Australian Government
Office of the Chief Scientist

Australian Academy of Science

THE IMPORTANCE OF ADVANCED BIOLOGICAL SCIENCES TO THE AUSTRALIAN ECONOMY

JANUARY 2016

Prepared for Office of the Chief Scientist and the
Australian Academy of Science by the
Centre for International Economics

Disclaimer

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FOREWORD

It is easy for us to take for granted the importance of recent advances in science. Indeed, because science is so important to every modern economy, we can easily adjust our expectations. Paradoxically, the importance of science becomes invisible.

In commissioning the work reported here, we had two specific goals.

First, we want to (again) highlight the importance of recent advances in science to economic production, and the opportunities and income this creates for all of us. In this report, we take a special focus on the biological sciences. It is estimated that if recent advances in the biological sciences had not occurred, and the knowledge generated from them had not been discovered, our economy would be 5% smaller today. This is our 'middle' or central estimate, falling in a range of 4.2% to 5.9%.

Second, and importantly, we want to highlight that advances in the biological sciences contribute to outcomes other than economic production on which Australians place great importance. For example, it is estimated that without recent advances in the biological sciences, and the new medical vaccines, diagnostics, treatments and practices that have been driven by those advances, the burden of disease in Australia would be 18% to 34% higher. Further, the report illustrates how recent advances in the biological sciences are contributing to improvements in the environment, and the extent to which those improvements are valued by Australians.

This work follows a report that examined the contribution of advances in the physical and mathematical sciences to the Australian economy (see AAS 2015). We have published a separate report titled *The importance of recent advances in science to the Australian economy* that synthesises the key messages and conclusions from the two studies.

In doing this work, the Centre for International Economics (the CIE) has taken a rigorous but conservative approach to estimating the impact of advances in the biological sciences.

ABOVE LEFT:
Australia's Chief Scientist,
Professor Ian Chubb AC

ABOVE RIGHT:
Professor Andrew Holmes AM PresAA FRS FTSE
President
Australian Academy of Science

ACKNOWLEDGEMENTS

The CIE thanks Professor Ian Chubb (Australia's Chief Scientist) and Dr Sue Meek (CEO of the AAS) for commissioning this research and for their support throughout the project. In addition, Roslyn Prinsley and Krisztian Baranyai (from the Office of the Chief Scientist) and Chris Hatherly, Poulomi Agrawal and Alistair Usher (from the AAS) helped keep the project on target in numerous practical ways. We are also grateful to Professor Hans Bachor FAA (Australian National University) for his unwavering support.

The analysis presented in this report would not have been possible without the contributions and enthusiasm of the Australian scientists, doctors and policy experts who participated in the AAS/CIE expert panel that was the foundation for this report. In addition, we would like to thank the other experts (academics, industry representatives and individuals) who engaged in discussions to test the views of the expert panel and provide other insights that helped us develop our work.

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ADVANCED BIOLOGICAL SCIENCES*—

underpinning Australian economic activity and worth $46 billion each year

Biological sciences help to support our national wealth.

We need to continue our national commitment to the advanced biological sciences if we are to recognise opportunities and capture the rewards. It is of substantial economic benefit.

There is a lot at stake.

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*Advanced means science undertaken and applied in the past 30 years.

3.6%

3.6% of Australian economic activity relies directly on advanced biological sciences.

464 000

4% of total Australian employment (about 464 000 jobs) is directly related to advanced biological sciences.

$12b

Exports associated with advanced biological sciences are worth around $12 billion a year. This is 5% of Australia's goods exports and equivalent to 4% of total Australian exports of goods and services.

$46b

The direct contribution of advanced biological sciences to the economy is around $46 billion per year.

18% to 34%

This is how much higher the burden of disease would be without advanced biological sciences.

5%

The total direct and flow-on impact of advanced biological sciences amounts to 5% of Australian economic activity or about **$65 billion per year.**

$83b to $156b

This is the value of health improvements from advanced biology.

SUMMARY

This report discusses the importance of advances in the biological sciences to the Australian economy, to Australians' health and to the environment. Over the past 30 years, those advances have led to new knowledge that, when applied, has:

- expanded our economy, as it has made us more productive
- improved our health, as it has led to better medical products and practices
- improved the environment, as it has helped to change our behaviour (directly and by informing better environmental management).

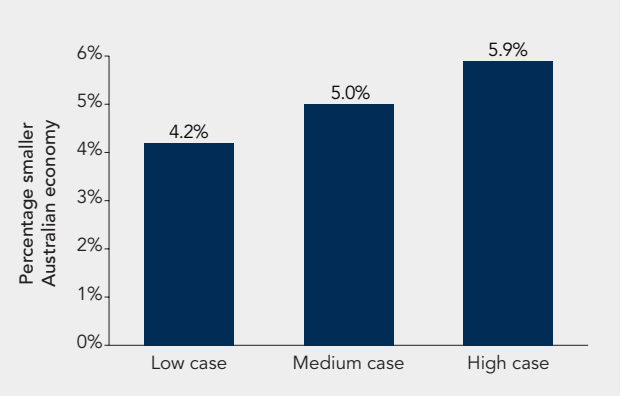
The CIE researched these impacts by hosting (with the AAS) an expert panel of 15 eminent Australian biologists, doctors and policy experts and by conducting extensive consultations with industry and other experts. Based on this research, we estimate that if advances in the biological sciences over the past 30 years had not occurred:

- our economy would be 4.2% to 5.9% smaller[1] (including the direct effect of lost productivity and the flow-on consequences of this)
- the burden of disease in Australia would be 18% to 34% higher.

These results are shown in Figures 1 and 2.

Furthermore, sound economic studies find that Australians place considerable value on potential improvements in the environment. For example, one study estimates that the value Australians would collectively place on a '1%' improvement in the Great Barrier Reef is from $434 million to $811 million. New knowledge discovered in advances in the biological sciences over the past 30 years justified the expansion and redesign of 'no-take zones' in the reef in 2004. This change in the management of the reef is improving its health and resilience.

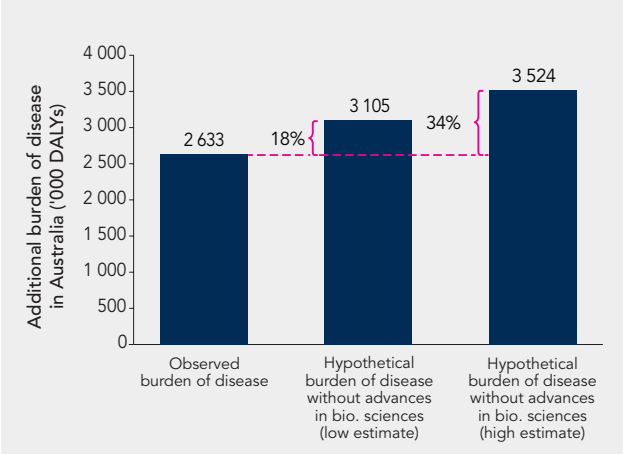
Figure 1 **How much smaller would the Australian economy be if advances in the biological sciences over the past 30 years had not occurred?**



Note: These estimates include the direct impact of lost productivity and the flow-on consequences of that productivity loss. The impact of advances in the biological sciences is calculated as a share of total output (economy-wide gross value added, or GVA). The measure of total output excludes the *Ownership of dwellings* industry, which makes up 9% of the total reported by the Australian Bureau of Statistics (ABS). We have excluded that industry because it is imputed by the ABS and does not employ any people.

Data source: The CIE.

Figure 2 **How much higher would the burden of disease in Australia be if advances in the biological sciences over the past 30 years had not occurred?**



DALYs = disability adjusted life years.

Data source: The CIE.

1 The range of this impact is 4.2% (the low case) to 5.9% (the high case). In the middle case, we estimate that the economy would be 5% smaller if advances in the biological sciences over the past 30 years had not occurred and the knowledge from those advances had been lost.

CHAPTER 1

1. INTRODUCTION

The Office of the Chief Scientist (OCS) and the Australian Academy of Science (AAS) commissioned the Centre for International Economics (the CIE) to investigate and measure the importance of recent advances in the biological sciences to the Australian economy. This work followed an earlier similar report that presented results on the importance of recent advances in the physical and mathematical sciences to the Australian economy (AAS 2015). A third report (AAS 2016) synthesises these two pieces of research and presents combined results on the importance of recent advances in the physical, mathematical and biological sciences to the Australian economy.

WHAT DO WE MEAN BY RECENT ADVANCES IN THE BIOLOGICAL SCIENCES?

Within the biological sciences, we measured the importance of recent advances in the 'core' disciplines: biochemistry, cell biology, genetics, microbiology, anatomy, physiology, plant biology, zoology and ecology. We defined 'recent advances' to be (broadly) advances in the past 30 years, which is the approximate time it takes for many discoveries in these disciplines to be developed and applied.[2] This is shown in Figure 1.1.

Our focus meant that we captured only the advanced scientific knowledge that goes beyond the traditional science taught in professional and vocational courses. It is the contemporary knowledge that allows companies to stay at the forefront of their industries and to create new business opportunities.

The nature of science is that research efforts are interlinked across the globe, so it is impossible to isolate and investigate just the 'Australian' component. Therefore, while Australians have contributed many globally significant advances to the biological sciences in the past 30 years, this report does not focus simply on the importance of advances made in Australia. It considers the importance to Australia's economy of advances made all over the world in that period.

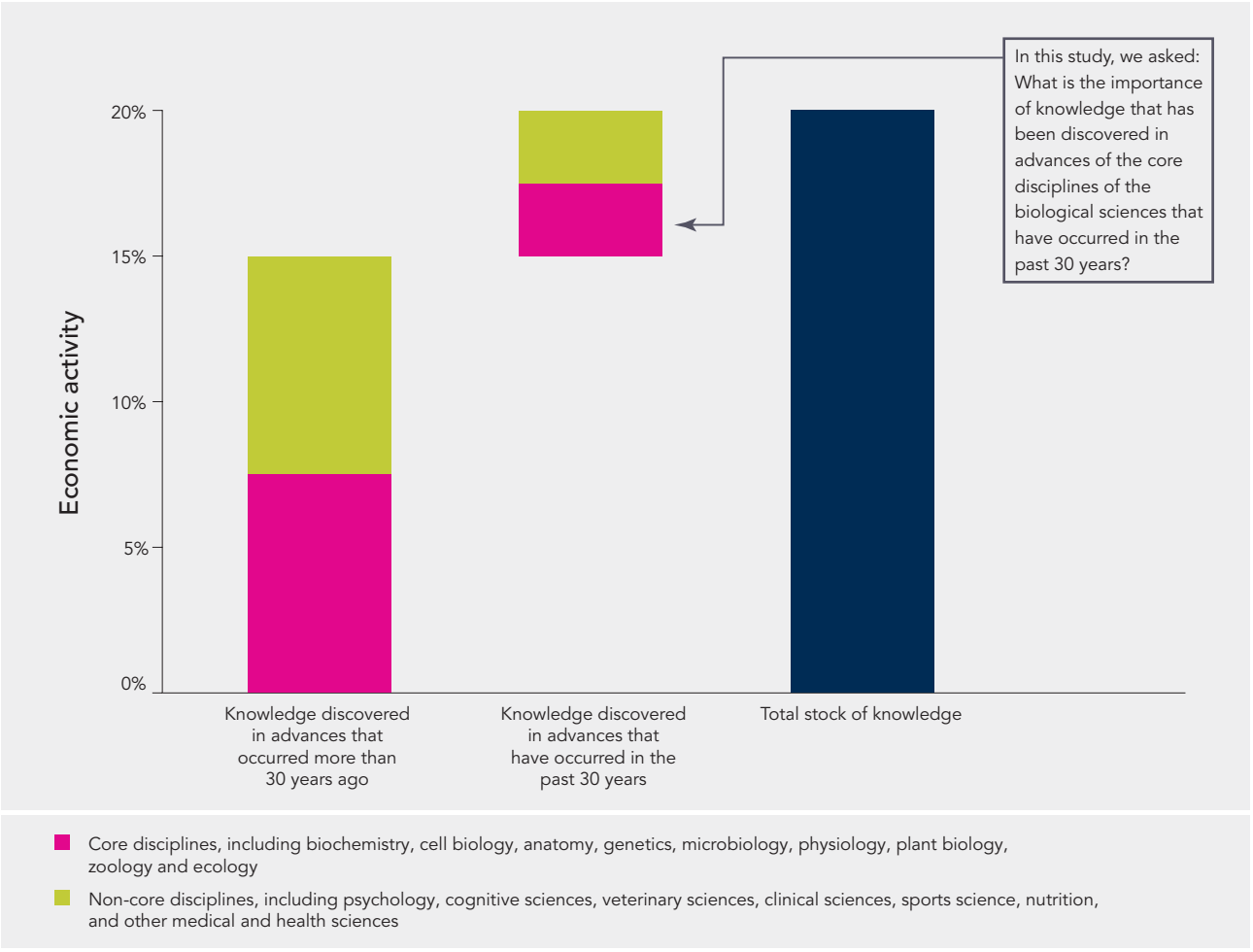
It is good that Australian science is integrated into global research efforts. This means that we benefit from discoveries made in other countries. In fact, an important aspect of Australian science is that it is one channel (among others) through which Australia benefits from discoveries made overseas.

WHY ARE RECENT ADVANCES IN THE BIOLOGICAL SCIENCES IMPORTANT?

Recent advances in the biological sciences are important because they are the source of new pieces of useful knowledge that, when applied in Australia, create valuable net benefits. For example, advances in the biological sciences are the basis for many discoveries of new medicines that improve our health.

2 In AAS (2015), which dealt with the physical and mathematical sciences, we considered advances that had occurred in the past 20 years. For this study, it was judged that, in general, it takes about 10 years longer (or 30 years in total) for advances in the biological sciences to be applied.

Figure 1.1 What is the total stock of knowledge created by advances in the biological sciences? Which part of this did we focus on in this project?



Data source: The CIE.

HOW DO WE MEASURE THIS IMPORTANCE?

As set out in AAS (2015), the Productivity Commission (PC 2006a) provided a comprehensive analysis of the limitations of using time-series analysis of economic data to try to understand the link between scientific research and economic outcomes (particularly productivity). As a consequence, our main approach drew on earlier techniques in literature on the economics of research and development (R&D; see, for example, Mansfield 1998). It also drew heavily on expert experience, in both academic disciplines and industry.

To measure the importance of advances in the biological sciences, we considered a series of 'counterfactuals' or 'thought experiments' that illustrate that importance:

- How much bigger is our economy as a result of the application—over time—of new, useful knowledge that has arisen out of recent advances in the biological sciences?
- How much better is our health as a result of new medicines, vaccines and medical practices (among other things) that have arisen as a result of those advances?
- How much has our environment improved as a result of better practices and better management that have arisen as a result of those advances?

Of course, it is not possible to observe these counterfactuals directly. Instead, we answered these questions by carefully sourcing, compiling and synthesising a range of expert

opinion, in combination with our own research. This expert opinion came from two key sources:

- an expert panel hosted by the CIE and the AAS on 23 and 24 July 2015 in Canberra for 15 eminent Australian biologists, doctors and policy experts
- extensive consultations conducted by the CIE with researchers, medical practitioners and industry representatives.

Appendix 2 lists and acknowledges the contribution of these individuals.

For the economy and human health, we quantified the importance of recent advances in the biological sciences (as far as it was possible for us to do so). Because it is impossible to know this importance with precision, we used all the information available to estimate ranges. It was not possible for us to comprehensively quantify the importance of recent advances to the environment on a national basis.

WHAT DOES THE LITERATURE TELL US?

There is very little in the literature that is directly relevant to the questions considered in this report. Insights and conclusions from the literature that are relevant are introduced (as required) in the chapters that follow and reviewed in Appendix 3.

THE CONCEPTUAL BACKGROUND FOR QUESTIONS AND COUNTERFACTUALS

This section examines the questions we asked about the impacts of the advanced biological sciences on the Australian economy, Australians' health and the environment. In many cases, we found it useful to pose a *counterfactual* (technically, a *counterfactual conditional*) to the question. In essence, a counterfactual is an enquiry about what would happen if circumstances and conditions were not as they are.

How much bigger is our economy as result of advances in the biological sciences?

How do we measure the size of the economy? What is economic growth?

The size of the economy is the total amount of output (or level of activity) that is produced in it. Private companies and governments use inputs (labour, capital, material and systems) to produce output. In the case of private companies, the output is sold to customers. In the case of government, output is provided to citizens as services (sometimes for a fee). The standard measure of the size of the economy, *gross domestic product* (GDP), is simply the total value of all of this output.

Firms and governments usually use the output of other producers as one input in their production. When measuring the size of the economy, it is important that any output that could be counted twice (as one industry's own output and as an input that is implicit in another industry's output) is not counted twice. At the level of individual industries, economists measure *gross value added* (GVA), which is an individual industry's contribution to total output (its output less the output of other producers that it uses as input). Total activity across the economy, GDP, is simply the sum of GVA across industries.[3]

In the Australian economy in 2012–13 (the financial year for which we did our analysis), the total value of output (GDP) was $1 297 billion (or around $54 000 per head of population).[4] To answer this question, we framed a counterfactual: *If recent advances in the biological sciences had not occurred, how much current activity would be lost?* We then took a 'bottom-up' approach: we considered production in each component industry of the economy (measured with GVA) and asked how much bigger it was as a result of recent advances in the biological sciences.

Economic growth is the year-to-year incremental expansion of the economy. Over time, economic growth causes the economy to expand significantly. In real terms (that is, excluding growth in prices due to inflation), the quantity of output produced grew on average by 3.3% per year over the 30 years to 2012–13. This means that output, in real terms, was larger in 2012–13 than in 1982–83 by a factor of 2.7.

3 Plus net taxes on products across industries.

4 The impact of advances in the biological sciences is calculated as a share of total output (economy-wide GVA). The measure of total output ($1 297 billion) excludes the Ownership of dwellings industry (which makes up 9% of the total reported by the ABS). We excluded this industry because it is imputed by the ABS and does not employ any people.

How do advances in the biological sciences affect growth and the level of economic activity?

There is no single industry in which the biological sciences are exclusively important. A farmer may use particular seeds that have been chosen by a biologist, while a doctor may prescribe a new treatment that has been developed with advanced biological knowledge.

In fact, knowledge discovered in recent advances in the biological sciences is important because it is embodied in the inputs (the labour, capital, material and systems) that firms and governments use right across the economy to produce output. The embodied knowledge makes those inputs more productive, and as a result the economy expands for two reasons:

- First, when inputs to production become more productive as a result of an advance in the biological sciences, there is a direct impact, which is an increase in production. This will come as either more output of existing products or new products.
- Second, there is an indirect or 'flow-on' impact. The increase in production of goods and services (the direct impact) lowers the price of goods and services for the individuals and firms that purchase them. Lower prices mean that those individuals and firms will now have free economic resources that, when devoted to new production, cause the economy to expand again (beyond the expansion driven by the direct impact). This is the flow-on impact.

The sum of the direct impact and the flow-on impact is the total expansion of the economy that is driven by the original advance in the biological sciences. In practice, the total impact will show up as an addition to economic growth over a number of years as the benefits of the advance wash around the economy. For all recent advances in the biological sciences, across all industries, our job was to estimate the total impact on the size of the economy that has accrued through additions to economic growth over time. This is illustrated in Figure 1.2.

How do advances in the biological sciences fit in with other factors that drive growth?

It is widely accepted that economic growth is driven by a number of factors, including:

- improvements in our political and economic institutions (which allow us to create new resources and better organise and direct our existing ones)
- investment (increases in the capital stock)
- gains from trade (or commercial expansion)
- scale effects (arising, for example, from population growth)
- increases in the stock of human knowledge (associated with, but not limited to, science), which allow for productivity improvements and the development of novel and more valuable products (see, for example, Mokyr 1990, 2002, 2014).

Investment, gains from trade and scale effects can contribute substantially to growth in the short term independently of the other factors. However, in the long term, that contribution wanes as those factors mature.

This leaves new knowledge, which is the dominant factor that drives economic growth over the long term. New knowledge is what allows us to get more out of our existing resources and opportunities and, of course, it is what we use to develop and create new resources and opportunities. As noted, when new knowledge does these things, it also adds to the size of the economy via flow-on effects. As the American Academy of Arts and Sciences recently noted:

> Basic research lies behind every new product brought to market, every new medical device or drug, every new defense and space technology, and many innovative business practices. To match the increasing pace of technological advancement across the globe, the United States must accelerate both the discovery of new scientific knowledge and the translation of that knowledge to useful purpose. (AAAS 2014, p. 11)

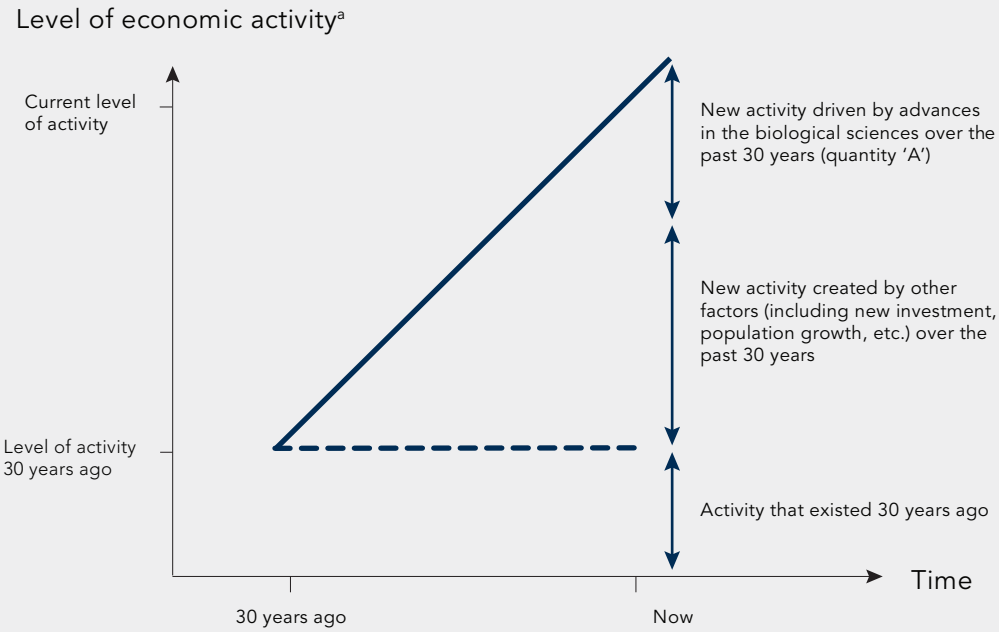
In this particular context, what is true for the United States is also true for Australia.

