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The Contribution of Research and Innovation to Productivity and Economic Growth

Amani Elnasri
Kevin J. Fox

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Amani Elnasri
University of New South Wales

Kevin J. Fox*
University of New South Wales

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Abstract

This paper examines the impact of investment in research and innovation on Australian market sector productivity. While previous studies have largely focused on a narrow class of private sector intangible assets as a source of productivity gains, this paper shows that there is a broad range of other business sector intangible assets that can significantly affect productivity. Moreover, the paper pays special attention to the role played by public support for research and innovation in the economy. The empirical results suggest that there are significant spillovers to productivity from public sector R&D spending on research agencies and higher education. No evidence is found for productivity spillovers from indirect public support for the business enterprise sector, civil sector or defence R&D. These findings could have implications for government innovation policy as they provide insights into possible productivity gains from government funding reallocations.

Keywords: Productivity, Innovation, Intangible assets, Public support.
JEL Classification Numbers: O3, O4 , H4

* **Corresponding Author:** Kevin J. Fox, School of Economics & CAER, University of New South Wales, Sydney 2052, Australia. E-mail: K.Fox@unsw.edu.au, Tel: +61-2-9385-3320. This paper is a contribution to a series of projects undertaken by the Australian Council of the Learned Academies to examine 'The Role of Science, Research and Technology in Lifting Australia's Productivity'. We thank the Productivity Commission and Melbourne Institute for providing us with their data on intangible investment. Financial support from the Australian Research Council (LP0884095) is gratefully acknowledged, as are helpful comments from Paula Barnes and Erwin Diewert. The views expressed in this paper are those of the authors. Any errors are our responsibility.

1 Introduction

Research and innovation are widely agreed to be major driving forces behind long-term productivity and economic growth. It is now well recognised that the productivity benefits from research and successful innovations are not fully absorbed by the innovating entities but, rather, they diffuse through the rest of the economy leading to positive externalities in growth and the productivity performance of the other using entities.

This paper attempts to have a closer look into some aspects of the Australian innovation system and its impact on the economy. Specifically, the objectives of the paper are three-fold. First, to extend a staff working paper of the Productivity Commission conducted by Barnes and McClure (2009), henceforth referred to as the 'the PC report', on the spending on a broad range of intangible assets for the Australian market sector. These intangibles are incorporated into the Australia National Accounts to provide estimates for recent years.[1] By recognising the additional investment in the economy when 'new' intangible expenditure is treated as investment, the paper adjusts the measures of the market sector gross value added (GVA), capital stock and factor income shares.[2] Using the growth accounting framework, these 'new' measures are employed to construct adjusted estimates of the market sector multifactor productivity (MFP) growth. Furthermore, in line with the method of the PC report, the paper develops two additional sets of the growth accounting components to assess the impact on these components when either a 'sub-group' of or 'all' intangibles are capitalised.[3] To construct the first set, only those intangibles which are currently capitalised by the ABS (computer software, artistic originals, and mineral exploration and scientific R&D) are included while in the other set the growth accounting components are estimated under the assumption that all intangibles are treated as intermediate inputs.

Second, the paper examines whether there are any productivity spillovers/excess returns from the investment in intangibles or if the returns for these intangibles are restricted to those firms producing or consuming them. Although there are a number of studies that have examined the impact of R&D on Australia's productivity, these studies did not examine the impact of other intangible assets nor did they adjust MFP growth for the capitalisation of knowledge and other intangibles. As in Haskel and Wallis (2010, 2013), henceforth collectively referred to as HW, outline, adjusting MFP growth to include intangibles is helpful in isolating private from social returns.[4] If MFP growth used in a regression model is not adjusted, then the ensuing estimates of the returns on the knowledge assets will suffer from measurement errors.

The third, and most important objective of the paper, is to examine the impact of public support for research and innovation on market sector productivity. Building on HW, the paper aims

[1]As far as can be ascertained, the PC report and an extension by de Rassenfosse (2012) are the only two previous attempts made to apply the Corrado, Hulten and Sichel (2005, 2006) methodology to measure a set of intangible assets beyond those currently capitalised in the Australian National Accounts.

[2]'New' intangibles refer to those intangibles which are currently not included in the National Accounts.

[3]A 'sub-group' of intangibles refers to those assets which are currently capitalised in the National Accounts while 'all' intangibles refers to a combination of National Accounts and 'new' intangibles.

[4]Haskel and Wallis (2013) is an updated and condensed version of the more comprehensive discussion paper, Haskel and Wallis (2010).

to investigate spillovers to productivity from various sources of public funding. More specifically, it is to answer the question of whether or not public support for research and innovation should focus on direct spending on public research institutions (such as Commonwealth Scientific and Industrial Research Organisation, CSIRO, and the Defence Science and the Technology Organisation, DSTO); funding of higher education (e.g., Australia Research Council, ARC); or provide indirect support to the business sector (for example, through tax incentives such as expanding the R&D Tax Concession to a broad range of intangibles).[5] Answering this question is crucial to informing and designing effective policy. Because governments are constrained by tight fiscal budgets, efficient innovation policies should focus on areas with higher expected social returns in order to maximize the benefits from public spending. For example, for the U.K. HW found strong evidence of spillovers from public R&D expenditure on research councils as opposed to other areas. Accordingly, their findings suggest that for maximum productivity impact in the U.K., government innovation policy should support direct spending on research councils rather than tax breaks, such as the R&D tax credit, to firms.

The paper proceeds as follows: Section 2 briefly provides the theoretical background on how investment in knowledge capital is linked to productivity and economic growth. Section 3 provides estimates of the Australian market sector intangible investment, intangible capital stock, and discusses their trends over the period 1974-75 to 2012-13. Section 4 presents the impact of capitalising intangibles in the growth accounting components by discussing three different definitions of capital (when all intangibles are capitalised, when only National Accounts intangibles are capitalised, and when all intangibles are treated as intermediate goods). Section 5 presents definitions and trends of Australian government spending on research and innovation. A simple analysis of the relationship between public support for R&D and market sector MFP is presented in Section 6. A more comprehensive analysis using econometric techniques is presented in Section 7. Section 8 concludes.

2 Investment in knowledge capital and economic & productivity growth

The New Growth Theory literature (e.g., Arrow 1962 and Romer 1990) has emphasised two points. First, the accumulation of knowledge, innovation or human capital by economic agents is the principal source of technological change (a key source of productivity growth) and hence economic growth. Second, the positive externalities and spillover effects of a knowledge-based economy can reduce the diminishing returns to capital accumulation and hence lead to economic development.

In the context of this literature, the existence of knowledge spillovers are explained by the distinctive characteristics of knowledge: non-rivalry and non-excludability. Knowledge is considered to be a good which is non-rival in nature because it can be made available to a number

[5] Public support for the business sector is delivered through a range of programs: The R&D Tax Concession (which accounts for about 50 % of total business support); Rural Research and Development Corporations; grant funding under the Commercial Ready Program; and the Automotive Competitiveness and Investment Scheme.

of users simultaneously without extra costs to the supplier. Unlike a tangible asset, knowledge is not 'consumed' by those who use it. It can be used at multiple times and by multiple users. On the other hand, the non-excludability means that if the knowledge is provided at all, it is available to everyone and its users cannot be denied access to it. The non-rivalry and non-excludability properties of knowledge are the attributes that drive economic growth. Accumulation of more ideas will enable the economy to develop further. Ideas are not subject to diminishing returns; rather, the increasing returns to knowledge boost economic growth.

In general, economic growth can be decomposed into two components: growth of factor inputs (such as capital, labour and land) and growth of productivity. Productivity is a measure of how efficiently an economy utilises finite resources to produce goods and services. Thus, it is a ratio of output to input. Total output can be increased by either increasing the utilisation of resources or by improving the efficiency with which resources are employed. In the long term, contributions through increased utilisation of resources will be limited by the finite endowment of resources. Thus, sustained economic growth will have to come mainly from productivity increases. There are several ways to improve productivity but knowledge capital (through new technology, skills, R&D and efficient services and production processes) is the most significant factor. Due to new technology, the same level of output can be produced with fewer inputs. Also, technology diffusion reduces inefficiencies because it enables firms to reach, or come closer, to the production frontier.

The effect of knowledge capital on productivity may work through various channels depending of the source of the knowledge. For example, R&D, a major component of knowledge capital, can be performed either by the business sector, public sector or beyond the borders of a country. Each of these types of R&D performers can be a source of significant domestic technological change. R&D performed by the business sector results in new goods and services, higher quality of output, and new production processes. These are sources of productivity growth at the firm and national levels. Many empirical studies confirm the positive impact of business R&D on productivity; see e.g. Griliches (1998) and Nadiri (1993). Business-performed R&D may be funded by business itself or by the government. Accordingly, business R&D may have a different effect on productivity, depending on its source of funding (which affects the research agenda and the incentive structure). For example, Lichtenberg (1993) tests whether government-funded R&D performed by firms had a different impact than business-funded R&D. The author's evidence suggests that while privately-funded R&D investment has a significant positive effect on productivity, government support for business R&D has a negative impact.

Besides their support for business R&D, governments are major R&D performers through government research agencies or through funding higher education R&D. Research agencies and university R&D are seen to have a strong effect on scientific, basic knowledge and on public missions. Basic research performed by universities enhances the stock of knowledge available for the society. It may open new opportunities for business research, which in turn might improve productivity. Nevertheless, there have been few attempts to measure the impact of public R&D on productivity. In a group of studies only some components of public research have been used in empirical frameworks. For example, Adams (1990) examines the contribution of fundamental stocks of knowledge, proxied by accumulated academic scientific papers and finds significant contributions to productivity growth in the U.S. manufacturing industries. Another example is Poole and Bernard (1992) who examine military innovations and find a negative impact on Canadian total factor productivity. Among the small number of studies that examined a broader definition of public sector R&D are Park (1995) and HW; Park (1995) conducts a panel data analysis of 10 OECD countries and finds that the public R&D effect on productivity growth becomes insignificant when business R&D is incorporated as an additional regressor.

The knowledge originating from abroad is a third source of new technology for any national economy. Evidence demonstrates many avenues through which knowledge can cross the boarders of a given country and, depending on the absorptive capacity, it may improve other countries' productivity (Mohnen 2001).

