respondents – including research organisations, universities etc.

Biotechnology is the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services (OECD, 1982). **Modern Biotechnology** includes: recombinant DNA technology, molecular and cellular biology, immunology, use of antibodies, protein engineering and other novel bioprocessing techniques. The term 'modern' is used to distinguish processes that have been developed in the last 30 years or so, from traditional biotech areas such as fermentation and extraction.

Unit of study Include information only for the business named on the front page. Do not provide consolidated data. Do not include subsidiary or associated businesses or accounting divisions that operate entirely outside New Zealand. For practical reasons I am sending the questionnaire to **parts** of some **large organisations**. In this case include information **only for the specified sub unit**.

A Involvement in Biotechnology

1. Please review the following list of biotechnologies and **tick** the applicable boxes. Do not include processes used ONLY for teaching. In each case, indicate **number of years used**.

Biotechnologies	Currently Used?	**If currently using, do you use them for**			**Number** of years in use
		Research & Development	Current Production	Environmental Purposes	
DNA Based		**What do you use it for?**			
Gene Probes *or* DNA Markers	❍ Yes	❍	❍	❍	
Bio-Informatics	❍ Yes	❍	❍	❍	
Genomics or Pharmacogenetics	❍ Yes	❍	❍	❍	
Genetic Engineering *or* DNA Sequencing *or* Synthesis *or* Amplification *or* Proteomics *or* Gene Therapy	❍ Yes	❍	❍	❍	
Biochemistry/Immunochemistry		**What do you use it for?**			
Vaccines *or* Immune Stimulants	❍ Yes	❍	❍	❍	
Drug Design & Delivery	❍ Yes	❍	❍	❍	
Antibodies	❍ Yes	❍	❍	❍	
Peptide *or* Protein or Enzyme Sequencing *or* Synthesis or Applications	❍ Yes	❍	❍	❍	
Cell Receptors *or* Signalling *or* Structural Biology or Pheromones	❍ Yes	❍	❍	❍	
Combinatorial Chemistry *or* 3D Molecular Modelling	❍ Yes	❍	❍	❍	
Biomaterials	❍ Yes	❍	❍	❍	
Microbiology or Virology or Microbial Ecology	❍ Yes	❍	❍	❍	
Bioprocessing Based and Environment		**What do you use it for?**			
Cell *or* Tissue *or* Embryo Culture *or* Manipulation *or* Somatic Embryo-genesis	❍ Yes	❍	❍	❍	
Extraction *or* Purification *or* Separation	❍ Yes	❍	❍	❍	
Fermentation *or* Bioprocessing *or* Biotransformation *or* Natural Products Chemistry	❍ Yes	❍	❍	❍	
Bioleaching *or* Biopulping *or* Biobleaching *or* Biodesulphurization	❍ Yes	❍	❍	❍	
Bioremediation *or* Biofiltration *or* Phytoremediation	❍ Yes	❍	❍	❍	
Other (please specify)		**What do you use it for?**			
	❍ Yes	❍	❍	❍	
	❍ Yes	❍	❍	❍	

If your business is NOT engaged in any biotechnology, stop here. Fill in J&K on the last page and return the questionnaire in the return prepaid envelope. Thank you for your assistance.

B About Your Business

The word 'business' is used to refer to ALL types of organisation

2. What is then main activity of this business? (Or enter ANZSIC Classification if known)

3. Do you consider that your business makes use of, or conducts R&D into **modern** biotechnology?

   Yes ❍ No ❍

4. Comments (if any) on whether your activities should be defined as **modern** biotechnology:

5. How would you describe the importance of traditional/modern biotech relative to the overall activities of your business. Please **tick** the appropriate box.

   - ❍ Mainly engaged in *modern* biotechnology
   - ❍ Mainly engaged in *traditional* biotechnology
   - ❍ Mainly engaged in *modern and traditional* biotechnology
   - ❍ Modern/traditional biotech is *not the main activity*

6. When was this business first formed?
   Indicate the original year of formation, ignoring changes of ownership, name or structure.

   Year

7. What did the founder(s) of this business do before it was formed?
   Only answer this question if formed since 1980. Please **tick** the appropriate box.

   - ❍ Worked for/ran business in NZ
   - ❍ Worked for Crown Research Institute or DSIR
   - ❍ Worked for another NZ research organisation
   - ❍ Worked for NZ university or polytech
   - ❍ Worked *overseas* in research organisation/university
   - ❍ Worked for/ran *overseas* business
   - ❍ Other (please specify):

8. When did this business first engage in biotech activity?

   Year

9. Would you describe your business as a 'spin-off'?

Yes ❍ No ❍ *Go to question 10*

If Yes, what did your firm spin-off from? Please **tick** the appropriate box

- ❍ University/hospital
- ❍ Another business
- ❍ Crown Research Institute
- ❍ Other Research Organisation
- ❍ Other

A Spin-off is defined as a new firm created to transfer and commercialise inventions and technology developed in universities, firms, laboratories or other 'parent' organisations.

C Human Resources

10. How many people does your business currently employ? ☐

11. How many of the **biotechnology staff members** in your business have these qualifications (include staff doing biotechnology R&D)?

Qualification	Head-count
PhD	
MSc or MPhil	
BSc or BTech	
Diploma or Certificate	
Other Qualification	
No Qualification	
Total Biotech Staff	

Data should be current or for end of last reporting period

Include all staff who mainly work in biotech.

Do NOT include staff performing indirect support to biotech activity e.g. central finance or personnel services, or central support services e.g. computer, security, cleaning

11b How many **Full-time equivalent** biotech staff members are there in your business? ☐
(*This is your total in Q 11, above adjusted to Full-time equivalents)*

12. How many employees work on **biotechnology R&D now** (Head-count)? ☐

13. How many employees worked on biotechnology R&D **in 1999**? ☐
A rough estimate is sufficient (Headcount)

D New Products and Processes

14. Please provide the number of biotechnology products or processes your business has at each stage of development

Development Stage	Number of biotech products	Number of biotech processes
Research and Development		
Trials/Regulatory Stage		
On the market/In production/Approved		
Of those **on the market**, how many were introduced in the last 3 years?		

15. Out of the **new products introduced on to the market** in the last 3 years, how many were new to your 'business', new to New Zealand, new to the world? Out of the **new processes introduced** how many were new to your 'business', new to New Zealand, new to the world?

New to where?	Number of New Products		Number of New Processes	
	2001	Last 3 years	2001	Last 3 years
No. New to your business				
No. New to New Zealand				
No. New to the World				
Total				

A **new product** is a product **introduced on to the market** whose characteristics or intended uses differ significantly from previously produced products. Also include **improved products** whose performance has been significantly enhanced or upgraded. Do not include fashion or aesthetic changes.
New processes involve **adoption of new or significantly improved production methods.**
New Products/Processes can be new to your business, to New Zealand or to the world.

Please name or outline up to three of the products/processes you included in Question 15.

E Patents

16. How many **biotech related patents** and/or pending patents does your business have in each region.
Indicate '0' if none.

	New Zealand	USA	Europe	Asia	Other	**Total**
Existing Patents						

17. Please indicate the number of **biotech related patent applications** your business submitted in the following Patent Offices.

Number of Patent **Applications**	New Zealand	USA	Europe	Asia	Other	**Total**
In 2001						
In last 3 years						

Optional
Is the number of new products/processes and patents a reasonable indicator of the innovative output of your organisation? If not why not?

F Information Sources

18. Please rate the importance of the following information sources on biotechnology as used by your business. *Use a scale where 1 is low importance and 5 is high importance.*

Rate the importance of each information source	Low 1	2	3	4	High 5	*Not Applicable*
Own staff or staff in parent/subsidiary 'business'	❍	❍	❍	❍	❍	❍
Hiring new staff with required 'know-how'	❍	❍	❍	❍	❍	❍
Personal contacts with others	❍	❍	❍	❍	❍	❍
Conferences/workshops/trade shows	❍	❍	❍	❍	❍	❍
Other Firms	❍	❍	❍	❍	❍	❍
Crown Research Institutes	❍	❍	❍	❍	❍	❍
Other Research Organisations	❍	❍	❍	❍	❍	❍
Universities, Polytechs, research networks	❍	❍	❍	❍	❍	❍
Hospitals	❍	❍	❍	❍	❍	❍
Government departments/agencies	❍	❍	❍	❍	❍	❍
Professional/industry associations	❍	❍	❍	❍	❍	❍
Other organisations						
Academic journals and trade publications	❍	❍	❍	❍	❍	❍
Library/literature search	❍	❍	❍	❍	❍	❍
Database retrieval services	❍	❍	❍	❍	❍	❍
Patent disclosures	❍	❍	❍	❍	❍	❍
Please suggest any others:						

19. Overall what is the relative importance of domestic vs international information sources and partnerships? **Tick** the appropriate box.

- ❍ New Zealand sources/partners more important than international
- ❍ Importance of New Zealand and international sources is about the same
- ❍ International sources/partners more important than New Zealand sources

G Partnerships and Alliances (Cooperation and Collaboration)

20. Does this business have any partnerships or alliances for undertaking biotech activities (research or production)?

    Yes ❍ No ❍ *Go to question 22*

    If Yes, indicate the **number** of different partner organisations **Number:** ☐

21. Please provide the information for the **three most important partnerships.**
    Tick as many spaces as necessary

	Partner A	*Partner B*	*Partner C*
Partner Name (*leave this out if you wish*)			
Year Partnership Started			
Partnership Characteristics			
Active participation by both parties	❍	❍	❍
Staff work/train at partner location (or vice versa)	❍	❍	❍
Work contracted out to/from other party	❍	❍	❍
Purpose of the Partnership			
Basic Research	❍	❍	❍
Product/Process Development	❍	❍	❍
Clinical/Field Trial	❍	❍	❍
Manufacturing	❍	❍	❍
Marketing/Distribution	❍	❍	❍
Regulatory Affairs	❍	❍	❍
Finance	❍	❍	❍
Other	❍	❍	❍
Partner Location			
*New Zealand (**local** - within 1 hours drive)*	❍	❍	❍
*New Zealand (**NOT local**)*	❍	❍	❍
Australia	❍	❍	❍
USA	❍	❍	❍
Europe	❍	❍	❍
Asia	❍	❍	❍
Other	❍	❍	❍
Partner Category			
A firm of smaller or equal size	❍	❍	❍
A larger firm	❍	❍	❍
Crown Research Institute	❍	❍	❍
Other Research Organisation	❍	❍	❍
University/Polytech/Research Network	❍	❍	❍
Hospital	❍	❍	❍
Government department/agency	❍	❍	❍
Other	❍	❍	❍
Partnership Outcome to date (score)			
1. Very productive	❍	❍	❍
2. Somewhat productive	❍	❍	❍

3. Not very productive	❍	❍	❍
4. Not at all productive	❍	❍	❍
5. Unproductive/negative effect overall	❍	❍	❍

H Factors Affecting Business Performance

22. How important are the following factors that may affect the amount of innovation produced by your business? *Use a scale where 1 is low importance and 5 is high importance*

	Low 1	2	3	4	High 5
Conditions in your business					
Quantity of funds available for R&D	❍	❍	❍	❍	❍
Quality of the R&D environment	❍	❍	❍	❍	❍
Number and quality of R&D staff	❍	❍	❍	❍	❍
One (or a few) 'Star Scientists'	❍	❍	❍	❍	❍
'Science push' or technological opportunity	❍	❍	❍	❍	❍
Quality of links with other organisations *in New Zealand*	❍	❍	❍	❍	❍
Quality of links with *overseas* organisations	❍	❍	❍	❍	❍
Ownership of intellectual property	❍	❍	❍	❍	❍
Appropriability (ability to profit from the innovation)	❍	❍	❍	❍	❍
Links with purchasers or consumers e.g. 'demand pull'	❍	❍	❍	❍	❍
Conditions in New Zealand					
Quality/quantity of Basic Science carried out	❍	❍	❍	❍	❍
Quality/quantity of Applied Science carried out	❍	❍	❍	❍	❍
R&D environment e.g. regulations, incentives, attitudes etc	❍	❍	❍	❍	❍
Please suggest any others:	❍	❍	❍	❍	❍

Any additional comments on factors affecting amount of innovation produced:

I Financial Data

*This information will be treated with **strict confidentiality**. It will be combined with other similar information to prepare aggregate analyses and descriptions.*

23. Please provide financial details in the following table. Please report for the year ended 30 June 2001 in thousands of dollars ($,000's). *Please make careful estimates if necessary.*

	2000/2001
Total Expenditure	NZ$,000
% of Total Expenditure on Biotech	%

Total Revenue/Sales	NZ$,000
% of Total Revenue/Sales from Biotech	%
% of Total Revenue/Sales from Biotech products/processes introduced in last 3 years	%

Total R&D Spending	NZ$,000
% of R&D Spending on Biotech	%

If you are unable or unwilling give precise answers please suggest ranges e.g. less than NZ$100,000, less than 1%, $1-$5 million

24. What was your revenue/sales and R&D expenditure 3 years ago?

	1997/98
Revenue/Sales	NZ$,000
R&D Expenditure	NZ$,000

J Your Comments

K Your Contact Details (this person goes in the draw to win $200)

Please provide your email/phone number if you are willing to be contacted about this study

Name:

Email: Phone No.