These insights jointly imply that it is individual advances in new knowledge that incrementally drive the expansion of our economy over the long term. In this work, we isolated and focused on the impact of new knowledge discovered in recent advances in the biological sciences.

How can we illustrate the counterfactual?

To answer our question *(How much bigger is the economy as a result of the application of new, useful knowledge discovered in recent advances in the biological sciences?)*, we added up all the incremental expansions in the economy that have occurred over time to get the total impact on the level of economic activity. This is quantity 'A' in Figure 1.2 which illustrates an alternative way of posing the question as our counterfactual *(If recent advances in the biological sciences had not occurred, how much current activity would be lost?)*. Again, the answer is 'A'.

Figure 1.2 How much bigger is our economy as a result of recent advances in the biological sciences?



a The 'level of economic activity' is a measure of the size of the economy. The 'current level of activity' is the size of the economy today. The 'level of activity 30 years ago' is the size of the economy 30 years ago.

Note: Quantity 'A' represents the answer to our question: *How much bigger is our economy, as a result of the application of new, useful knowledge discovered advances in the biological sciences that have occurred in the past 30 years?*

Data source: The CIE

Further impacts: the diffusion of biological skills around the economy

The described direct and flow-on impacts of advances in the biological sciences on the economy probably understate advanced biology's full impact. In fact, there are many people who train in the biological sciences but who do not directly apply their science knowledge in their jobs. That is, for the purposes of this exercise, they cannot be considered 'labour inputs' that embody knowledge from the biological sciences. However, the problem solving and critical thinking skills that they developed in their biological science training are still valuable to their employers.

Using the ABS' ANZSIC 2006 industry classification system, the Australian economy can be split into 506 industry classes. This study found that 123 (or 24%) of the industry classes produce output from inputs that embody knowledge from advances in the biological sciences.

In the 2011 Census, the ABS divided the economy into 717 industry classes. Of those, 494 (or 69%) had at least one employee with a non-school qualification in the biological sciences.

The contrast between these data is consistent with the idea that advanced biological science skills are valuable to businesses in many parts of the economy, whether or not they are strictly science based (that is, they use these skills directly).

The spread of science across the economy is also illustrated by the fact that a very low percentage of people with a qualification in the biological sciences work in the key biology-based industries. Figure 1.3 shows total employment among people with a non-school qualification in the biological sciences, split by the industry those individuals work in (expressed as a share of the total). Such people are spread right across the economy:

- *Higher education* (which includes universities) is a large employer of people with a non-school qualification in the biological sciences. In Figure 1.3 it is the leading employer, employing 16.9% of them.
- *Scientific research services* is the next largest employer (8%).

- The 10th largest employer, *Computer system design and related services*, employs only 1.4% of these graduates (suggesting that many graduates are spread diffusely around the economy).

How much better is our health as a result of advances in the biological sciences?

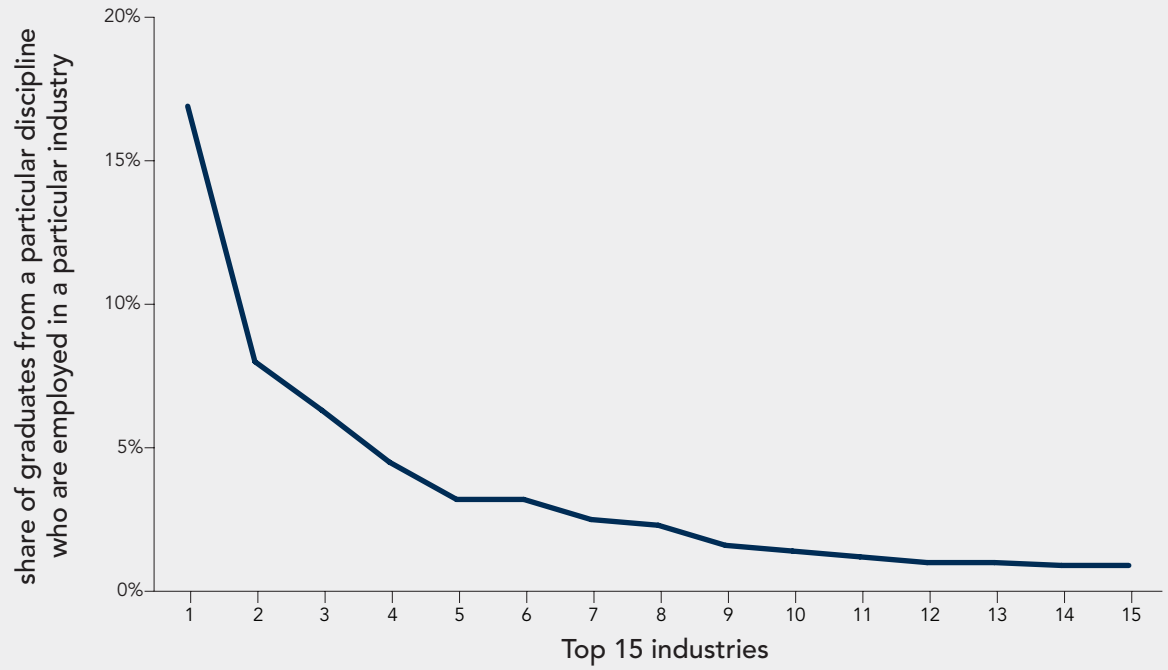
How do we measure health?

The state of health of the population, and changes in health, can be assessed by observing the incidence, prevalence and severity of ill-health in society using 'burden of disease' data.

Burden of disease analysis was developed by the World Health Organization (WHO). It quantifies the difference between the current observed health status of a nation and an ideal health status (in which the entire population lives to an advanced age free of disability and disease). The total burden of disease is determined by calculating the burden for individual diseases. Two things are considered for each disease or medical condition:

- *years of life lost due to disease* (YLL), which is the difference between the years lived before death attributed to that disease and an 'ideal' full life span

Figure 1.3 Employment destinations of individuals with a non-school qualification in biological sciences



1. Higher Education	6. Central Government Administration	11. Scientific Testing and Analysis Services
2. Scientific Research Services	7. Pathology and Diagnostic Imaging Services	12. Engineering Design and Engineering Consulting Services
3. State Government Administration	8. Secondary Education	13. Local Government Administration
4. Hospitals (Except Psychiatric Hospitals)	9. Human Pharmaceutical and Medicinal Product Manufacturing	14. Combined Primary and Secondary Education
5. Management Advice and Related Consulting Services	10. Computer System Design and Related Services	15. Cafes and Restaurants

Data source: ABS, 2011 Census; The CIE.

- *years lost to disability* (YLD), which measures the burden of non-fatal diseases and conditions by counting the average duration of a disability, multiplied by a 'severity weight' for each condition.

The burden imposed on society by a disease or medical condition is measured in *disability adjusted life years* (DALYs), which are years that are lost to disease and disability and are the sum of YLL and YLD. For example, the burden of a certain type of cancer (measured in DALYs) will include the average extent to which the cancer reduces the length of people's lives (YLL) plus any period that people spend in ill-health before they die or recover (YLD).

Table 1.1 shows an estimate of the total burden of disease in Australia and the top six most burdensome diseases (for 2003). The total burden is around 2.6 million DALYS, which is approximately evenly split between 1.28 million YLL and 1.35 million YLD. Among individual groups of diseases, malignant neoplasms (cancers) are the most burdensome: they cause a total burden of nearly 500 000 DALYs, which is mostly YLL (lives cut short).

The figures in Table 1.1 could be contextualised and interpreted as follows. There were 37 222 deaths from cancer in 2003, and the observed YLL associated with those deaths was 411 953. This means that, on average, each person who died from cancer in 2003 died 11 years earlier than the 'ideal' age they would have lived to had they not suffered from cancer or another disease (411 953 YLL divided by 37 222 deaths).

Recasting our counterfactual

Given that our starting point is burden of disease data, to answer the question (*How much better is our health as a result of recent advances in the biological sciences?*), we recast it as a counterfactual (*How much higher would the burden of disease in Australia be if not for the application of new medicines, vaccines and practices (among other things) that have arisen as a result of advances in the biological sciences?*)

How do advances in the biological sciences drive reductions in the burden of disease?

The advanced biological sciences provide the basic, underlying knowledge that gives doctors, dentists and researchers a deeper understanding of the medical conditions of patients. In the past 30 years, breakthroughs in those sciences have transformed the way we think about and treat many diseases, dramatically improving the health of Australians. Examples of this are discussed in case studies in this report.

Discoveries in the advanced biological sciences have underpinned the invention of new products (including vaccines, diagnostics and treatments) that greatly improve patient health. Those sciences are also leading doctors, dentists and other health professionals to improve their approach over time, and this improves patient health.

Table 1.1 Burden of disease in Australia, by disease and total, 2003

Disease or condition	YLL	YLD	Total burden: DALYs
	Years	Years	Years
Malignant neoplasms	411 953	87 463	499 416
Cardiovascular disease	369 365	104 429	473 794
Mental disorders	23 154	327 391	350 545
Nervous system and sense organ disorders	54 127	258 638	312 766
Chronic respiratory disease	71 339	115 398	186 737
Diabetes mellitus	32 295	111 536	143 831
Other diseases and conditions	316 545	349 137	665 681
Total, all diseases and conditions	**1 278 778**	**1 353 992**	**2 632 770**

Note: Table shows only top six most burdensome disease groups and totals.

Source: Begg et al. (2007).

In what context do advances in the biological sciences drive changes in the burden of disease?

The impacts of advances in the biological sciences sit alongside other factors that can substantially change the burden of disease over the long term. All these factors work together, which means that we had to isolate and estimate the impact of advances only in the biological sciences. The other factors include:

- changes in the age structure of the population (for example, an ageing population tends to increase the prevalence of diseases such as cancer)
- changes in the size of the population (a larger population, all else being equal, will lead to a greater absolute burden of disease)
- changes in behaviour (for example, increases in the consumption of healthier food or decreases in smoking tend to reduce the burden of disease)
- changes in the environment (improvements in the environment, such as a reduction in pollution, tend to reduce the burden of disease)
- recent advances in other sciences that also help to reduce the burden of disease (which means we must be careful to isolate and measure only the contribution of the biological sciences, not all sciences together).

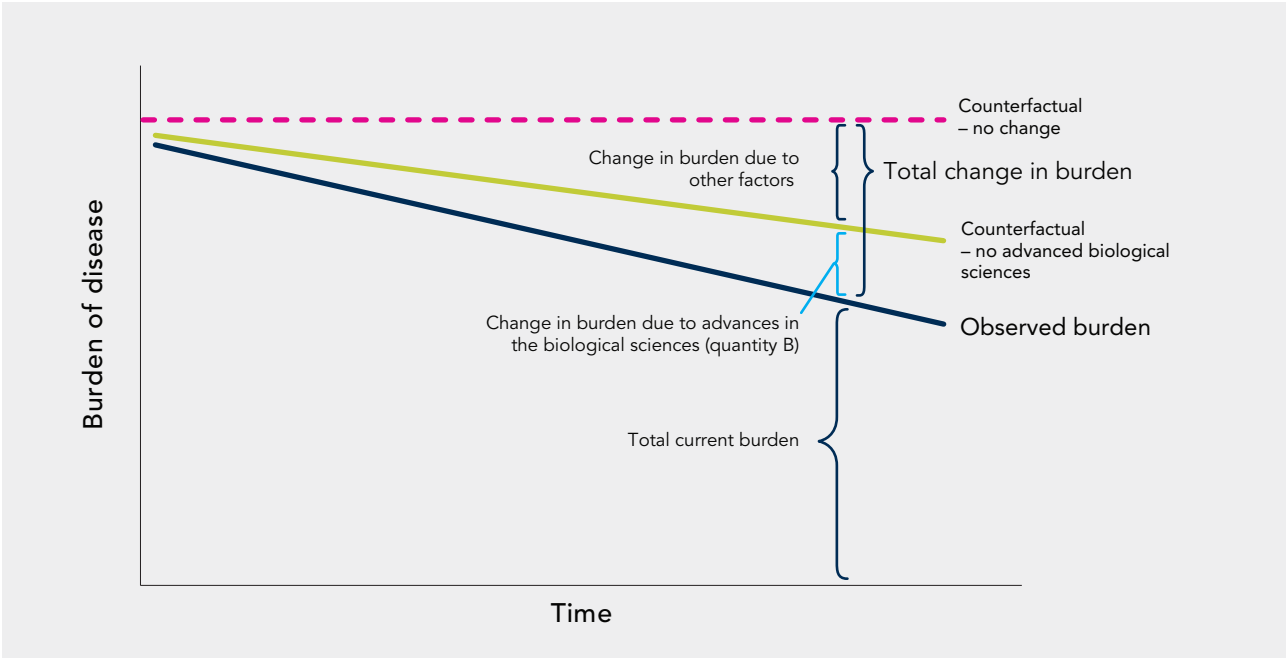
How can we illustrate the impact of advances in the biological sciences?

As noted, our question is: *How much higher would the burden of disease be in Australia if not for advances in the biological sciences over the past 30 years?* This is quantity 'B' in Figure 1.4, which shows the following.

- For illustrative purposes only, the chart assumes that the burden of disease is falling over time.
- This assumed fall in the burden of disease is driven in part by improvements that flow from advances in the biological sciences over the past 30 years (quantity 'B'). For example, this could be caused by new vaccines that prevent diseases from occurring (such as Gardasil, which prevents the development of some cancers).
- It is assumed in Figure 1.4 that other factors, in net terms, have also contributed to the fall in the burden of disease. This may include behavioural changes (for example, a reduction in smoking rates).

The primary challenge for this study, and for comparing it to observed data or literature, is that there is very little information on the attribution of changes in the burden of disease to medical improvements (as a result of advanced biology) and other factors.

Figure 1.4 Change in the burden of disease over time



Data source: The CIE.

How has the environment improved due to advances in the biological sciences?

Most people acknowledge that the health of the environment is deteriorating, and a significant driver of this is human activity. Therefore, another way to think of our counterfactual is: *How much worse would the environment have been, if not for the application of new knowledge from recent advances in biology?*

Can we measure the environment? How valuable are improvements in the environment?

Most parts of the 'environment'—the air we breathe, the water we drink, the soil we use to grow our crops—are irreplaceable. This means, ultimately, that the value of the entire 'environment' is infinite. While this conclusion may be striking to some, it is not helpful for policy purposes.

It is more helpful to consider how the environment changes and how this creates or destroys value. For example, what cost (or loss of value) would we place on the loss of a park in our local area? Answers to these types of questions are helpful, because we can compare the value created (or lost) to the value created by the human activity that caused the changes. For example, we could evaluate whether we should use land that is currently a local park to develop new dwellings by comparing the loss of value generated by the loss of the park to the value created by the new dwellings.

Chapter 4 presents two examples of economic studies in Australia that attempted to calculate the value of making improvements to two of our most important ecosystems:

- Rolfe and Windle (2010) found that the total value Australian society would place on a '1%' improvement in the Great Barrier Reef ranged from $433.6 million to $811.3 million.
- Hatton Macdonald et al. (2011) found that the total value Australian society would place on improving the Coorong (the system of wetlands at the end of Murray) from 'poor habitat' to 'good habitat' was $5.8 billion.

The Productivity Commission (Baker and Ruting 2014) has discussed three broad methods that economists use to discover the value people ascribe to improvements in the environment (summarised in Table 1.2).

How can advanced biology help to improve the environment?

The application of new knowledge discovered in recent advances in the biological sciences can change our behaviour in way that improves the environment.

First, our behaviour can change as a direct result of the application of new knowledge:

- Case study 2.2 (page 22) shows how advanced biology was used to create 'self-healing' concrete, which has the potential to substantially reduce the amount of concrete we need to produce. The production of concrete is a significant source of greenhouse gases, so this innovation may help to improve the environment significantly.

Table 1.2 Methods used to value ecosystem services

Method	Example	Benefits	Costs
Revealed preference	Infer values from observed behaviour For example, use costs and time required to travel to a certain site to estimate its value (its aesthetic or recreational value)	Widely accepted as a measure of the 'use' value of a site	Cannot be used to estimate non-use values Less applicable to valuing prospective changes
Stated preference	Derive value from surveys For example, in choice modelling, economists attempt to infer values by giving respondents choices between policy options	Can be used to estimate the value of a wide range of ecosystem services	Results are less accepted than revealed preference Robustness of results can improve with proper survey design
Benefit transfer	Apply values derived for one ecosystem to another	Used if no primary research is available	May not be valid in some circumstances

Sources: Baker and Ruting (2014); The CIE.

- Case study 2.6 (page 25) shows how the development and use of genetically modified cotton allowed Australian farmers to substantially reduce and change their use of insecticides and herbicides, with the net result being an improvement in the health of the environment.

Second, our behaviour can change because of better environmental management, informed by the biological sciences.

Case study 4.1 (page 44) shows how recent advances in biological knowledge underpinned a substantial change in how the Great Barrier Reef is managed, which is resulting in significant improvements in the health of the reef and its resilience to future shocks.

Figure 1.5 summarises how the application of knowledge from advances in the biological sciences helps the environment.

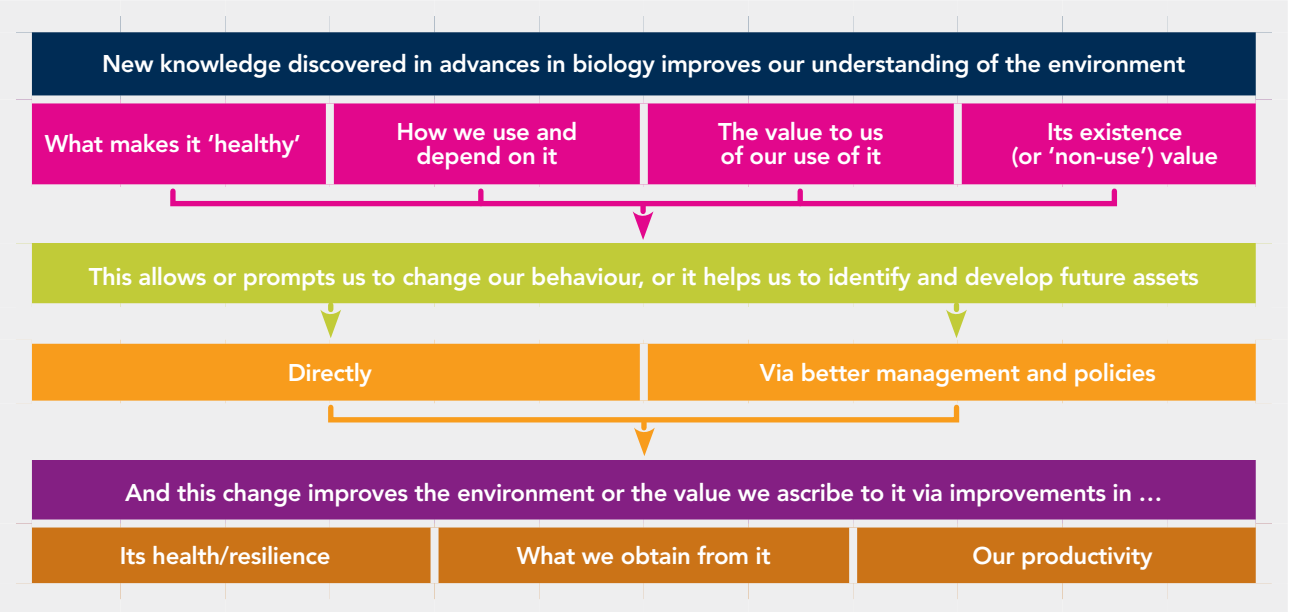
It is important to note that there are many cases where the application of biological knowledge from the environment is not yet complete, partly because the body of relevant knowledge is still developing and partly because relevant policies can take a long time to develop and implement.

THE STRUCTURE OF THIS REPORT

This rest of this report is structured as follows.

- Chapter 2 answers our first question: How much bigger is our economy as a result of the application of new, useful knowledge discovered in recent advances in the core biological sciences?
- Chapter 3 answers our second question: How much better is our health as a result of new medicines, vaccines and practices (among other things) that have arisen as a result of recent advances in the biological sciences?
- Chapter 4 tackles the third question: How much has our environment improved as a result of better practices and better management that have arisen as a result of recent advances in the biological sciences?
- Appendix 1 acknowledges and lists the experts who contributed to this project, including the project steering committee, expert panel participants and other experts who were consulted.
- Appendix 2 provides the detailed results of this study.
- Appendix 3 reviews literature on health economics that provides useful background to this study.
- Appendix 4 explains the CIE-REGIONS model that was used in some of this research.