The Australian literature has a limited number of studies that have quantitatively examined Australia's innovation system and its impact. Most of these studies have focused on the link between productivity and R&D, ignoring the effect of the other types of intangible capital. The R&D measures employed by these studies largely relates to business R&D (e.g., Shanks and Zheng 2006 and Louca 2003). Moreover, the empirical evidence obtained by these studies was mixed or generally not supportive of the productive role of business R&D. For example, Shanks and Zheng (2006) outline that despite the advances in data collection and methods applied in the study, the research was unable to find a consistently robust measure of the impact of R&D on productivity and the estimated effect of R&D was implausibly large.[6]

There are a small number of cases in which the role of higher education R&D is assessed. One example is a study by Burgio-Ficca (2004) who finds evidence of a positive relationship between higher education R&D and gross state product. With the exception of PC (2007) there is no study which has explicitly scrutinised the effects of publicly funded R&D.[7] Although the findings of PC (2007) suggest significant aggregate economic, social and environmental benefits from publicly supported science and innovation, the quantitative estimates are found to be unreliable.

As mentioned above, the existing body of the Australian literature does not extend to a search of the contribution of the other types of knowledge assets beyond R&D. Despite its importance, R&D is not the only source of new technology. Innovation can result from the contribution made by other types of intangible capital, and extends beyond physical capital accumulation. Some recent studies suggest new methods for defining and measuring intangible capital by measuring investment in innovation-related assets such as skills development, non-scientific R&D, design, organisational improvements and so forth. More discussion of these intangibles is provided in the next section.

[6] For a concise summary and discussion of this and related work, see Parham (2006).

[7] There are a small number of studies which might have partially addressed this question by employing data on the gross expenditure on R&D (GERD, an aggregate measure of business, government and higher education R&D). However, using GERD as a measure will not isolate the effects of government or higher education R&D.

3 Intangible investment

Despite the increase in their prominence, research and innovation, among a large set of 'intangible' assets, are largely ignored in National Accounts and corporate financial reports because they are hard to understand and measure. Two recent studies by Corrado, Hulten and Sichel (2005, 2006), henceforth collectively referred to as CHS, have drawn the attention of researchers to the importance of measuring and capitalising these intangibles. Using U.S. data, CHS have developed a methodology to capitalise a broad range of intangibles and, by applying a growth accounting framework, demonstrated how the conventional growth rates of inputs, output and productivity measures changed as a consequence. Following CHS, researchers in a number of other advanced countries (e.g., United Kingdom, Japan, Netherlands, Canada and Australia) have conducted similar studies, and found results similar to those of CHS.

Following the recommendations of the System of National Accounts (SNA) 1993, some statistical agencies have begun to change the treatment of intangible assets in their National Accounts.[8] Australia was one of the first countries to capitalise computer software, artistic originals and mineral exploration in 1993. In addition, as part of the revisions to implement the recommendations contained in SNA 2008, Australia started to capitalise scientific R&D in 2009. Nevertheless, intangible assets are not restricted to these four elements. Firms also invest in other types of intangible assets which may represent a source of economic growth; however, these investments are treated in the National Accounts as current expenses. Excluding investment in intangibles underestimates total investment, which in turn may misrepresent the measures of output, capital services, factors income shares and consequently productivity.

CHS classify intangibles into three categories: computerised information, innovative property and economic competencies. Each of these categories is composed of several specific intangibles which are reported in Table 1.

CHS construct measures of these intangibles for the U.S. and use them to examine their contribution to labour productivity growth. They find that the U.S. invests substantially in intangible assets (12.1% of GDP in intangible assets in 2003, CHS 2005). In addition, they find that capitalising intangibles has considerably increased labour productivity growth. In particular, they find it increased by 0.8 % from 1995 to 2003.

The work of CHS has motivated studies in other advanced countries where authors find that these countries have significantly invested in intangibles. For example, Marrano and Haskel (2006) find that the private sector in the U.K. invested 10.1% of GDP on intangibles in 2004. In Finland, the private sector invested 9.1% of GDP in intangible assets (Jalava et al. 2007). The Netherlands invested 8.4% of GDP between 2001 and 2004 (van Rooijen-Horsten et al. 2008). Fukao et al. 2009 find that Japan invested 7.5% of GDP from 1995 to 2002 while Baldwin et al. (2012) find that the Canadian business sector invested 13.2% of GDP in intangible assets in

[8] Until recently, expenditures on intangible assets were not recorded as final expenditures in the calculation of gross domestic product. Rather, they were classified as intermediate inputs. The new treatment recognises expenditure on intangible assets as fixed investment and the depreciation of these assets in the consumption of fixed capital.

Table 1 Definitions of Intangibles, CHS

1. Computerised information
Computer software
Computer databases

2. Innovative property
Scientific R&D; Social sciences R&D (Business R&D)
Mineral exploration
Copyright and licence costs (Artistic originals)
Other product development, design and research
  New product development in financial industry
  New architectural and engineering designs

3. Economic competencies
Brand equity
  Advertising
  Market research
Firm-specific human capital
Organisational capital
  Purchased
  Own account

2008. Hao et al. (2009) conducted an international comparison between France, Germany and Italy and found that the shares of intangible investment in GDP in these three countries are 8.3%, 7.1% and 5.2% respectively in 2004. Finally, the PC report suggests that Australia has invested 5.9% of GDP in 2005-06.

3.1 Measuring intangibles

For Australia, the PC report and de Rassenfosse (2012) are the only existing studies that have applied the methodology of CHS to measure and classify a range of 'new' intangibles.[9] The PC report provides estimates over the period 1974-75 to 2005-06 and de Rassenfosse (2012) extends these estimates to 2010-11. However, due to measurement challenges and difficulties in obtaining adequate information, the authors of these studies were required to make a number of assumptions to enable them to obtain measures over time: 'Given the experimental nature of the methodology, the assumptions required, measurement challenges and data limitations, the estimates should be interpreted as only indicative' (Barnes and McClure 2009, p. XIII).

This paper depends on different sources to collect data on investment in intangibles. For those assets which are already capitalised in the National Accounts, the data is sourced from the ABS website. For investment in 'new' intangibles, the estimates of both the PC report and de Rassenfosse (2012) are reconciled to form a series over the period 1974-75 to 2012-13.[10] While

[9] A third relevant study is Barnes (2010) in which the author extends the estimates of the PC report to a sectoral level.

[10] The caveat expressed by the authors of the earlier studies about the experimental nature of the estimates is also applied in this paper. One of the original objectives of this paper was to contribute to the Australian literature by providing improvements and refinements to the existing estimates of intangible assets. Unfortunately, due to severe data limitations and measurement challenges, the endeavours made to improve measurement of new intangibles were of little avail.

a more detailed discussion of the definitions and sources of all data used in the paper is available in the Appendix, a brief description of the investment data in intangibles is provided below.

Computerised information

Computer software is already treated as investment in the Australian National Accounts. A time series for gross fixed capital formation and capital stock is available for the full period 1974-75 to 2012-13. The ABS computer software implicit price deflator (IPD) is used to obtain the real investment series.

Innovative property

CHS define four types of innovative property which are:

(i) Business expenditure on R&D

Australian business expenditure on R&D (BERD) is available from the ABS Research and Experimental Development, Businesses (Cat. no. 8104.0). A consistent series for the market sector (excluding Agriculture, forestry & fishing) was compiled for 1974-75 to 2005-06 by Shanks and Zheng (2006) and the PC report.[11] For this paper, it is updated and extended to 2012-13 using revised and updated data from the ABS Cat. no. 8104.0. The ABS's IPD for R&D is used to obtain the real investment series.

(ii) Mineral exploration and (iii) Artistic originals

Mineral exploration and Artistic originals are already treated as investment in the Australian National Accounts. Time series for gross fixed capital formation and capital stock are available for the full period 1974-75 to 2012-13. The ABS's IPDs for Mineral exploration and Artistic originals are used to obtain the respective real investment series.

(iv) Other product development, design and research

This type of 'non-scientific' R&D is currently treated as intermediate expenditure in the National Accounts. According to CHS, it consists of:

New product development in the financial industry

The PC report has constructed a series for 20% of total intermediate purchases by the financial services industries to cover the period 1974-75 to 2005-06. de Rassenfosse (2012) has extended the series to 2010-11 by applying a relevant growth rate to the year 2004-05 data point from the PC report.[12] Assuming linear growth in recent years, this paper extends the series to 2012-13. The ABS's IPD for the Finance & Insurance industry is used to obtain the real investment series.

[11] The ABS did not directly survey farms and other businesses in this industry until 2005-06. Agriculture has been excluded from the 2005-06 to 2012-13 data to maintain comparability over time.

[12] See the Appendix for details.

New architectural and engineering designs
The PC report has constructed a series for 50% of the revenue of architectural and engineering industries to cover the period 1974-75 to 2005-06. de Rassenfosse (2012) has extended the series to 2010-11 by using turnover data from the ABS Counts of Australian Businesses, including Entries and Exits for classes of Architectural Services and Engineering Design and Engineering Consulting Services. Assuming linear growth in the recent years, this paper extends the series to 2012-13. The ABS's IPD for the market sector GVA is used to obtain the real investment series.

Economic competencies

The components of economic competencies defined by CHS are currently treated as intermediate expenditure in the National Accounts. They fall into three categories:

(i) Brand equity

Spending on brand development is measured by the spending on advertising and market research:
Advertising
This type of expenditure is available from an annual survey of the industry conducted by the Commercial Economic Advisory Service of Australia (CEASA). The ABS's IPD for the market sector GVA is used to obtain the real investment series.

Market research
The PC report has constructed a series as the double of the revenue of the market research industry. Interpolation and backdating were performed to construct a series to cover the period 1974-75 to 2005-06. de Rassenfosse (2012) has extended the series to 2010-11 by using turnover data from the ABS Counts of Australian Businesses, including Entries and Exits for the class Market Research and Statistical Services.[13] Assuming linear growth for recent years, the paper extends the series to 2012-13. The ABS's IPD for the market sector GVA is used to obtain the real investment series.