Thank You Very Much!

Please put in the enclosed, prepaid envelope and return to: FREEPOST 472,
Dan Marsh, Department of Economics, University of Waikato, Private Bag 3105, Hamilton

Appendix 5 1998/99 Survey of Modern Biotechnology: Questionnaire

Part 10 Comments and Additional Information

37 How long did it take you to complete this questionnaire?

Include:

- The time spent reading the instructions, working on the questions and obtaining information
- The time spent by all employees in collecting and providing this information

hrs mins

38 Please make any additional comments below which might be useful to us in analysing the information you have given:

39 Please provide details of the person completing this questionnaire:

Name

Position

E-mail

Phone ( )

Fax ( )

Signature

Date

Thank you for your time and effort

www.stats.govt.nz has the main results of all our surveys

Biotechnology Survey

Statistics NEW ZEALAND Te Tari Tatau

BIO/01

Biotechnology Survey 1998/99

Please correct any errors in this panel

Return date:

Purpose of this survey:

The purpose of this survey is to collect statistics to develop an understanding of the use of modern biotechnology in New Zealand. The statistics collected by this survey will be used to measure the contribution of modern biotechnology to the New Zealand economy; and in the formulation of policies and procedures in support of modern biotechnology business activity.

Compulsory requirement:

The taking of this survey has been approved by the Minister of Statistics and the return of this questionnaire duly filled in and signed is a compulsory requirement under the Statistics Act 1975.

Confidentiality of information supplied:

Only people authorised by the Statistics Act 1975 are allowed to see your individual information, and they must use it only for statistical purposes. Your information will be combined with similar information to prepare summary statistics.

For help and information:

Phone: 0800 809 464

Fax: 09 357 2195

E-mail: surveys@stats.govt.nz

Mail: Statistics New Zealand
Freepost 10007
Private Bag 92003
Auckland

Please return this completed questionnaire, in the reply paid envelope enclosed, **within 15 days** of receiving it.

D. M. Macaskill

Dianne Macaskill
Acting Government Statistician

What is modern biotechnology?

The New Zealand Biotechnology Association defines modern biotechnology as:
"The application of scientific and engineering principles to the processing of material by biological agents and the processing of biological materials to improve the quality of life by isolating, modifying and synthesising the genetic instructions responsible for actual biological processes."

Biotechnology Output

The output of modern biotechnology includes both **processes** as well as **products**.

What are biotechnology processes?

Biotechnology processes are a range of techniques dealing with recombinant DNA, cell fusion, plant and animal cell cloning, monoclonal antibodies, tissue culture, and bioprocess engineering.

A total of 58 biotechnology processes classified into four groups are printed on pages 4 through 19.

What are biotechnology products?

Biotechnology products are the goods / services produced for research and commercial use through the utilisation of one or more biotechnology processes.

Development Stages

The process of using modern biotechnology for commercial purposes is divided into four main stages.
These stages are outlined below:

Research / Product Development Stage

Refers to the development of biotechnology output through research and development (R&D)

Clinical / Field Trial Stage

Refers to the testing of processes and products in actual clinical or field trials

Part of the Production Stage

The biotechnology process or product is used as an input into another distinct product or process

Part of the Product Sold Stage

The biotechnology product or process becomes part of the final product sold

What is Research & Development (R&D)?

"Research and development refers to investigative work which is of actual or potential use in the development of new or enhanced materials, products, services or processes. R&D directed towards duplicating work already developed by others should only be included if the knowledge or technology required for development is not available to this business."

Part 9 Problems Affecting Biotechnology Research and Development Work

34 Tick as many spaces as you need to show the constraints to biotechnology research and development activities faced by this business over the accounting period:

i. Access to capital ○
ii. Access to management experts ○
iii. Access to trained biotechnology research and technical experts ○
iv. Access to suitably experienced biotechnology research and technical experts ○
v. Access to biotechnology research data and/or information ○
vi. Access to technology ○
vii. Lack of information about markets ○
viii. Regulations ○
ix. Implications of Treaty of Waitangi claims ○
x. Other (Please specify) ○

35 In the 12 months ending 30 June 1999, did this business try to recruit any staff from outside New Zealand for biotechnology research and development work?

Yes ○
No ○ → Go to question 37

36 In the 12 months ending 30 June 1999, were any of these overseas recruitment bids successful?

Yes ○ No ○

Tick as many spaces as you need to show which countries staff were recruited from

i. Australia ○
ii. Asia ○
iii. Europe ○
iv. USA ○
v. Other (Please specify) ○

Tick as many spaces as you need to show why this business' overseas recruitment bids failed

i. Inability to match overseas salary levels ○
ii. Personal income taxes ○
iii. Immigration rules and procedures ○
iv. Advancement opportunities ○
v. Loss of professional networks ○
vi. Other (Please specify) ○

Please go to next page →

Part 7 Research Publications and Conferences

31 In the 12 months ending 30 June 1999, did any staff member of this business:

	Yes	No
i. Publish an article on biotechnology in a refereed journal?	○	○
ii. Attend a conference (national or international) on a biotechnology subject?	○	○
iii. Present a research paper at such a conference (national or international) on biotechnology?	○	○

Part 8 Human Resources Supporting Biotechnology Activity

32 Please give the number of employees (or Head-count) and their full-time equivalents as at 30 June 1999.
Note: Full-time equivalents may be given to a decimal point.

Full-time equivalents (FTEs) are measured in terms of full-time equivalent years. For example, a full-time person spending 40% of his/her working time on biotechnology during half of the survey year would contribute 0.4 persons x 0.5 years = 0.2 full-time equivalent years to the biotechnology effort.

Do NOT include:
- staff performing indirect support to biotechnology activities
- central finance or personnel services
- centralised support services eg computer departments, security, cleaning, cafeteria etc.

(If information is not available, please make careful estimates)

Biotechnology Employees

i. Head-count as at 30 June 1999	
ii. FTEs during the year ended 30 June 1999	
iii. Biotechnology positions unfilled as at 30 June 1999	

33 How many of this business' biotechnology staff members have these qualifications as at 30 June 1999? Include staff doing biotechnology research and development work.

Qualification	Head-count
i. Ph D	
ii. M Phil / M Sc	
iii. B Sc / B Tech	
iv. Diploma / Certificate	
v. Other	

Part 1 Instructions

1 **Include information only for the business named on the front page - do NOT provide consolidated data.**

Do NOT include:
- Subsidiary or associated businesses
- Accounting divisions that operate entirely outside New Zealand

2 **Please keep a record of the time it takes you to complete this questionnaire. You are asked to record this in question 37, page 28.**

Include:
- The time spent reading the instructions, working on the questions and obtaining information
- The time spent by all employees in collecting and providing this information

3 **Survey Reference Period**

Unless otherwise specified, please provide data for the year ended **30 June 1999** OR your last accounting year that ended within the 12 months up to 30 June 1999.

Please go to next page →

Part 2 Use of Biotechnology Processes by This Business

4 For each process listed, work across these pages to answer every question in the column headings.

5 **DNA Based: Technology using chemistry of DNA as a major component**

Biotechnology Processes Please see page 2 for the definition of biotechnology processes.	**Was this process used in operations by this business during the accounting year?**
1. Genetic Engineering / Recombinant DNA The manipulation of an organism's genetic material by introducing or eliminating specific genetic changes through modern molecular biology techniques	○ Yes → ○ No →
2. Gene Probes A section of DNA or RNA of known structure or function which is marked with a radioactive isotope, dye or enzyme that can be used to detect the presence of a similar sequence from any biological material	○ Yes → ○ No →
3. Bio-informatics Computer-based analysis of biological information (bio-info), especially genomics and molecular modelling (eg DNA/RNA/ protein sequencing and databases for genes of humans, plants, animals and micro-organisms)	○ Yes → ○ No →
4. Genomics The use and organisation of information of biological interest, including the construction and analysis of genes that may be used to search for new genes of interest, matching existing genes etc.	○ Yes → ○ No →
5. Pharmacogenetics The study of the genetics of drug production, action or assimilation	○ Yes → ○ No →
6. DNA Sequencing A method to determine the order of nucleotides on a gene or DNA fragment	○ Yes → ○ No →
7. DNA Synthesis Design and synthesis of a DNA molecule from existing information of its constituent bases	○ Yes → ○ No →
8. DNA Amplification Process of increasing the number of copies of a particular gene of chromosomal sequence	○ Yes → ○ No →

25 Has this business ever had to abandon or not start a biotechnology development activity because further work had been blocked by lack of access to basic research data or information?

○ Yes
○ No

26 In the last 3 years has this business been involved in litigation relating to patent infringements?

○ Yes → How many different cases? ☐
○ No

27 In the last 3 years has this business been involved in disputes relating to access to research data or information?

○ Yes → How many different cases? ☐
○ No

28 In the last 3 years has this business entered into any informal arrangements to share information with any of these organisations? Tick as many spaces as you need.

	In NZ	Outside NZ
Another business	○	○
University	○	○
Crown Research Institute	○	
Hospital	○	○
Other (Please specify)	○	○

☐

29 In the last accounting year has this business acquired the right to use intellectual property from any of these? Tick as many spaces as you need.

	In NZ	Outside NZ
Another business	○	○
University	○	○
Crown Research Institute	○	
Hospital	○	○
Other (Please specify)	○	○

☐

30 Please write in the number of successful biotechnology-related patent applications made by this business:

i. In the last year ending June 30 1999 ☐

ii. In the last 5 years ☐

Please go to next page →

Part 5 Financial and Trade Information

18 Please provide financial information for **total business** activity and the estimated amount for biotechnology activity.

Note: Please report data for the accounting year ended 30 June 1999 or the latest financial year for which records are available. Do NOT include sales and operations of your subsidiaries located outside New Zealand.

What is the end-date of the accounting year you will report for: / / 1999

19 Total income: (If this information is not available, please make a careful estimate.)

	Total	% Biotechnology
	$	%

20 Total expenditure: (If this information is not available, please make a careful estimate.)

	Total	% Biotechnology
	$	%

21 What is the total amount exported by this business as a percentage of total production of goods / services? (If this information is not available, please make a careful estimate.) %

22 Biotechnology-related exports of this business as a percentage of total production: (If this information is not available, please make a careful estimate.) %

Part 6 Intellectual Property (IP) Rights and Patents

23 Has this business ever had to abandon or not start a biotechnology development activity because further work was blocked by IP Rights or some knowledge protected by another organisation?

- ○ Yes
- ○ No → Go to question 25

24 Tick as many spaces as you need to show which of these reasons caused this?

- Was unable to purchase this IP ○
- Was unable to licence this IP ○
- Any other reason ○

Answer each of these questions for each process listed.

In which stage has this process been used?			If NOT used, does this business plan to use this process in the next three years?	If no plan to use in the next 3 years, this is because:	
Research & product / process development	Part of the production process	Part of the product sold		It has no application to this business	It is not cost-effective
○	○	○	○ Yes ○ No →	○	○
○	○	○	○ Yes ○ No →	○	○
○	○	○	○ Yes ○ No →	○	○
○	○	○	○ Yes ○ No →	○	○
○	○	○	○ Yes ○ No →	○	○
○	○	○	○ Yes ○ No →	○	○
○	○	○	○ Yes ○ No →	○	○
○	○	○	○ Yes ○ No →	○	○

5 continued next page →

Part 2 Use of Biotechnology Processes by This Business

For each process listed, work across these pages to answer every question in the column headings.

5 DNA Based: Technology using chemistry of DNA as a major component (continued)

Biotechnology Processes Please see page 2 for the definition of biotechnology processes	Was this process used in operations by this business during the accounting year?
9. Gene Therapy Replacement of a defective gene in an organism suffering from a genetic defect	○ Yes → ○ No →
10. Rational Drug Design Analysis of the structures of active sites of enzymes and receptors in order to design pharmocologically active synthetic molecules	○ Yes → ○ No →
11. Other (Please specify)	○ Yes → ○ No →

6 Biochemistry / Immunochemistry Based: Technology which utilises immunochemistry / antibodies or enzymes as a major component

1. Vaccines The agent containing antigens produced from killed, attenuated or live pathogenic micro-organisms or their genetic material used to stimulate the immune system to protect the host	○ Yes → ○ No →
2. Immune Stimulants Compounds that induce the immune system to produce antibodies or antibody containing lymphocytes	○ Yes → ○ No →
3. Drug Design and Delivery Development of drugs where the raw materials and/or processes involve the use of biotechnology	○ Yes → ○ No →
4. Combinatorial Chemistry An approach to chemical synthesis that enables the creation of large numbers of organic compounds by putting chemical building blocks together in every possible combination. It is used to synthesise novel compounds, which are screened, or tested, against biological targets as part of the drug discovery process	○ Yes → ○ No →

Part 4 Strategic Partnership / Alliance

15 In the last 3 years, did this business have any partnership / alliance for undertaking biotechnology activity (research and/or production)?

Note: Partnership / alliance is defined as an agreement with another business to undertake business activities without merging.

○ Yes ○ No → Go to question 18

16 Tick as many spaces as you need to show the purposes of these partnership / alliance(s).

i. Product / process development ○
ii. Clinical / field trial ○
iii. Manufacturing ○
iv. Marketing / distribution ○
v. Regulatory affairs ○
vi. Finance ○
vii. Other (Please specify) ○

17 Tick as many spaces as you need to show which of these New Zealand and overseas organisations this business made partnership / alliance(s) within the last 3 years?