Figure 1.5 How advances in the biological sciences help the environment



Data source: The CIE

CHAPTER 2

2. THE IMPACT OF ADVANCES IN THE BIOLOGICAL SCIENCES ON PRODUCTION

This chapter answers the question: How much bigger is the economy as a result of the application of new, useful knowledge discovered in recent advances in the biological sciences? The answer to the counterfactual—the data presented in this chapter—can be interpreted as an estimate of how much smaller the economy would be if those advances had not occurred. This total impact on the economy is the direct impact plus the flow-on impact.

THE DIRECT IMPACT OF RECENT ADVANCES IN THE BIOLOGICAL SCIENCES

As noted in Chapter 1, recent advances in the biological sciences have a direct impact on the economy because they are the source of new, useful knowledge that is embodied in inputs (labour, capital, material and systems) that are used to produce output. If these advances had not occurred, and this knowledge had not been discovered, those inputs would be less productive or would not exist.

The ABS divides the Australian economy into 506 industry classes. Across the industry classes, total output in the economy was $1 297 billion in 2012–13.[5] Combining the results of our expert panel, consultations and research (outlined in Chapter 1), which considered industry classes individually, yields the following results, which are summarised in Table 2.1.

- 123 (of 506) industry classes were identified as producing some output using inputs that embody knowledge discovered in recent advances in the biological sciences.
- For a single industry class, gross value added (GVA) measures its own contribution to economy-wide output. (An industry's GVA is its total output less the output of other industry classes that it uses as inputs). For the 123 industry classes identified, total GVA was $379 billion in 2012–13.
- Of that output, 12.1% (or $46 billion) was estimated to be produced using inputs that embody knowledge discovered in recent advances in the biological sciences. This was 3.6% of economy-wide output in 2012–13.

Table 2.1 Gross value added, by sector, 2012–13

	Total	Science-based	Science share
	$b, current prices	$b, current prices	%
GVA of science-based industry classes[a]	379	46	12.1
GVA of other industry classes[b]	918	0	0
Total output (economy-wide GVA)	**1 297**	**46**	**3.6**

a Classes with inputs that embody knowledge discovered in recent advances in the biological sciences.
b Excludes the Ownership of dwellings industry (which makes up 9% of the total reported by the ABS).
Sources: ABS; The CIE.

5 The impacts of advances in the biological sciences are calculated as a share of total output (economy-wide GVA). The measure of total output ($1 297 billion) excludes the Ownership of dwellings industry (which makes up 9% of the total reported by the ABS). We excluded this industry because it is imputed by the ABS and does not employ any people.

As noted in Chapter 1, total GVA across all industries does not exactly equal GDP (the standard measure of the total size of the economy). GDP is total GVA across all industries plus net taxes on products. For clarity, we excluded explicit analysis of taxes on products and simply assumed that the pattern of those taxes in sectors subject to the direct impact assessed here is similar to the pattern in other sectors.

Overall, we estimate that 3.6% of Australia's economy (3.6% of our production of goods and services) uses inputs that embody knowledge discovered in recent advances in the biological sciences. This is the direct impact of those advances on the economy.

Key industries using advanced biological sciences

Table 2.2 shows the industry classes that produce the most output using inputs that embody knowledge discovered in recent advances in the biological sciences. The largest are in health. The biological sciences are also important in agriculture but, as its industry classes are very small (the 49 industry classes in agriculture make up only 2.6% of the economy), they do not appear in Table 2.2. Case Study 2.9 and Table 2.3 provide more information on agriculture.

Variation and uncertainty in these results

The CIE sought a wide variety of opinions (from the expert panel participants and other experts) to estimate the direct impact of recent advances in the biological sciences. From those opinions, it was clear that in some industries the importance of the biological sciences is uncertain. We used the spectrum of values obtained from the experts to estimate the range of the importance of the biological sciences in applicable industry classes. Summing up across classes gave the range of direct impact on the whole economy (shown in Figure 2.1):

- In the 'low' case, $38 billion of output in 2012–13 (or 2.9% of the economy) was produced using knowledge discovered in recent advances in the biological sciences.
- In this context, the results presented above are the 'middle' case. In the middle case, $46 billion of output in 2012–13 (or 3.6% of the economy) was produced using knowledge discovered in recent advances in the biological sciences.
- In the 'high' case, $54 billion of output in 2012–13 (or 4.2% of the economy) was produced using such knowledge.

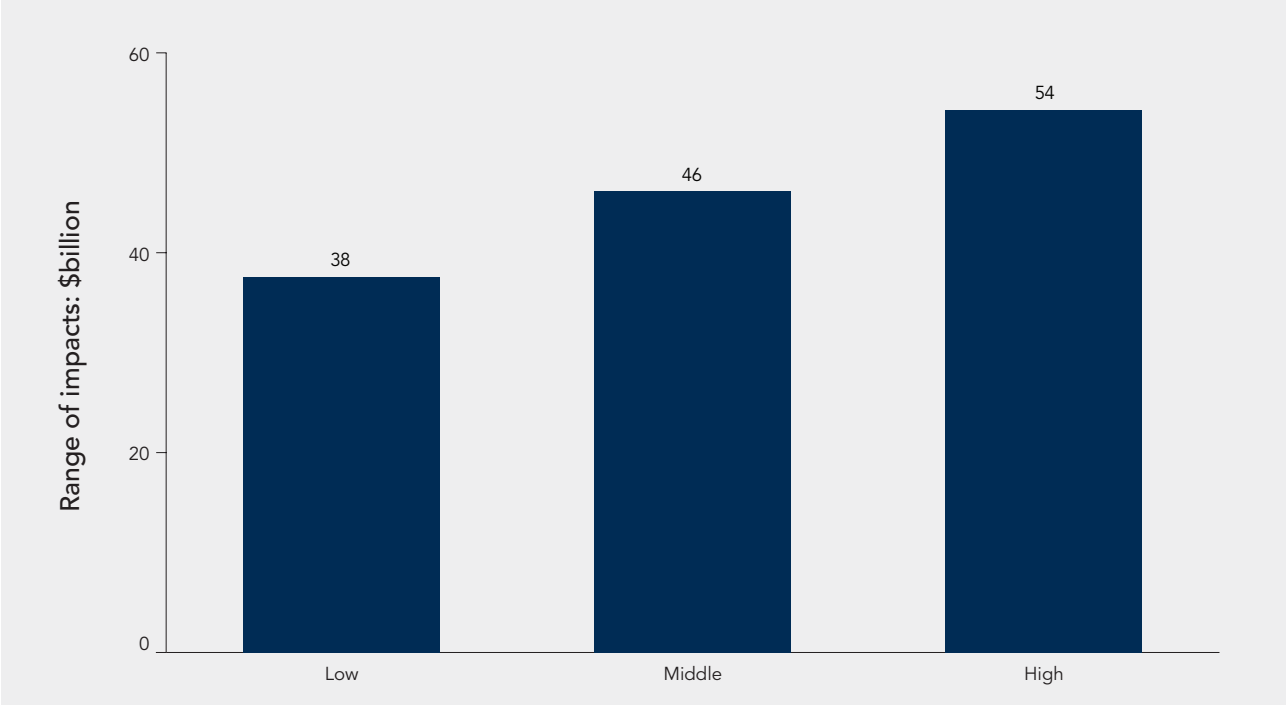
Table 2.2 Top 10 industry classes, GVA based on the biological sciences, 2012–13

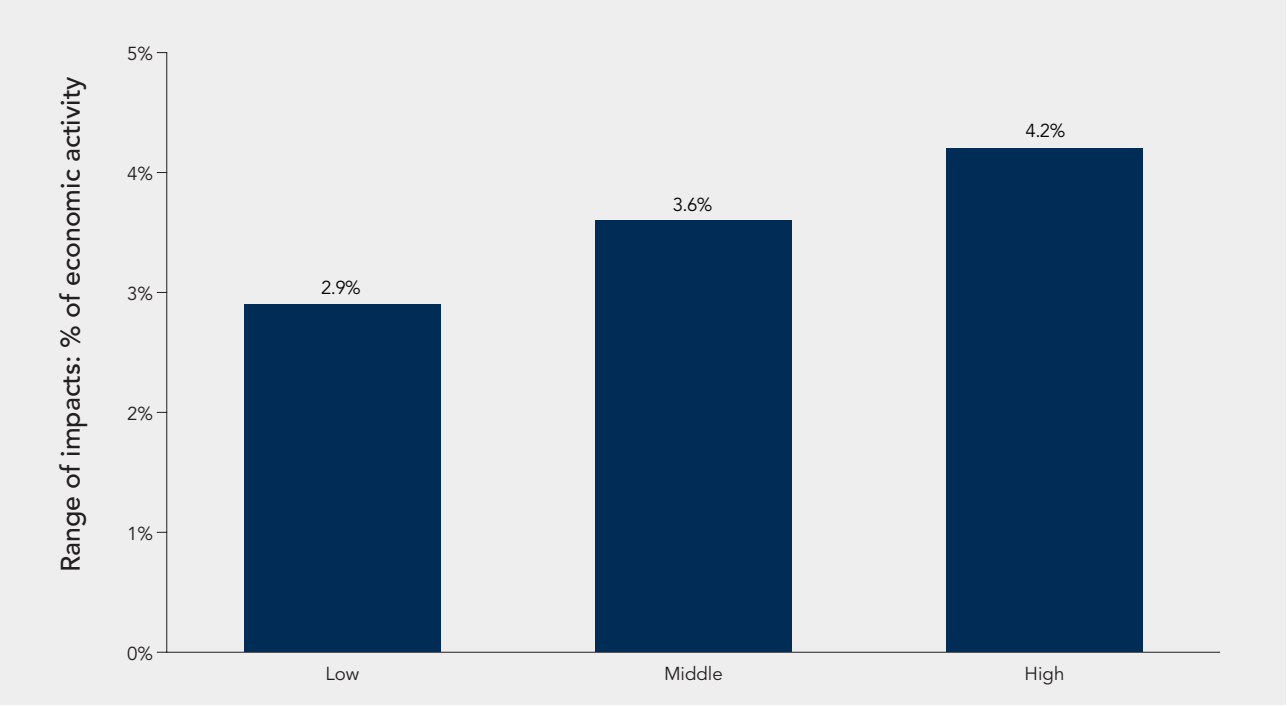
Industry classes		Total GVA	Science-based GVAa	Science share
		$b, current prices	$b, current prices	%
8511	General Practice Medical Services	14	8	57.5
8531	Dental Services	7	5	80.0
8401	Hospitals (except Psychiatric Hospitals)	13	4	33.9
8512	Specialist Medical Services	5	2	46.1
6910	Scientific Research Services	4	2	54.0
7711	Police Services	9	2	20.0
700	Oil and Gas Extraction	32	2	5.0
1841	Human Pharmaceutical and Medicinal Product Manufacturing	2	1	50.0
801	Iron Ore Mining	23	1	5.0
8539	Other Allied Health Services	9	1	10.0
Total of other science-based industry classes		**260**	**17**	**6.7**
Total of science- based sector		**379**	**46**	**12.1**

a GVA based on the biological sciences' and 'science based GVA' is output produced from inputs that embody knowledge discovered in recent advances in the biological sciences.

Sources: ABS; The CIE.

Figure 2.1 Direct impact of recent advances in the biological sciences, by case, 2012–13





Note: The impacts of advances in the biological sciences are calculated as a share of total output (economy-wide GVA). The measure of total output excludes the *Ownership of dwellings* industry (which makes up 9% of the total reported by the ABS).

Data source: The CIE.

THE FLOW-ON IMPACT OF ADVANCES IN THE BIOLOGICAL SCIENCES

The direct impact of recent advances in the biological sciences (calculated above) represents an increase in the availability of goods and services in the economy. As noted in Chapter 1, that increase has a flow-on effect: it lowers the price of those goods and services for the individuals and firms that purchase them. Lower prices create savings, which means that those individuals and firms will as a result have free economic resources that when devoted to new production drive the economy to expand further. This is the flow-on impact.

The correct way to measure the flow-on impact is with an economy-wide computable general equilibrium (CGE) model. The CIE's model—CIE-REGIONS—is such a model.[6] The estimates from CIE-REGIONS suggest that the flow-on impact on the economy of recent advances in the biological sciences is equivalent to 1.5% of economy-wide production (on top of the direct impact, which is equivalent to 3.6% of economy-wide production).

Uncertainty in these results

The range of results for the direct impact implies that there is a range of results for the flow-on impact. The results are shown in in Figure 2.2:

- In the 'low' case, the direct impact of recent advances in the biological sciences is equivalent to only 2.9% of the economy, which means that the flow-on impact shrinks to 1.0% of the economy (or $12 billion).
- In the 'middle' case, the direct impact of those advances is equivalent to 3.6% of the economy, with a flow-on impact of 1.5% of the economy ($19 billion).
- In the 'high' case, the direct impact is equivalent to 4.2% of the economy, which means that the flow-on impact grows to 2.0% of the economy ($26 billion).

Not all flow-on impacts are captured

Our CGE modelling suggests that the flow-on impact of recent advances in the biological sciences is smaller than the direct impact. This is in contrast to AAS (2015), which found that the direct and flow-on impacts of recent advances in the physical and mathematical sciences were about equal in magnitude.

Note that the flow-on impacts presented here do not capture all of the flow-on impacts of advanced biology: in particular, the flow-on health and environmental impacts are not covered in the CGE modelling. They are considered separately in Chapters 3 and 4, respectively.

THE TOTAL IMPACT

Middle case

Adding the results presented above, in the middle case, we estimate that the total impact of recent advances in the biological sciences on the economy is equivalent to 5.0% of economy-wide output (or $65 billion of GVA in 2012–13), as shown in Figure 2.2. This implies that if recent advances in the biological sciences had not occurred, the economy would be 5% smaller today:

- 3.6% of production would be lost as a direct result of losing the knowledge discovered in these advances.
- This direct loss of production would cause price rises. This would drive a reallocation of resources that would see the economy shrink by a further 1.5%.

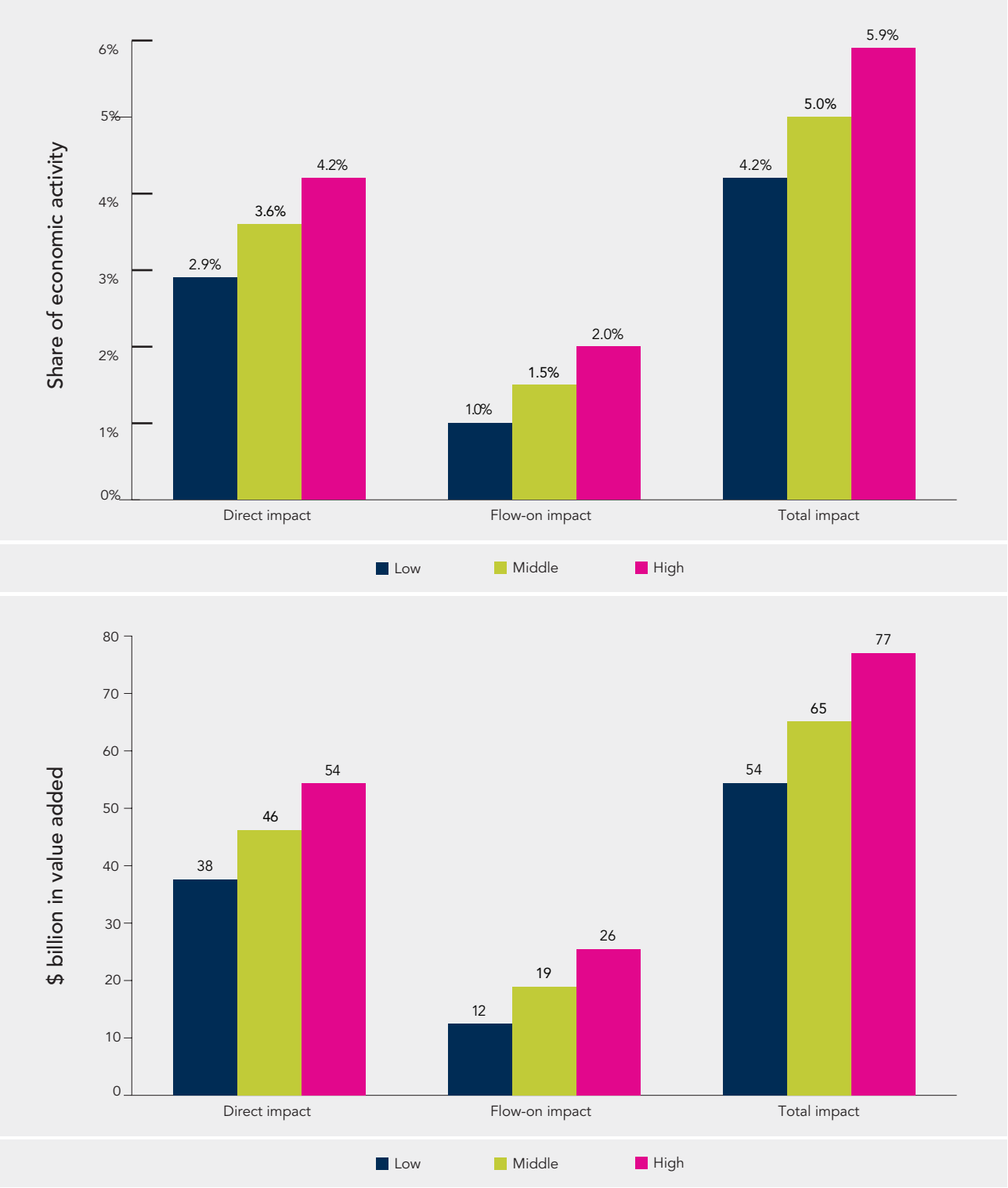
High and low cases

The uncertainty in the direct and flow-on impacts implies that there is uncertainty in the total impact. If recent advances in the biological sciences had not occurred, in the 'low' case the economy would be 4.2% smaller (equivalent to a loss of GVA of $54 billion). In the 'high' case, the economy would be 5.9% smaller (equivalent to a loss of GVA of $77 billion).

Close inspection of Figure 2.2 shows that, in the low and high cases, the total impact of advances in the biological sciences does not exactly equal the direct impact plus the flow-on impact. This is because the uncertainties in the flow-on effects are estimated independently.

6 A technical explanation of the CIE-REGIONS model is in Appendix 4.

Figure 2.2 The impact of recent advances in the biological sciences on the economy



Note: The impacts of advances in the biological sciences are calculated as a share of total output (economy-wide GVA). The measure of total output excludes the *Ownership of dwellings* industry (which makes up 9% of the total reported by the ABS).

Data source: The CIE.

EVALUATION OF THESE RESULTS

There are earlier reports in the literature that attempt to measure the importance of science to economies. Compared to the methodology used in those previous reports, the CIE's methodology is superior in a number of ways (see AAS 2015 for a discussion). Furthermore, in this report on the advanced biological sciences we have included non-market impacts.

CASE STUDIES

The following case studies illustrate the impact of the advanced biological sciences on production.

Case study 2.1: The creation of new medical products

Advanced biology is crucial to all the steps taken in the creation of new vaccines and medical therapies: discovery (the initial scientific breakthrough), development, trialling, manufacture and updating (if applicable). Advances in the biological sciences allow us to create new and better vaccines and therapies.[7]

CSL is an example of an established Australian company that creates new vaccines and therapies. Its own research facilities (which are located across the globe and include two in Melbourne) are sources of advances in the biological sciences. CSL also collaborates with researchers at universities and other institutions. In 2014–15, CSL's R&D expenditure was US$463 million. It made a net profit of $1.4 billion.

CSL's CSL654 therapy, a treatment for haemophilia that is in the final stages of development and will be released to the market next year, is a good recent example of a treatment that was discovered, developed, trialled and manufactured within a single commercial setting.

Discovery

Breakthroughs in the biological sciences can improve our understanding of disease and prompt the discovery of new vaccines and therapies.

Protein therapies (purified and concentrated proteins) correct protein deficiencies in our bodies that are causing disease or preventing us from recovering from disease. Protein therapies are the largest part of CSL's business, and it maintains a research group that makes discoveries that lead to new protein therapies.

Development

While the discovery that led to the vaccine Gardasil (see Case study 3.3) occurred at the University of Queensland, CSL did the development work that turned the discovery into a vaccine that could be trialled.

Trialling

Trialling is the process of checking the efficacy and safety of medical treatments. The act of testing treatments and taking the measurements required for those checks is a clinical procedure and is not relevant to this study. However, within clinical trials, the data that are measured and how we measure them are changing as our understanding of disease changes with advances in the biological sciences. Therefore, those advances are important for the trialling of medical treatments.

Manufacture

As noted, protein therapies (purified and concentrated proteins) are the largest part of CSL's business. These therapies can be produced in two ways: with advanced fractionation or with recombinant technology.

Advanced fractionation

Immunoglobulins are antibodies that occur naturally in our blood plasma. They play a crucial role in our immune system: they recognise and attach to pathogens such as bacteria and viruses before either neutralising the pathogens or attracting other parts of the immune system to attack them.

If someone is deficient in immunoglobulins, this needs to be corrected with an immunoglobulin therapy.

A crucial point is that naturally occurring immunoglobulins can recognise and attach to thousands of types of bacteria and viruses. Immunoglobulins produced artificially (with recombinant technology) cannot replicate this natural variety. Therefore, to manufacture its immunoglobulin therapies, CSL uses fractionation to extract naturally occurring immunoglobulins from blood plasma, before concentrating them into therapies. While the fractionation process is relatively old, it is the subject of continuous innovation, and this requires the application of new knowledge from advances in the biological sciences.