(ii) Firm-specific human capital

No single data source provides a time series of Australian employer-provided training expenditure. The PC report constructed a series to cover the period 1974-75 to 2005-06 using different data sources with a number of assumptions. The main source was the direct costs and wage costs of employee time in training for market sector industries (excluding agriculture) from the ABS Training surveys. de Rassenfosse (2012) has extended the series to 2010-11 by forecasting. Assuming linear growth for recent years, the paper extends the series to 2012-13. The average weekly fulltime ordinary earnings deflator is used to obtain the real investment series.

[13]Due to a change in ANZSIC classification, there is a break in the series in 2006-07 vs. 2007-08. See the Appendix for more details.

(iii) Organisational capital

The investment in organisational capital as suggested by CHS is made up of two components, purchased and own account:

Purchased

Using the ABS Industry Survey, the PC report has constructed the series as 77% of sales of all business management services to cover the period 1974-75 to 2005-06. de Rassenfosse (2012) has extended the series to 2010-11 by using turnover data from the ABS Counts of Australian Businesses, including Entries and Exits for the class 6962 Management Advice and Related Consulting Services. Assuming linear growth in the recent years, the paper extends the series to 2012-13. The ABS's IPD for the market sector GVA is used to obtain the real investment series.

Own account

The PC report constructed the series as 20% of salaries of Managers and Administrators (excluding farm managers and IT managers) in the market sector to cover the period 1974-75 to 2005-06. de Rassenfosse (2012) has extended the series to 2010-11 by using the ABS data on employee earnings, benefits and trade union membership. Assuming linear growth in the recent years, the paper extends the series to 2012-13. The ABS's IPD for the market sector GVA is used to obtain the real investment series.

3.2 Trends in Australian intangibles

Table 2 presents estimates of nominal intangible investment in the market sector for some selected years of the study period: 1974-75, 1984-85, 1994-95, 2004-05 and 2012-13. As seen from the table, investment in intangibles has increased over time and reached about $80 billion in 2012-13, constituting 28% of market sector total investment in that year. With the exception of the last few years, total investment in intangibles grew more rapidly than investment in tangibles; see Figure 1. The ratio of intangibles to tangibles increased continuously from 0.29 in 1974-75 to 0.53 in 2004-05; however, it decreased to 0.38 by 2012-13. Of all intangibles only computer software, artistic originals, mineral exploration and R&D have been capitalised in the Australian System of National Accounts. As shown in the table the investment in these four intangibles constitutes less than half of total intangible investment. In 2012-13, National Accounts intangibles accounted for 41% of total intangible investment while the new intangibles accounted for 59%.

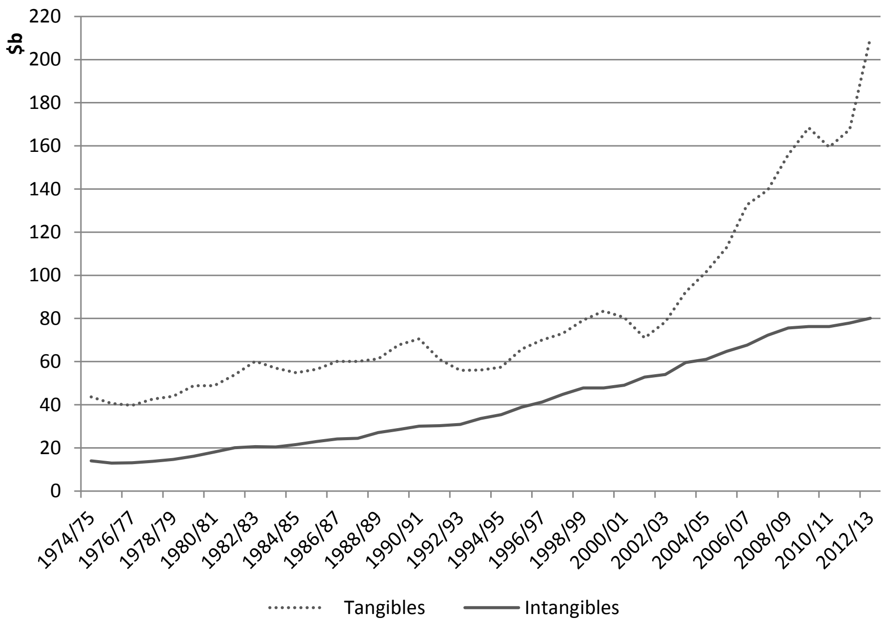
Table 2 and Figure 2 show that the composition of the intangible investment has changed considerably over the last three and half decades. For the first four years presented in Table 2, the economic competencies category is the largest component of intangible investment with an average share of 51%. The second component was the innovative property with an average share of 40%. However, by 2012-13, these two categories of intangibles had reversed their contribution ranking; economic competencies decreased to 41% while the share of innovative property increased to 47%. Investment in computerised information has dramatically increased over time, although remaining the smallest component of intangibles. Figure 2 illustrates the

Table 2 Estimates of nominal intangible investment in the Australian market sector

Categories	1974-75	1984-85	1994-95	2004-05	2012-13
			millions of dollars		
Computerised information	16	454	3,447	7,181	9,298
Innovative property	921	3,849	9,124	18,965	37,743
Scientific R&D; Social sciences R&D (Business R&D)	199	614	2,782	7,010	14,483
Mineral exploration	209	1,308	1,299	1,731	7,150
Copyright and licence costs (Artistic originals)	33	127	306	939	2,268
Other product development, design and research	480	1,800	4,737	9,286	13,841
New product development in financial industry	342	1,310	3,133	5,311	8,338
New architectural and engineering designs	137	490	1,604	3,975	5,504
Economic competencies	1,259	4,926	11,276	23,374	33,428
Brand equity	653	2,830	4,679	8,365	10,362
Advertising	648	2,774	4,420	7,391	9,463
Market research	5	56	260	974	899
Firm-specific human capital	301	1,024	2,669	3,870	5,791
Organisational capital	306	1,073	3,927	11,138	17,276
Purchased	21	232	1,944	7,058	9,143
Own account	284	840	1,983	4,081	8,133
Total intangibles investment	2,196	9,229	23,847	49,520	80,469
New intangibles	1,739	6,726	16,013	32,659	47,270
National Accounts intangibles	457	2,503	7,835	16,861	33,199
Tangibles	7,675	29,760	47,951	93,555	209,955
Total investment	9,871	38,989	71,798	143,075	290,424
Share of computerised information %	1	5	15	15	12
Share of innovative property %	42	42	38	38	47
Share of economic competencies %	57	53	47	47	41
Share of intangible investment%	22	24	33	35	28
Share of tangible investment%	78	76	67	65	72
Ratio intangible to tangible investment	0.29	0.31	0.50	0.53	0.38

The share of tangible (intangible) investment is the ratio of tangibles (intangibles) to total investment.
The shares of computerised information, innovative property, and economic competencies are calculated relative to all intangibles.

Figure 1 Market sector real tangible and intangible investment (1974-75 to 2012-13)
2011-12 dollars, chain volume measures



extent of the shift towards investment in computerised information and organisational capital over time. The share of organisational capital has increased, while that of economic competencies as a group has decreased, influenced by the decrease in brand equity and firm specific human capital. The share of innovative property decreased slightly; however, it started to recover by the end of the period as the involvement of firms in business R&D has increased noticeably during the recent years.

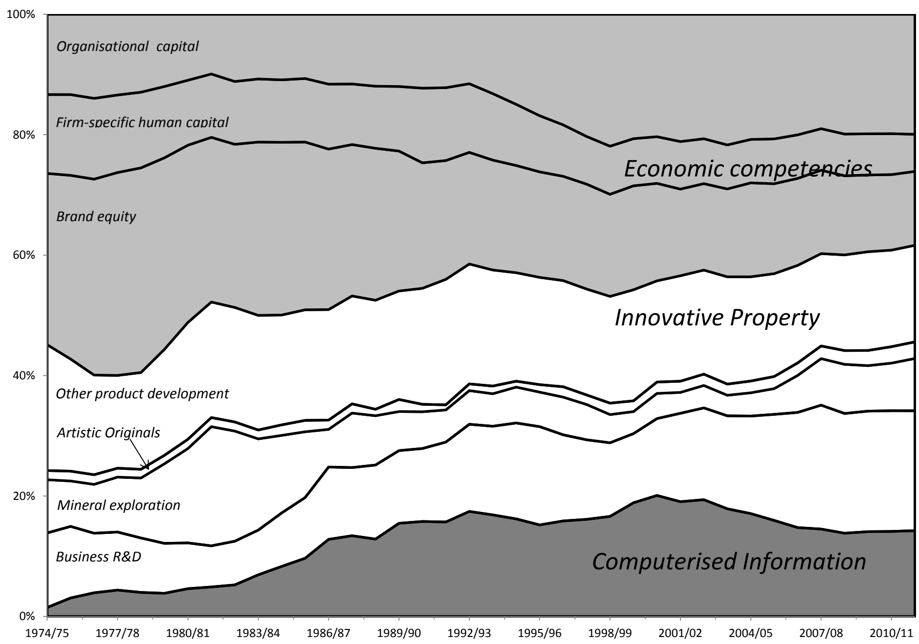
3.3 Intangible capital stocks

The paper uses the ABS stock estimates of software, mineral exploration and artistic originals. To estimate the end-of-period t stock of 'new' intangibles, $R(t)$, the perpetual inventory method (PIM) is used:

$$R(t) = N(t) + (1 - \delta)R(t - 1), \tag{1}$$

where $N(t)$ is the period t investment in intangible capital, $R(t-1)$ is the period $t-1$ real intangible capital stock and δ is the depreciation rate. The implementation of the PIM for estimating intangible capital requires an estimate of initial period 0 capital stock, R^0. Different assumptions were made in previous studies to estimate R^0. For example, CHS (2006) assumed an initial stock of zero in a specific year for each asset while others, such as the PC report, have assumed a constant rate of investment growth for the period prior to the first data point for investment and applied the formula $R^0 = N^0/(\delta + g)$, where g is equal to the average annual growth rate of intangible investment over the period of the study.

Figure 2 Shares of nominal total intangible investment, by asset type
Percent



The depreciation rate, δ, used for each intangible in the PIM is reported in Table 3. The depreciation rates for software, mineral exploration and artistic originals are the average rates of the ABS for those assets. Others are the rates suggested by CHS.