1. New Zealand organisations:

i. Crown Research Institute ○
ii. University ○
iii. Polytechnic ○
iv. Related-business research / Professional Association ○
v. Unrelated-business research / Professional Association ○
vii. Other (Please specify) ○

2. Overseas organisations:

	Australia	USA	Europe	Asia	Other
i. University	○	○	○	○	○
ii. Other organisations (Please specify)	○	○	○	○	○

Please go to next page →

13 In the last 3 years, has this business implemented a new or a significantly improved bio-industry sector **product / service**?

Yes → How many? ____

No

14 In the next 3 years, does this business plan to implement a new or a significantly improved bio-industry sector **product / service**?

Yes → How many? ____

No

Answer each of these questions for each process listed.

In which stage has this process been used?			If NOT used, does this business plan to use this process in the next three years?	If no plan to use in the next 3 years, this is because:	
Research & product / process development	Part of the production process	Part of the product sold		It has no application to this business	It is not cost-effective
○	○	○	○ Yes ○ No →	○	○
○	○	○	○ Yes ○ No →	○	○
○	○	○	○ Yes ○ No →	○	○
○	○	○	○ Yes ○ No →	○	○
○	○	○	○ Yes ○ No →	○	○
○	○	○	○ Yes ○ No →	○	○
○	○	○	○ Yes ○ No →	○	○

6 continued next page →

Part 2 Use of Biotechnology Processes by This Business

For each process listed, work across these pages to answer every question in the column headings.

6 Biochemistry / Immunochemistry Based (continued)

Biotechnology Processes Please see page 2 for the definition of biotechnology processes	Was this process used in operations by this business during the accounting year?	
5. Diagnostic Tests A test used to determine the source of a problem or a method of determining the nature of a disease by analysing the symptoms	○ Yes → ○ No →	
6. Peptide / Protein Synthesis Procedure to link two or more amino acids joined by a linkage called a peptide bond	○ Yes → ○ No →	
7. Peptide / Protein Sequencing The process of determining the sequence of a polypeptide or cluster of polypeptides, or the process of creating a new substance from precursor molecules	○ Yes → ○ No →	
8. Cell Receptors Functional proteinaceous structures found in the membrane (surface) of cells that tightly bind specific molecules (organic, protein or viruses)	○ Yes → ○ No →	
9. Cell Signalling The mechanism used by cells to induce or trigger events at remote sites within cells	○ Yes → ○ No →	
10. Bio-sensing Use of biological molecules (eg enzymes, antibodies) in conjunction with a transducer to low level detection of substances such as sugars and proteins in body fluids, pollutants in water etc.	○ Yes → ○ No →	
11. Pheromones Compounds emitted by insects and spread through the air for the purpose of attracting the opposite sex	○ Yes → ○ No →	
12. Three Dimensional Molecular Modelling Description of the characteristics of molecules through a 3D spatial representation	○ Yes → ○ No →	

4. Food Processing (eg using enzymes, bacteria and yeast culture)

i. **Brewing / Wine producing** ..... ○
ii. **Baking** ..... ○
iii. **Dairy** ..... ○
iv. **Functional Foods / Nutriceuticals**
(eg probiotics, unsaturated fatty acids, unspecified food additives) ..... ○

5. Aquaculture

i. **Fish health** (eg diagnostics, therapeutics) ..... ○
ii. **Broodstock genetics**
(eg tracking superior traits, genetic modification / engineering) ..... ○
iii. **Bioextraction**
(eg carageenan from seaweed, antifreeze proteins from fish, flavours) ..... ○

6. Mining / Energy / Petroleum / Chemicals

i. **Microbiologically enhanced petroleum / mineral recovery** ..... ○
ii. **(Cleaner) Industrial Processing**
(eg biodesulphurisation, bio-cracking, bio-recovery) ..... ○

7. Forest Products

i. **Silviculture**
(eg tissue culture, somatic embryogenesis, genetic markers, genetic engineering) ..... ○
ii. **(Cleaner) Industrial Processing**
(eg biopulping, biobleaching, biological prevention of sapstain) ..... ○

8. Environment

i. **Biofiltration**
(eg treatment of organic emissions to air / water) ..... ○
ii. **Bioremediation and Phytoremediation**
(eg cleanup of sewage water and toxic waste sites using micro-organisms) ..... ○
iii. **Diagnostics**
(eg detection of toxic substances using bioindicators, biosensors, immunodiagnostics) ..... ○
iv. **Custom Synthesis - Chemical or Biological**
(eg peptides, proteins, nucleotides, hormones, growth factors, biochemicals) ..... ○

9. Other (Please specify) ..... ○

Please go to next page →

9 If this business neither presently nor in the next 3 years plans to use any of the modern biotechnology processes listed in part 2, go to part 10 on page 28, sign at the end and return the questionnaire using the pre-paid envelope provided.

10 In the last 3 years, did this business implement a new or significantly improved biotechnology **process** in the production line?

Yes ◯ → How many processes? ☐

No ◯ → Go to question 12

11 How many of these new or significantly improved processes were:

i. New to this business ☐

ii. New to New Zealand ☐

iii. New to the world ☐

Part 3 Bio Industry Sector

12 Tick as many spaces as you need to show the bio-industry sectors that best describe the products and/or services produced by this business.

1. Human Health-Bio

i. **Diagnostics**
(eg immunodiagnostics, geneprobes, biosensors, medical laboratory) ..... ◯

ii. **Therapeutics**
(eg vaccines, immune stimulants, biopharmaceuticals, rational drug design, drug delivery, combinatorial chemistry) ..... ◯

iii. **Gene Therapy**
(eg gene identification, gene constructs, gene delivery, gene replacement) ..... ◯

2. Bio-Informatics

i. **Genomics and Molecular Modelling**
(eg DNA/RNA/protein sequencing & databases for genetic information from humans, plants, animals and micro-organisms) ..... ◯

3. Ag-Bio

i. **Plant Biotechnology**
(eg tissue culture, embryogenesis, genetic markers, genetic engineering) ..... ◯

ii. **Animal Biotechnology** (eg diagnostics, therapeutics, embryo transplantation, genetic markers, genetic engineering) ..... ◯

iii. **Biofertilizers / Biopesticides / Bioherbicides / Biological Feed Additives / Microbial Pest Control** (eg bacteria, fungi, yeasts) ..... ◯

iv. **Non-Food Applications of Agricultural Products** ..... ◯

Answer each of these questions for each process listed.

In which stage has this process been used?			If NOT used, does this business plan to use this process in the next three years?	If no plan to use in the next 3 years, this is because:	
Research & product / process development	Part of the production process	Part of the product sold		It has no application to this business	It is not cost-effective
◯	◯	◯	◯ Yes ◯ No →	◯	◯
◯	◯	◯	◯ Yes ◯ No →	◯	◯
◯	◯	◯	◯ Yes ◯ No →	◯	◯
◯	◯	◯	◯ Yes ◯ No →	◯	◯
◯	◯	◯	◯ Yes ◯ No →	◯	◯
◯	◯	◯	◯ Yes ◯ No →	◯	◯
◯	◯	◯	◯ Yes ◯ No →	◯	◯

6 continued next page →

Part 2 Use of Biotechnology Processes by This Business

For each process listed, work across these pages to answer every question in the column headings.

Answer each of these questions for each process listed.

6 Biochemistry / Immunochemistry Based (continued)

Biotechnology Processes Please see page 2 for the definition of biotechnology processes	Was this process used in operations by this business during the accounting year?	In which stage has this process been used?			If NOT used, does this business plan to use this process in the next three years?	If no plan to use in the next 3 years, this is because:	
		Research & product / process development	Part of the production process	Part of the product sold		It has no application to this business	It is not cost-effective
13. Structural Biology The study of the three dimensional structures of biological molecules (such as proteins) and their mutual interactions as a means of understanding the functions of these molecules within the cell	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
14. Antigens A substance that stimulates the production of specific neutralising antibodies in an immune response. Any chemical substance, usually protein that interacts with an antibody	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
15. Monoclonal Antibodies A monoclonal antibody is a highly specific antibody which is derived from a line of specialised cells and which recognises only one specific complimentary antigen	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
16. Antibodies Proteins that circulate in the blood stream and bind to foreign invading substances (antigens eg bacteria, toxins, certain viruses) with a great deal of specificity	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
17. Microbiology / Microbial Ecology Study of organisms that are too small to be seen with the naked eye	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
18. Biomaterials Any biologically derived material which is used for its material properties rather than its biological properties	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
19. Other (Please specify)	○ Yes → ○ No →						

Please go to next page →

Part 2 Use of Biotechnology Processes by This Business

For each process listed, work across these pages to answer every question in the column headings.

Answer each of these questions for each process listed.

8 Bioprocessing Based (continued)

Biotechnology Processes Please see page 2 for the definition of biotechnology processes	Was this process used in operations by this business during the accounting year?	In which stage has this process been used?			If NOT used, does this business plan to use this process in the next three years?	If no plan to use in the next 3 years, this is because:	
		Research & product / process development	Part of the production process	Part of the product sold		It has no application to this business	It is not cost-effective
17. Bioindicators The use of organisms to indicate the status of an environment	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
18. Micro-selected Breeding of Plants and Animals Using modern biotechnological tools to accelerate selection	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
19. Natural Products Chemistry The study of a biological material or a biologically-derived material using analytic methods, normally being the isolation and identification of the novel chemicals within a biological material	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
20. Microbio-inoculants Naturally occurring bacterial inoculates used to promote plant growth	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
21. Somatic Embryo-genesis Propagation of genetically desirable plant and tree lineages by tissue culture methods	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
22. Other (Please specify)	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
		○	○	○	○ Yes ○ No →	○	○

Please go to next page →

Part 2 Use of Biotechnology Processes by This Business

For each process listed, work across these pages to answer every question in the column headings.

Answer each of these questions for each process listed.

7 Environmental Biotechnologies: Biotechnologies used for pollution control

Biotechnology Processes Please see page 2 for the definition of biotechnology processes	Was this process used in operations by this business during the accounting year?	In which stage has this process been used?			If NOT used, does this business plan to use this process in the next three years?	If no plan to use in the next 3 years, this is because:	
		Research & product / process development	Part of the production process	Part of the product sold		It has no application to this business	It is not cost-effective
1. Bioaugmentation The process of increasing the efficiency of the naturally occurring microbial population to concentrate or accumulate specific compounds. This is usually achieved by adding nutrients, oxygen or water	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
2. Bio-reactors Enclosed containers in which micro-organisms are maintained under controlled conditions for the purpose of creating or destroying specific compounds	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
3. Biological Gas Cleaning The use of micro-organisms to break down or degrade hazardous substances in a gas stream into less hazardous or non-toxic substances	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
4. Bio-remediation The use of naturally occurring or genetically modified micro-organisms to breakdown or degrade hazardous substances into less hazardous or non-toxic substances	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
5. Phytoremediation The use of plants to treat or clean environmental pollution	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
6. Other (Please specify)	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
		○	○	○	○ Yes ○ No →	○	○
		○	○	○	○ Yes ○ No →	○	○

8 continued next page →

Part 2 Use of Biotechnology Processes by This Business

For each process listed, work across these pages to answer every question in the column headings.

Answer each of these questions for each process listed.

8 Bioprocessing Based (continued)

Biotechnology Processes Please see page 2 for the definition of biotechnology processes	Was this process used in operations by this business during the accounting year?	In which stage has this process been used?			If NOT used, does this business plan to use this process in the next three years?	If no plan to use in the next 3 years, this is because:	
		Research & product / process development	Part of the production process	Part of the product sold		It has no application to this business	It is not cost-effective
9. Biotransformation Conversion of one chemical or material into another using a biological catalyst	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
10. Bio-leaching Use of micro-organisms to leach metals from ore	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
11. Bio-pulping The use of enzymes to degrade wood structures to produce pulp for paper making purposes	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
12. Bio-bleaching The use of enzymes to bleach paper fibre	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
13. Bio-desulphurisation The removal of organic or inorganic sulphur from coal by bacterial or soil micro-organisms	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
14. Bio-pesticide Manufacturing Biological pest control through the use of naturally occurring microbes or bacteria	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
15. Extraction / Concentration / Purification / Separation The retrieval of a compound of interest from a raw material	○ Yes → ○ No →						
16. Biofiltration The treatment of sewage or industrial wastewaters using active biomass growing on a solid support	○ Yes → ○ No →						

Please go to next page →

Part 2 Use of Biotechnology Processes by This Business

For each process listed, work across these pages to answer every question in the column headings.

Answer each of these questions for each process listed.