7 Sources: The CIE; Dr Andrew Nash (Senior Vice President Research, CSL)..

Recombinant technology

While fractionation is useful for making immunoglobulin therapies, it is not useful for all therapies. Because some proteins exist in our blood in very small quantities, it is not commercially feasible to extract and concentrate them using fractionation technology. An alternative is to use recombinant technology, in which proteins are produced artificially (they are expressed from genetically modified material). CSL manufactures monoclonal antibodies—which are used to treat cancer and inflammation—with recombinant technology.

Drug updating

CSL manufactures the flu vaccine that is used in Australia. Each year, CSL identifies which strains of the flu virus are prevalent, updates (changes) the vaccine so that it prevents those strains, trials the new vaccine and then manufactures it. Advanced biology is crucial to performing each of these steps every year. No other vaccine is changed or updated as regularly as the flu vaccine.

Case study 2.2: Self-healing concrete

The problem: cracking concrete

Seventy per cent of Europe's infrastructure is made of concrete. However, concrete cracks and deteriorates over time, and its production is responsible for between 7% and 12% of global CO2 emissions.[8]

The solution: use microbiology to create self-healing concrete

As a solution, Hendrik Marius Jonkers (Delft University, the Netherlands) has used microbiology to make concrete self-healing. This markedly improves the life span of concrete and therefore the lifespan of buildings, bridges and roads. When concrete lasts longer, less of it has to be produced, which reduces CO2 emissions.

To make self-healing concrete, a special bacterium (either Bacillus pseudofirmus or Sporosarcina pasteurii, which occur naturally in highly alkaline lakes near volcanoes) and calcium lactate are added to the concrete mix.

The bacteria are activated when they come into contact with water, as happens when the concrete develops cracks. They then consume the calcium lactate and start to secrete limestone, which fills up the cracks.

Benefits of the solution

The bacteria are able to lie dormant in the concrete for up to 200 years and only begin their work once cracks have started to appear in the concrete.

Currently, self-healing concrete costs twice as much to produce as regular concrete. A large part of this cost is for the calcium lactate. Jonkers and his team are currently developing a sugar-based alternative that would bring down the cost of the bio-concrete much closer to the cost of regular concrete.

Potential economic benefits

The potential economic benefits created by this technology, including cost savings and greenhouse gas abatement, will occur in the future. As the technology is still being developed, it is not possible to estimate those benefits.

Case study 2.3: Treating tooth decay with RECALDENT

Until recently, dentistry has primarily involved the simple diagnosis and the simple treatment of oral disease. Practically, this has meant that the focus has been tooth decay, which causes 70% of tooth loss.[9]

Healthy teeth

When a tooth is healthy, it has a well-formed surface of enamel and dentin. These tissues have a high concentration of calcium and phosphate minerals.

A basic problem: tooth decay

The mouth is full of naturally occurring bacteria. When they are not removed with brushing and flossing they form a thin, slightly yellow layer of plaque on the teeth. Plaque therefore indicates a significant build-up of bacteria in the mouth.

The bacteria produce acids when they consume sugar (provided in the food and drinks we consume), and those acids erode away (or 'demineralise') healthy enamel and dentin. This is tooth decay. Advanced tooth decay leads to cavities in the teeth.

8 Sources: EPO (2015); The CIE.

9 Sources: Professor Eric Reynolds AO; Dental Health Services Victoria.

Original solution

Until recently, the focus of dentists has been on diagnosing tooth decay and treating it remedially. Until the 1950s, this involved removing teeth and installing dentures. From the 1960s to the 2000s, dentists used 'drilling and filling', in which healthy enamel is drilled away (from around the cavity) and a filling is used to plug the hole.

New solution, underpinned by the advanced biological sciences

Advances in our understanding of the biology of the mouth have changed dentists' approach to tooth decay in two ways. First, the focus has changed to preventing disease and retaining healthy mouth tissue.

Second, Australian researchers (at the University of Melbourne and elsewhere) have developed RECALDENT, which contains calcium and phosphate. The minerals are delivered to the teeth, which build back healthy tissue where tooth decay has eroded it. This 'remineralisation' retains healthy tissue and is thus desirable compared to 'drilling and filling'.

Remineralisation can occur in various ways. Consumers can purchase and chew gum that contains RECALDENT, and thus build back healthy tissue themselves. Furthermore, as a preventive or remedial measure, dentists can apply Tooth Mousse (a product that contains RECALDENT) to areas of tooth decay.

Economic benefits

The contribution of advances in the biological sciences to dentistry are large (as illustrated here and in Case study 3.4). As noted in Table 2.1, based on all information obtained, we estimate (in the middle case) that 80% of activity in dentistry uses inputs that embody knowledge from the advanced biological sciences. This means that those sciences contributed $5 billion in GVA to the industry in 2012–13.

However, this figure understates the benefits. As discussed in Chapter 3, the health benefits (better oral health) that these advances create are highly valuable in and of themselves. As explained in Case study 3.4, researchers are beginning to understand more about the links between oral health and health more generally. This means that the value of the contribution of the advanced biological sciences to dentistry could be large, given their potential impacts on health more generally.

Case study 2.4: NOGALL (a genetically modified biocontrol for crown gall)

The original problem: crown gall disease

Until a biocontrol was invented, crown gall disease dramatically stunted the growth and yield of stone fruit trees (almond, peach, plum, cherry) and roses right around the world. The informed guess of Professor Allen Kerr is that the disease reduced yields in stone fruit nurseries by 50% and in orchards by 10%.[10]

Plants affected by crown gall develop large bulbous tumours (galls) on their crown (the point at the soil line where the roots join the stem). Scientists had known for some time that the disease was caused by *Agrobacterium tumefaciens*, a pathogenic bacterium in soils.

The initial solution

Plant pathologists led by Professor Kerr at the University of Adelaide discovered a non-pathogenic strain of *Agrobacterium*, dubbed K84, that produced an antibiotic called agrocin 84. This antibiotic was found to inhibit the growth of *A. tumefacien*s, and this suggested that it could be used to prevent plants from developing crown gall disease.

In 1973, Professor Kerr's group released K84 as a biocontrol agent for the disease. Initially, it was highly effective and was used in Europe, Africa, and North and South America.

A new problem: *A. tumefaciens* picks up resistance

About five years after the initial success of non-pathogenic K84, Greek researchers found that mixing it with pathogenic *A. tumefaciens* was giving rise to pathogenic bacteria that could cause crown gall but that were resistant to agrocin 84. This clearly reduced the effectiveness of the K84 biocontrol. The Greek researchers noted that pathogens that were able to produce agrocin 84 were also resistant to it.

A new solution, using genetic engineering

A joint project between Professor Schell's group (then at the University of Ghent, Belgium) and Professor Kerr's group found that the ability to produce agrocin 84 was encoded in genes on a plasmid, which is a small piece of circular DNA. The plasmid was being transferred from K84 to *A. tumefaciens*, giving the latter the ability to produce agrocin 84 and resistance to it. With Dr SK Farrand (University of

10 Sources: Professor Allen Kerr; Prime Minister's Prizes for Science.

Illinois), Professor Kerr identified the region on the plasmid that was mediating the transfer of the plasmid from K84 to *A. tumefaciens*. Professor Kerr's team then used genetic engineering to delete this DNA region from K84. The result was a new genetically modified bacterium called K1026 that could release agrocin 84 but would not pass on agrocin 84 resistance to *A. tumefaciens* (meaning that it could control crown gall over the long term).

Commercialisation

From 1988, a New South Wales company called Bio-Care Technology began to sell K1026 as the product NOGALL. It was the first genetically modified organism to be sold to the public, and was sold in many countries.

Benefits

Crown gall on stone fruit has now virtually disappeared from Australia. This eliminates a problem that was costing 50% of production in some stone fruit nurseries and 10% of production in orchards.

Case study 2.5: The biological sciences' contribution to agriculture

What do the statistics say?

In 2012–13 (the year of focus for this research), total GVA in the agriculture industry was $34.2 billion, or 2.6% of the economy. 'Rural exports' (which include live animals and unprocessed bulk farm commodities as well as manufactured food products, including frozen meat and dairy products) were worth $42.6 billion in 2014–15 and made up 16.6% of goods exports.[11]

Given these numbers, while advanced biology is important to agriculture, the overall economy-wide importance of its contribution is small compared to contributions in other areas. Across all the component industry classes of agriculture, we estimate 17% of total output was produced using inputs that embody knowledge discovered in recent advances in the biological sciences. This is $5.9 billion worth of output.

How does knowledge from advanced biology help agriculture?

Advances in the biological sciences help agriculture in three broad ways:

- They increase production. Agricultural industries in which this is particularly significant are listed in Table 2.3.
- They reduce the impact of diseases. Case study 2.4 shows how genetic engineering was used to eliminate crown gall disease in Australia, which had a substantial impact on the stone fruit and flower industries.
- They help reduce farmers' environmental impact. Case study 2.6 explains how the development and use of genetically modified cotton has reduced and changed the use of pesticides and herbicides in cotton production, thus avoiding environmental impacts that would otherwise have been incurred.

How important are these changes?

Because agricultural production is relatively small, the value of contributions from advances in biological sciences to total GVA are also relatively small. However, where those advances help farmers reduce their impact on the environment, this contribution has the potential to be very valuable in the non-market economy (as Australians place substantial importance on the environment).

The example of the Coorong (see Chapter 4) highlights just how valuable innovations that improve the environment could be. The nature of biology means that to properly measure its importance we need to consider its impact on non-market outcomes (such as human health and the environment) in addition to its impact on production. Its impacts in those areas are discussed further in Chapters 3 and 4.

11 Source: The CIE.

Table 2.3 Top 10 agriculture industry classes, GVA based on the biological sciences, 2012–13

Industry classes		Total GVA	Science-based GVA[a]	Share of science
		$b, current prices	$b, current prices	%
149	Other Grain Growing	2.1	0.9	40
145	Grain-Sheep or Grain-Beef Cattle Farming	3.1	0.6	20
142	Beef Cattle Farming (Specialised)	5.3	0.5	10
131	Grape Growing	1.4	0.4	30
160	Dairy Cattle Farming	2.7	0.3	10
152	Cotton Growing	0.4	0.3	70
171	Poultry Farming (Meat)	0.5	0.2	50
301	Forestry	0.7	0.2	30
141	Sheep Farming (Specialised)	2.2	0.2	10
411	Rock Lobster and Crab Potting	0.4	0.2	50
Other agriculture		15	2	13
Total agriculture		**34.2**	**5.9**	**17**

a GVA based on the biological sciences' and 'science based GVA' is output produced from inputs that embody knowledge discovered in recent advances in the biological sciences.

Sources: ABS; The CIE.

Case study 2.6: The development and use of genetically modified cotton in Australia

Australia exported $1.5 billion worth of cotton in 2014–15. This was 0.6% of our total goods exports ($255 billion in 2014–15).[12]

The problems: insects, weeds and environmental damage

The yield of cotton crops, like the yields of other crops, can be significantly reduced by insects and weeds. Major insect pests—caterpillars of the *Helicoverpa* species, aphids, thrips, mirids and whitefly—cause damage by eating the plants. Weeds are a problem because they can reduce the sunlight, water and nutrients available for the cotton crop, reduce the quality of the crop, reduce water flow in irrigation channels and act as refuges for insects.

Until the mid-1990s, farmers controlled insects and weeds with chemicals. To deal with the problem of *Helicoverpa*, for example, insecticide chemical sprays contained toxins from *Bacillus thuringiensis*, which kills the caterpillar by disrupting its digestive system. Before the introduction of genetically modified (GM) cotton, the annual control and damage costs for *Helicoverpa* in the cotton industry were estimated at $102–$161 million.

Furthermore, an important problem with these chemicals was the significant damage they inflicted on the environment. That damage was a source of significant community concern.

The insecticides used included broad spectrum insecticides that do damage to organisms beyond the target pests.

The herbicides used included residual' insecticides Compared to non-residual herbicides, they remain active in the ground for a longer period, which increases the risk that they will do unintended damage to the environment.

The solution: GM cotton and its strategic use

Scientists have genetically modified cotton, creating new varieties that are insect resistant and tolerant to certain types of herbicides.

12 Sources: ABS cat. no. 5638.0; Holtzapffel et al. (2008).

For example, scientists at the CSIRO developed 'Bt' cotton, to which they added genes from *Bacillus thuringiens*. The added genes release the toxins that kill *Helicoverpa* (as occurs with chemical insecticides). Two varieties of genetically modified Bt cotton have been used: Ingard (from 1996), which releases one type of Bt toxin, and Bollgard II (from 2006), which releases two types of Bt toxin. Switching to a product that releases two types of toxins reduces the probability that *Helicoverpa* will develop resistance.

Scientists have also genetically modified cotton so that it is tolerant to the non-residual herbicides glyphosate and glufosinate-ammonium.

Cotton varieties that combine these desirable properties have been produced. 'Round-up Ready / Bollgard II' cotton tolerates the herbicide glyphosate and is insect resistant.

Today in Australia, over 99% of the cotton crop is a GM variety of some form.

Benefits of the solution

The biggest benefits of GM cotton are reduced costs for farmers and better environmental outcomes:

- In the 10 years to 2008, the adoption of Bt cotton varieties allowed farmers to reduce the quantity of insecticides they used by 70%–85% per hectare:
- Farmers' adoption of Ingard cotton after 1998 (when the price was lowered) saved them an estimated US$54–US$90 per hectare, as savings on insecticide costs more than offset more expensive seed.
- Farmers' adoption of Bollgard II saved them an estimated US$193–US$196 per hectare.

In addition, the adoption of Bt cotton and integrated pest management strategies allowed farmers to use 'softer' insecticides that are less harmful. The results are substantial. For example, in samples of water taken from four rivers in northern NSW, the percentage of samples containing endosulfan (an insecticide known to kill native fish) fell from around 60% in the early 1990s to below 10% in the early 2000s.

GM cotton caused the total amount of herbicides used by cotton farmers to increase. However, within this increase there was a switch from residual herbicides to the non-residual herbicide glyphosate. The use of residual herbicides did not fall to zero (as some weeds are resistant to non-residuals).

Community perceptions of the cotton industry have improved with these changes.

CHAPTER 3

3. THE IMPACT OF ADVANCES IN THE BIOLOGICAL SCIENCES ON HEALTH

This chapter answers the question: *How much better is our health as a result of new medicines, vaccines and medical practices (among other things) that have arisen from recent advances in the biological sciences?* It does so by answering the counterfactual: *How much higher would the burden of disease be, if not for the application of new, useful knowledge from the advanced biological sciences?*

In a perfect world, the impact of medical advances (due to advances in the biological sciences) on the burden of disease could be estimated by examining the statistical relationship between all medical advances (including new vaccines, medications, diagnostics, surgical procedures and medical devices) and the burden of disease.

Lichtenberg (2015) conducted a similar analysis by looking at the impact of pharmaceutical innovation on health outputs in Australia. He clearly noted in his paper that:

> pharmaceutical innovation is not the only type of medical innovation that is likely to reduce premature mortality … [however,] measures of non-pharmaceutical medical innovation are not available for Australia.

Lichtenberg used the available data to conduct this analysis but recognised the limitations in those data. No other similar studies exist for Australia. Given the observed data limitations, further examination of the impact of medical advances required a different approach. Therefore, to conduct the analysis for this study, the CIE relied on the expert opinion of eminent Australian doctors and scientists in the medical field.

THE IMPACT OF RECENT ADVANCES IN THE BIOLOGICAL SCIENCES

Table 3.1 shows the CIE's estimate of the impact of recent advances in the biological sciences on the burden of disease in Australia. The results are shown as a range ('low' and 'high'), as the impact of the advanced biological sciences is uncertain (because of the number of factors, in addition to those sciences, that affect the burden of disease and because of the inherent uncertainty in the estimation procedure).

For all diseases in Australia, we estimate that without the application of knowledge from recent advances in the biological sciences, the burden of disease would have been higher by between 18% (in the low case) and 34% (in the high case); that is, the burden of disease (2.6 million DALYs) would have been between 471 806 and 890 896 DALYs higher if not for the application of knowledge from recent advances.

Estimating the range of impacts

Based on feedback from individual experts consulted by the CIE and the limited evidence available from the literature, it was possible that results obtained through the expert panel were generous estimates of the impact of biology on the burden of disease.

Therefore, the expert panel results are set as the upper bound of the likely impact (the 'high' case). Where additional information was available through consultation and literature, it was used to inform the value of the low case. In particular, where additional information was available, it indicated that the appropriate weighted (by DALYs) adjustment to estimate the lower bound was slightly higher than 50% of the expert panel results. Therefore, for the disease groups for which further information was not available, the low case was assumed to be 50% of expert panel outcomes. The results are set out in Table 3.1.

Table 3.1 The impact of recent advances in the biological sciences on the burden of disease in Australia

Diseases and conditions	Observed burden of disease (2003)	How much higher would this burden be, if not for the application of new, useful knowledge from the advanced biological sciences?			
	DALYs	Per cent		DALYs	
		Lower	Upper	Lower	Upper
Cancer (malignant neoplasms)	499 416	27	54	133 600	267 201
Cardiovascular disease	473 794	35	40	163 459	189 518
Mental disorders	350 545	0	28	0	98 217
Nervous system and sense organ disorders	312 766	15	26	46 915	80 298
Chronic respiratory disease	186 737	16	32	30 214	60 427
Diabetes mellitus	143 831	2	4	3 230	6 459
Other diseases and conditions	665 681	14	28	94 388	195 236
All diseases and conditions	**2 632 770**	**18**	**34**	**471 806**	**890 896**

Note: Table shows only the top six most burdensome diseases and the totals.

Sources: Begg et al. (2007); expert panel; consultations; The CIE.

What these results mean, using the example of cancer survivability

Table 3.2 shows the burden of disease for cancer, along with the low and high case for the impact of the advanced biological sciences, broken down in into components for YLL and YLD.

There were 37 222 deaths from cancer in 2003 (according to the ABS), and the observed years of life lost associated with those deaths was 411 953. This means that each cancer sufferer died, on average, 11 years earlier than the 'ideal' age expected without illness (411 953 YLL divided by 37 222 deaths).

As shown, the CIE estimates that without the application of useful knowledge from the advanced biological sciences, the YLL associated with cancer would have been 25% to 50% higher. Assuming the same number of deaths, this implies that if advances from the advanced biological sciences were somehow removed, each cancer suffer would have died 14 to 17 years earlier than the 'ideal' age without illness.

Therefore, we can interpret the results in Table 3.2 as saying that the overall effect of recent advances in biological sciences on survivability in cancer is equivalent to giving cancer sufferers an extra 3–6 years of life. Furthermore, the advanced biological sciences have also improved the quality of life of sufferers by reducing the duration of illness or the degree to which sufferers are 'disabled' by 35%–70% (again, this assumes that the number of sufferers has not changed).

Table 3.2 The impact of recent advances in the biological sciences on the burden of disease from cancer in Australia

Burden of cancer, by component	Observed burden of disease (2003)	How much higher would this burden be, if not for the application of new, useful knowledge from the advanced biological sciences?			
	DALYs	Per cent		DALYs	
		Lower	Upper	Lower	Upper
Years of life lost (YLL)	411 953	25	50	102 988	205 977
Years lost to disability (YLD)	87463	35	70	30 612	61 224
Total burden	**499 416**	**27**	**54**	**133 600**	**267 201**

Sources: Begg et al. (2007); AIHW; expert panel; consultations; The CIE.

VALUING THE HEALTH IMPACT OF RECENT ADVANCES IN THE BIOLOGICAL SCIENCES

It is possible to value the reduction in the burden of disease by borrowing a concept from regulatory economics: the 'value of a statistical life year'.

The value of a statistical life (VSL) is used to estimate the value that society places on reducing the average number of deaths per year by one. Related to the VSL is the *value of a statistical life year* (VSLY), which is the value of adding one year to the average life.

The Office of Best Practice Regulation recommends using a VSLY of $175 437 [13] in 2012–13 dollars. The office has estimated this figure with willingness-to-pay concepts,[14] and it can therefore be interpreted as the value society places on adding one year to the average life.

Applying the VSLY to the estimated reduction in Australia's burden of disease from the application of advanced biological sciences (471 806 to 890 896 DALYs) results in an estimate of the value to Australians of between $83 billion and $156 billion.

We interpret this result as follows: Australians (collectively) would be willing to pay between $83 billion and $156 billion for the reduction in the burden of disease (or the improvement in health) that recent advances in biological sciences have achieved.

CASE STUDIES

The following case studies illustrate the impact of the recent advances in biological sciences on the health of Australians.

Case study 3.1: Gardasil

The problem: cervical cancer

Cervical cancer causes 250 000 deaths worldwide each year (Frazer 2014) and was forecast to cause 250 deaths in Australia in 2015 (Cancer Australia 2015).[15]

Before the discovery and development of the vaccine Gardasil, no vaccine was available. If a woman is diagnosed with cervical cancer, treatment options include surgery (to remove cancers from the cervix), radiotherapy and chemotherapy. Those treatments have significant negative side effects. If the cancer has spread out of the pelvis, it is not usually considered 'curable'.

Partial solution: discovery of Gardasil vaccine

Gardasil acts as a vaccine against cervical cancer and anal cancer by preventing infection with the virus that causes then, the human papillomavirus (HPV). It introduces non-infectious virus-like particles that mimic the HPV virus into the body. This activates the body's natural immune response, which protects against future infection by the real HPV virus (UQ 2015).