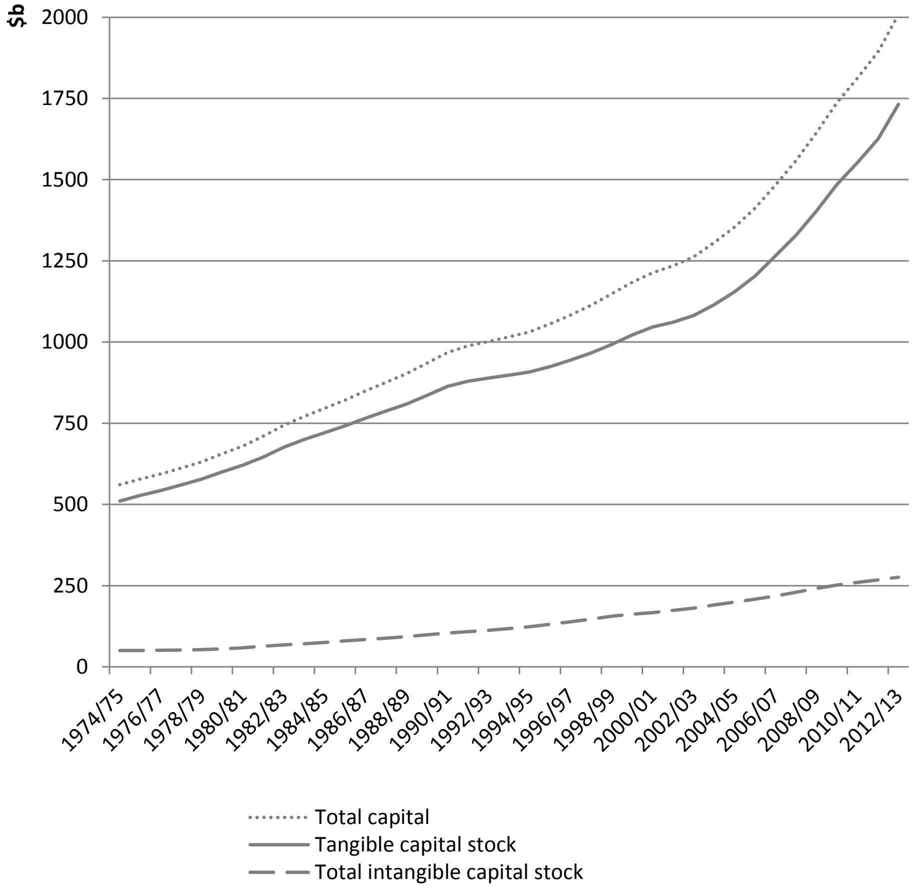
Table 3 Depreciation rate assumptions

Intangible	Rate (%)
Computer software	20
Innovative property	
Business R&D	20
Mineral exploration	10
Artistic originals	60
Other product development, design and research	20
Economic competencies	
Brand equity	60
Firm-specific human capital	40
Organisational capital	40

Between 1974-75 and 2012-13, the total stock of intangibles grew from \$50 billion to \$276 billion in real terms with an average annual growth rate of 5%; see Figure 3. The real tangible capital stock increased from \$540 billion to \$1,732 billion over the same period - an average annual growth rate of 3%. Intangible investment increased in importance relative to tangible investment over this period. The percentage of intangible capital in total capital grew from 9%

in 1974-75 to 14% in 2012-13, around 55% of which is currently capitalised.

Figure 3 Tangible, intangible and total capital stock, market sector, 1974-75 to 2012-13
2011-12 dollars, chain volume measures



3.3.1 The rental price of intangible capital

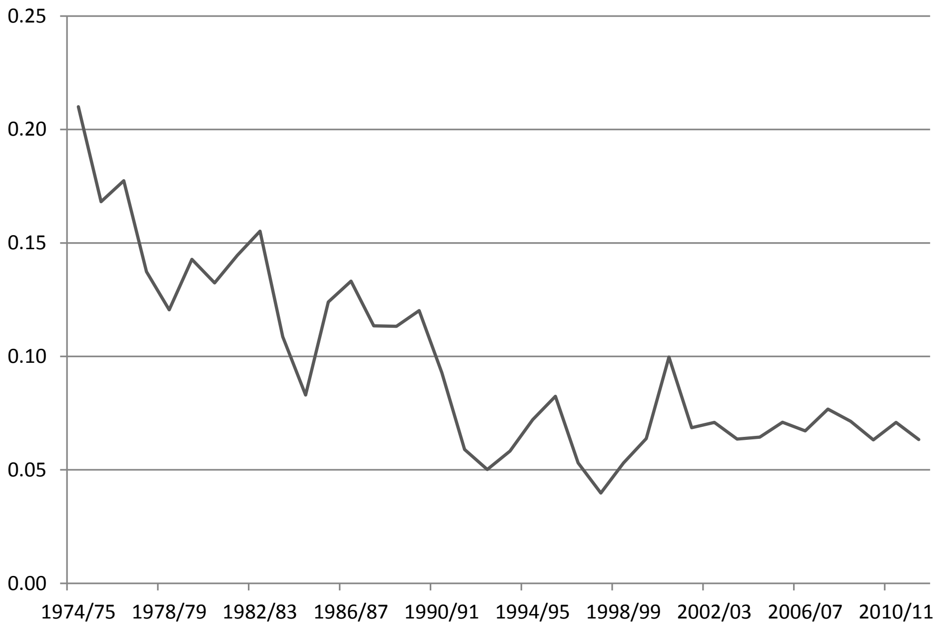
An estimate of the rental price (user cost) of intangible capital is required for the purpose of calculating MFP. The formula used in this paper is based on the ABS standard methodology for measuring capital services (ABS 2013):

$$r_j = T_j(i.p_j + \delta_j.p_j - p_j + p_{j(t-1)}) + p_j x, \tag{2}$$

where j is the asset type, r_j is the rental price, T_j is the income tax rate, i is the internal rate of return, p_j is the price deflator, δ_j is the depreciation rate and x is a non-income tax parameter, which is assumed to be the same for all assets types.

Two approaches have been used in previous studies for estimating the nominal rate of return on capital for intangible assets: endogenous rates of return calculated from capital income and exogenous rates of return chosen from observed market rates such as the interest rate on government bonds.[14] CHS (2006) and Marrano, Haskel and Wallis (2009) used endogenous rates of return to calculate the user cost of intangible capital for the U.S. and the U.K. respectively. Van Rooijen-Horsten et al. (2008) used exogenous rates of return for the Netherlands. The PC report used the ABS hybrid methodology.[15] This paper treats the intangibles like any other fixed asset in the growth accounting; thus, the ABS exogenous interest rate is used; see Figure 4.

Figure 4 Internal rate of return (IRR) for the market sector, all intangibles treated as capital



Data source: ABS unpublished National Accounts data (IRR floor rate: CPI growth plus 4%.)

4 Growth accounting with intangible capital

CHS (2006) demonstrate the effect of treating intangibles expenditure as investment (rather than as an intermediate input) on the National Accounts measures. Their model is based on three goods: a consumption good with real output volume in period t of $C(t)$ with price $P^C(t)$; a tangible investment good $I(t)$ with price $P^I(t)$; and an intangible good $N(t)$ with price $P^N(t)$. When intangibles are regarded as being intermediate goods, labour L and tangible capital K are

[14] An endogenous rate of return, i, can be calculated by assuming that capital income, Q, is equal to capital rent, $\sum_j r_j K_j$ where r_j is the user cost and K_j is the real capital stock. Reorganising (2) to include Q and K_j, i can be calculated as $i = Q - \sum_j K_j(T_j(\delta_j.p_j - p_j + p_{j(t-1)}) + p_j x / (\sum_j K_j T_j p_j)$.

[15] The ABS methodology uses an endogenous rate of return unless the endogenous rate falls below the level of consumer price index (CPI) growth plus 4%. If the rate falls below this level, CPI growth plus 4% is used as the rate of return. In practice, the rate of return rarely rises above this mark and can therefore be considered to be an exogenous rate of return for most years.

allocated to the production of all three goods, and N is an input to C and I. The production functions, $F^i(\cdot)$ and flow accounts for each of the three sectors, $i = N, I, C$, are then as follows:

$$\begin{aligned}
&\textit{Intangible sector} \quad && N(t) = F^N(L_N(t), K_N(t), t); \\
& && P^N(t)N(t) = P^L(t)L_N(t) + P^K(t)K_N(t), && (3)\\
&\textit{Tangible sector} \quad && I(t) = F^I(L_I(t), K_I(t), N_I(t), t); \\
& && P^I(t)I(t) = P^L(t)L_I(t) + P^K(t)K_I(t) + P^N(t)N_I(t), && (4)\\
&\textit{Consumption sector} \quad && C(t) = F^C(L_C(t), K_C(t), N_C(t), t); \\
& && P^C(t)C(t) = P^L(t)L_C(t) + P^K(t)K_C(t) + P^N(t)N_C(t), && (5)
\end{aligned}$$

where tangible capital accumulates according to the PIM. The production functions in these equations are linked to the accounting identities by the assumption that each input is paid the value of its marginal product. In this formulation, $N(t)$ is both an output and an immediate input to the production of the other products, and therefore nets out in the aggregate. Thus, $N(t)$ does not appear in the total output, $\acute{Y}_t$, identity:

$$P^Y(t)\acute{Y}(t) \quad = P^C(t)C(t) + P^I(t)I(t) = P^L(t)L(t) + P^K(t)K(t), \tag{6}$$

where $L = L_N + L_I + L_C$ and $K = K_N + K_I + K_C$.