8 Bioprocessing Based: Processing of any natural material of biological origin

Biotechnology Processes Please see page 2 for the definition of biotechnology processes	Was this process used in operations by this business during the accounting year?	In which stage has this process been used?			If NOT used, does this business plan to use this process in the next three years?	If no plan to use in the next 3 years, this is because:	
		Research & product / process development	Part of the production process	Part of the product sold		It has no application to this business	It is not cost-effective
1. Cell Culture A population of cells grown for microbiological testing, cell culture development or in fermenters to study their biology or to manufacture products	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
2. Tissue Culture A technique for growing cells from multi-cellular organisms in an artificial medium	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
3. Embryo Culture A technique for growing embryos from multi-embryo organisms in an artificial medium	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
4. Cell Manipulation Ability to grow and modify a range of cell types under laboratory conditions	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
5. Tissue Manipulation Ability to grow and modify a range of tissue types under laboratory conditions	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
6. Embryo Manipulation Ability to grow and modify a range of embryo types under laboratory conditions	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
7. Fermentation Micro-organic process in which the metabolism of sugars for energy is accompanied by the formation of alcohol and/or lactic acid and solvents. Include processes such as wine, cheese and yoghurt making, brewing, yeast production etc.	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○
8. Bioprocessing Production stages that include fermentation, recovery and purification	○ Yes → ○ No →	○	○	○	○ Yes ○ No →	○	○

8 continued next page →

Appendix 6 Additional Regression Results

In Chapter 6 some model results were simplified by omission of non-significant variables. In this Appendix regression results are provide for the 'full' model. This comprises all variables included in the theoretical framework, except for variables where data were not available (see discussion in Chapter 6.1).

Tables A6.1 and A6.2 provide full results for alternative models where the indicator for innovative output is biotech R&D expenditure (Table A6.1) or number of biotech R&D staff (Table A6.2). These results may be compared with Table 6.5 where innovative output is represented by three dummy variables specifying different levels of biotech expenditure.

Table A6.3 details the full model including additional variables describing alliance characteristics – see Chapter 6, Table 6.12 for a simplified model of alliance characteristics vs. innovative output.

Table A6.1 Estimates for a Model based on Biotech R&D Expenditure (Full Model)

Variable	Coefficient (Std Error)	%
	2002	
Constant	-1.225	
	(0.854)	
Biotech R&D Spending ($m)	0.000	0.0
	(0.000)***	
Primary industry	1.216	237.4
	(0.583)**	
Non-food manufacturers	0.891	143.7
	(0.513)*	
Scientific research	0.591	80.6
	(0.542)	
Tertiary education	0.078	8.1
	(0.589)	
Other industrial group	0.179	19.6
	(0.796)	
Strategic alliance	1.154	217.1
	(0.466)**	
Modern biotech	0.215	23.9
	(0.340)	
R&D	0.328	38.9
	(0.620)	
No. of R&D processes	0.017	1.7
	(0.048)	
Biotech percentage	0.001	0.1
	(0.003)	
Number of observations	61	
Pseudo R^2	0.1177	

Notes:
1. * significant at 10%; ** significant at 5%; *** significant at 1%
2. % denotes percent change in expected count for unit increase in X
3. *na* denotes no data available for this variable.
4. This analysis uses the Negative Binomial Regression Model
5. Dependent variable is innovative output (innout1)
6. Data are from the 2002 Biotech Survey.
7. Table 6.7 (Chapter 6) provides the same model with non-significant variables omitted.

Table A6.2 Estimates for a Model based on Number of Biotech R&D Staff (Full Model)

Variable	Coefficient (Std Error)	%
	2002	
Constant	-1.294	
	(0.834)	
Number of Biotech R&D Staff	0.016	1.6
	(0.005)***	
Primary industry	1.061	188.8
	(0.560)*	
Non-food manufacturers	0.889	143.2
	(0.495)*	
Scientific research	0.620	85.9
	(0.525)	
Tertiary education	-0.074	-7.1
	(0.562)	
Other industrial group	0.209	23.3
	(0.777)	
Strategic alliance	1.173	223.3
	(0.453)***	
Modern biotech	0.337	40.1
	(0.326)	
R&D	0.282	32.6
	(0.606)	
No. of R&D processes	-0.025	-2.5
	(0.051)	
Biotech percentage	0.003	0.3
	(0.003)	
Number of observations	61	
Pseudo R^2	0.1252	

Notes:
1. * significant at 10%; ** significant at 5%; *** significant at 1%
2. % denotes percent change in expected count for unit increase in X
3. *na* denotes no data available for this variable.
4. This analysis uses the Negative Binomial Regression Model
5. Dependent variable is innovative output (innout1)
6. Data are from the 2002 Biotech Survey.
7. Table 6.7 (Chapter 6) provides the same model with non-significant variables omitted.

Table A6.3 Estimates for the 'Full' Model; Alliance Characteristics vs. Innovative Output

Variable	Coefficient	Std Error	%
Constant	-0.463	1.079	
Dummy 1 for biotech expenditure	0.009	0.409	0.9
Dummy 2 for biotech expenditure	0.289	0.390	33.4
Dummy 3 for biotech expenditure	0.828	0.448*	128.9
Primary industry	0.927	0.489*	152.7
Non-food manufacturers	0.843	0.407**	132.3
Scientific research	0.584	0.427	79.4
Tertiary education	-0.353	0.460	-29.8
Other industrial group	-0.194	0.758	-17.6
Alliance outcome	0.096	0.158	10.0
Staff work or train at partner location	-0.225	0.185	-20.1
Work contracted out to/from other party	-0.062	0.180	-6.0
Active participation by both parties	0.005	0.301	0.5
Alliance with international partner	0.114	0.171	12.0
Alliance with a firm	0.598	0.165***	81.8
Modern biotech	0.051	0.272	5.2
R&D	0.103	0.750	10.9
No. of R&D processes	0.029	0.033	2.9
Biotech percentage	0	0.003	0.0
Number of observations	61		
Pseudo R^2	0.1350		

Notes:
1. * significant at 10%; ** significant at 5%; *** significant at 1%
2. % denotes percent change in expected count for unit increase in X
3. *na* denotes no data available for this variable.
4. This analysis uses the Negative Binomial Regression Model
5. Dependent variable is innovative output (innout1)
6. Data are from the 2002 Biotech Survey.
7. Table 6.12 (Chapter 6) provides the same model with non-significant variables omitted.

References

Abramovitz, M. (1952). Economics of Growth. In B. F. Haley (Ed.), *A Survey of Contemporary Economics* (pp. 132-178). Homewood, Ill: Richard D Irwin Inc.

Aghion, P., & Howitt, P. (1992). A Model of Growth Through Creative Destruction. *Econometrica, 60*, 323-351.

Alchian, A. A. (1950). Uncertainty, Evolution and Economic Theory. *Journal of Political Economy, 58*, 211-221.

Alic, J. A. (1994). *The North American System of Innovation.* Paper presented at the Transnational Institute Conference on Innovation, Competition and Sustainability, August 14-21, Simon Fraser University Vancouver.

Alston, J. M., Pardey, P. G., & Smith, V. H. (1998). Financing Agricultural R&D in Rich Countries: What's Hapening and Why. *Australian Journal of Agricultural and Resource Economics* March.

Andersen, B., Metcalfe, J. S., & Tether, B. S. (1999). Distributed Innovation Systems and Instituted Economic Processes. In J. S. Metcalfe & I. Miles (Eds.), *Innovation Systems in the Service Economy: Measurement and Case Study Analysis* (Vol. 18). Boston: Kluwer.

Andersen, E. S. (1992). Approaching National Systems. In B.-Å. Lundvall (Ed.), *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. London: Pinter Publishers.

Antonelli, G., & De Liso, N. (1997). Introduction: An Appraisal of the Economic Analysis of Technological Change: The Path to the Last Decade. In G. Antonelli & N. De Liso (Eds.), *Economics of Structural and Technological Change*. London: Routledge, UK.

Archibugi, D., Cohendet, P., Kristensen, A., & Schaffer, K.-A. (1994). *Evaluation of the Community Innovation Survey (CIS) - Phase 1* (EIMS Publication No. 11): European Commission and IKE Group, Department of Business Studies, Aalborg, Denmark.

Arocena, R., & Sutz, J. (1999, June 9-12). *Looking at National Systems of Innovation from the South.* Paper presented at the DRUID's Summer Conference on National Innovation Systems, Industrial Dynamics and Innovation Policy, Rebild, Denmark.

Arora, A., & Gambardella, A. (1990). Complementarities and External Linkages: The Strategies of the Large Firms in Biotechnology. *Journal of Industrial Economics, 38(4)* June, 361-379.

Arrow, K. J. (1962a). The Economic Implications of Learning By Doing. *Review of Economic Studies, 29* June, 155-173.

Arrow, K. J. (1962b). Economic Welfare and the Allocation of Resources for Inventions. In R. R. Nelson (Ed.), *The Rate and Direction of Inventive Activity*: Princeton University Press.

Arrow, K. J. (1987). Oral History I: An Interview. In G. Feiwel (Ed.), *Arrow and the Ascent of Modern Economic Theory* (pp. 191-242). London: Macmillan.

Arundel, A. (2003). *Biotechnology Indicators and Public Policy*. OECD, Paris. (STI Working Papers 2003/5)

Arundel, A., & Rose, A. (1999). The Diffusion of Environmental Biotechnology in Canada: Adoption Strategies and Cost Offsets. *Technovation, 19(9)* September, 551-560.

Arvanitis, S., & Hollenstein, H. (1994). Demand and Supply Factors in Explaining the Innovative Activities of Swiss Manufacturing Firms. *Economics of Innovation and New Technology, 3*, 15-30.

Arvanitis, S., & Hollenstein, H. (1996). Industrial Innovation in Switzerland: A Model-based Analysis with Survey Data. In A. Kleinknecht (Ed.), *Determinants of Innovation* (pp. 13-62): Macmillan.

Australian Bureau of Statistics. (1996-97). *Innovation in Manufacturing, Australia*.

Australian Venture Capital Journal. (2000). Almost $1 billion Invested in 1999. *Australian Venture Capital Journal, 9(85)* March, 6-14.

Bannock, G., Baxter, R., & Davis, E. (1992). *The Penguin Dictionary of Economics* (Fifth Edition ed.). London: Penguin Books Ltd.

Baptista, R. (1998). Clusters, Innovation, and Growth: A Survey of the Literature. In P. Swann & M. Prevezer & D. Stout (Eds.), *The Dynamics of Industrial Clustering: International Comparisons in Computing and Biotechnology*: Oxford University Press.

Barone, E. (1908/1935). The Ministry of Production in the Collectivist State. In F. von Hayek (Ed.), *Collectivist Economic Planning*. London: Routledge (Italian Original 1908).

Barro, R. J. (1997). *Determinants of Economic Growth*.

Bartholomew, S. (1997). National Systems of Biotechnology Innovation: Complex Interdependence in the Global System. *Journal of International Business Studies, 28(2)*, 241-266.

Beise, M., & Stahl, H. (1999). Public Research and Industrial Innovations in Germany. *Research Policy, 28(4)* April, 397-422.

Bell, M., & Albu, M. (1999). Knowledge Systems and Technological Dynamism in Industrial Clusters. *World Development, 27(9)* September, 1715-1734.

Berry, M. (2003). *Innovation by Design: The Economic Drivers of Dynamic Regions* (Lab.report 01): lab.3000.

Biotechnology Taskforce. (2003). *Growing the Biotechnology Sector in New Zealand. A Framework for Action. Report from the Biotechnology Taskforce*.

BIOTENZ. (1998). *BIOTENZ Promotional Brochure* (Promotional Brochure). Auckland.

BIOTENZ. (2001). *Biotech21: A Biotenz Strategy for the New Zealand Biotechnology Sector in the 21st Century*.

Black, J. (2002). *A Dictionary of Economics*. Oxford: Oxford University Press.

Boulding, K. (1985). *The World as a Total System*.

Boulding, K. (1991). What is Evolutionary Economics? *Journal of Evolutionary Economics, 1(1)*, 9-17.

Boyer, R., Amable, B., & Barré, R. (1997). Les Systémes d'innovation a l'ére de la Globalization. *Economica, Paris*.

Bozeman, B., Crow, M., & Tucker, C. (1999, June 9-12). *Federal Laboratories and Defense Policy in the US National Innovation System.* Paper presented at the DRUID's Summer Conference on National Innovation Systems, Industrial Dynamics and Innovation Policy, Rebild, Denmark.

Bozeman, B., & Kingsley, G. (1997). R&D Value Mapping: A New Approach to Case Study-Based Evaluation. *Journal of Technology Transfer, 22(2)*, 33-42.

Bozeman, B., & Klein, H. K. (1999). The Case Study as Research Heuristic: Lessons from the R&D Value Mapping Project. *Evaluation and Program Planning, 22* February, 91-103.

Breschi, S., & Malerba, F. (1997). Sectoral Innovation Systems: Technological Regimes, Schumpeterian Dynamics and Spatial Boundaries. In C. Edquist (Ed.), *Systems of Innovation: Technologies, Institutions and Organisations*. London: Pinter.

Breschi, S., Malerba, F., & Orsenigo, L. (2000). Technological Regimes and Schumpeterian Patterns of Innovation. *Economic Journal, 110(463)* April, 388-410.

Bresnahan, T. (1989). Empirical Studies of Industries with Market Power. In R. Schmalensee & R. D. Willig (Eds.), *Handbook of Industrial Organization* (Vol. II, pp. 1012-1057): Elsevier Science Publishing Company.

Bryant, K., Healy, M., & Lombardo, L. (1996). *Charting National Innovation Systems: An Australian Approach* (Study Prepared for the OECD Project on National Innovation Systems).