13 This is based on the recommended value of $182 000 in 2014 dollars, adjusted for inflation (OBPR 2014).
14 Various methods can be used to calculate VSLY (including willingness-to-pay and human capital approaches). The willingness-to-pay method is preferred by Australian governments. Both approaches are discussed in Appendix 3.
15 Sources: References cited.

The development of the vaccine started in 1991 with the expression of the human papillomavirus L1 and L2 proteins together. The vaccine was further developed in the early 1990s by research groups from around the world who expressed the proteins in different forms, including groups from the University of Queensland, Georgetown University, the National Cancer Institute and the University of Rochester (McNeil 2006). Once the technologies for the vaccines were developed, two different vaccine companies then developed and tested products in clinical trials for commercial development (Frazer 2014).

The development of Gardasil is a clear example of how biological research conducted collaboratively by different people and institutions around the world has significantly increased knowledge and understanding and resulted in tangible improvements in health outcomes. Australian researchers played major roles in the research efforts.

Future benefits

The vaccine protects against around 70% of cervical cancer cases, 80% of anal cancer cases and 90% of genital warts cases (Gardasil 2015). In 2014, about 73% of Australian 15-year-old girls and 60% of 15-year-old boys had been vaccinated (National HPV Vaccination Program Register 2015). The full benefit of the vaccination program is expected in several decades, when the vaccinated population reaches the age at which cervical cancer is commonly diagnosed (around 50).

Case study 3.2: The impact of the advanced biological sciences on periodontics

Advances in our understanding of the biology of the mouth are driving substantial changes in dentistry. Apart from improvements in the treatment of tooth decay (see Case study 2.3), the focus of dentistry is evolving. According to Professor Eric Reynolds AO, dentists are becoming 'physicians of the mouth' who focus (more generally) on the health of the mouth and link from that to overall health.[16]

An increased focus on gum disease

Gum disease occurs when the process that drives tooth decay attacks gums (that is, naturally occurring bacteria produce acid that erodes healthy tissue in gums). Advanced gum disease is periodontitis, in which small holes form in gums under or behind teeth. The superficial result is loose teeth and bad breath. The important result is a sharp increase in the build-up of bacteria in the mouth, as the holes allow bacteria to grow because they cannot be dislodged by brushing and flossing.

Advanced genetics has established genetic predisposition as one cause of the disease.

Why is preventing and treating gum disease important?

Epidemiologists have found statistical links between periodontitis and other significant diseases, including cancer and stroke. Dental and biological researchers believe that the bacteria that build up in periodontitis escape into the bloodstream and this causes the other significant diseases that have been linked to periodontitis. One of the symptoms of periodontitis is bleeding while brushing. Perversely, therefore, brushing could be one way that bacteria from periodontal disease get into our blood.

Diagnosing and treating gum disease

Traditionally, dentists and periodontists (specialists in periodontal disease) have diagnosed periodontitis visually or mechanically (by measuring pocket depths). Treatment has ranged from cleaning affected surfaces to surgery (including implants).

More recently, researchers at the Oral Health Cooperative Research Centre (based at the University of Melbourne), CSL and other organisations have been developing new ways of tackling periodontitis. This has been facilitated by breakthroughs in the advanced biological sciences.

Diagnosing periodontitis

Researchers are developing a kit that uses monoclonal antibodies to detect the level of bacteria in our mouths. This detection could be used to diagnose periodontitis.

Treating periodontitis

Researchers are developing antibody-based therapeutics for periodontitis. The goal is to produce both a preventative and a vaccine.

16 Sources: Professor Eric Reynolds AO; Oral Health CRC (2013–14); American Academy of Periodontology; Dental Health Services Victoria

Case study 3.3: Herceptin (a treatment for some breast cancers)

The problem: breast cancer

As noted in Chapter 6, cancer is the most 'burdensome' disease in Australia. It causes the highest combination of premature deaths and years lost to disability. Some treatments are available for cancer (including, for example, chemotherapy). However, those treatments can have substantial side effects and may not be effective in some cases.[17]

One relatively recent solution: monoclonal antibodies

A recent innovation in the fight against cancer is the use of monoclonal antibodies. According to the US Cancer Society, the US Food and Drug Administration has approved more than a dozen monoclonal antibodies over the past couple of decades to treat cancers.

The use of antibodies to treat certain diseases is advanced biology. Antibodies attach to proteins called antigens (part of a virus cell, cancer cell, etc.) and then recruit other parts of the immune system to destroy the cells containing the antigen. Researchers can design antibodies (called monoclonal antibodies) to attach themselves to certain types of antigens and thus treat certain types of diseases. Monoclonal antibodies are used to treat rheumatoid arthritis, certain types of cancers and human respiratory syncytial virus in children.

HER2-positive breast cancer

HER2 (human epidermal growth factor receptor 2) is a gene in breast cells. Normally, it helps control how a healthy breast cell grows, divides and repairs itself.

In around 25% of breast cancer cases, the cancer cells contain HER2 genes that do not work correctly. They make too many copies of themselves, and this puts too many (associated) HER2 receptors on the surface of the cancer cells. These receptors promote the rapid growth of the cancer cells in a phenomenon called 'HER2 gene amplification'. Breast cancers that grow in this fashion are considered aggressive because of the speed at which they grow.

Pathologists can determine whether a particular case of breast cancer is spread by HER2 gene amplification (it is usually diagnosed as 'HER2-positive breast cancer').

Herceptin: a treatment for HER2-positive breast cancer

The drug Herceptin is a monoclonal antibody that works by attaching itself to HER2 receptors on the surface of the cancer cells and blocking them from receiving growth signals. This can help slow or even stop the growth of HER2-positive breast cancer.

In addition, Herceptin can alert the immune system to the cancer cells to which it is attached, and the immune system can destroy those cells.

Herceptin does have some known side effects, including high blood pressure, joint and back pain, hot flashes, headache and diarrhoea.

Case study 3.4: Cardiovascular disease and statins

Cardiovascular disease: a problem that has declined in Australia

Cardiovascular disease involves narrowed or blocked blood vessels that can lead to heart attack, angina or stroke. While these conditions can and do cause death, the number of deaths caused by them has been in significant decline around the developed world since the 1960s, including in Australia. Currently, cardiovascular disease claims around 45 000 Australian lives a year. Had the mortality rate remained at 1968 levels, that figure would be around 200 000 (AIHW 2014a).[18]

As discussed in more detail in Appendix 3, the reduction in cardiovascular disease can be attributed to behavioural change and medical improvements.

Behavioural improvements

Epidemiology studies identified links between cardiovascular disease and factors such as smoking and obesity, as well as other conditions such as high blood pressure. Following these findings, public health policies have significantly lowered the prevalence of smoking, which has had a large impact in reducing cardiovascular disease.

Medical advances, including statins

Additionally, medical advances have been targeted at reducing cardiovascular risk by lowering blood pressure and cholesterol.

17 Source: The CIE.
18 Sources: References cited.

Statins are one of a number of drugs that have been developed and used to lower cardiovascular disease incidence and mortality. The main effect of statins is to lower cholesterol levels in patients.

Statins work by blocking an enzyme that is involved in the formation of low-density lipoproteins, and therefore limits the accumulation of lipids in arteries. The use of statins reduces the risk of atherosclerotic disease, including coronary heart disease, stroke and cardiovascular mortality (CTTC 2010).

Meta-analyses of statins trials have demonstrated that treatment with statins leads to a one-fifth reduction in the five-year incidence of major coronary events, revascularisation and ischaemic strokes per 1 mmol/litre reduction in low-density lipoprotein cholesterol levels. (CTTC 2010).

Case study 3.5:Personalised medicine

Personalised medicine is the identification and use of variations in a person's genetic makeup (relative to 'normal') to prevent, diagnose and treat disease more effectively.[19]

The 'problem': the practice of medicine before personalised medicine

The use of personalised medicine is not yet commonplace. Therefore, in most cases our own recent experiences are of medicine before this innovation. For many diseases, the focus is on diagnosis and treatment after onset. Diagnosis is often based on symptoms that might be indicative for several diseases. In addition, treatment can involve multiple drugs or techniques, some of which are not effective. Doctors might try one treatment and, if that is not effective, try others.

Disease prevention can be non-specific. For example, doctors advise against smoking because it causes 'cancer' (generally). While this is important, there may be other steps we could take to reduce the likelihood of contracting specific diseases.

The breakthrough in the advanced biological sciences

Cutting-edge research in the advanced biological sciences includes ongoing worldwide efforts to identify and map all the genes in the human genome. For an individual, we can now use tests to identify variations in his or her genes (relative to 'normal').

How this is affecting medicine?

Many diseases are associated with variations in genes. Doctors can use genetic tests to identify variations in individuals' genes and apply that knowledge in two broad ways.

More accurate predictive medicine

With genetic testing, doctors can more accurately measure the risk of an individual contracting a specific disease. The doctor can tailor preventive treatments that relate to the disease and help the patient make choices relating to lifestyle, reproductive matters, screening and preventive treatments that reduce the likelihood of contracting the disease. For example, Angelina Jolie recently underwent a proactive double mastectomy after tests showed that she carried BRCA1, the genetic marker for breast cancer (which her mother, who died of the disease, also carried).

Treatment optimisation

The take-up of drugs (treatments) by the body involves enzymes in our bodies. However, enzymes have genetic variations, which means they vary slightly among people.

For a particular patient, pharmacogenomics is the practice of discovering which drug they should take, given their disease and their genetic make-up. This is important, as in some cases, taking the wrong drug creates more costs than benefits.

An example of optimising the treatment of AIDS

Abacavir is a drug used for treating human immunodeficiency virus (HIV) infection. However, 5%–8% of patients can develop an allergic reaction (Stevens Johnson syndrome) that is potentially life threatening.

In 2008, researchers in Western Australia showed that Caucasians with the HLA-B*5701 allele were particularly susceptible to this allergic reaction. They developed a DNA genetic test that detects whether an HIV patient has a marker for HLA-B*5701. If so, the patient is not prescribed Abacavir. This test is one of the few DNA genetic tests funded through Medicare.

With the discovery and application of this DNA genetic test, the number of patients on Abacavir who develop Stevens Johnson syndrome has fallen to 3.4%.

19 Sources: NHMRC (2011); McMullan (2015).

EVALUATION OF THE IMPACT ON THE BURDEN OF DISEASE

Alternative approaches to measuring the burden of disease and changes over time

Figure 3.1 illustrates one hypothetical scenario of changes in the burden of disease over time and the counterfactual scenarios to which the observed burden can be compared. In this example, we assumed that the burden of disease has declined over time and that this decline is attributed to two broad drivers: medical improvements due to advanced biology, and other factors such as behavioural change.[20]

In addition to medical improvements and behavioural changes, the burden of disease is likely to be influenced by changes in the population level and age structure (for example, an older age structure would lead to an increasing burden). However, these complicating factors can be removed from the equation by using an age-standardised rate of burden.

If there were no improvements in medical technology and no change in environmental or behavioural factors that influence health outcomes, the burden of disease (as an age-standardised rate) would remain constant over time (as illustrated by the dotted line in Figure 3.1).

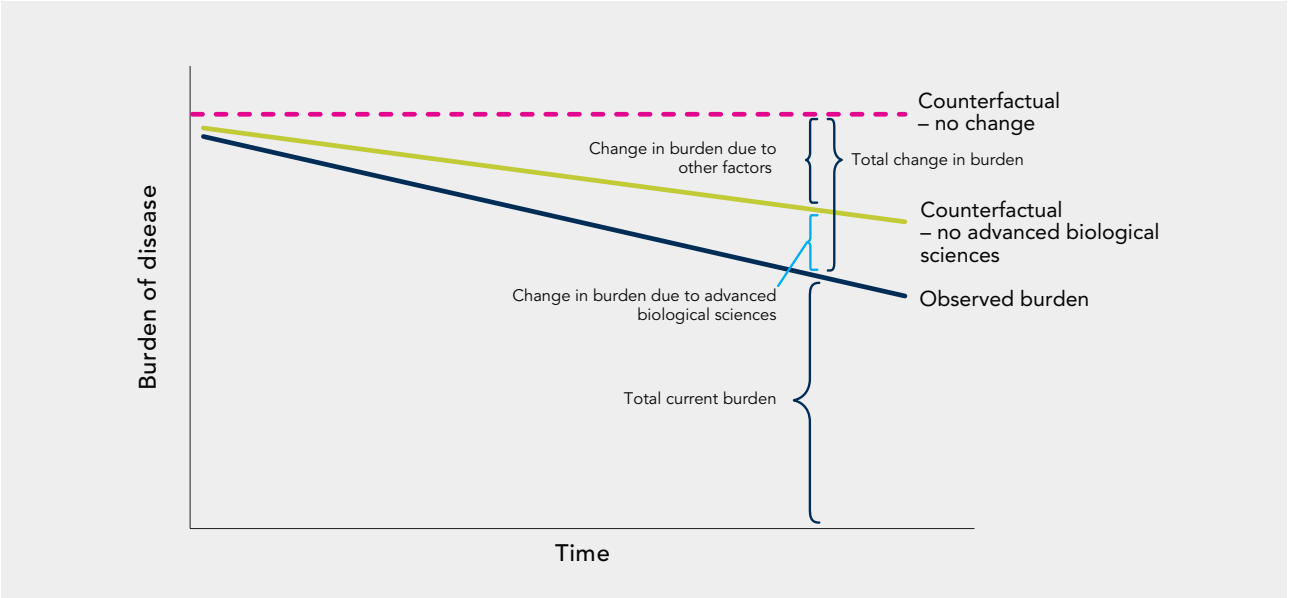
The observed burden of disease is shown to decline by the solid teal line in the chart. The current level of burden is measured as the height of this line and is the value that is measured in studies of the economic cost of particular conditions.

The total change in burden (the difference between the dotted and solid teal lines) is observed in historical data (as discussed later in this section).

However, in this study we were interested in isolating the impact of recent advances in biological sciences on the burden of disease, so the total change in burden was broken down into the two major drivers: medical improvements (assumed to be due to advanced biology) and other factors (such as behavioural change).

In Figure 3.1 we have shown that the other factors act to reduce the burden of disease. This could be, for example, a result of reduced rates of smoking that help to lower the incidence of cardiovascular disease. The remainder of the reduction in burden can be attributed to new medical treatments from advanced biological sciences. To continue the cardiovascular disease example, this may be the use of statins to reduce the incidence of heart disease or improved surgical procedures that increase survival rates from stroke.

Figure 3.1 Change in the burden of disease over time



Data source: The CIE.

20 Two alternative examples are described in Appendix 3 in which the other factors act to increase the burden of disease over time. However, the concepts described here and the relationship between the measures of the burden of disease remain consistent.

The remainder of this section puts the results of this study into the context of other related literature. The discussion shows that, although direct comparisons are not appropriate, the results of this study are broadly consistent with the literature.

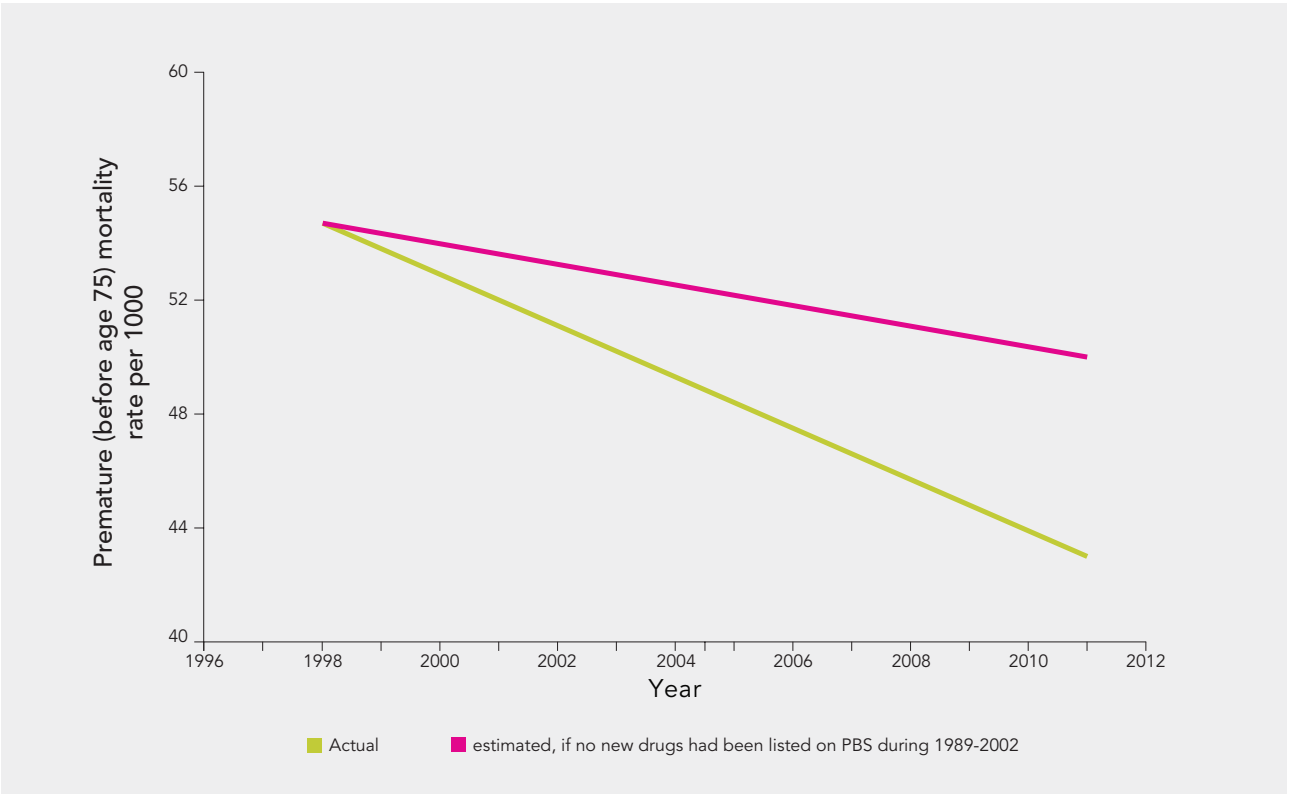
Comparison with relevant literature

Lichtenberg (2015) conducted a similar analysis to that attempted in this study by looking at the impact of pharmaceutical innovation on health outcomes in Australia. More specifically, he used econometric analysis to assess the effect of pharmaceutical innovation, measured by the number of new drugs listed in the Pharmaceutical Benefits Scheme (PBS), on declines in premature mortality (changes in years of potential life lost). Figure 3.2 is a simplified illustration of the results of his analysis. The two lines in the chart are effectively equivalent to the 'observed burden' and 'counterfactual—no advanced biological sciences' lines in Figure 3.1.

Lichtenberg found that new pharmaceuticals had the greatest impact on mortality nine years after being listed in the PBS. If no new drugs had been listed in the PBS between 1989 and 2002, the number of years of potential life lost before age 75 in 2011 would have been 16.5% higher. He estimated that 60% of the decline in premature mortality (deaths before age 75) between 1998 and 2011 was due to previous pharmaceutical innovation.

The most relevant result from Lichtenberg (2015) for comparison with our study is that the number of years of potential life lost before age 80 in 2011 would have been 22% higher if no new drugs had been listed in the PBS between 1989 and 2002.

Figure 3.2 The estimated impact of pharmaceutical innovation on mortality rates



Data source: Based on Lichtenberg (2015, Figure 6).

As noted by Lichtenberg, pharmaceutical innovation is just one type of medical advance leading to improved health outcomes. Therefore, we would expect the estimated impact of all medical advances to be greater than Lichtenberg's estimate of 22%. Furthermore, Lichtenberg uses a measure of premature mortality relative to age 80 (or 75). In this study, we found that the YLL due to all diseases would have been 23%–37% higher were it not for the application of advanced biological knowledge. The YLL figures used in this study are relative to a standard 'ideal' life expectancy, which is greater than the life expectancy used in potential years of life lost measures as used by Lichtenberg.[21] Again, this would mean that the estimated impact in Lichtenberg (2015) would be lower than estimated in this study.

Beyond the work conducted by Lichtenberg, the literature does not present estimates of the impact of medical advances on health outcomes directly comparable to those in this study. Other work, as described in the remainder of this chapter, can provide some context for our results, but it should be interpreted with care when being related to the results of this study.

Comparison between our results and observed changes in the burden of disease

One way to place the estimated impact of the advanced biological sciences into context is to show the results in the context of observed changes in the burden of disease over time. However, there are limited time-series data available on the burden of disease in Australia:

- The Australian Institute of Health and Welfare (AIHW) publishes burden of disease figures for Australia. The latest data currently available are for 2003; just one other year of historical data, for 1993, has been provided (Begg et al. 2007).
- AIHW (2015) provides data on the fatal burden of disease (YLLs) for 2010, but the methodology for this study differs from Begg et al. (2007), so the results cannot be compared.
- AIHW is expected to release data on the burden of disease for 2011 in 2016. This will include historical data for 2003. Again, the methodology will differ from Begg et al. (2007) and so will not be directly comparable.
- The Australian Bureau of Statistics (ABS 2007–2015) published data on the causes of deaths in Australia, and a consistent time series of age-standardised death rates can be constructed from 1995 to 2013. Data on the years of potential life lost (YPLL)[22] are available for the period from 2005 to 2013.
- The World Health Organization (WHO) maintains a mortality database (WHO 2015), which includes deaths and death rates for Australia up to 2011.
- The Institute for Health Metrics and Evaluation at Washington University maintains a database of global burden of disease data (IHME 2015). A global burden of disease study was released in 2010 and updated in 2013. Data can be downloaded for Australia in five-year increments from 1990 to 2010, and for 2013. However, there are a number of limitations to these data:
  - The results are not comparable to the Australian-specific Begg et al. (2007) study due to methodological differences.
  - Morbidity results are based on data and modelling not specific to Australia.
  - For the 2010 study (and this is assumed to be the case for the 2013 update), Australian mortality data were only available up to 2006, and modelling techniques were applied to estimate rates to 2013 (AIHW 2014b).
  - The burden of disease data clearly show a discontinuity in 2005, when a previous steady decline stops and the burden of disease is reported to remain relatively constant to 2013. An explanation for this disjoint was not found.