If intangibles are treated as capital, a different model applies. The output of the intangible, $N(t)$, now appears in the production functions of the consumption and tangible investment sectors as a cumulative stock. In the same way as tangible capital, the intangible capital stock $R(t)$ accumulates according to the PIM. The sectoral equations become:

$$\begin{aligned}
&\textit{Intangible sector} \quad && N(t) = F^N(L_N(t), K_N(t), R_N(t), t); \\
& && P^N(t)N(t) = P^L(t)L_N(t) + P^K(t)K_N(t) + P^R(t)R_N(t), && (7)\\
&\textit{Tangible sector} \quad && I(t) = F^I(L_I(t), K_I(t), R_I(t), t); \\
& && P^I(t)I(t) = P^L(t)L_I(t) + P^K(t)K_I(t) + P^R(t)R_I(t), && (8)\\
&\textit{Consumption sector} \quad && C(t) = F^C(L_C(t), K_C(t), R_C(t), t); \\
& && P^C(t)C(t) = P^L(t)L_C(t) + P^K(t)K_C(t) + P^R(t)R_C(t), && (9)
\end{aligned}$$

where $P^R(t)$ is the rental price associated with the services of the intangible stock. The total output, Y_t, identity must be expanded to included the flow of new intangibles on the product side and the flow of services from the intangible stock on the income side:

$$\begin{aligned}
P^Y(t)Y(t) \quad &= P^C(t)C(t) + P^I(t)I(t) + P^N(t)N(t) = P^L(t)L(t) + P^K(t)K_t(t) \\
&+P^R(t)R_t(t), && (10)
\end{aligned}$$

where $N = N_N + N_I + N_C$ and $R = R_N + R_I + R_C$.

Further, CHS (2006) modify the standard Solow (1957) Multifactor Productivity (MFP) growth definition to include investment in intangibles. When treated as intermediate input, intangibles expenditure does not appear in the $M\acute{F}P$ growth equation:

$$\Delta \ln M\acute{F}P = \Delta \ln \acute{Y} - \acute{s}_K \Delta \ln K - \acute{s}_L \Delta \ln L, \tag{11}$$

where $\acute{s}_L = P^L L/(P^L L + P^K K)$ and $\acute{s}_K = P^K K/(P^L L + P^K K)$. When treated as capital, intangibles appear as an additional input in the revised MFP growth equation, which becomes:

$$\Delta \ln MFP = \Delta \ln Y - s_K \Delta \ln K - s_L \Delta \ln L - s_R \Delta \ln R, \tag{12}$$

where $s_L = P^L L/(P^L L + P^K K + P^R R)$, $s_K = P^K K/(P^L L + P^K K + P^R R)$ and $s_R = P^R R/(P^L L + P^K K + P^R R)$.

A comparison of (11) and (12) reveals that capitalising intangibles can change the National Accounts and productivity growth in many ways. The level of aggregate output increases because it includes the value of output of the intangible goods. The share of labour income in GDP declines, while the share of capital income increases due to the expanded total capital stock. In addition, the growth of output is higher because investment in intangibles is typically expected to increase at a rate higher than that of tangible capital. The effect on MFP growth is unclear, depending on the change in output growth relative to the change in input growth. MFP may rise (fall) if capitalising intangibles raises the output growth rate by less (more) than it raises the growth in inputs.

This section presents the impact of capitalising intangibles on the components of the production function and MFP. It uses the estimates of intangible investment presented here along with the ABS's National Accounts data on market sector GVA, labour input and input income shares.[16] Following the PC report, three different definitions of capital are used to analyse the impact of intangibles on the growth accounting estimates: (i) including tangible and all intangible assets, (ii) including tangible assets and National Accounts intangible assets only, and (iii) including tangible assets only.[17]

Output

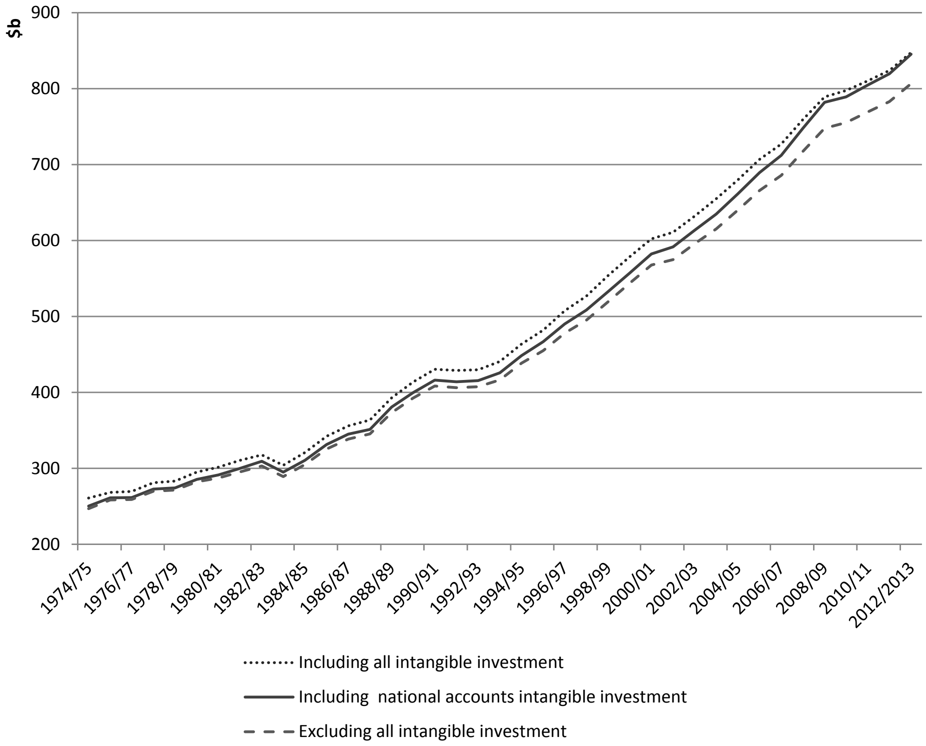
Figure 5 compares market sector GVA for each of the three definitions of capital. It has been shown in Table 2 that over the period 1974-75 to 2012-13 investment in new intangibles is larger than investment in National Accounts intangibles. Thus, new intangibles make a larger

[16] A detailed description of data sources for these variables is provided in the Appendix.

[17] The estimates of National Accounts intangibles, and thus the ensuing MFP indexes, developed in this paper are not identical to the ABS official estimates. Several factors may explain this. (i) There is a difference in the level of aggregation at which the estimates are constructed. Due to data limitations, the paper aggregates all assets in all industries in a single stage then uses rental prices to construct capital services. On the other hand, the ABS constructs capital services indexes for each of the twelve market sector industries separately then aggregates these indexes together using relevant weights, (ii) The ABS BERD data includes some R&D related to financial services and architectural/engineering services. The scope of these types of R&D as discussed in CHS is broader than those activities that may be covered by the BERD survey. Thus, separate estimates for these types of R&D are developed and the ABS-based BERD estimates were reduced to avoid double counting. (iii) The rental prices and the PIM version used by the ABS to construct capital stock is more complex than the method used in this paper.

contribution to the total GVA than National Accounts intangibles.

Figure 5 Market sector gross value added, 1974-75 to 2012-13
2011-12 dollars, chain volume measures



Capital services

Aggregate capital services indexes are constructed using the volume index of capital stock of each asset weighted by its rental price weight. Figure 6 presents the total capital services indexes for each of the three definitions. As shown in the figure, capitalising intangibles has increased the growth in capital services. This indicates that growth in capital services from intangibles was faster than growth in capital services from tangibles.

Factor income shares

Capitalising intangibles has noticeably changed the factor income shares over the period 1974-75 to 2012-13. Table 4 shows the upward (downward) trend in the capital (labour) share of total factor income. Investment in new intangible assets increases the capital income share by a greater percentage than the National Accounts intangible assets. This is because investment in new intangibles represents a larger proportion of total investment than investment in the National Accounts intangibles.

Multifactor productivity

Figure 7 shows that capitalising intangibles expenditure has changed the rate of MFP growth.

Figure 6 Capital services, market sector, 1974-75 to 2012-13
Index 1974-75= 100

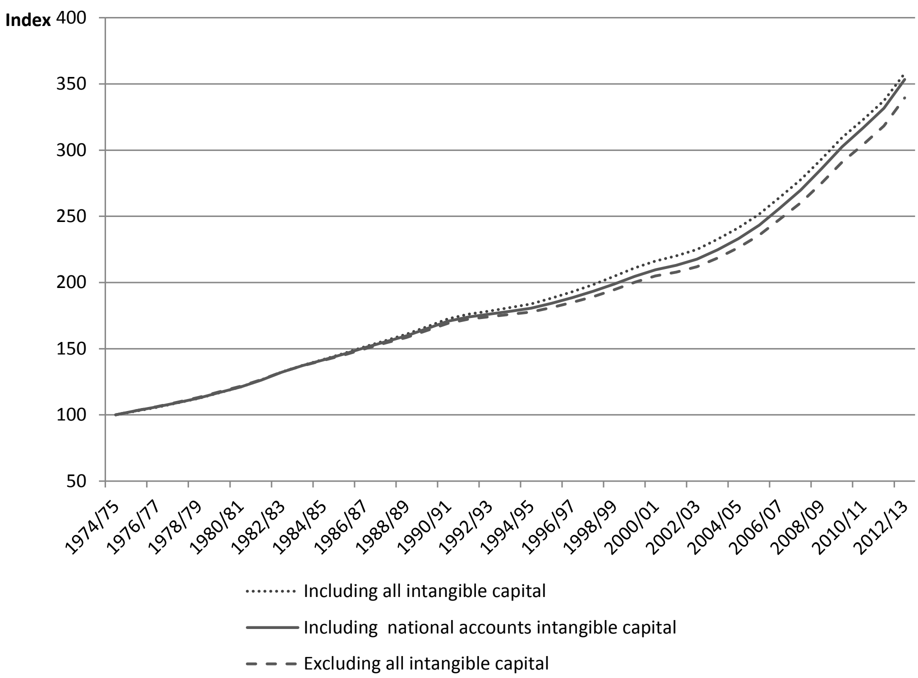
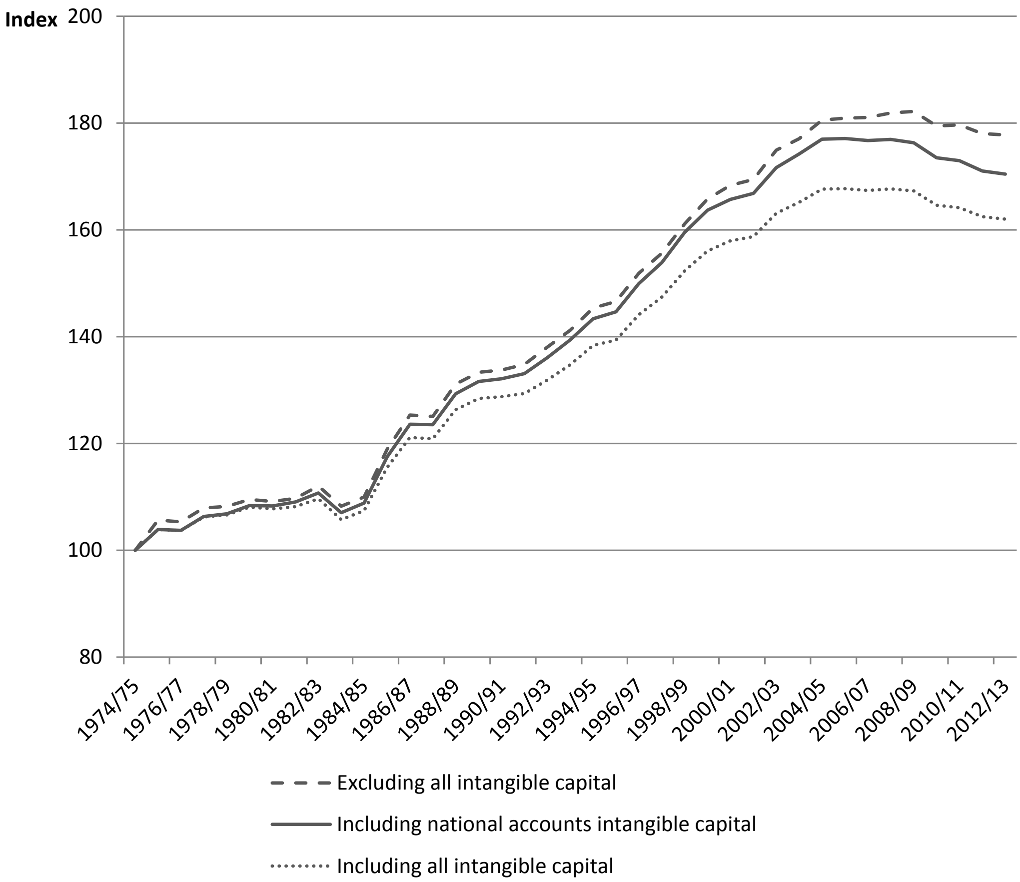