Bud, R. (1989). History of 'Biotechnology'. *Nature, 337(6202)* 5 January, 10.

Bull, A., Holt, G., & Lilly, M. (1982). *Biotechnology: International Trends and Perspectives*: OECD, Paris.

Bush, V. (1945). *Science: the Endless Frontier*: National Science Foundation, Washington.

Cameron, A. C., & Trivedi, P. K. (1986). Econometric Models Based on Count Data: Comparisons and Applications of Some Estimators and Tests. *Journal of Applied Econometrics, 1*, 29-53.

Cappelen, A., Fagerberg, J., & Verspagen, B. (1999, June 9-12). *Lack of Regional Convergence.* Paper presented at the DRUID's Summer Conference on National Innovation Systems, Industrial Dynamics and Innovation Policy, Rebild, Denmark.

Capron, H., & Cincera, M. (1997). *National Innovation Systems: Pilot Study of the Belgian Innovation System* (Study Prepared for the OECD Project on National Innovation Systems): OECD.

Caragata, P. (2000). Could you Sell your Great Ideas to a Venture Capitalist? *The Independent Business Weekly, 8 March*, 12.

Carlsson, B. (Ed.). (1995). *Technological Systems and Economic Performance: The Case of Factory Automation* (Vol. 5). Dordrecht: Kluwer.

Carlsson, B. (Ed.). (1997). *Technological Systems and Industrial Dynamics* (Vol. 10). Dordrecht: Kluwer.

Carlsson, B., & Jacobsson, S. (1997a). In Search of Useful Public Policies: Key Lessons and Issues for Policy Makers. In B. Carlsson (Ed.), *Technological Systems and Industrial Dynamics* (Vol. 10). Dordrecht: Kluwer.

Carlsson, B., & Jacobsson, S. (1997b). The Technological System for Factory Automation. In B. Carlsson (Ed.), *Technological Systems and Industrial Dynamics* (Vol. 10, pp. 37-59). Dordrecht: Kluwer.

Carlsson, B., Jacobsson, S., Holmén, M., & Rickne, A. (1999, June 9-12). *Innovation Systems: Analytical and Methodological Issues.* Paper presented at the DRUID's Summer Conference on National Innovation Systems, Industrial Dynamics and Innovation Policy, Rebild, Denmark.

Carlsson, B., & Stankiewicz, R. (1991). On the Nature, Function, and Composition of Technological Systems. *Journal of Evolutionary Economics, 1(2)*, 93-118.

Carlsson, B., & Stankiewicz, R. (1995). On the Nature, Function and Composition of Technological Systems. In B. Carlsson (Ed.), *Technological Systems and Economic Performance: The Case of Factory Automation* (Vol. 5). Dordrecht: Kluwer.

Carlton, D. W., & Perloff, J. M. (2000). *Modern Industrial Organization*: Addison-Wesley Longman.

Cassie, F. (2000, April 14). University GM Research 'Can of Worms'. *NZ Education Review, 4(48),* 1.

Cassiolato, J. E., & Lastres, H. M. M. (1999, June 9-12). *Local, National and Regional Systems of Innovation in the Mercosur.* Paper presented at the DRUID's Summer Conference on National Innovation Systems, Industrial Dynamics and Innovation Policy, Rebild, Denmark.

Chesnais, F. (1993). The French National System of Innovation. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 192-229). New York: Oxford University Press.

Clark, D. N., Pavlovich, K., & Simpson, B. (1999). *The Horticulture and Food Research Institute of New Zealand Ltd*. Waikato Management School, Department of Strategic Management and Leadership.

Clark, N., & Juma, C. (1988). Evolutionary Theories in Economic Thought. In G. Dosi & C. Freeman & R. Nelson & G. Silverberg & L. Soete (Eds.), *Technical Change and Economic Theory* (pp. 197-220). London and New York: Frances Pinter and Columbia University Press.

Cohen, W. M., & Klepper, S. (1992). The Tradeoff Between Firm Size and Diversity in the Pursuit of Technological Progress. *Small Business Economics, 4(1),* 1-14.

Cohen, W. M., & Klepper, S. (1996). A Reprise of Size and R&D. *Economic Journal, 106* July, 925-951.

Cohen, W. M., & Levin, R. C. (1989). Empirical Studies of Innovation and Market Structure. In R. Schmalensee & R. D. Willig (Eds.), *Handbook of Industrial Organization* (Vol. II): Elsevier Science Publishing Company.

Cole, S., & Phelan, T. J. (1999). The Scientific Productivity of Nations. *Minerva, 37,* 1-23.

Cooke, P., & Morgan, K. (1994). The Regional Innovation System in Baden-Wurttenberg. *International Journal of Technology Management, 3/4.*

Cooke, P., Uranga, M., & Etxebarria, G. (1998). Regional Systems of Innovation: An Evolutionary Perspective. *Environment & Planning A, 30(9)* Sep, 1563-1584.

Coombs, R., & Metcalfe, J. S. (2000). *Universities, the Science Base and the Innovation Performance of the UK*. CRIC, University of Manchester. (Briefing Paper No 5)

Cooper, R. (2003). *The New Zealand Biotechnology Industry Capability Survey*: BIOTENZ.

Correa, C. (1998). Argentina's National Innovation System. *International Journal of Technology Management, 15(6-7),* 721-760.

Crépon, B., Duguet, E., & Mairesse, J. (1998). Research, Innovation and Productivity: An Econometric Analysis at the Firm Level. *Economics of Innovation & New Technology, 7(2)* October.

Dahlman, C. J., & Frischtak, C. R. (1993). National Systems Supporting Technical Advance in Industry: The Brazilian Experience. In R. R. Nelson

(Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 414-450). New York: Oxford University Press.

Dalum, B., Johnson, B., & Lundvall, B.-Å. (1992). Public Policy in the Learning Society. In B.-Å. Lundvall (Ed.), *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning* (pp. 296-317). London: Pinter Publishers.

Darroch, J. (1998). *National Systems of Innovation and the New Zealand Experience*. Department of Marketing, Massey University.

Dasgupta, P. (1987). The Economic Theory of Technology Policy: An Introduction, *Economic Policy and Technological Performance*. Cambridge: Cambridge University Press.

Dasgupta, P., & Stiglitz, J. (1980). Industrial Structure and the Nature of Innovative Activity. *Economic Journal, 90* June, 266-293.

Dasgupta, P., & Stoneman, P. (Eds.). (1987). *Economic Policy and Technological Performance*. Cambridge: Cambridge University Press.

David, P. A. (1975). *Technical Choice, Innovation and Economic Growth*. Cambridge: Cambridge University Press.

David, P. A. (1995). *Science Reorganized? Post-Modern Visions of Research and the Curse of Success*. MERIT. (Research Memoranda Number 002)

De Liso, N., & Metcalfe, J. S. (1996). On Technological Systems and Technological Paradigms: Some Recent Developments in the Understanding of Technological Change. In E. Helmstader & M. Perlman (Eds.), *Behavioural Norms, Technical Progress, and Economic Growth*: Michigan University Press.

Deeds, D. L., & Hill, C. W. L. (1996). Strategic Alliances and the Rate of New Product Development: An Empirical Study of Entrepreneurial Biotechnology Firms. *Journal of Business Venturing, 11*, 41-55.

den Hertog, P., Roeland, T. J. A., Boekholt, P., & van der Gaag, H. (1995). *Assessing the Distribution Power of National Innovation Systems Pilot Study: The Netherlands* (Study Prepared for the OECD Project on National Innovation Systems): OECD.

Denison, E. F. (1985). *Trends in American Economic Growth*. Washington DC: Brookings Institution.

Department of Trade and Industry. (1988). *Biotechnology in New Zealand: A Business Perspective*. Wellington, New Zealand.

Devlin, A. (2003). *An Overview of Biotechnology Statistics in Selected Countries*. OECD, Paris. (STI Working Papers 2003/13)

Diebold, J. (1952). *Automation: The Advent of the Automatic Factory*. New York: Van Nostrand.

Domar, E. (1946). Capital Expansion, Rate of Growth, and Employment. *Econometrica, 14* April, 137-147.

Dosi, G. (1982). Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directives of Technological Change. *Research Policy, 13*, 3-20.

Dosi, G. (1988). Sources, Procedures, and Microeconomic Effects of Innovation. *Journal of Economic Literature, 26* September, 1120-1171.

Dosi, G., Freeman, C., Nelson, R., Silverberg, G., & Soete, L. (Eds.). (1988). *Technical Change and Economic Theory*. London and New York: Frances Pinter and Columbia University Press.

Drejer, I. (1999, June 9-12). *Comparing Patterns of Interdependence in National Systems of Innovation: A Study of Germany, Great Britain, Japan and the United States.* Paper presented at the DRUID's Summer Conference on National Innovation Systems, Industrial Dynamics and Innovation Policy, Rebild, Denmark.

Drucker, P. (1993). *Post-Capitalist Society*. New York: Harper Business.

Edquist, C. (1998). *The ISE Final Report: Scientific Findings of the 'Innovation Systems and European Integration' (ISE) Research Project*. Linköping: Innovation Systems and European Integration' (ISE) Research Project, Systems of Innovation Research Programme, University of Linköping.

Edquist, C. (Ed.). (1997). *Systems of Innovation: Technologies, Institutions and Organisations*. London: Pinter.

Edquist, C., & Hommen, L. (1999). Systems of Innovation: Theory and Policy for the Demand Side. *Technology in Society, 21(1),* 63-79.

Edquist, C., Hommen, L., Johnson, B., Lemola, T., Malerba, F., Reiss, T., & Smith, K. (1998). *The ISE Policy Statement: The Innovation Policy Implications of the 'Innovation Systems and European Integration' (ISE) Research Project.* Linköping: Innovation Systems and European Integration' (ISE) Research Project, Systems of Innovation Research Programme, University of Linköping.

Edquist, C., & Lundvall, B.-Å. (1993). Comparing the Danish and Swedish Systems of Innovation. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 265-298). New York: Oxford University Press.

Eliasson, G., & Eliasson, Å. (1997). The Pharmaceutical and Biotechnological Competence Bloc and the Development of Losec. In B. Carlsson (Ed.), *Technological Systems and Industrial Dynamics* (Vol. 10). Dordrecht: Kluwer.

Engelbrecht, H.-J., & Darroch, J. (1999). A Comparative Macro-Level Assessment of New Zealand's National Innovation System. *Prometheus, 17(3)* September, 283-298.

Enright, M. (1996). Regional Clusters and Economic Development: A Research Agenda. In U. Staber & N. Schaefer & B. Sharma (Eds.), *Business Networks: Prospects for Regional Development* (pp. 190-214). Berlin: de Gruyter.

Environmental Risk Management Authority. (1999). *Briefing for the Incoming Government* (ER-BR-01-1 11/99). Wellington: Environmental Risk Management Authority.

Ernst & Young. (1999a). *Australian Biotechnology Report 1999*. Canberra: Ernst & Young.

Ernst & Young. (1999b). *Bridging the Gap: Ernst & Young's 13th Biotechnology Industry Annual Report.* Palo Alto, California: Ernst & Young.

Ernst & Young. (2003). *Review of New Zealand's Biotechnology Sector. Summary Report*.

Eurostat. (2001). *The Third Community Innovation Survey (CIS III).*

Eveleens, W. (1995). *Data Measurement Issues in Studying the Relationship Between Technological Change and Productivity Growth in New Zealand.* Unpublished Master of Commerce in Economics, University of Auckland, Auckland.

Filippi, M. (1999, January 7-9, 1999). *Proximity and Co-ordination : How Spatial Economics Tries to Better Understand Spatial Agglomeration Activity ?* Paper presented at the The DRUID 1999 Winter Conference, Seeland, Denmark.

Foltz, J., Barham, B., & Kim, K. (2000). Universities and Agricultural Biotechnology Patents Production. *Agribusiness, 16(1)*, 82-95.

Fontes, M., & Novais, A. Q. (1998). The Conditions for the Development of a Biotechnology Industry in Portugal: The impact of Country Specific Factors. *Technology Analysis & Strategic Management, 10(4)*.

Foundation For Research Science and Technology. (1998). *A Profile of the Human Capital Resource in New Zealand*. Wellington: Foundation For Research Science and Technology,.

Fransman, M., & Tanaka, S. (1995). The Strengths and Weaknesses of the Japanese Innovation System in Biotechnology. In M. Fransman & G. Junne & A. Roobeek (Eds.), *The Biotechnology Revolution?* (pp. 431-483). Oxford: Blackwell.

Frater, P., Stuart, G., Rose, D., & Andrews, G. (1995). *The New Zealand Innovation Environment*. Wellington: The Berl Foundation.

Freeman, C. (1974). *The Economics of Industrial Innovation* (1st edn, Harmondsworth, Penguin, 2nd edn, 1982, London, Pinter ed.). Harmondsworth: Penguin.

Freeman, C. (1987). *Technology and Economic Performance: Lessons from Japan*: Pinter.

Freeman, C. (1988). Japan: A New National System of Innovation? In G. Dosi & C. Freeman & R. Nelson & G. Silverberg & L. Soete (Eds.), *Technical Change and Economic Theory*. London and New York: Frances Pinter and Columbia University Press.