Overall, there are some useful time-series data on mortality rates available but very limited time-series data on the burden of disease. We conclude that there are not sufficient reliable data to compare our results with the overall change in the burden of disease. Even if suitable data were available, observed changes in the burden of disease would provide only part of the relevant information. We still need evidence on the contribution of medical advances, as opposed to other factors, to the changes. This is discussed in the following section.

21 YLLs used by Begg et al. (2007) and the basis for the figures used in this report are constructed around an 'ideal' age of 82.5 years for women and 80 years for men.

22 YPLL differs from YLL measures. YPLL measures the years lost up to a specified age, in this case age 79. YLL measures are expected to be slightly higher, as they use a higher reference year (in Begg et al., the age used is 82.5 in women and 80 in men).

Comparison with other literature

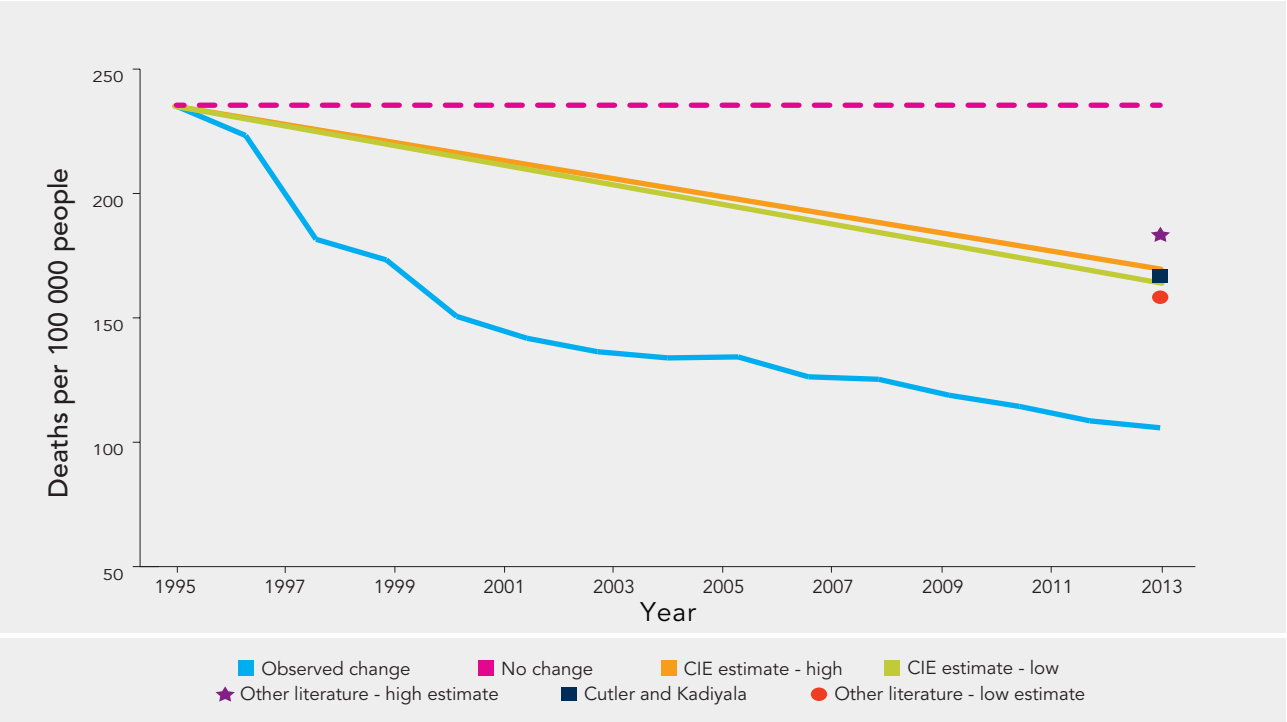
Deloitte Access Economics (2011a) estimated the impact on health outcomes of research funded by the National Health and Medical Research Council (NHMRC). In doing this, it relied on an estimate that 50% of improvements in health outcomes are due to research (33% due to research on medical treatments and the remainder due to research on behavioural factors). These assumptions appear to be based on initial research by Cutler and Kadiyala (2001) on the reduction in mortality from cardiovascular disease in the United States.

It is estimated that YLL due to cardiovascular disease would be 35%–40% higher without recent advances in the biological sciences. Data from the ABS (2007–2015) show that the mortality rate for cardiovascular disease declined by 55% between 1995 and 2013. Based on Cutler and Kadiyala (2001), we could attribute a decline of 18% to medical research and 37% to other factors. In other words, the mortality rate would have been 41% higher had it not been for medical research. This result is consistent with the findings of our study.

Other studies estimate that between 23% and 47% of historical changes in mortality from cardiovascular disease are due to new and improved treatments (see Appendix 3 for details of the literature). Based on the historical changes in mortality from cardiovascular disease, and these figures from the literature, we can say that the mortality rate would have been 28%–58% higher without new treatments.

These results from the literature are shown in Figure 3.3, along with the CIE estimates (based on estimated change in YLL due to advanced biology) and the observed change in the mortality rate for cardiovascular disease. The chart shows that the CIE estimates are consistent with the available literature, despite not being directly comparable.

Figure 3.3 Observed and estimated change in mortality rates for cardiovascular disease in Australia



Data source: The CIE, based on ABS (2007–2015), Cutler and Kadiyala (2001) and other literature as discussed in Appendix 3.

A number of studies in the literature look at the current economic cost of selected health conditions (the height of the observed burden line illustrated in Figure 3.1). These studies do not generally look at how much of the economic cost could reasonably be avoided or reduced through interventions, either medical or behavioural. Nor do they provide insight into how and why economic costs may have changed over time. Therefore, it is not appropriate to compare the results of this study with estimates of the economic cost of particular conditions.

EVALUATION OF THE VALUE WE ASCRIBE TO THE IMPACT ON HEALTH

The value of improved health outcomes to the economy is realised in a number of ways:

- avoiding healthcare expenditure
- avoiding productivity losses associated with patients and carers who are unable to work
- reducing deadweight losses associated with government expenditure on health care
- reducing the non-financial costs associated with the burden of disease.

Because it is the most significant source of benefit, in this report we have focused on the last of these—the reduction in the non-financial costs associated with the burden of disease in the community. This value was estimated using the value of statistical life years, a measure of society's willingness to pay to add one year to the average life.

The willingness-to-pay approach provides an *ex ante* measure of the amount that individuals are willing to pay for various perceived gains, for a certain improvement in health, the prevention of an impaired health state or a reduction in risk of an adverse event (Abelson 2007). This implicitly incorporates some values for labour productivity as well as pain and suffering associated with a death or illness.

By convention, the value of a statistical life is assumed to be the life of a young adult with at least 40 years of life ahead; however, it is not the life of any particular individual. This implies that the utility of consumption is constant for all ages, whereas it may be higher at some ages than others (Abelson 2007). Many of the improvements in health outcomes that come from advanced biology are more applicable to older populations, so our estimate of the value of the reduced burden of disease is likely to be overstated.

There are many examples in the literature in which the current economic cost of a particular condition was estimated by summing the various values listed above.[23] We decided to focus on the non-financial costs associated with the burden of disease for the following reasons:

- The literature shows that the non-financial costs of diseases far outweigh the financial costs. In some cases, non-financial costs are up to 92% of total estimated economic costs (Deloitte Access Economics 2011b); the lowest estimate in the reviewed literature was 55% (Deloitte Access Economics 2011c).
- The impact of advanced biology on direct health expenditure is very complex. The overall impact depends on whether treatments are new, replace existing treatments or supplement other treatments. It also depends on a treatment's take-up and its effect on subsequent use of the health system (for example, by reducing the need for longer hospital stays or subsequent treatment). It is often observed that new medical treatments and technologies increase health expenditure (for example, see PC 2005).
- As discussed below, estimating the impact of health improvements on GDP (realised through productivity improvements) and adding this to the calculated value associated with the burden of disease is problematic, and the increment is likely to be relatively small.
- Finally, there are major limitations of data availability and uncertainty that make further valuation of the benefits of improved health outcomes difficult.

23 Some of this literature is discussed in Appendix 3.

The impact of health improvements on gross domestic product

Productivity costs are often the largest financial costs of poor health. The measure of the productivity losses from death and poor health reflects the reduction in labour supply as people are unable to work due to their own health conditions, or because of the time they need to provide informal care to others.

Verikios et al. (2015) projected the economy-wide effects of changes in the health of the Australian workforce. They found that if the health of 10% of workers aged 49 to 60 were to be improved by one health status category (that is, from poor to fair, or fair to good), real GDP would increase by around 0.1% over the period from 2011 to 2030. The same health improvement in workers aged 29 to 38 leads to an increase in GDP of 0.008%. Applying these percentage changes to current GDP figures yields values of $1 297 million and $104 million, respectively.

The productivity implications of the estimated improvement in health outcomes due to the application of knowledge from recent advances in biological sciences could be roughly approximated using these figures:

- If a 10% health improvement were applied to the entire working age population (say, 18 to 69),[24] the expected change in GDP would be around 0.216%,[25] or $2 801 million.
- The estimated impact of advanced biology on health outcomes was 18% to 34%; this means that the expected change in GDP may be between $5 042 million and $9 523 million.

This may be a generous estimate. Many of the health improvements expected from the application of advanced biological knowledge are likely to affect older Australians, many of whom may have retired from the workforce, and therefore might not greatly affect productivity.

Even with these generous assumptions, the estimated productivity impacts are far lower than the estimated non-financial value of the reduced burden of disease, based on willingness-to-pay measures and the value of a statistical life year (between $83 billion and $156 billion).

The estimated non-financial value of the reduced burden of disease incorporates some valuation of productivity impacts. Therefore, it is not appropriate to add the two estimates.

24 There will be some people under 18 or over 69 working, but many between 60 and 69 not working.

25 Verikios et al. (2015) report results only for the two age brackets. If we assume that the impact on ages 18–29 is equivalent to that on ages 29–38, and the total impact on ages 39–69 is twice the impact on the 49–60 bracket, we get a change in GDP of 0.216%.

CHAPTER 4

4. THE IMPACT OF ADVANCES IN THE BIOLOGICAL SCIENCES ON THE ENVIRONMENT

This chapter presents a number of case studies to illustrate the importance of biology in contributing to environmental outcomes. Lack of comprehensive data means that we are unable to provide economy-wide estimates of the impact of biology on the environment. Nevertheless, a key insight from the consultations conducted by the CIE is that advanced science (especially ecology, soil science, marine biology and related disciplines) provides knowledge that contributes to more effective environmental management, which in turn increases the value of the natural resources and ecosystems used in Australia.

The illustrations presented here indicate the nature of the impacts, many of which can be surprising.

The biological sciences are central to natural resources system management. They play an important role in understanding the ways in which natural ecosystems deliver a range of services to humans, as well as in enhancing the management of the various natural systems that support humans. Importantly, many of the impacts of natural systems on human outcomes are not directly priced in economic transactions, so the value of improved natural resources outcomes (and therefore the value of biology) cannot be measured directly but must be inferred through a range of indirect measurement techniques.

ILLUSTRATING WHAT IS AT STAKE

Two studies have been conducted into Australians' willingness to pay to improve ecosystems and their management.

The value of a small improvement in the Great Barrier Reef

Rolfe and Windle (2010) used choice modelling to conclude that Australia-wide willingness to pay (or the national value created) for a '1%' improvement in the Great Barrier Reef ranges from $433.6 million to $811.3 million. Case study 4.1 illustrates one way in which biological research can contribute to improvements in the reef.

The value of improvements in the health of the Coorong

Hatton Macdonald et al. (2011) used a choice modelling study to estimate the willingness to pay of households across Australia for various improvements in the health of the Murray. Using a normal discount rate (5%) and the conservative assumption that non-respondents to the survey had a willingness to pay of $0, the authors estimated that across Australian households there is a total willingness to pay $5.8 billion for an improvement in the health of the Coorong from 'poor habitat' to 'good habitat'.

HOW ADVANCES IN THE BIOLOGICAL SCIENCES CAN HELP THE ENVIRONMENT

Advances in the biological sciences have the potential to improve environmental management and to reveal surprising sources of environmental benefits. At the same time, the application of new biological knowledge in pursuit of production benefits can sometimes bring gains for the environment.

Knowledge improves management

New knowledge discovered through advances in biology improves our understanding of a number of aspects of natural systems, including:

- the determinants of the 'health' of the systems
- the many ways in which human activities depend on the health of the systems.

Combined with valuation techniques from economics and other disciplines, this allows increased understanding of the value of improvements in natural systems (both in terms of direct use and in terms of the value of the existence, or indirect use, of environmental resources). This in turn helps to identify changes in behaviour and environmental management that would allow environmental values to increase. (See Figure 1.5 in Chapter 1.)

Case study 4.1 on the Great Barrier Reef provides an illustration of this broad process.

Sometimes environmental outcomes are an indirect result of production benefits

The following are examples in which environmental benefits have been the indirect result of the use of advanced biological knowledge to increase production:

- **Self-healing concrete.** Recent advances in microbiology have led to the creation of 'self-healing' concrete, which has the potential to substantially reduce the need to produce new concrete. While this has clear production benefits, it may also have a substantial environmental impact—concrete production is a significant source of greenhouse gas emissions, so reduced demand for new concrete will reduce emissions. (See Case study 2.2 in Chapter 2.)
- **Genetically modified cotton.** The development and use of GM cotton has allowed Australian farmers to substantially reduce and change their use of insecticides and herbicides. While this has clear production benefits, it has also led to environmental improvements through a reduction in the potential for the runoff of harmful chemicals. (See case study 2.11 in Chapter 2.)
- **Biological control of rabbits**. Biological control of rabbits, including through agents released in the past 30 years, has led to substantial economic benefits. For example, the economic savings generated by the release of rabbit haemorrhagic disease virus in 1995 are estimated to have been around $350 million a year since then. This control has also led to a variety of (as yet unvalued) environmental benefits, including the regeneration of native vegetation and increases in populations of native animals—including spinifex hopping mice, common wombats and western grey kangaroos (See Cox et al. 2013).

Sometimes biological research reveals unexpected sources of environmental benefits

Results from biological research have helped in other environmental management efforts, often in surprising ways:

- Detailed research designed to increase understanding of the impact of bushfires (both natural and planned) led to the important discovery that *planned* fires release only a small proportion of carbon stored in forests (2%–3%) and that carbon emissions from planned burns were half the emissions generated through wildfire. This has important implications for the management of greenhouse gas emissions in Australia. (This research was undertaken by the Bushfire CRC[26]; see Bell et al. 2014).
- Research into the biology of soils indicates that there are many key links between soil biodiversity and human health. This suggests a variety of benefits arising from better management of soil resources (see Wall et al. 2015).
- Recent biological research has expanded understanding of the role of different pollinators for crops, which has implications for the management of ecosystems for direct human benefit (Rader et al. 2015).
- Biologically based research indicates that that Australia's quarantine system (which is in large part based on biology) generates significant net benefits, and that our system could beneficially be applied in other countries (Keller et al. 2007).
- Analysis of biological research undertaken in developing countries as part of Australia's aid program indicates that $1.2 billion of benefits return to Australia as a direct consequence of that research. Much of the benefit (almost 50%) comes from indirect protection from invasive species as a result of the successful application of biological research in our near neighbours (Harding et al. 2009; ACIAR 2006).
- Recent research has indicated that the successful control of feral cats and the control of foxes are closely related and need to be undertaken at the same time. (Case study 4.2 illustrates these findings.)

26 Bushfire CRC ended in 2014; its legacy website is at http://www.bushfirecrc.com/.

CASE STUDIES

The case studies presented here illustrate a variety of means by which advanced biological research can contribute to improved environmental outcomes and through this to improved outcomes for a range of human activities.

Case study 4.1: Advanced biological sciences drive a healthier, more resilient Great Barrier Reef

The problem: a decline in live coral and fish in the Great Barrier Reef

The Great Barrier Reef (GBR) lost half of its coral cover (the proportion of reef covered by live stony coral) in the 27 years to 2012 (AIMS 2012). Corals are the architects of the reef, providing shelter to fish and many other species, as well as protecting shorelines. Furthermore, numbers of fish are also depleted in areas that are heavily fished compared to remote or well-protected regions.[27]

Advances in the advanced biological sciences

A key advance in the biological sciences in the past 30 years has been an increase in our understanding of the importance of biodiversity and the movement of species. In the context of the GBR, we now understand more about the interdependence of corals and other associated ecosystems (including mangroves, seagrasses, algal beds, deeper water systems and so on).

The resulting policy innovation (a partial solution to the problem)

Before 2004, 'no-take zones' (NTZs), where fishing is banned, covered less than 5% of the GBR Marine Park. The NTZs focused on coral reefs, especially those in remote, pristine areas (Day et al. 2003).

The implication for biodiversity is that, even if our goal is merely to protect pristine corals, it is not enough to focus exclusively on them. We need to protect the other systems that these reefs depend on (including seagrasses, mangroves and so on). Therefore, in 2004, our management approach changed substantially in two interrelated ways.

Target biodiversity, not just pristine remote reefs

In 2004, the extent of NTZs was substantially increased to cover 33% of the GBR Marine Park. Not only did NTZ coverage of corals increase, but many new NTZs were applied to non-coral areas (such as seagrass beds). The policy was called the Representative Areas Program, in which each type of ecosystem was 'represented' in the coverage of NTZs. The specific goal of this policy was to protect biodiversity in the GBR, and not just coral reefs.

In addition, the layout of the expanded network of NTZs was not random. Computer modelling and expert and stakeholder opinion were used to carefully design the NTZ network to support the movement and interaction of species between NTZs and other desirable ecological outcomes. The design also incorporated social and economic information and goals.

Target reef resilience

While the specific aim of the Representative Areas Program was to protect biodiversity, this aim was adopted because supporting biodiversity ultimately supports the health of the GBR. As a healthier reef is better able to withstand and recover from shocks (such as cyclones and coral bleaching, which occurs when sea temperatures rise to stressful levels), the policy is forward looking and seeks to improve the resilience of the GBR.

The benefits of increasing NTZs

Studies confirm that NTZs successfully achieve simple goals. Following the 2004 policy change, McCook et al. (2010) recorded a doubling in the number and size of targeted fish in new NTZ areas in different parts of the GBR.

Furthermore, current research is yielding clear evidence that NTZs create broad benefits that support the health and therefore the resilience of corals. This means that they are likely to be supporting the health and resilience of the entire reef ecosystem, as corals provide the structure that underpins other ecosystems in the GBR.

27 Sources: Professor Terry Hughes (ARC Centre for Excellence, Coral Reef Studies, James Cook University); Great Barrier Reef Marine Park Authority; the cited publications.

Reduced coral disease inside GBR NTZs

Lamb et al. (2015) found that the incidence of disease is significantly lower (by a factor of 4) for corals in NTZs than for corals in non-NTZ areas. The authors investigated a number of explanations and concluded that discarded or lost fishing gear (including lines and hooks) damages corals and that disease is initiated in and then spreads from damaged sites. This source of disease is obviously far more prevalent in non-NTZ areas than in NTZs.

More grazing of seaweed by herbivorous fish inside Caribbean NTZs

Seaweed competes with coral for space in reef environments. In extreme cases, unchecked seaweed growth can overwhelm and eventually replace large tracts of corals (a phenomenon scientists call a 'regime shift'). Seaweeds are naturally controlled by herbivorous fish and sea urchins, which eat seaweed. Live corals in the Caribbean were substantially reduced (and have yet to recover) after the herbivorous urchin *Diadema antillarum* suffered a mass disease-induced mortality in 1983.

Mumby et al. (2006) studied the grazing intensity of herbivorous parrotfish on seaweed on reefs in and next to the Exuma Cays Land and Sea Park in the Bahamas, where fishing has been banned since 1986. They found that grazing intensity was twice as high on reefs inside the park than it was on reefs outside the park, with an associated fourfold reduction in seaweed cover.

This is because parrotfish are fished in the Bahamas. Inside the park, parrotfish are protected from fishing and their grazing intensity remains high. This impact was partly offset by the effect of increased predation of parrotfish by predators, which also benefited from the protection from fishing. This net benefit for parrotfish (less fishing, offsetting more predation) was particularly evident for larger species of parrotfish (which are targeted by spearfishers).

On nearby reefs where parrotfish fishing is less intense, the authors calculated that grazing by parrotfish drops by 4%–8% due to the effect of increased predation. One caveat for this study (identified by Hughes et al. 2007) is that it is a snapshot in time. The investigation of these effects *over time* is required.

In contrast to the Caribbean, in Australia herbivorous parrotfish are generally not fished. Consequently, parrotfish are both large and very abundant even on the GBR, even if NTZs are reducing their grazing by promoting predation. However, it should be emphasised that the GBR is generally considered to be a reef that is well managed by world standards.