Table 4 Capital and labour income shares, market sector 1974/75 to 2012/13

	1974/75 – 1984/85	1984/85 – 1994/95	1994/95 – 2004/05	2004/05 – 2012/13
Including all intangibles				
New Intangibles	0.050	0.054	0.062	0.059
The ABS Intangibles	0.015	0.023	0.030	0.037
Intangibles	0.064	0.076	0.093	0.096
Tangibles	0.322	0.366	0.376	0.399
Total capital	0.386	0.442	0.469	0.495
Labour	0.614	0.558	0.531	0.505
Including national accounts intangibles				
The ABS Intangibles	0.015	0.024	0.032	0.040
Tangibles	0.338	0.386	0.401	0.424
Total capital	0.354	0.411	0.433	0.464
Labour	0.646	0.589	0.567	0.536
Excluding all intangibles				
Capital	0.344	0.396	0.414	0.441
Labour	0.656	0.604	0.586	0.559

In particular, it indicates that MFP growth has decreased. This can be explained by the fact that the inclusion of intangibles has raised output growth by a lower rate than it has raised the growth in inputs. Although, the rate of MFP growth has decreased across the period, the pattern of the growth remains unchanged. Specifically, the improvement in productivity during the productivity growth cycle of 1998-99 to 2003-04 and the overall decline during the recent productivity growth cycle is still present after capitalising intangibles.

Figure 7 Multifactor productivity, market sector, 1974-75 to 2012-13
Index 1974-75= 100



5 Government spending on science and innovation

Besides fulfilling public needs (such as improving the products and services offered or better delivery of functions), the economic rationale for governmental involvement in the area of research and innovation is the existence of market failure associated with research and innovation. This market failure is typically due to the diffusion of knowledge beyond the control of the inventor, which implies that the private rate of return to research and innovation is lower than its social return. Thus, governments intervene to eliminate this wedge between private and social returns.

Another reason for the provision of public support is that governments may want to stimulate research and innovation performed by the business sector. This is likely to be below the socially optimal level as firms are often discouraged from engaging in research activities by the inherently high risk of research (Arrow 1962). Therefore, governments intervene to assist firms either by mitigating their private costs or by raising awareness of the technological opportunities that are available to reduce both the cost and uncertainty of research and innovation.

Similar to many other OECD-member governments, the Australian government devotes a considerable amount of funding to promote research and innovation in the country. At present there are two main sources of data on public support for R&D and innovation: the Science, Research and Innovation Budget Tables (SRIBTs) and the ABS survey on R&D. With each Federal Budget, the Australian government publishes SRIBTs which provide an overview of government support for science, research and innovation over a period of ten years. The SRIBTs summarise the total of Australian Government support by sectors of performance as well as providing a decomposition of the total expenditure by program and socio-economic objectives. On the other hand, the ABS survey on public spending on R&D captures R&D expenditure at the points at which R&D is performed.

Several technical challenges make the outlays data from the SRIBTs not strictly comparable with the R&D expenditure data captured by the ABS; see Matthews and Howard 2000 for more discussion on this issue. For the purpose of econometric investigation, this paper focuses on the SRIBTs data because the breakdown of spending is more relevant to our research question. Nevertheless, extra interesting information is available from the ABS survey data, which may shed more light on Australia's innovation system. Therefore, a brief snapshot of the ABS survey data will also be presented.

The SRIBTs classify government support for research and innovation into four sectors of performance: Commonwealth research agencies, the higher education sector, the business enterprise sector, and a "multisector". Figure 8 presents public spending estimated for the year 2012-13. As shown in the figure, the higher education sector is the most important direct recipient of science and innovation funding from the Australian Government, receiving around 32% of total public support followed by the business enterprise sector and the multisector (or "civil" sector) which respectively received 25% and 23% of the total support. The research agencies sector has received the smallest portion of support which is equivalent to 20% of total support.

The public funds devoted to each of these sectors is allocated to different areas. An analysis of the $8.9 billion outlay by the Australian Government for R&D and innovation in 2012-13 shows the following:

Higher Education Research

The Performance Based Block Funding (PBBF) accounts for 67% of total funding to the higher education sector. The PBBF is provided through a number of 'performance based' arrangements such as the Research Training Scheme (RTS), the Institutional Grants Scheme (IGS), the Research Infrastructure Block Grants scheme (RIBG) and the Australian Postgraduate Awards scheme (APA).[18] The Australian Research Council (ARC) funding accounts for 31% of total funding to higher education. Other R&D Support accounts for 2%.

[18]These arrangements are known as 'performance based' because allocations to each institution depend on its past 'performance' as assessed by various formulae administered through the Department of Education, Employment and Workplace Relations.

Business Enterprise Sector

Government support for business sector science and innovation activity is delivered through a range of programs. The main program is the R&D Tax Concession which accounts for about 81% of total business support in 2012-13. Other Innovation Support and Other R&D Support account for 18% and 1% respectively.

Research Agencies

Two main organisations — the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Defence Science and Technology Organisation (DSTO)— dominate the research funding allocated to public sector research agencies. In 2012-13, the CSIRO accounted for 41% of the total public sector research agency funding while the DSTO accounts for 25%. Other public R&D agencies account for 34%.[19]

Multisector

About 46% of the multisector funding is devoted to the National Health and Medical Research Council (NHMRC) and Other Health grants, which predominantly go to universities and private nonprofit Medical Research Institutes (MRIs). The Cooperative Research Centres (CRCs) and Rural Funds also have strong university components and they constitute around 8% and 12% of the multisector outlays respectively. Energy and the Environment has a share of 13% and the Other Science Support is 21%.

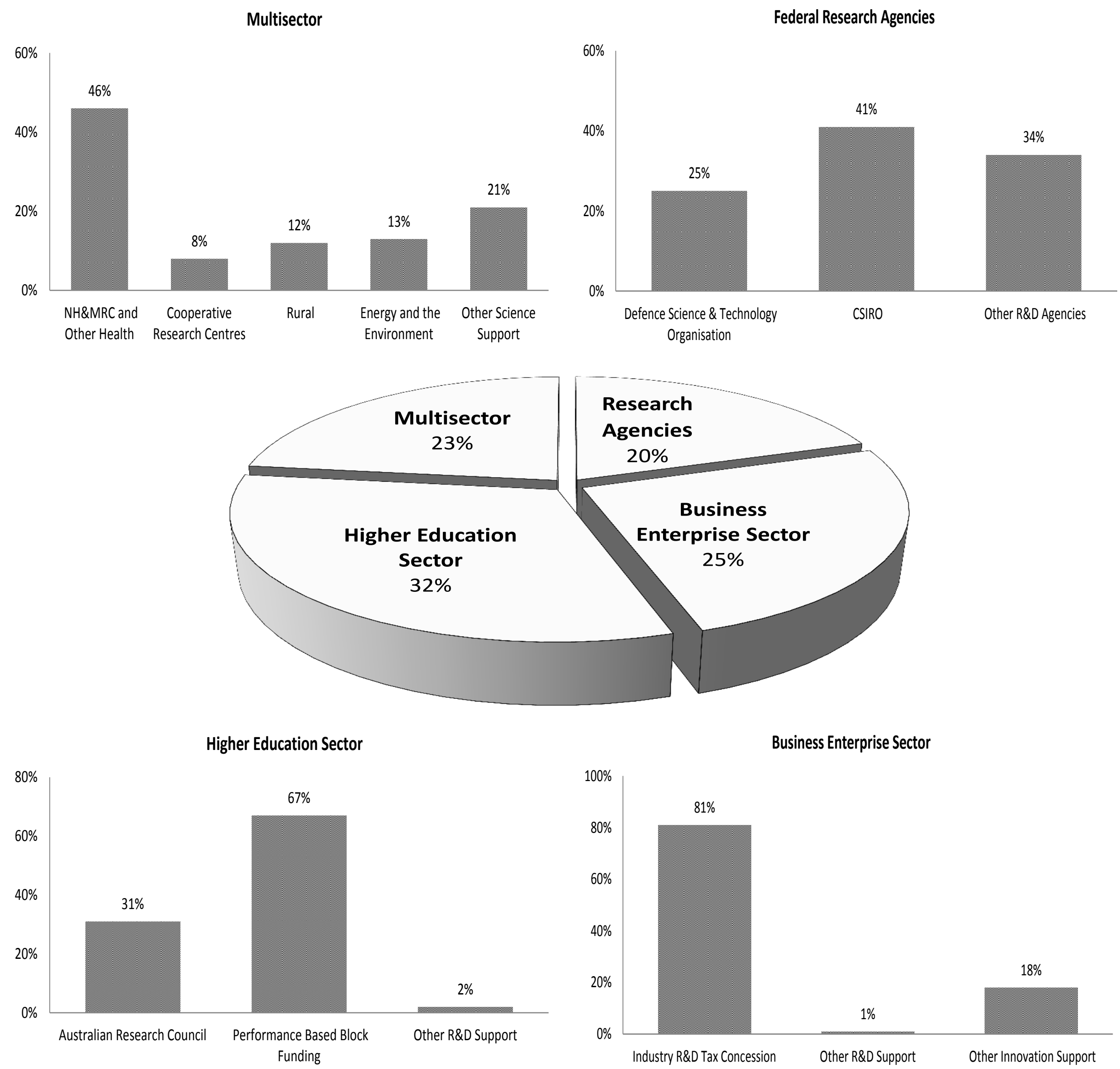
Figure 9 depicts a long-term perspective of the Australian Government support for research and innovation and its components. The total support has increased in real terms over the past two decades; however, it has fallen as a share of GDP. There have been noticeable changes in the role of the government support across its four components of funding. In particular, indirect public support for the business enterprise sector and the multisector has grown in real terms during the past two decades. However, support to higher education and direct support to research agencies has barely grown. This has meant that the share of public support to the multisector has roughly doubled between 1993-94 and 2012-13 while support to the higher education has halved. A number of factors can account for this changing pattern in government investment including, an increased focus on collaboration in the multisector and progressive increases in claims on the R&D Tax Concession in the business enterprise sector.