Freeman, C. (1991). Networks of Innovators: A Synthesis of Research Issues. *Research Policy, 20(5)*, 499-514.

Freeman, C. (1992). Formal Scientific and Technical Institutions in the National System of Innovation. In B. Lundvall (Ed.), *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning* (pp. 169-187). London: Pinter Publishers.

Freeman, C. (1994). The Economics of Technical Change. *Cambridge Journal of Economics, 18(5)*, 463-514.

Freeman, C. (1995a). The National System of Innovation in Historical Perspective. *Cambridge Journal of Economics, 19(1)* February, 5-24.

Freeman, C. (1995b). Technological Revolutions: Historical Analogies. In M. Fransman & G. Junne & A. Roobeek (Eds.), *The Biotechnology Revolution?* Oxford: Blackwell.

Freeman, C. (Ed.). (1990). *The Economics of Innovation* (Vol. 2). Aldershot: Edward Elgar Publishing Company.

Fujita, M., Krugman, P., & Venables, A. J. (1999). *The Spatial Economy: Cities, Regions and International Trade*. Cambridge, MA: MIT Press.

Furman, J. L., Porter, M. E., & Stern, S. (2002). The Determinants of National Innovative Capacity. *Research Policy, 31(6)* August, 899-933.

Gassler, H., Frölich, J., & Kopcsa, A. (1996). Selective Information on the National System of Innovation as an Important Input for the Technology Management of Firms. *International Journal of Technology Management, 11*, 329-342.

Goto, A. (2000). Japan's National Innovation System: Current Status and Problems. *Oxford Review of Economic Policy, 16(2)*, 103-113.

Gregory, R. (1993). The Australian Innovation System. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 324-352). New York: Oxford University Press.

Griliches, Z. (1958). Research Cost and Social Returns: Hybrid Corn and Related Innovations. *Journal of Political Economy, 66(5)*, 419-431.

Griliches, Z. (1986). Productivity, R&D, and Basic Research at the Firm Level in the 1970's. *American Economic Review, 76* March, 141-154.

Griliches, Z. (1990). Patent Statistics as Economic Indicators: A Survey. *Journal of Economic Literature, 28(4)* December, 1661-1707.

Griliches, Z. (1992). The Search for R&D Spillovers. *Scandinavian Journal of Economics, 94 (Supplement)*, 29.

Griliches, Z. (1994). Productivity, R&D, and the Data Constraint. *American Economic Review, 84(1)* March, 1-23.

Grossman, G. M., & Helpman, E. (1991). *Innovation and Growth in the Global Economy*. Cambridge, MA: MIT Press.

Hall, B. H., & Reenen, J. V. (2000). How Effective are Fiscal Incentives for R&D? A Review of the Evidence. *Research Policy, 29(4-5)* April, 449-469.

Hall, L. A., & Bagchi-Sen, S. (2002). A Study of R&D, Innovation, and Business Performance in the Canadian Biotechnology Industry. *Technovation, 22(4)* April, 231-244.

Hansen, J. (1992). Innovation, Firm Size, and Firm Age. *Small Business Economics, 4(1)*, 37-44.

Harrod, R. F. (1939). An Essay in Dynamic Theory. *Economic Journal, 49* March, 14-33.

Hay, D. A., & Morris, D. J. (1991). *Industrial Economics and Organization*: Oxford University Press.

Hazeldine, T. (1998). *Taking New Zealand Seriously: The Economics of Decency*: Harper Collins.

Helliwell, J. F. (1999, 30 June-2 July). *The Scope for National Policies in a Global Economy.* Paper presented at the NZ Association of Economists 40th Annual Conference, Rotorua.

Henderson, J. V. (1986). The Efficiency of Resource Usage and City Size. *Journal of Urban Economics, 19*, 47-70.

Henderson, R., Orsenigo, L., & Pisano, G. P. (1999). The Pharmaceutical Industry and the Revolution in Molecular Biology: Interactions Among Scientific Institutional, and Organisational Change. In D. Mowery & R. R. Nelson (Eds.), *The Sources of Industrial Leadership* (pp. 267-311): Cambridge University Press.

Hicks, J. (1973). *Capital and Time: A Neo-Austrian Theory*. Oxford: Clarendon Press.

Hinloopen, J. (2003). Innovation Performance Across Europe. *Economics of Innovation & New Technology, 12(2)* April, 17.

Hodgson, G. (1994). Neoclassical Microeconomic Theory, Critique of. In G. M. Hodgson & W. J. Samuels & M. R. Tool (Eds.), *The Elgar Companion to Institutional and Evolutionary Economics*: Edward Elgar.

Hodgson, G. M. (1988). *Economics and Institutions*. Cambridge: Polity Press.

Hodgson, G. M. (1994). Evolution and Optimality. In G. M. Hodgson & W. J. Samuels & M. R. Tool (Eds.), *The Elgar Companion to Institutional and Evolutionary Economics*: Edward Elgar.

Hodgson, P., Howe, J., Saunders, R., & Winsley, P. (1998). *Technological Learning and Knowledge Application Review*. Wellington: Foundation For Research Science and Technology,.

Hoffman, K., Parejo, M., Bessant, J., & Perren, L. (1998). Small Firms, R&D, Technology and Innovation in the UK: A Literature Review. *Technovation, 18(1)*, 39-55.

Hopper, K., & Thorburn, L. (2003). *2002 BioIndustry Review: Australia and New Zealand*: Advance Consulting & Evaluation.

Hotz-Hart, B. (1996). *Das Nationale Innovations System der Schweiz: Struktur und Dynamik im Lichte der Weltwirtschaftlichen Herausforderunge*. Socioeconomic Institute - University of Zurich, Switzerland.

Hou, C.-M., & Gee, S. (1993). National Systems Supporting Technical Advance in Industry: The Case of Taiwan. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 384-413). New York: Oxford University Press.

Howells, J. (1999). Regional Systems of Innovation? In D. Archibugi & J. Howells & J. Michie (Eds.), *Innovation Policy in a Global Economy*. Cambridge: Cambridge University Press.

Hunt, D. M., Clarke, R. T. J., Bell, D. J., Earle, R. L., Joblin, K. N., & Scott, D. B. (1983). *Biotechnology in New Zealand*. New Zealand Department of Scientific and Industrial Research.

Hutschenreiter, G., Joerg, L., Ohler, F., & Polt, W. (1996). *Tracing Knowledge Flows Within the Austrian System of Innovation* (Study Prepared for the OECD Project on National Innovation Systems).

Institute for Scientific Information. (2000). *National Science Indicators on Diskette, 1981-98*: Institute for Scientific Information.

Jacobsen, V. (1991). *Contestable Funding: A New Deal for Research and Development in New Zealand*. The Centre for Independent Studies. (CIS Policy Monographs 19)

Janszen, F. H. A., & Deganaars, G. H. (1998). A Dynamic Analysis of the Relations Between the Structure and the Process of National Systems of Innovation Using Computer Simulation: The Case of the Dutch Biotechnological Sector. *Research Policy, 27(1)* May, 37-54.

Jewkes, J., Sawers, D., & Stillerman, R. (1958). *The Sources of Invention*. London: Macmillan.

Johnson, B. (1992). Institutional Learning. In B. Lundvall (Ed.), *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning* (pp. 23-44). London: Pinter Publishers.

Johnson, D. K. N., & Mareva, M. (2002). *It's a Small(er) World: The Role of Geography and Networks in Biotechnology Innovation*(Wellesley College Department of Economics Working Paper No. 2002-01)

Joly, P.-B., & de Looze, M.-A. (1996). An Analysis of Innovation Strategies and Industrial Differentiation Through Patent Applications: The Case of Plant Biotechnology. *Research Policy, 25(7)* October, 1027-1045.

Jones, C. I., & Williams, J. C. (1998). Measuring the Social Return to R&D. *Quarterly Journal of Economics, 113(4)*, 1119-1135.

Jones, C. I., & Williams, J. C. (2000). Too Much of a Good Thing? The Economics of Investment in R&D. *Journal of Economic Growth, 5(1)* March, 65-85.

Karaömerlioglu, D. C. (1998). Technology as a System: Industrial and Technological Systems. *International Journal of Technology Management, 15(6/7),* 681-690.

Katz, B. G., & Phillips, A. (1982). Government, Technological Opportunities and the Emergence of the Computer Industry. In Giersch (Ed.), *Emerging Technologies* (pp. 419-466): Tübingen.

Katz, J. M., & Bercovich, N. A. (1993). National Systems of Innovation Supporting Technical Advance in Industry: The Case of Argentina. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 451-475). New York: Oxford University Press.

Keck, O. (1993). The National System for Technical Innovation in Germany. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 115-157). New York: Oxford University Press.

Keller, W. (2001). *International Technology Diffusion*. National Bureau of Economic Research. (NBER Working Paper No. W8573)

Kennedy, M. J. (1991). The Evolution of the Word Biotechnology. *Trends in Biotechnology, 9(7)* July, 218-220.

Kennedy, M. J., & Davies, R. J. (1994). *The Impact of Biotechnology on New Zealand Industry 1984-1994*: SIR Publishing.

Khan, H. A. (1998). *Technology, Development and Democracy Limits of National Innovation Systems in the Age of Postmodernism*.

Kim, L. (1993). National System of Industrial Innovation: Dynamics of Capability Building in Korea. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 357-383). New York: Oxford University Press.

Kingsley, G., Bozeman, B., & Coker, K. (1996). Technology Transfer and Absorption - An R&D Value Mapping Approach to Evaluation. *Research Policy, 25(6)* September.

Krugman, P. (1994). *The Fall and Rise of Development Economics*. MIT, Cambridge, MA.

Krugman, P. (1995). *Development, Geography and Economic Theory*. Cambridge, MA: MIT Press.

Krugman, P. (1996). *What Economists can Learn from Evolutionary Theorists (A talk given to the European Association for Evolutionary Political Economy)*. MIT, Cambridge, MA.

Lambert, D. (1992). Zero-inflated Poisson Regression with an Application to Defects in Manufacturing. *Technometrics, 34*, 1-14.

Laursen, K., & Christensen, J. L. (1996). *The Creation, Distribution and Use of Knowledge: A Pilot Study of the Danish Innovation System* (Study Prepared for the OECD Project on National Innovation Systems): OECD.

Levin, R. C., Klevorick, A. K., Nelson, R. R., & Winter, S. G. (1987). Appropriating the Returns from Industrial Research and Development. *Brookings Papers on Economic Activity* 3, 783-820.

Lipsey, R., & Carlaw, K. (2002). *What Does Total Factor Productivity Measure?*

List, F. (1841/1904). *The National System of Political Economy*. London: Longman.

Long, J. S., & Freese, J. (2001). *Regression Models for Categorical Dependent Variables Using Stata*: Stata Press.

Lucas, R. E. (1988). On the Mechanics of Economic Development. *Journal of Monetary Economics, 22(1)* July, 3-42.

Lucas, R. E. (1993). Making a Miracle. *Econometrica, 61(2)* March, 251-272.

Lundvall, B.-Å. (1985). *Product Innovation and User-Producer Interaction*. Aalborg University Press, Aalborg.

Lundvall, B.-Å. (1992a). Introduction. In B.-Å. Lundvall (Ed.), *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. London: Pinter Publishers.

Lundvall, B.-Å. (Ed.). (1992b). *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. London: Pinter Publishers.

Lundvall, B.-Å., & Christensen, J. L. (1999, June 9-12). *Extending and Deepening the Analysis of Innovation Systems - with Empirical Illustrations from the DISKO Project.* Paper presented at the DRUID's Summer Conference on National Innovation Systems, Industrial Dynamics and Innovation Policy, Rebild, Denmark.

Mairesse, J., & Mohnen, P. (2001). *To Be or Not To Be Innovative: An Exercise in Measurement*. National Bureau of Economic Research. (NBER Working Paper No. W8644)

Mairesse, J., & Mohnen, P. (2002). Accounting for Innovation and Measuring Innovativeness: An Illustrative Framework and an Application. *American Economic Review, 92(2)* May, 226-230.

Malerba, F. (1992). Learning by Firms and Incremental Technical Change. *Economic Journal, 102* July, 845-859.

Malerba, F. (1993). The National System of Innovation: Italy. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 230-259). New York: Oxford University Press.

Malerba, F. (1999, June 9-12). *Sectoral Systems of Innovation and Production.* Paper presented at the DRUID's Summer Conference on National Innovation Systems, Industrial Dynamics and Innovation Policy, Rebild, Denmark.

Malerba, F., Breschi, S., & Lissoni, F. (1998). *Patterns of Technological Entry and Exit: Evidence from France, Germany, Italy and the UK*. Linköping: Innovation Systems and European Integration (ISE) Research Project, Systems of Innovation Research Programme, University of Linköping.

Malerba, F., & Montobbio, F. (2000, June 15-17). *Sectoral Systems and International Technological and Trade Specialisation.* Paper presented at the DRUID Conference on The Learning Economy - Firms, Regions and Nation Specific Institutions, Rebild/Denmark.

Malerba, F., & Orsenigo, L. (1995). Schumpeterian Patterns of Innovation. *Cambridge Journal of Economics, 19(1)* February, 47-65.