The transfer of benefits from NTZs to other areas

For NTZs to be an effective tool for managing the health of entire reef ecosystems, they must generate benefits that are transferred outside their boundaries. Scientists are gathering evidence that this is indeed the case.

Harrison et al. (2012) studied coral trout and stripey snapper in the Keppel Island group in the GBR. The authors used tissue samples and DNA parentage analysis to show that fish in NTZs export a significant share of their offspring to non-NTZ areas and other NTZs. For example, they identified 58 juvenile coral trout as the progeny of adults sampled within three NTZ reserves. Of those, 83% (48) were collected from non-NTZ areas (reefs open to fishing), 7% were collected from their parents' NTZ reef and 10% were collected from another NTZ. Using these results (and others) the authors calculated that Keppel Islands NTZs, which cover 28% of the total area, contribute around half of total recruitment (the creation of new, juvenile fish) in the islands. The authors explain that this is due to the greater fish numbers and fish size (which contributes to fecundity) in NTZs.

In addition, healthy corals in NTZs help to maintain and restore coral in non-NTZ areas, as corals are also able to exchange larvae between reefs.

Case study 4.2: Systems thinking and feral animal control

Results from recent biological research have changed the nature of efforts to control feral cats and foxes (which are predators of native fauna) in Western Australia.

Until about four years ago, efforts by the Western Australian Department of Parks and Wildlife to control feral cats and foxes were essentially separate. In the south-west of the state, foxes were the main target for controls; in the arid zone, cats were the main target. However, recent biological research has prompted the department to think of these feral predators as a 'system' and to integrate control efforts. Now, in the south-west zone, cat control and fox control are integrated.

This follows research by Risbey et al. (2000), who conducted experiments on Heirisson Prong, which is a semi-arid site in Western Australia. They examined three zones:

- one where both foxes and cats were controlled
- one where only foxes were controlled
- one where neither foxes nor cats were controlled.

Counts of small mammals that are eaten by cats and foxes doubled in the zone where both foxes and cats were controlled. But surprisingly, in the zone where only foxes were controlled, counts of small mammals decreased by 80%, and the count of feral cats increased. Where neither foxes nor cats were controlled, mammal counts showed no trend change.

Conclusion

Biological research clearly has a considerable amount to offer for environmental outcomes. However, further impact research is needed to confirm the magnitude of many of those benefits and to allow them to be placed on a consistent economy-wide basis.

APPENDIXES

APPENDIX 1: STEERING COMMITTEE, EXPERT PANEL AND CONSULTATIONS

Here we acknowledge those who contributed to the research that underpins this report.

STEERING COMMITTEE

The steering committee provided direction for the research and helped define the 'advanced biological sciences'.

Table A1.1 Steering committee

Member	Organisation
Professor Kiaran Kirk	ANU
Professor Ian Frazer	Translational Research Institute Pty Ltd
Dr TJ Higgins	CSIRO
Dr Mark Stafford-Smith	CSIRO

Source: The CIE.

EXPERT PANEL PARTICIPANTS

The expert panel (held on 23 and 24 July in Canberra) provided insights on the impact of the advanced biological sciences on production, health and the environment that are the basis of this research.

Table A1.2 Expert panel participants

Expert panel participant	Organisation
Professor Daniel Hoyer	University of Melbourne
Professor Maria Kavallaris	UNSW
Professor Claire Wade	University of Sydney
Dr Julian Clarke	WEHI
Professor Robert Costanza	ANU
Professor Breit Neilan	UNSW
Professor Fiona Wood	UWA
Professor Gary Egan	Monash University
Professor Geoff Donnan	Florey Institute
Dr Beth Woods	Queensland Government
Dr Mark Stafford-Smith	CSIRO
Dr TJ Higgins	CSIRO
Dr Jeremy Burdon	CSIRO
Professor Ian Frazer	Translational Research Institute Pty Ltd
Professor Kiaran Kirk	ANU

Source: The CIE.

CONSULTATIONS

In addition to the expert panel, the CIE attempted to consult as many other experts as possible to get a range of views on the impact of advanced biology and to get further case studies.

Table A1.3 Individuals who provided insight on the impact of advanced biology

Individual	Organisation
Alex Baker	Leaf Resources
Professor Emily Banks	ANU
Professor Jeff Bennett	ANU
Professor Helen Christensen	Black Dog Institute
Dr Matt Colloff	CSIRO
Dr Steven Cork	ANU
Professor Robert Costanza	ANU
Professor Anne Kelso and Professor Davina Ghersi	NHMRC
Professor Terry Hughes	ARC Centre of Excellence for Reef Studies
Professor Allen Kerr	–
Susan Killion	AHHA
Professor Susan Kurrle	University of Sydney
Ashley Millar	WA Department of Parks and Wildlife
Dr Nick Musgrave and Dr Michael Harrison	Sullivan Nicolaides Pathology
Dr Andrew Nash	CSL
Dr Phoebe Phillips	ASMR
Professor Perminder Sachdev	UNSW
Professor Paul Sutton and Sharolyn Anderson	UniSA
Professor Eric Reynolds	University of Melbourne
Associate Professor Stephen Tobin	RACS
Dr Ian Williams	Camp Hill Medical Centre

Source: The CIE.

APPENDIX 2: DETAILED RESULTS

Table A2.1 Industry classes: GVA based on the biological sciences, 2012–13

Industry classes		Total GVA	Science-based GVA[a]	Science share
		$b, current prices	$b, current prices	%
8511	General Practice Medical Services	14	8	58
8531	Dental Services	7	5	80
8401	Hospitals (except Psychiatric Hospitals)	13	4	34
8512	Specialist Medical Services	5	2	46
6910	Scientific Research Services	4	2	54
7711	Police Services	9	2	20
700	Oil and Gas Extraction	32	2	5
1841	Human Pharmaceutical and Medicinal Product Manufacturing	2	1	50
801	Iron Ore Mining	23	1	5
8539	Other Allied Health Services	9	1	10
8520	Pathology and Diagnostic Imaging Services	5	1	17
149	Other Grain Growing	2	1	40
804	Gold Ore Mining	17	1	5
6970	Veterinary Services	3	1	30
1214	Wine and Other Alcoholic Beverage Manufacturing	4	1	20
7530	Local Government Administration	14	1	5
145	Grain–Sheep or Grain–Beef Cattle Farming	3	1	20
142	Beef Cattle Farming (Specialised)	5	1	10
2811	Water Supply	10	1	5
6925	Scientific Testing and Analysis Services	2	0	20
131	Grape Growing	1	0	30
803	Copper Ore Mining	7	0	5
8102	Higher Education	9	0	4
8532	Optometry and Optical Dispensing	2	0	15
600	Coal Mining	18	0	2
1111	Meat Processing	3	0	10
2412	Medical and Surgical Equipment Manufacturing	1	0	20
6221	Banking	54	0	1
6921	Architectural Services	5	0	5
160	Dairy Cattle Farming	3	0	10
2922	Waste Remediation and Materials Recovery Services	1	0	40
152	Cotton Growing	0	0	70

Industry classes		Total GVA	Science-based GVA[a]	Science share
		$b, current prices	$b, current prices	%
171	Poultry Farming (Meat)	0	0	50
301	Forestry	1	0	30
141	Sheep Farming (Specialised)	2	0	10
8533	Physiotherapy Services	2	0	10
8591	Ambulance Services	2	0	10
807	Silver–Lead–Zinc Ore Mining	4	0	5
411	Rock Lobster and Crab Potting	0	0	50
529	Other Agriculture and Fishing Support Services	2	0	10
1133	Cheese and Other Dairy Product Manufacturing	2	0	10
809	Other Metal Ore Mining	4	0	5
1192	Prepared Animal and Bird Feed Manufacturing	1	0	30
123	Vegetable Growing (Outdoors)	2	0	10
192	Pig Farming	0	0	40
806	Nickel Ore Mining	3	0	5
7600	Defence	4	0	4
5309	Other Warehousing and Storage Services	3	0	5
8211	Sports and Physical Recreation Instruction	3	0	5
1112	Poultry Processing	1	0	10
172	Poultry Farming (Eggs)	1	0	20
203	Onshore Aquaculture	0	0	100
510	Forestry Support Services	0	0	30
805	Mineral Sand Mining	3	0	5
2921	Waste Treatment and Disposal Services	0	0	30
144	Sheep–Beef Cattle Farming	1	0	10
139	Other Fruit and Tree Nut Growing	1	0	12
419	Other Fishing	0	0	50
151	Sugar Cane Growing	1	0	10
802	Bauxite Mining	2	0	5
1842	Veterinary Pharmaceutical and Medicinal Product Manufacturing	0	0	50
2812	Sewerage and Drainage Services	0	0	20
6999	Other Professional, Scientific and Technical Services nec	1	0	9
5301	Grain Storage Services	0	0	20

Industry classes		Total GVA	Science-based GVA[a]	Science share
		$b, current prices	$b, current prices	%
412	Prawn Fishing	0	0	50
1199	Other Food Product Manufacturing nec	2	0	5
9113	Sports and Physical Recreation Venues, Grounds and Facilities Operation	2	0	5
159	Other Crop Growing nec	0	0	20
6922	Surveying and Mapping Services	1	0	5
9111	Health and Fitness Centres and Gymnasia Operation	1	0	5
8599	Other Health Care Services nec	1	0	5
1113	Cured Meat and Smallgoods Manufacturing	1	0	10
919	Other Construction Material Mining	1	0	5
134	Apple and Pear Growing	0	0	20
202	Offshore Caged Aquaculture	0	0	50
2619	Other Electricity Generation	1	0	5
5511	Motion Picture and Video Production	1	0	5
1812	Basic Organic Chemical Manufacturing	0	0	20
990	Other Non-Metallic Mineral Mining and Quarrying	1	0	5
302	Logging	1	0	10
136	Citrus Fruit Growing	0	0	10
9112	Sports and Physical Recreation Clubs and Sports Professionals	1	0	5
201	Offshore Longline and Rack Aquaculture	0	0	20
133	Berry Fruit Growing	0	0	10
8922	Nature Reserves and Conservation Parks Operation	0	0	20
1090	Other Mining Support Services	4	0	1
191	Horse Farming	1	0	5
193	Beekeeping	0	0	20
8402	Psychiatric Hospitals	0	0	50
7714	Correctional and Detention Services	3	0	1
121	Mushroom Growing	0	0	10
911	Gravel and Sand Quarrying	1	0	5
414	Fish Trawling, Seining and Netting	0	0	50
7320	Packaging Services	1	0	5
8910	Museum Operation	0	0	20
1012	Mineral Exploration	2	0	1

Industry classes		Total GVA	Science-based GVA[a]	Science share
		$b, current prices	$b, current prices	%
7713	Fire Protection and Other Emergency Services	2	0	1
1120	Seafood Processing	0	0	10
199	Other Livestock Farming nec	0	0	10
135	Stone Fruit Growing	0	0	10
7313	Gardening Services	2	0	1
1131	Milk and Cream Processing	0	0	5
8921	Zoological and Botanical Gardens Operation	0	0	20
3605	Fruit and Vegetable Wholesaling	1	0	1
4121	Fresh Meat, Fish and Poultry Retailing	1	0	1
3602	Meat, Poultry and Smallgoods Wholesaling	1	0	1
413	Line Fishing	0	0	50
137	Olive Growing	0	0	10
4122	Fruit and Vegetable Retailing	1	0	1
420	Hunting and Trapping	0	0	10
1011	Petroleum Exploration	1	0	1
143	Beef Cattle Feedlots (Specialised)	0	0	10
132	Kiwifruit Growing	0	0	50
3211	Land Development and Subdivision	1	0	1
3604	Fish and Seafood Wholesaling	0	0	1
3603	Dairy Produce Wholesaling	0	0	1
7312	Building Pest Control Services	0	0	1
122	Vegetable Growing (Under Cover)	0	0	10
1829	Other Basic Polymer Manufacturing	0	0	10
5514	Post-production Services and Other Motion Picture and Video Activities	0	0	1
146	Rice Growing	0	0	40
9121	Horse and Dog Racing Administration and Track Operation	0	0	1
6620	Farm Animal and Bloodstock Leasing	0	0	1
Sum		**379**	**46**	**12.1**
Total, economy wide result		**1 297**	**46**	**3.6**

a GVA based on the biological sciences' and 'science based GVA' are output produced from inputs that embody knowledge discovered in recent advances in the biological sciences.

Note: The impacts of advances in the biological sciences are calculated as a share of total output (economy-wide GVA). The measure of total output excludes the Ownership of dwellings industry (which makes up 9% of the total reported by the ABS). We have excluded this industry as it is imputed by the ABS and does not employ any people.

Source: The CIE.

Table A2.2 Detailed results for the impact of advances in the biological sciences on health (level of burden of disease)

Disease or condition	Actual data: observed burden of disease			Counterfactual: What would this burden be, if not for the impact of knowledge discovered in recent advances in the biological sciences?					
				Low case			High case		
	YLL	YLD	DALYs	YLL	YLD	DALYs	YLL	YLD	DALYs
Malignant neoplasms	411 953	87 463	499 416	514 941	118 075	633 016	617 929	148 687	766 616
Cardiovascular disease	369 365	104 429	473 794	496 796	140 457	637 253	517 111	146 201	663 312
Mental disorders	23 154	327 391	350 545	23 154	327 391	350 545	23 154	425 608	448 762
Nervous system and sense organ disorders	54 127	258 638	312 766	54 127	305 553	359 681	56 834	336 230	393 064
Chronic respiratory disease	71 339	115 398	186 737	78 473	138 478	216 951	85 607	161 557	247 165
Diabetes mellitus	32 295	111 536	143 831	35 525	111 536	147 061	38 754	111 536	150 290
Unintentional injuries	84 599	41 263	125 862	105 748	43 326	149 075	126 898	45 389	172 287
Musculoskeletal diseases	7 027	98 481	105 508	8 784	123 101	131 885	10 540	147 721	158 262
Genitourinary diseases	24 087	41 161	65 249	24 690	41 161	65 851	25 292	41 161	66 453
Intentional injuries	56 050	3 139	59 189	61 655	3 217	64 872	67 260	3 296	70 556
Diseases of the digestive system	27 710	30 246	57 957	30 481	37 808	68 289	33 253	45 370	78 622
Infectious and parasitic diseases	30 665	14 021	44 685	38 331	17 526	55 857	45 997	21 031	67 028
Acute respiratory infections	23 750	11 752	35 502	24 938	11 752	36 690	26 126	11 752	37 877
Neonatal causes	18 974	15 584	34 558	22 769	17 142	39 911	26 564	18 701	45 264
Congenital anomalies	16 897	16 331	33 228	18 587	16 331	34 918	20 277	16 331	36 607
Endocrine and metabolic disorders	13 598	14 968	28 565	14 957	16 464	31 422	16 317	17 961	34 278
Oral conditions	102	24 406	24 507	127	26 846	26 973	153	29 287	29 439
Skin diseases	2 173	18 130	20 302	2 390	19 943	22 333	2 607	21 756	24 363
Other neoplasms	7 694	3 209	10 903	8 078	3 370	11 448	8 463	3 530	11 993
Chronic fatigue syndrome	108	8 781	8 890	108	8 781	8 890	108	8 781	8 890
Nutritional deficiencies	458	5739	6 197	470	5 882	6 352	481	6 026	6 507
Sudden infant death syndrome	2 428	0	2 428	3 035	0	3 035	3 642	0	3 642
Maternal conditions	226	1 926	2 152	248	2 022	2271	271	2 119	2 390
Total	**1 278 778**	**1 353 992**	**2 632 770**	**1 568 412**	**1 536 164**	**3 104 575**	**1 753 636**	**1 770 030**	**3 523 666**

Source: Begg et al. (2007); The CIE.

Table A2.3 Detailed results for the impact of advances in the biological sciences on health (per cent change in the burden of disease)

Disease or condition	Actual data: observed burden of disease			Counterfactual: How much higher would this burden be, if not for the impact of knowledge discovered in recent advances in the biological sciences?					
				Low case			High case		
	YLL	YLD	DALYs	YLL	YLD	DALYs	YLL	YLD	DALYs
Malignant neoplasms	411 953	87 463	499 416	25	35	27	50	70	54
Cardiovascular disease	369 365	104 429	473 794	35	35	35	40	40	40
Mental disorders	23 154	327 391	350 545	0	0	0	0	30	28
Nervous system and sense organ disorders	54 127	258 638	312 766	0	18	15	5	30	26
Chronic respiratory disease	71 339	115 398	186 737	10	20	16	20	40	32
Diabetes mellitus	32 295	111 536	143 831	10	0	2	20	0	4
Unintentional injuries	84 599	41 263	125 862	25	5	18	50	10	37
Musculoskeletal diseases	7 027	98 481	105 508	25	25	25	50	50	50
Genitourinary diseases	24 087	41 161	65 249	3	0	1	5	0	2
Intentional injuries	56 050	3 139	59 189	10	3	10	20	5	19
Diseases of the digestive system	27 710	30 246	57 957	10	25	18	20	50	36
Infectious and parasitic diseases	30 665	14 021	44 685	25	25	25	50	50	50
Acute respiratory infections	23 750	11 752	35 502	5	0	3	10	0	7
Neonatal causes	18 974	15 584	34 558	20	10	15	40	20	31
Congenital anomalies	16 897	16 331	33 228	10	0	5	20	0	10
Endocrine and metabolic disorders	13 598	14 968	28 565	10	10	10	20	20	20
Oral conditions	102	24 406	24 507	25	10	10	50	20	20
Skin diseases	2 173	18 130	20 302	10	10	10	20	20	20
Other neoplasms	7 694	3 209	10 903	5	5	5	10	10	10
Chronic fatigue syndrome	108	8 781	8 890	0	0	0	0	0	0
Nutritional deficiencies	458	5 739	6 197	3	3	3	5	5	5
Sudden infant death syndrome	2 428	0	2 428	25	0	25	50	0	50
Maternal conditions	226	1 926	2 152	10	5	6	20	10	11
Total	**1 278 778**	**1 353 992**	**2 632 770**	**23**	**13**	**18**	**37**	**31**	**34**

Source: Begg et al. (2007); The CIE.

APPENDIX 3: DETAILED DISCUSSION OF THE IMPACT OF RECENT ADVANCES IN THE BIOLOGICAL SCIENCES ON HEALTH

MEASURING HEALTH AND BIOLOGICAL SCIENCE

In general, benefits from health-related biological knowledge can be realised in three ways:

- improved health outcomes now and in the future
- avoidance of direct health system expenditure
- avoidance of indirect costs (productivity loss, financial costs, deadweight loss).

Improved health outcomes

Improved health outcomes may be through the reduced incidence, prevalence and severity of diseases; that is, avoiding the contraction or occurrence of disease in the first place, lessening the number of people suffering from the disease at any point in time by curing diseases faster, and reducing the effect that a disease has on the quality of life of patients. In this report, health outcomes are quantified using a burden of disease approach and measured using disability adjusted life years (DALYs). Improvements in health outcomes act to reduce the burden of disease.

New biological or medical developments can lead to health treatments that:

- are less invasive
- are better quality, more sophisticated and more accurate (for example, in diagnostics and imaging), resulting in fewer errors
- reduce the need for surgery
- reduce recovery and hospitalisation time
- accelerate diagnostic processes and improve treatment planning
- produce better health outcomes.

Difficulties in linking advances in biology to health outcomes

Quantifying the benefits of medical technologies, let alone of biological developments, on health outcomes is challenging, as outlined by the Productivity Commission (PC 2005):

- With so many factors affecting health outcomes, isolating the impact of medical technologies can be difficult, which clearly extends to the question of isolating the particular impact of advanced biology.
- There can be a significant lag between the use of medical technologies and the health benefits, particularly for preventive interventions and vaccinations. This lag is significantly longer when considering the benefits of the initial biological discovery rather than the applied technologies.
- Selecting the most appropriate indicator of health outcomes poses challenges, as alternative measures all have strengths and weaknesses.
- There are limited data available, and those that are available are generally drawn from trial results that may not be fully applicable beyond the trial conditions.
- The benefits of medical treatments may change over time as the application and use of them are improved.
- Only limited studies have been undertaken in Australia, and studies that assess aggregate health benefits rather than focusing on a single disease or treatment are also limited.
- Most studies that are available look at the benefit of medical technologies or treatments but not just recent or new developments.