To explore how public R&D resources are allocated according to the intended purpose or outcome of the research, we employ the ABS survey data on public R&D.[20] Figure 10 presents a comparison between 1992-93 and 2011-12 in breaking down expenditure on R&D by socio-economic objective. As seen in the figure, the largest share of government R&D expenditure was directed towards economic activities followed by defence and environment activities. However,

[19] Other public R&D agencies include the Australian Nuclear Science and Technology Organisation (ANSTO); Geoscience Australia; Antarctic Division; Australian Institute of Marine Science (AIMS); Bureau of Meteorology Research Centre; Environmental Research Institute of the Supervising Scientist; Australian Animal Health Laboratory; Great Barrier Reef Marine Park Authority; and the Anglo-Australian Telescope.

[20] Note that the ABS surveys have been conducted every two years.

Figure 8 Australian Government spending on research and innovation 2012-13



social activities such as education and training, and social development and community activities receive a small share of government R&D expenditure.

The ABS data also breaks down Commonwealth expenditure on R&D by the type of activities: basic research, applied research and experimental development. Basic research is further broken into two types, pure and strategic basic research. Applied research is a critical input to the innovation system and is often seen to be more immediately relevant and applicable for end-users, specifically industry, than basic research. In Figure 11 it is shown that the Commonwealth and State governments focus more on applied research and strategic basic research at the expense of pure basic and experimental development research.

Figure 9 Total Australian Government support for research and innovation 1993-94 to 2012-13

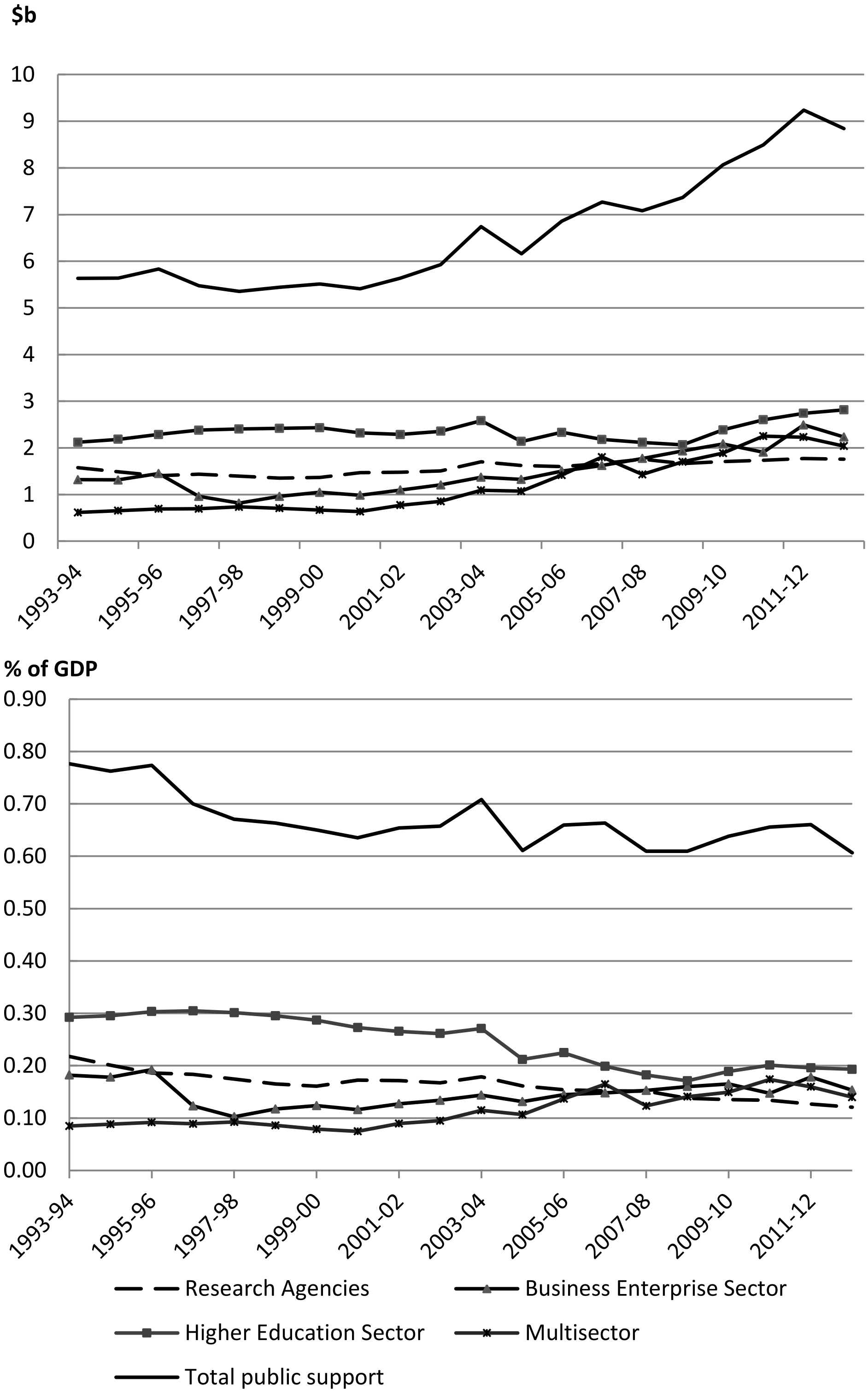
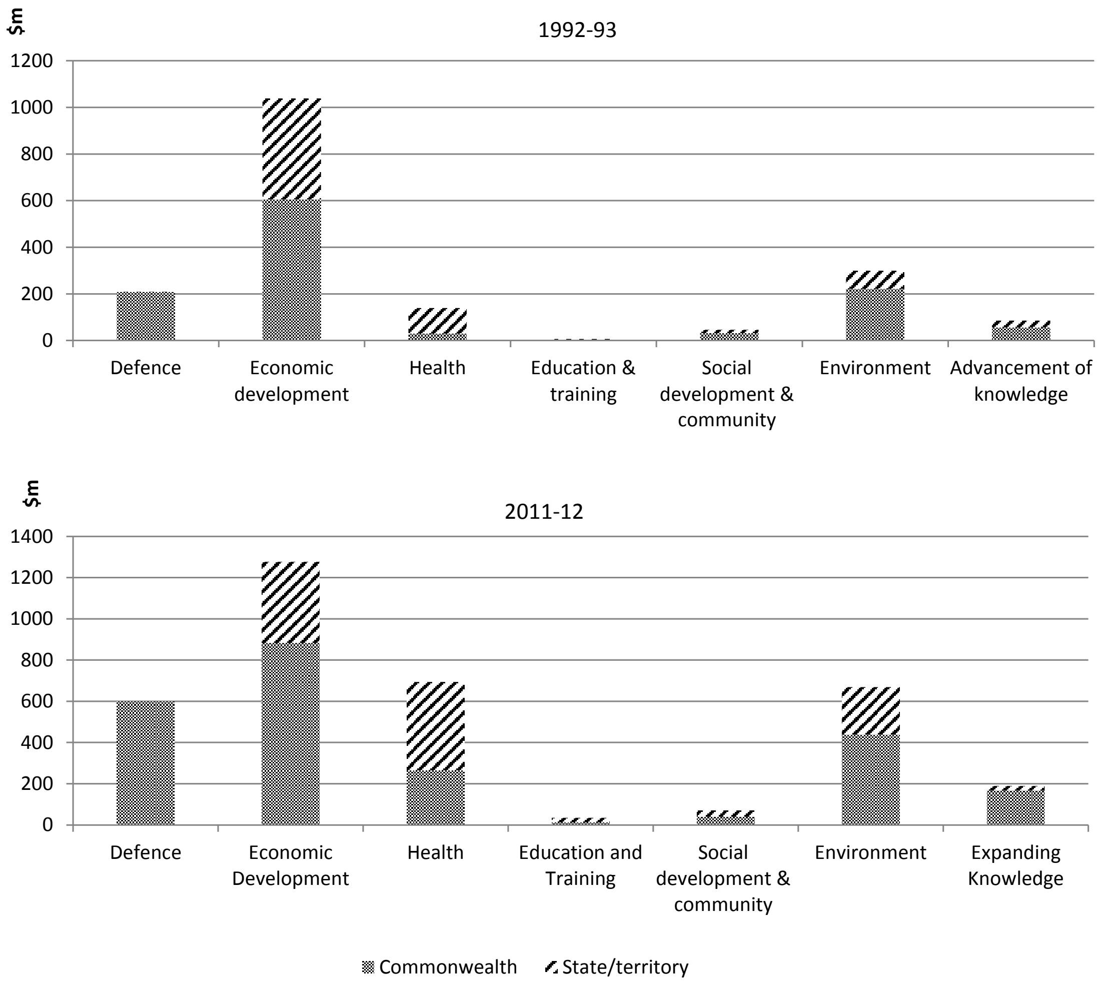