Malo, S., & Geuna, A. (1999). *Science-Technology Linkages in an Emerging Research Platform: The Case of Combinatorial Chemistry and Biology*. SPRU. (SPRU Electronic Working Paper No. 37)

Malthus, T. R. (1820). *Principles of Political Economy*.

Mansfield, E. (1980). Basic Research and Productivity Increase in Manufacturing. *American Economic Review, 70*, 863-873.

Mansfield, E., & et al. (1997). Social and Private Rates of Return from Industrial Innovations. *Quarterly Journal of Economics, 91*, 221-240.

Marsh, D. (1980). *Economic, Social and Technical Aspects of Improved Animal Draught Technology*. Unpublished MSc, University of Reading, Reading.

Marsh, D. (1999). *National Innovation Systems: What Can We Learn from the Literature?* Department of Economics, University of Waikato.

Marsh, D. (2000, 28 June-1 July). *Fostering Innovation in a Small Open Economy: The Case of the New Zealand Biotechnology Sector.* Paper presented at the Eighth International Schumpeter Society Conference. Change Development and Transformation; Transdisciplinary Perspectives on the Innovation Process, Manchester, UK.

Marsh, D. (2001a, 7-9 February). *Does New Zealand Have an Innovation System for Biotechnology?* Paper presented at the R&D Management Conference 2001: Levering Research and Technology, Wellington, NZ.

Marsh, D. (2001b). *Modern Biotechnology in New Zealand: Further Analysis of Data from the Biotechnology Survey 1998/99*. Hamilton: Department of Economics. http://ideas.repec.org/s/wai/econwp.html.

Marsh, D. (2001c). *Modern Biotechnology in New Zealand: Methodological Issues and Analysis of Free Text Responses from the Biotechnology Survey 1998/99*. Hamilton.

Marsh, D. (2002). *Innovation in Biotechnology. A Nationwide Study.* Hamilton: Department of Economics.

Marsh, D. (2003). Does New Zealand Have an Innovation System for Biotechnology? *Technovation, 23(2)* February, 103-112.

Marsh, D., & Oxley, L. (2002, June 6-8). *What Drives Innovation in the New Economy? The Case of the New Zealand Biotechnology Sector.* Paper presented at the DRUID Summer Conference "Industrial Dynamics of the New and Old Economy - Who is Embracing Whom?" Copenhagen/Elsinore, Denmark.

Marshall, A. (1920). *Principles of Economics* (Eighth ed.). London: Macmillan.

Marshall, A. (1932/1890). *Elements of Economics* (3rd Edition ed. Vol. Volume 1: Elements of Economics of Industry). London: Macmillan.

Marshall, K. R. (2001). *Does New Zealand Science Underpin Bio-Business.* Paper presented at the B2B2B: Bio-Science to Bio-Enterprise to Bio-Business, University of Waikato, Hamilton.

Martin, B. R., & Johnston, R. (1999). Technology Foresight for Wiring up the National Innovation System: Experiences in Britain, Australia and New Zealand. *Technological Forecasting and Social Change, 60(1)* January.

Martin, B. R., & Salter, A. (1996). *The Relationship Between Publicly Funded Basic Research and Economic Performance - A SPRU Review*. Brighton: Science Policy Research Unit (SPRU), University of Sussex, for HM Treasury.

Mason, E. S. (Ed.). (1959). *The Corporation in Modern Society*. Cambridge: Harvard University Press.

Massey, P. (1995). *New Zealand: Market Liberalization in a Developed Economy*. London: Macmillan.

Mazoyer, P. (1999). *A Study of the Innovation System for Biotechnology in New Zealand* (Report No. 1072). Wellington: Ministry of Research, Science and Technology.

McCallum, J. C. P. (1995). National Borders Matter: Canada-US Regional Trade Patterns. *American Economic Review, 85* June, 615-623.

McFetridge, D. G. (1993). The Canadian System of Industrial Innovation. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 299-323). New York: Oxford University Press.

McKelvey, M. (1996). *Evolutionary Innovations: The Business of Biotechnology*. Oxford: Oxford University Press.

McKelvey, M. (2001). Economics of Biotechnology. In W. Lazonick (Ed.), *IEBM Handbook of Economics*. London: International Thomson Business Press.

McKenzie, L. W. (1998). Turnpikes. *American Economic Review, 88(2)* May, 1-14.

McMillan, G. S., Narin, F., & Deeds, D. L. (2000). An Analysis of the Critical Role of Public Science in Innovation: the Case of Biotechnology. *Research Policy, 29(1)* January, 1-8.

McNiven, C. (2001a). *Biotechnology Use and Development 1999*. Statistics Canada. (88F006XIE No. 7)

McNiven, C. (2001b). *Practices and Activities of Canadian Biotechnology Firms: Results from the Biotechnology Use and Development Survey 1999*. Statistics Canada. (88F006XIE No. 11)

Metcalfe, J. S. (1995a). The Economic Foundations of Technology Policy: Equilibrium and Evolutionary Perspectives. In P. Stoneman (Ed.), *Handbook of the Economics of Innovation and Technological Change* (pp. 409-512): Blackwell.

Metcalfe, J. S. (1995b). Technology Systems and Technology Policy in an Evolutionary Framework. *Cambridge Journal of Economics, 19(1)* February, 25-46.

Metcalfe, J. S. (1998). *Innovation Systems and Endogenous Growth Theory*. CRIC, University of Manchester.

Metcalfe, J. S. (2000, 28 June-1 July). *Presidential Address.* Paper presented at the Eighth International Schumpeter Society Conference. Change Development and Transformation; Transdisciplinary Perspectives on the Innovation Process, Manchester, UK.

Mills, R. A., & Langdon, A. (1997). *Management of Technology in New Zealand: A Cultural Development.* Paper presented at the Conference IAMOT97, Gotenberg, Sweden 25-28 June.

Ministry of Research Science and Technology. (2002). *New Zealand Research and Development Statistics 1999/2000*. Wellington: Ministry of Research Science and Technology.

Ministry of Research Science and Technology. (2003a). *New Zealand Biotechnology Strategy: A Foundation for Development with Care*. Wellington: Ministry of Research Science and Technology.

Ministry of Research Science and Technology. (2003b). *Research and Development in New Zealand 2002*. Wellington: Ministry of Research Science and Technology and Statistics New Zealand.

Mohnen, P., & Dagenais, M. (2002). Towards an Innovation Intensity Index: The Case of CIS 1 in Denmark and Ireland. In A. Kleinknecht & P. Mohnen (Eds.), *Innovation and Firm Performance. Econometric Explorations of Survey Data*. London: Palgrave.

Momma, S., & Sharp, M. (1999). Developments in New Biotechnology Firms in Germany. *Technovation, 19(5)* February, 267-282.

Mowery, D., & Oxley, J. (1995). Inward Technology Transfer and Competitiveness: The Role of National Innovation Systems. *Cambridge Journal of Economics, 19(1)* February, 67-93.

Mowery, D., & Ziedonis, A. (1998). Market Failure or Market Magic? Structural Change in the US National Innovation System. *STI Review, 22*.

Mowery, D. C. (1998). The Changing Structure of the US National Innovation System: Implications for International Conflict and Cooperation in R&D Policy. *Research Policy, 27(6)* Sept, 639-654.

Mowery, D. C., & Rosenberg, N. (1979). The Influence of Market Demand Upon Innovation: A Critical Review of Some Recent Empirical Studies. *Research Policy, 8(2)* April, 102-153.

Mowery, D. C., & Rosenberg, N. (1993). The US National Innovation System. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 29-75). New York: Oxford University Press.

Muzart, G. (1998). *Description of National Innovation Surveys Carried Out or Foreseen in 1997-99 in OECD and Non-CIS-2 Participants and NESTI Observer Countries* (STI Working Papers 1999/1, DSTI/DOC(99)1): OECD.

Myers, S., & Marquis, D. (1969). *Successful Industrial Innovation*. Washington, DC: National Science Foundation.

Mytelka, L. K. (1999). New Trends in Biotechnology Networking. *International Journal of Biotechnology, 1(1),* 30-41.

Nelson, R. (1981). Research on Productivity Growth and Productivity Differences: Dead Ends and New Departures. *Journal of Economic Literature, 19.*

Nelson, R. (1988). Institutions Supporting Technical Change in the US. In G. Dosi & C. Freeman & R. Nelson & G. Silverberg & L. Soete (Eds.), *Technical Change and Economic Theory*. London and New York: Frances Pinter and Columbia University Press.

Nelson, R. (1994). Routines. In G. M. Hodgson & W. J. Samuels & M. R. Tool (Eds.), *The Elgar Companion to Institutional and Evolutionary Economics*: Edward Elgar.

Nelson, R. R. (1959). The Simple Economics of Basic Research. *Journal of Political Economy, 67*, 297-306.

Nelson, R. R. (1987). *Understanding Technical Change as an Evolutionary Process*. Amsterdam: North-Holland.

Nelson, R. R. (1992). National Innovation Systems: A Retrospective on a Study. *Industrial and Corporate Change, 1(2),* 347-374.

Nelson, R. R. (1993a). A Retrospective. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 505-523). New York: Oxford University Press.

Nelson, R. R. (1995). Recent Evolutionary Theorizing about Economic Change. *Journal of Economic Literature, 33 (1)* March, 48-90.

Nelson, R. R. (1997). How New is New Growth Theory? *Challenge, 40(5)* Sept/Oct.

Nelson, R. R. (Ed.). (1993b). *National Innovation Systems: A Comparative Analysis*. New York: Oxford University Press.

Nelson, R. R., & Rosenberg, N. (1993). Technical Innovation and National Systems. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 1-21). New York: Oxford University Press.

Nelson, R. R., & Winter, S. G. (1982). *An Evolutionary Theory of Economic Change*. Cambridge Massachusetts: Belknap Press.

Nelson, R. R., & Wolff, E. N. (1997). Factors Behind Cross-Industry Differences in Technical Progress. *Structural Change and Economic Dynamics, 8(2)* June, 205-220.

New Zealand Trade Development Board. (2000). *Back to the Future, New Zealand's Biotechnology Industry*. Auckland: New Zealand Trade Development Board.

Nightingale, P. (2000, 28 June - 1 July). *Rethinking Pharmaceutical Innovation: Risk, Institutional Legacies and the Integration of Specialised Knowledge.* Paper presented at the Eighth International Schumpeter Society Conference. Change Development and Transformation; Transdisciplinary Perspectives on the Innovation Process, Manchester, UK.

Niosi, J., Saviotti, P., Bellon, B., & Crow, M. (1993). National Innovation Systems: In Search of Workable Concept. *Technology in Society, 15*.

Odagiri, H., & Goto, A. (1993). The Japanese System of Innovation: Past, Present, and Future. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 76-114). New York: Oxford University Press.

OECD. (1994). *The Measurement of Scientific and Technological Activities. Using Patent Data as Science and Technology Indicators: Patent Manual 1994*. Paris: OECD.

OECD. (1997a). *National Innovation Systems*. Paris: OECD.

OECD. (1997b). *Oslo Manual: Proposed Guidelines for Collecting and Interpreting Technological Innovation Data* (Revised Edition). Paris: OECD.

OECD. (1999). *OECD Science, Technology and Industry Scoreboard 1999 Benchmarking Knowledge-Based Economies*. Paris: OECD.

OECD. (2001). *OECD Science, Technology and Industry Scoreboard 2001 Towards a Knowledge-Based Economy*. Paris: OECD.

OECD. (2002a). *Dynamising National Innovation Systems*.

OECD. (2002b). *The Measurement of Scientific and Technological Activities. Frascati Manual 2002: Proposed Standard Practice for Surveys on Research and Experimental Development*. Paris: OECD.

OECD. (2003a). *OECD Science, Technology and Industry Scoreboard 2003: Towards a Knowledge-Based Economy*. Paris: OECD.

OECD. (2003b). *Report on the Fourth Ad Hoc Meeting on Biotechnology Statistics Held on 12-13 May 2003*. Paris.

OECD. (2003c). *A Statistical Framework for Biotechnology Statistics*. Paris.

Office of the Prime Minister. (2002). *Growing an Innovative New Zealand*. Wellington: Government of New Zealand.

Ogilvie, B. (2003). Personal Communication.

Ohmae, K. (1990). *The Borderless World*. New York: Harper.

Orsenigo, L. (1989). *The Emergence of Biotechnology*. New York: St Martin's Press.

Orsenigo, L., Pammolli, F., & Riccaboni, M. (2001). Technological Change and Network Dynamics Lessons from the Pharmaceutical Industry. *Research Policy, 30(3)* March, 485-508.

Packer, J. E., Robertson, J., & Wansbrough, H. (Eds.). (1998). *Chemical Processes in New Zealand*. Auckland: New Zealand Institute of Chemistry.

Padmore, T., & Gibson, H. (1998). Modelling Systems of Innovation II: A Framework for Industrial Cluster Analysis in Regions. *Research Policy, 26(6)* February, 605-624.

Parish, M. (1998). *Identifiable Success Factors Within the National Systems of Innovation of Sweden, Finland and Denmark.* Unpublished MMS (Technology), Victoria University, Wellington.

Patel, P., & Pavitt, K. (1994). National Innovation Systems: Why they are Important, and How they might be Measured and Compared. *Economics of Innovation and New Technology, 3*, 77-95.