Part of the difficulty in addressing the question of the impact of biological science on health is that health outcomes are influenced by a number of factors:

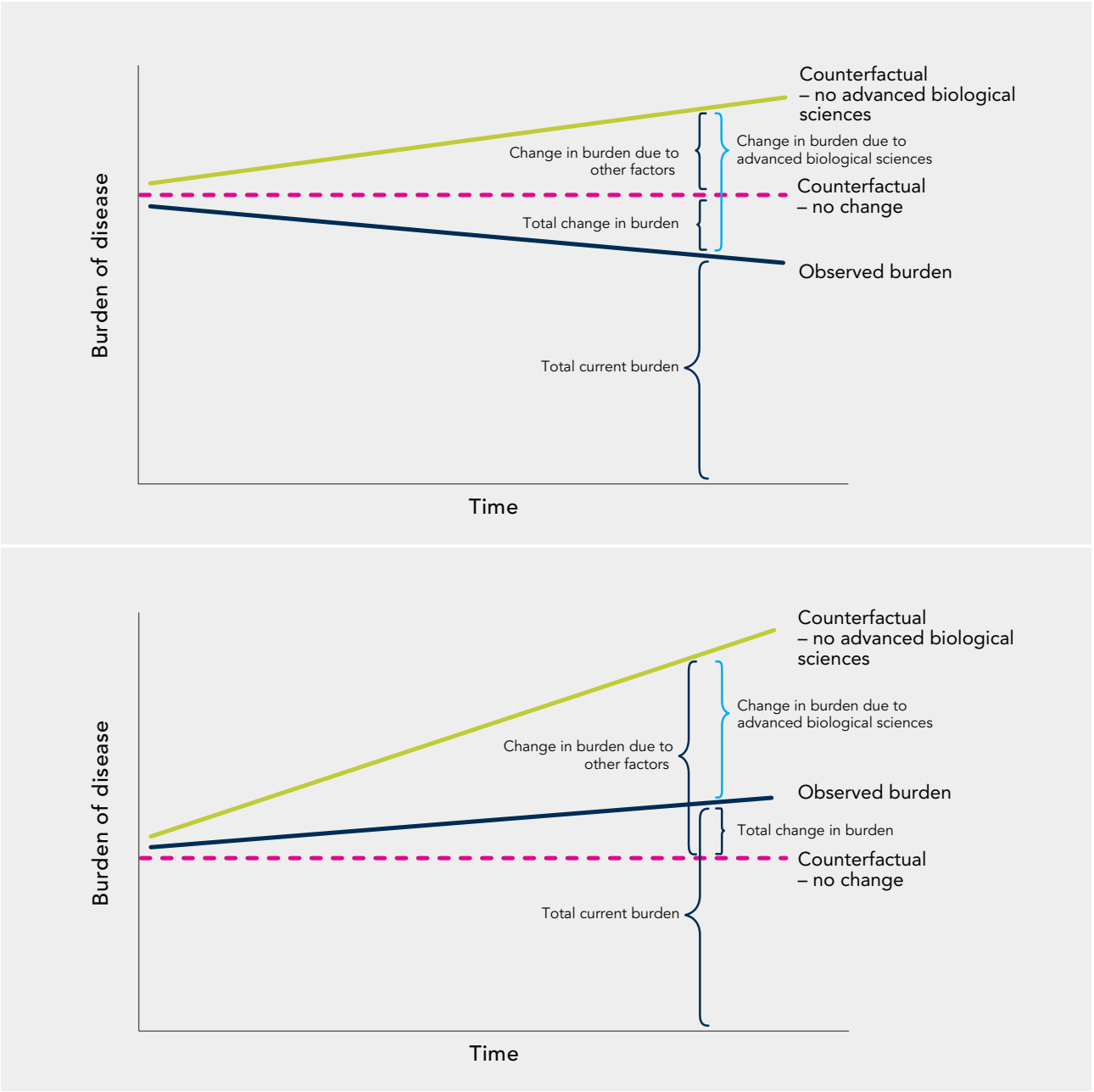
- Medical developments can reduce the years of life lost and may lead to either an increase or a decrease in years lived with disability.
- Behavioural changes (including changes in public health policies) can either increase or decrease the incidence and severity of diseases.
- Population changes lead to overall changes in burdens without necessarily changing the rate of burden per head of population.
- Changes in the structure of the population—particularly an ageing population profile—can change the burden of disease due to an increase or decrease in the size of the population that is most susceptible.

Furthermore, there is a significant time lag between the biological research and the realisation of health outcomes. Manton et al. (2009) studied correlations between US health outcomes and the funding of the National Institutes of Health. That analysis found that the lag between research and observed changes in health outcomes was up to 25 years in the case of cancer research.

Approaches to measuring the burden of disease and changes over time

Figure 3.1 in this report illustrates how we can think about changes in the burden of disease over time and the counterfactual scenarios to which the observed burden can be compared. That chart assumes that the burden of disease declines over time and that factors other than medical treatments contribute to that decline. Figure A3.1 illustrates two alternative but slightly more complex situations, in which other factors may increase the burden of disease. For example, increasing rates of obesity act to increase the incidence of diabetes. Depending on the relative size of impacts, the overall burden of disease may increase or decrease.

Figure A3.1 Alternative illustrations of the change in burden of disease over time



Data source: The CIE.

Avoidance of health system expenditure

Health research can lower the cost of health care through a number of avenues, including the development of new therapies or treatments that reduce the number of patients (for example, vaccines that reduce the incidence of disease) and therapies that lower the cost of treatment per patient (Buxton et al. 2004).

The impact of biological advances on direct health expenditure is difficult to determine—even the direction can be unclear. In many cases, new treatments are more expensive than traditional treatments and therefore research often leads to higher health expenditure. For example, a new pharmaceutical is usually more expensive than older pharmaceuticals. Some advances do lead to lower health expenditure, particularly where they lead to lower incidence of disease, less time in hospital, or both.

The initial cost of a new treatment or procedure is often higher than the cost of existing treatments (particularly in the case of pharmaceutical products). However, the quality of the outcome is likely to be better and there may be offsetting savings from a reduced need for ongoing treatments. PC (2005) notes that in some cases low-technology solutions are often at least as effective in managing a disease. Preventive measures and lifestyle changes may be the most effective ways of reducing the burden of disease.

Available data on health expenditure

Data on healthcare expenditure are collected by the Australian Institute of Health and Welfare (AIHW), but the detail is not sufficient to fully assess the impacts of particular developments on health expenditure. For example, expenditure is allocated between hospital services, out-of-hospital medical expenses and prescription pharmaceuticals, and for individual diseases, but cannot be examined in any more detail (for example, to compare the costs of different types of treatments). Furthermore, expenditure per person is reported by the AIHW using the whole population as the denominator rather than as prevalence data (expenditure per capita, as opposed to expenditure per case).

Projections of healthcare expenditure in AIHW (2008) made an assumption about the cost per case of disease that was common across all diseases and was based on observed changes in the past. No adjustment was made to account for differences in treatments and advances between disease types. In AIHW (2009), the impact of a number of National Health and Hospitals Reform Commission health reforms on health expenditure was estimated. However, most of those reforms were focused on changing behaviours, patient management and preventive measures, rather than on implementing new treatments based on new biological research.

Avoidance of indirect expenditure

Improved health outcomes may lead to the avoidance of indirect costs. Indirect costs can include loss of productivity and expenditure on 'regrettables' (such as costs associated with carers taking time off work, travel costs of patients, informal community care costs and so on).

It is generally recognised that a healthier population will lead to improved economic outcomes. Improved health outcomes have been estimated to lead to:

- an increase in GDP per capita of around 4% for each extra year of life expectancy (Bloom et al. 2004, cited in PC 2005)
- higher workforce participation among older workers (Cai and Kalb 2005 and Walker 2004, cited in PC 2005)
- improved labour productivity (Gross 2003, cited in PC 2005).

A healthier population is more likely to be engaged and productive in the workforce. However, an improvement in health outcomes cannot necessarily be converted into a direct impact on productivity or labour force participation rates. For example, improvements in the quality of life in the elderly (most of whom are not in the workforce, regardless of their health status) are unlikely to affect productivity. Similarly, health improvements that may avoid deaths but do not avoid significant disease burden may not change people's ability to work. However, health improvements in middle-aged working people may have a significant impact on productivity if their health improves sufficiently for them to continue working. Some of these dynamics are explored in Verikios et al. (2015), where the authors found that the greatest impact on GDP is achieved by improving the health of people aged 49 to 60.

LITERATURE ON THE IMPACT OF THE ADVANCED BIOLOGICAL SCIENCES ON HEALTH

This section reviews the literature, comparing other researchers' results to those in this report where possible.

Studies that link advances in science to health outcomes

No comprehensive study of the impact of advances in biological or medical knowledge on overall health outcomes was found in the literature.

There have been analyses of selected conditions, but they are neither consistent nor comprehensive enough to aggregate to a total impact on a nation's health or burden of disease. There are a number of studies on the role that new treatments have had in the recent observed reduction in cardiovascular disease. There are also studies that look at new pharmaceutical products.

Cardiovascular disease

Cutler and Kadiyala (1999, 2001) considered the contribution of various factors to the reduction in cardiovascular disease mortality in the United States between 1950 and 1994.

In the 1999 study (which seems to have formed the basis of subsequent research, as discussed further below), they concluded that the most important source of better health (two-thirds of the mortality reduction) was public information. The remaining third was attributed to technological change in the treatment of acute episodes and in pharmaceuticals to limit risk factors.

In the 2001 study, Cutler and Kadiyala concluded that:

- one-third of the reduction in mortality was attributed to better intensive treatment of acute incidents (particularly heart attacks)
- one-third was attributed to the increased use and effectiveness of medication for hypertension and high cholesterol
- one-third was attributed to behavioural changes (particularly reduced smoking and fat intake, along with reduced alcohol and salt use).

Hotchkiss et al. (2014) conducted a modelling exercise to apportion the recent decline in coronary heart disease mortality to changes in major risk factors and to increases in treatments in Scotland. They found that increases in medical treatments accounted for almost half of the decline. The age-standardised coronary heart disease mortality rate fell by 43% between 2000 and 2010, and 43% of the fall was attributed to the take-up of medical and surgical treatments. The most significant course of treatment was found to be the use of statins for hyperlipidaemia, which accounted for 13% of the total mortality reduction. Statins also made a significant contribution to reducing deaths through secondary prevention.

The Hotchkiss et al. modelling was conducted by forming a counterfactual baseline for the period of 2000 to 2010 in which the health outcomes of 2000 were applied to the population demographics as observed to 2010. The modelling therefore isolated the changes in mortality due to treatment and changes in risk factors from changes in the age, sex and socioeconomic status of the population. The treatments considered included those that addressed risk factors (such as statins to lower cholesterol and β blockers and ACE inhibitors to lower blood pressure). Risk factors considered included smoking, physical inactivity, body mass index, blood pressure, cholesterol and diabetes.

Ford and Capewell (2011) noted that declining mortality from coronary heart disease was driven by trends in risk factors and changes in cardiac treatments. They reviewed the literature on the proportion of the decline attributed to treatments compared to changes in risk factors in the population. The reviewed studies all assessed slightly different factors, but broadly speaking the effects of cardiac treatments were estimated to have accounted for between 23% and 47% of the decline in coronary heart disease mortality. Changes in risk factors explained between 44% and 76%.

Pharmaceuticals

A number of studies have looked at the impact of pharmaceuticals on health outcomes (PC 2005). The studies vary in the periods and pharmaceuticals studied and in their outcome measures. For example, Lichtenberg (2004a, cited in PC 2005) found that in Puerto Rico, newer drugs (introduced between 1970 and 2000) led to the mortality rate being 16% lower than it would have been if all drugs consumed were of pre-1970 vintage. Several studies also found that pharmaceuticals had a greater impact on quality of life than on mortality (see Frech and Miller 2004, Gross 2003, Lichtenberg 2001 and Lichtenberg 2002a, cited in PC 2005).

Most recently, Lichtenberg (2015) found that the number of years of potential life lost before age 80 in 2011 would have been 22% higher if no new drugs had been listed in the PBS between 1989 and 2002. Further details on Lichtenberg's results are included in Chapter 3 of this report.

The value of research

In an effort to understand the social value of medical research, Murphy and Topel (1999) compared the economic value of increased longevity with the investment in health and medical research in the United States. However, they did not assign numerical values to the changes in longevity that are due to medical research rather than other factors.

Access Economics (2003) assumed that half of the gains in Australian health improvements between 1960 and 1999 were directly or indirectly due to health R&D (this assumption appears to be based indirectly on original research by Cutler and Kadiyala in 1999 and 2001).

McGuire and Raikou (2007) found that health sector R&D in the United Kingdom between 1970 and 2000 led to monetarised gains in longevity equivalent to two years of GDP growth (or £2.58 trillion). The investment in R&D was less than 1% of the estimated gains. The approach used, however, did not account for the impact of lifestyle and environment changes, which are likely to account for a significant proportion of improved life expectancy.

The economic cost of particular conditions

There is a large body of literature that looks at the economic cost of individual health conditions in Australia. These studies appropriately consider the full range of costs that can be attributed to the condition and that therefore can be avoided (to some extent) by efforts to reduce the overall incidence or burden of that condition.

Deloitte Access Economics has produced a number of these reports, some of which are summarised in Table A3.1. While each study takes a slightly different approach, many include costs such as:

- direct healthcare costs for the specific condition (including hospital costs, outpatient medical treatments, aged and community care and pharmaceuticals)
- indirect financial costs, such as informal care, productivity losses (for patients and carers) and the deadweight loss associated with government expenses
- financial costs associated with conditions that are considered to be caused by the condition of interest (for example, the impact of sleep disorders on cardiovascular disease and motor vehicle accidents)
- non-financial costs (the burden of disease), often measured using DALYs and converted to a monetary value using the value of a statistical life year.

However, the results of the individual reports cannot be summed because of the differing approaches used, the different years for which the cost is estimated and the overlap in the populations with different conditions. For example, some studies include the costs of associated health conditions, which may lead to the double counting of some costs.

As an example, in Deloitte Access Economics (2011d), cardiovascular disease caused by sleep disorders is included in the cost of sleep disorders, but would also be included in a study of cardiovascular disease. Of total direct health costs of $818 million, just $274 million was attributed directly to sleep disorders. Total indirect financial costs were estimated at $4 251 million, of which the only item that included some costs attributed to sleep disorders rather than associated conditions was the deadweight loss associated with raising tax revenue for public expenditure, and only a small fraction of that amount is due to the treatment of sleep disorders rather than associated conditions. If the deadweight loss is generously attributed fully to sleep disorders, just 15% of financial costs estimated in the study are directly due to sleep disorders and the remainder are due to associated conditions.

It is also important to note that the questions that these studies address differ significantly from the question that is being dealt with in our report. These studies of the economic cost of individual conditions examine the total cost that a condition imposes on society (the height of the 'observed burden' line in Figures 3.1 and A3.1). They do not seek to understand what costs have been, or could reasonably be, avoided through particular interventions. Our study sought to understand the extent that costs have been avoided due to the application of knowledge from recent advances in biological sciences—that is, how much greater the burden (or cost) would have been if not for the knowledge.

Table A3.1 Summary of studies on the economic cost of individual conditions

Condition	Economic costs	Comments	Reference
Sleep disorders	Financial costs (direct and indirect): $5.1 billion Non-financial costs: $31.4 billion (190 000 DALYs) Total economic cost: $36.4 billion	There is a causal relationship between sleep disorders and other illnesses and injuries. The study looks at the total cost of the sleep disorders and the subsequent conditions. This gives rise to potential double counting across studies. Assumptions about the prevalence of sleep disorders were based on other studies, with some adjustments. The estimates were not, therefore, consistent with Begg et al. (2007). Total DALYs estimated for sleep disorders were 154 400 in 2010, compared to 26 953 for all 'other nervous system and sense organ disorders' (which contains sleep disorders as well as many other conditions) in 2003 in Begg et al. (2007). This shows that the prevalence assumptions underlying studies in the literature vary considerably.	Deloitte Access Economics 2011d
Incontinence	Financial costs (direct and indirect): $19.1 billion Non-financial costs: $23.8 billion (140 108 DALYs) Total economic cost: $42.9 billion	Inpatient hospital costs may include costs for other conditions in people with incontinence.	Deloitte Access Economics 2011c
Parkinson's disease	Financial costs (direct and indirect): $775.4 million Non-financial costs: $7.6 billion (46 069 DALYs) Total economic cost: $8.3 billion		Deloitte Access Economics 2011b
Eating disorders	Financial costs (direct and indirect): $17.2 billion Non-financial costs: $52.6 billion (303 865 DALYs) Total economic cost: $69.8 billion		Deloitte Access Economics 2012

THE VALUE OF A STATISTICAL LIFE YEAR

In policy analysis, is it often convenient to represent changes in outcomes for human health and lives in quantities that can be compared to monetary outcomes. In fact, it is not always possible or desirable to report human health outcomes in monetary terms. Two approaches to attempting this challenging task are used in the literature—willingness-to-pay approaches and a human capital approach. Each aims to estimate the value of an average or statistical life.

The human capital approach tends to measure the direct and indirect losses realised when a life is lost. Most applications of the human capital approach do not incorporate non-financial values. However, suffering and loss of quality of life are real costs and should be incorporated where possible, for example by using values for compensation as a proxy for estimating the value of loss of quality of life. Other costs that may be included in the human capital approach include medical expenses, long-term care, coronial expenses and premature funeral costs.

The willingness-to-pay approach measures the total intangible losses associated with a death or injury. The values are estimated using stated preference surveys or revealed preference methods that reflect what individuals are willing to pay to avoid expected injury and death.

Australian governments have recommended using willingness-to-pay measures rather than the human capital method because of drawbacks of the human capital approach:

- Public policy is concerned with measuring what individuals are willing to pay to reduce the possibility of accidents, rather than the value of what is lost.
- The human capital approach, because it is based on future income and productivity, cannot be used for non-working individuals.
- The human capital approach does not allow for pain and suffering.

We have used the value of statistical life year recommended by the Office of Best Practice Regulation (OBPR 2014), which is based on a willingness-to-pay approach.

APPENDIX 4: THE CIE-REGIONS MODEL

The CIE-REGIONS model is a general equilibrium model of the Australian economy. It was developed by the CIE, updated from the publicly available MMRF-NRA model developed by the Centre of Policy Studies for the Productivity Commission (PC 2006b).

Some of the key aspects that make this model especially suited for this task are as follows:

- It uses the latest input–output table.
- It provides a detailed account of industry activity, investment, imports, exports, changes in prices, employment, household spending and savings and many other factors.
- It identifies 58 industries and commodities (Table A4.1).
  - It accounts for Australia's six states and two territories as distinct regions, including specific details about the budgetary revenues and expenditures of each of the eight state and territory governments and the Australian Government (the government finances in CIE-REGIONS align as closely as is practicable to the ABS government finance data).
  - It includes a detailed treatment of the fiscal effects of the goods and services tax (GST).
  - It specifically accounts for major taxes, including land taxes, payroll taxes, stamp duties and others at the state level, as well as income taxes, tariffs, excise, the GST and other taxes at the federal level (Table A4.2).
  - It traces out the impact of transfers between governments.
- It accounts for differing economic fundamentals in the states (for example, the mining industry in Western Australia and Queensland).
- It can produce results on employment and value added at the regional level.
- It can be run in a static or dynamic mode. The dynamic version allows analysis to trace impacts over time as the economy adjusts, which is particularly useful over the medium to longer terms.

The CIE has used CIE-REGIONS to analyse the impacts of a range of policy changes, including state tax reform, local infrastructure development, and industrial development strategies.

Table A4.1 CIE-REGIONS industries/commodities and margin services

1	Livestock	30	Electricity generation—hydro
2	Crops	31	Electricity generation—other
3	Forestry	32	Electricity supply
4	Fishing	33	Gas supply
5	Coal	34	Water and sewerage services
6	Oil	35	Construction
7	Gas	36	Wholesale trade
8	Iron ore	37	Retail trade
9	Other metal ores	38	Mechanical repairs
10	Other mining	39	Hotels, cafes and accommodation
11	Food, beverage and tobacco	40	Road passenger transport
12	Textiles, clothing and footwear	41	Road freight transport
13	Wood products	42	Rail passenger transport
14	Paper products	43	Rail freight transport
15	Printing	44	Pipeline transport
16	Petroleum products	45	Ports services
17	Chemicals	46	Transport services
18	Rubber and plastic products	47	Water freight transport
19	Other non-metal mineral products	48	Ship charter
20	Cement and lime	49	Air passenger transport
21	Iron and steel	50	Air freight transport
22	Other non-ferrous metals	51	Communication services
23	Metal products	52	Finance
24	Transport equipment	53	Business services
25	Other equipment	54	Ownership of dwellings
26	Other manufacturing	55	Government administration and defence
27	Electricity generation—coal	56	Education
28	Electricity generation—gas	57	Health
29	Electricity generation—oil	58	Other services
Margin services			
Gas supply (part of commodity 33)		Pipeline transport (part of commodity 44)	
Wholesale trade (part of commodity 36)		Ports services (part of commodity 45)	
Retail trade (part of commodity 37)		Water freight transport (part of commodity 47)	
Hotels, cafes & accommodation (part of commodity 39)		Air freight transport (part of commodity 50)	
Road freight transport (part of commodity 41)		Finance (part of commodity 52)	
Rail freight transport (part of commodity 43)			

Source: CIE-REGIONS database.

Table A4.2 Federal and state taxes

Federal taxes	State, territory and local government taxes
Goods and service tax	Payroll tax
Sales taxes	Land tax
Excises and levies	Municipal rates
Labour income tax	Fire surcharges
Company income tax	Stamp duties on
Non-residents income tax	– insurance
Import duties	– financials
Export taxes	– motor vehicle
	– residential property
	– non-residential property
	– non-residential non-real estate

Source: CIE-REGIONS database..

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ABBREVIATIONS AND ACRONYMS

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AAS	Australian Academy of Science
AIHW	Australian Institute of Health and Welfare
CGE	computable general equilibrium
CIE	Centre for International Economics
CRC	cooperative research centre
DALYs	disability adjusted life years
GBR	Great Barrier Reef
GDP	gross domestic product
GM	genetically modified
GST	goods and services tax
GVA	gross value added
HIV	human immunodeficiency virus
HPV	human papillomavirus
NHMRC	National Health and Medical Research Council
NTZ	no-take zone
OCS	Office of the Chief Scientist
PBS	Pharmaceutical Benefits Scheme
R&D	research and development
VSL	value of a statistical life
VSLY	value of a statistical life year
WHO	World Health Organization
YLD	years lost to disability
YLL	years of life lost
YPLL	years of potential life lost