Pattinson, W., Van Beuzekom, B., & Wyckoff, A. (2001). *Internationally Comparable Indicators on Biotechnology: A Stocktaking, A Proposal for Work and Supporting Material*. Statistics Canada. (88F0017MIE No. 9)

Pavitt, K. (1984). Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory. *Research Policy, 13(6)*, 343-373.

Pearsall, J. (Ed.). (1999). *The Concise Oxford Dictionary*. Oxford: Oxford University Press.

Petersen, G. (1998). Science in New Zealand Beyond 2000. Have we Lost the Plot? *NZ Science Review, 55(3)*, 4-10.

Pew Initiative on Food and Biotechnology. (2001). *Harvest on the Horizon: Future Uses of Agricultural Biotechnology*.

Pockley, P. (1998). New Zealand puts its Science to Profit. *Nature, 391* January 29, 426-427.

Popper, S. W., & Wagner, C. S. (2001). *New Foundations for Growth: The U.S. Innovation System Today and Tomorrow* (MR-1338.0/1-OSTP): RAND's Science and Technology Policy Institute.

Porter, M. (1990). *The Competitive Advantage of Nations*. London: Macmillan.

Porter, M. E. (1998). Clusters and the New Economics of Competition. *Harvard Business Review* Nov-Dec, 77-90.

Porter, M. E., & Stern, S. (2000). *Measuring the "Ideas" Production Function: Evidence from International Patent Output*. National Bureau of Economic Research. (NBER Working Paper No. W7891)

Prevezer, M., & Toker, S. (1996). The Degree of Integration in Strategic Alliances in Biotechnology. *Technology Analysis & Strategic Management, 8(2)*, 117-133.

Radosevic, S. (1998). Defining Systems of Innovation: A Methodological Discussion. *Technology in Society, 384* 20(1), 75-86.

Ramanathan, R. (2002). *Introductory Econometrics with Applications* (Fifth ed.): Harcourt College Publishers.

Ricardo, D. (1821/1951). On the Principles of Political Economy and Taxation. In P. Sraffa (Ed.), *The Works and Correspondence of David Riccardo* (Vol. 1). Cambridge: Cambridge University Press.

Rickne, A. (2002). Regional Characteristics and Performance: Evidence from Biomaterials Firms. In B. Carlsson (Ed.), *Technological Systems in the Bio Industries: An International Study*: Kluwer.

Rolleston, W. (1999). *Leveraging the Biology Revolution.* Paper presented at the Conference: Opportunities for Collaboration between Business, CRIs and Tertiary Institutions, Auckland.

Romer, D. (1996). *Advanced Macroeconomics*: McGraw-Hill.

Romer, P. (1986). Increasing Returns and Long-Run Growth. *Journal of Political Economy, 94(5)* October, 1002-1037.

Romer, P. (1990). Endogenous Technological Change. *Journal of Political Economy, 98(5)* Part 2, S71-S102.

Romer, P. M. (1987). Growth Based on Increasing Returns Due to Specialization. *American Economic Review, 77(2)* May, 56-62.
Romer, P. M. (1993). Idea Gaps and Object Gaps in Economic Development. *Journal of Monetary Economics, 32(3)*, 543-573.
Rosenberg, N. (1974). Science, Invention and Economic Growth. *Economic Journal, 84* March, 90-108.
Rosenberg, N. (1976). *Perspectives in Technology*: Cambridge University Press.
Rothwell, R. (1992). Successful Industrial Innovation: Critical Factors for the 1990s. *R&D Management, 22(3)*, 221-239.
Rothwell, R., Freeman, C., Horlsey, A., Jervis, V., Robertson, A., & Townsend, J. (1974). SAPPHO updated - project SAPPHO phase II. *Research Policy, 3(3)* November, 258-291.
Rothwell, R., & Zegveld, W. (1985). *Reindustrialization and Technology*. Harlow, UK: Longman.
Royal Commission on Genetic Modification. (2001). *Report of the Royal Commission on Genetic Modification*. Wellington.
Royal Society of New Zealand. (2000). Royal Commission on Genetic Modification. *Royal Society Alert, 122* 18 April, 1-14.
Royal Society of New Zealand. (2002). Centres of Research Excellence Announced. *Royal Society Alert, 214* 7 March.
Sandström, A., Backlund, A., Helena, H., Markusson, N., Norgren, L., & Westerlund, L. (2001). *The Swedish Biotechnology Innovation System* (VINNOVA Innovation i fokus VF 2001:2). Stockholm: The Swedish Agency for Innovation Systems.
Saunders, C., & Cagatay, S. (2003). Commercial Release of First-Generation Genetically Modified Food Products in New Zealand: Using a partial Equilibrium Trade Model to Assess the Impact on Prducer Returns in New Zealand. *Australian Journal of Agricultural and Resource Economics, 47(2)*, 233-259.
Saviotti, P. P. (1998). Industrial Structure and the Dynamics of Knowledge Generation in Biotechnology. In J. Senker (Ed.), *Biotechnology and Competitive Advantage : Europe's Firms and the US Challenge* (pp. 19-43). Cheltenham, UK: Edward Elgar.
Scherer, F. M. (1980). *Industrial Market Structure and Economic Performance*: Houghton Mifflin.
Scherer, F. M. (1982a). Demand-Pull and Technological Invention: Schmookler Revisited. *Journal of Industrial Economics, 30(3)* March, 225.
Scherer, F. M. (1982b). Inter-Industry Technology Flows in the United States. *Research Policy, 11* August, 227-245.
Scherer, F. M. (1999). *New Perspectives on Economic Growth and Technological Innovation*. Washington, D.C: Brookings Institution.
Schibany, A. (1998). *Cooperative Behaviour of Innovative Firms in Austria*: OECD.
Schmookler, J. (1966). *Invention and Economic Growth*. Cambridge, Mass: Harvard University Press.
Schmutzler, A. (1999). The New Economic Geography. *Journal of Economic Surveys, 13(4)*, 355-379.
Schumpeter, J. (1912/1934). *The Theory of Economic Development* (Originally published in German in 1912, Eng. tr. 1934 ed.). Cambridge, Massachusetts: Harvard University Press.

Schumpeter, J. (1939). *Business Cycles: A Theoretical, Historical and Statistical Analysis of the Capitalist Process*. New York: McGraw Hill.
Schumpeter, J. (1942). *Capitalism, Socialism and Democracy*. New York: McGraw-Hill.
Scobie, G., Mullen, J., & Alston, J. M. (1991). The Returns to Investment in Research on Australian Wool Production. *Australian Journal of Agricultural Economics, 35(2)* August, 179-195.
Simon, S. (n.d.). *Poisson Regression Model*. Children's Mercy Hospital. Available: http://www.childrens-mercy.org/stats/model/poisson.asp [2003, 14 January].
Simpson, B., & Craig, J. (1997). A Policy for Science Innovation: The New Zealand Experience. *Science and Public Policy, 24(2)* April, 70-78.
Smith, A. (1776/1976). *An Inquiry into the Nature and Causes of the Wealth of Nations*. Oxford: Clarendon Press.
Smith, K. (1991). *Economic Returns to R&D: Methods, Results and Challenges*(Science Policy Support Group Review Paper No.3, London.)
Soete, L. (1994, August 14-21). *European Comparative Innovation Systems.* Paper presented at the Transnational Institute on Innovation Conference, Competition and Sustainability, Simon Fraser University Vancouver.
Solow, R. A. (1957). Technical Change and the Aggregate Production Function. *Review of Economics and Statistics, 39* August, 312-320.
Sommer, J. (2001, 7-9 February). *Voices from the Grassroots of Science: Tales of Hope and Woe.* Paper presented at the R&D Management Conference 2001: Levering Research and Technology, Wellington, NZ.
Sornn-Friese, H. (2000). Frontiers of Research in Industrial Dynamics and National Systems of Innovation
Industry and Innovation. *Industry and Innovation, 7(1)* June, 1.
Springall, L. (2000). Where are the Great Ideas? Say Venture Capitalists. *The Independent Business Weekly, 5 July*.
Stata Corporation. (2003). Stata Statistical Software.
Statistics New Zealand. (2000a). *Biotechnology Survey 1998/99.* Wellington: Statistics New Zealand.
Statistics New Zealand. (2000b). *Draft Objectives for the Biotechnology Survey*. Statistics New Zealand.
Statistics New Zealand. (2001). *Modern Biotechnology Activity in New Zealand*. Wellington. http://www.stats.govt.nz.
Statistics New Zealand. (2002). *Innovation in New Zealand 2001*. Wellington. http://www.stats.govt.nz.
Stern, S., Porter, M. E., & Furman, J. L. (2000). *The Determinants of National Innovative Capacity*. National Bureau of Economic Research. (Working Paper W7876)
Stoneman, P. (1983). *The Economic Analysis of Technological Change*. Oxford: Oxford University Press.
Stoneman, P. (1987). *The Economic Analysis of Technology Policy*. Oxford: Oxford University Press.
Stoneman, P. (Ed.). (1995). *Handbook of the Economics of Innovation and Technological Change*: Blackwell.
Suranyi-Unger Jr., T. (1994). Technology. In D. Green (Ed.), *The McGraw-Hill Encyclopedia of Economics* (Second Edition ed., pp. 982-983): McGraw-Hill.

Takayama, A. (1974). *Mathematical Economics*. Hinsdale, Illinois: The Dryden Press.

Tether, B. S. (2001). *Identifying Innovation, Innovators and Innovative Behaviours: A Critical Assessment of the Community Innovation Survey*. CRIC, University of Manchester. (Discussion Paper No 48)

Teubal, M. (1993). The Innovation System of Israel: Description, Performance and Outstanding Issues. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 476-502). New York: Oxford University Press.

Tradenz. (1994). The Foreign Exchange Earning Potential of the Pharmaceutical and Biotechnology Industry in New Zealand. *New Zealand Biotechnology Association Newsletter, 25* December, 44-55.

U.S. Congress. (1991). *Biotechnology in a Global Economy* (OTA-BA-494). Washington, DC: Office of Technology Assessment,.

Upton, S. (1995). Contracting in the Science Sector: An Overview. *Public Sector, 18(4)* December, 2-5.

van Beuzekom, B. (2001). *Biotechnology Statistics in OECD Member Countries: Compendium of Existing Statistics*. OECD, Paris. (STI Working Papers 2001/6)

van Geenhuizen, M. (1999). How Small Biotechnology Firms Survive in the Dutch Pharmaceutical Industry: An Exploratory Analysis. In R. Oakey & W. During & S.-M. Mukhtar (Eds.), *New Technology-based Firms in the 1990s* (Vol. VI). Amsterdam: Pergamon.

Vekstein, D. (1999). Defense Conversion, Technology Policy and R&D Networks in the Innovation System of Israel. *Technovation, 19(10)* September, 615-629.

Vithlani, H. (1997). *An Empirical Study of the UK Innovation System* (Study Prepared for the OECD Project on National Innovation Systems): Department of Trade and Industry.

Walker, W. (1993). National Innovation Systems: Britain. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 158-191). New York: Oxford University Press.

Wells, A. (1997). *Institutional Mapping of Australia's System of Innovation: First Step* (Study Prepared for the OECD Project on National Innovation Systems).

Wiig, H., & Wood, M. (1995). *What Comprises a Regional Innovation System? An Empirical Study* (1/95). Oslo: STEP Group.

Wijnberg. (1994). National Systems of Innovation: Selection Environments and Selection Processes. *Technology in Society, 16(3)*, 313-320.

Williams, J., Campbell, H., Gandar, P., Cassels, G., & Reynolds, P. (2001, 7-9 February). *Enhancing the Role of Private Sector Research and Development in the New Zealand Innovation System.* Paper presented at the R&D Management Conference 2001: Levering Research and Technology, Wellington, NZ.

Winsley, P., Couchman, P., & Gilbertson, D. (1998). Future Developments for New Zealand's Science and Technology System. *Prometheus, 16(1)*, 57-68.

Winsley, P., & Hammond, L. (1997). Policies for Transforming the Science and Technology System in New Zealand 1988-1997. *Prometheus, 15(2)*, 267-278.

Wong, P.-K. (1999, June 9-12). *National Innovation Systems for Rapid Technological Catch-Up: An Analytical Framework and a Comparative Analysis of Korea, Taiwan and Singapore.* Paper presented at the DRUID's Summer Conference on National Innovation Systems, Industrial Dynamics and Innovation Policy, Rebild, Denmark.

Wright, J. C. (2000). *The Economics of Genetic Modification* (Background paper prepared for the Royal Commission on Genetic Modification).

Zucker, L. G., & Darby, M. R. (1996). Star Scientists and Institutional Transformation: Patterns of Invention and Innovation in the Formation of the Biotechnology Industry. *Proceedings of the National Academy of Sciences, 93(23)* November 12, 12709-12716.

Zucker, L. G., Darby, M. R., & Armstrong, J. (1994). *Inter-Institutional Spillover Effects in the Commercialization of Bioscience*. Institute for Social Science Research, University of California, Los Angeles. (ISSR Working Papers in the Social Sciences 1994-95, Vol. 6(3))

Zysman, J. (1996). Nations, Institutions and Technological Development. *International Journal of Technology Management, 12(5/6).*