Figure 10 Breakdown of underpinning research funded by the Commonwealth and State/territory by socio-economic objective, 1992-93 and 2011-12



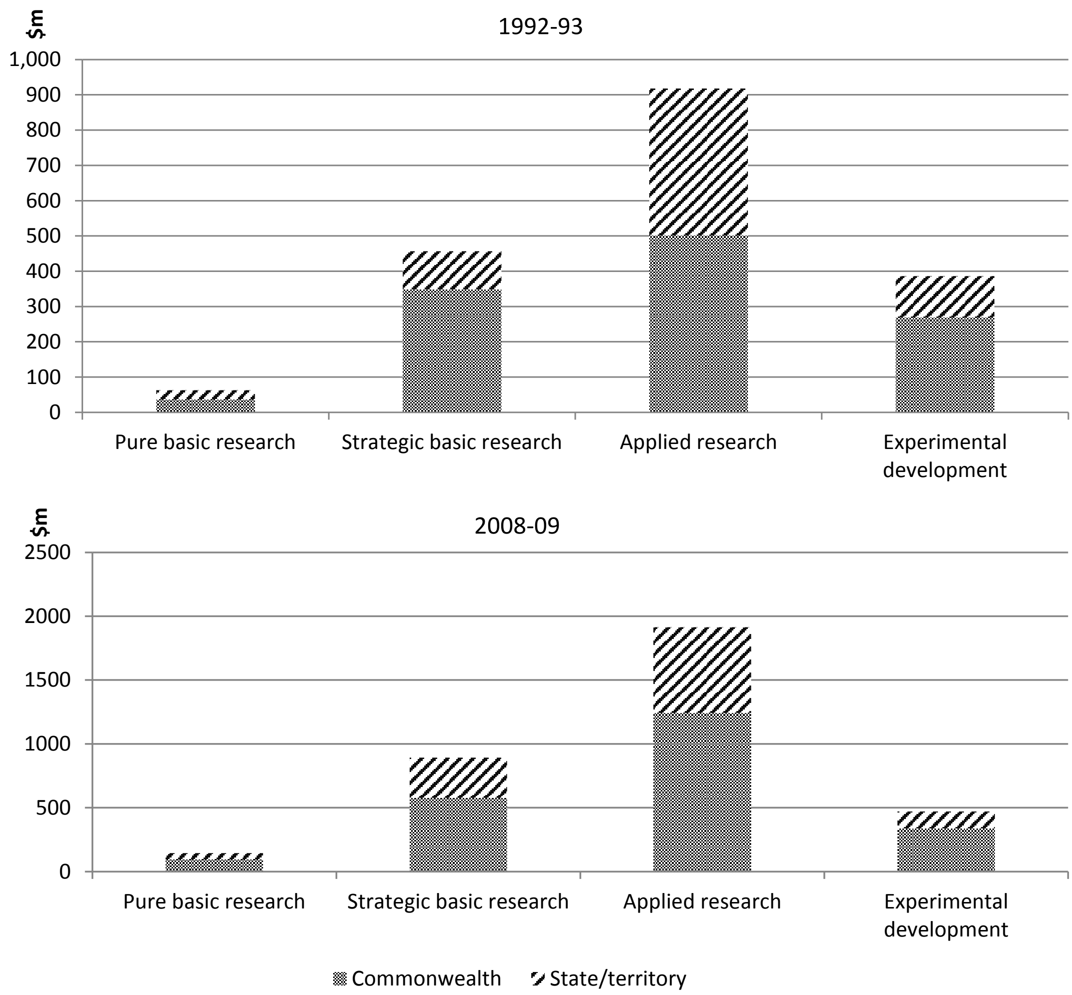
6 The relation between public support for R&D and market sector MFP growth

Trends in Australia's MFP (adjusted for the inclusion of intangibles) were outlined in Section 4. Section 5 has highlighted the key trends in public spending on R&D. This section investigates the bi-variate relationship between productivity growth and the growth of the public R&D stock.[21]

Figure 12 plots MFP growth, smoothed by a three year centred moving average, against the capital stock growth of public support for research agencies, higher education, and business enterprise. Productivity and public support for higher education activities are moving together

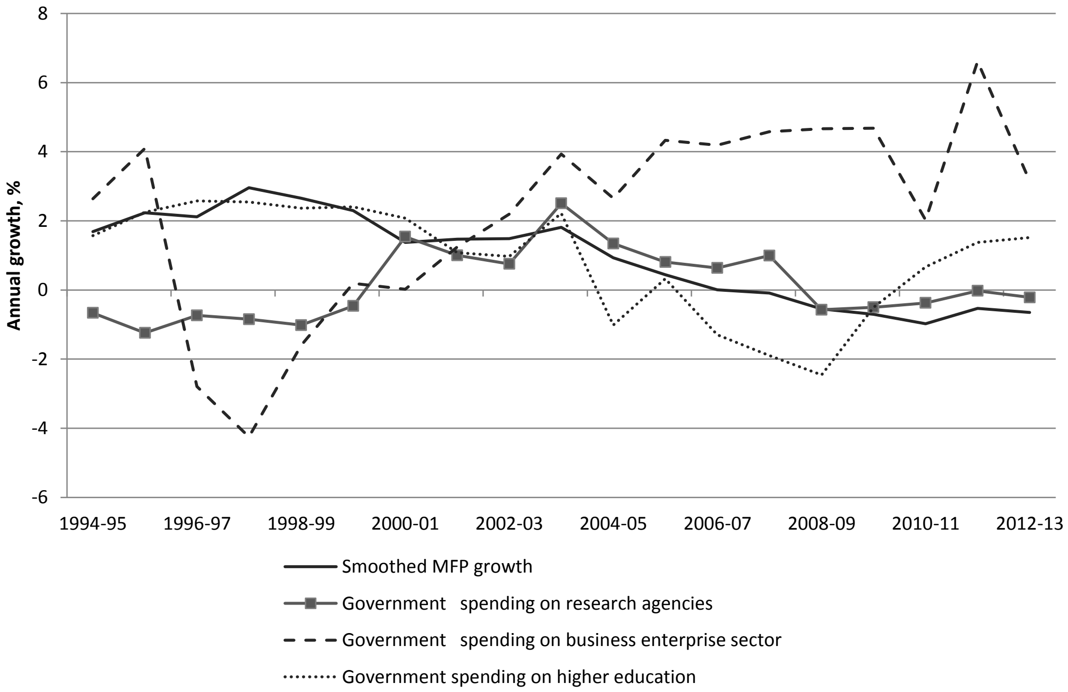
[21]Most of the previous studies that examined the relationship between R&D and economic or productivity growth have avoided the problem of obtaining an estimate of R&D capital stock by employing a measure of R&D intensity (i.e. a ratio of R&D expenditures to the value of production). However, this method implicitly assumes that the depreciation rate of R&D is zero which is not necessarily a realistic assumption. The approach here is to use the stock of public sector R&D estimated by using PIM and assuming a depreciation rate identical to the business sector R&D presented in Table 3.

Figure 11 Commonwealth support for R&D, by type of activity, 1992-93 and 2008-09



throughout the period, which gives the appearance of a strong relationship. Similarly, with the exception of the early years, there is a co-movement between productivity and research agencies' activities, again suggesting a positive correlation between them. Conversely, the divergent trends in productivity and the public support for business enterprise which are seen to dominate the whole period suggest a negative relationship. However, this casual analysis presupposes a contemporaneous relationship between R&D and productivity presented in Figure 12; it is more likely that there are lagged effects of R&D expenditure on productivity since knowledge typically takes time to disseminate. The correlations suggested by the bi-variate plots may therefore represent an overly simplistic analysis. There might also be other potential influences on productivity which could be obscuring actual causal relationships. Therefore, to provide stronger evidence on the relationship between productivity and public knowledge, a detailed econometric analysis accounting for other influences is required.

Figure 12 Market sector MFP growth and public support for research agencies, higher education and the business enterprise sector (1993/94-2012/13)



Note: MFP growth rates smoothed by a three year centred moving average.

7 Econometric analysis

7.1 The model

In line with HW, consider the following production function:

$$Y_t = A_t F(L_t, K_t, N_t^{PRV}, N_t^{PUB}), \tag{13}$$

where Y_t, L_t,K_t, N_t^{PRV} denote value-added output, labour input, tangible and private intangible capital respectively. N_t^{PUB} is capitalised public support for research and innovation, and A_t is any increase in output not accounted for by the increase in the above four factors of production.

Assuming a general Cobb-Douglas representation for the production technology, the production function $F(\cdot)$ can be written in terms of natural logarithms as follows:

$$\ln Y_t = \ln A_t + \sum_{X=L,K,N^{PRV}} \varepsilon_X \ln X_t + \varepsilon_{N^{PUB}} \ln N_t^{PUB}, \tag{14}$$

where $X = L, K, N^{PRV}$, and ε_X is the elasticity of output with respect to each input.

For estimation purposes, assume:

$$\ln A_t = \alpha_o + \upsilon_t, \tag{15}$$

where υ_t is an iid error term. In addition, we assume that the elasticity ε_X equals the factor income share, s_X, plus a term, d_x, to account for either deviations from perfect competition or spillovers due to that factor:

$$\varepsilon_X = s_X + d_x \qquad \forall X. \tag{16}$$

Taking N_t^{PUB} to be *freely available* public support for research and innovation, it does not have an observable factor share and hence the output elasticity, $\varepsilon_{N^{PUB}}$ must be econometrically estimated.

Again following the standard Solow (1957) growth accounting approach, an expression for the level of MFP can be obtained from (14) as follows:[22]

$$\ln MFP_t \equiv \ln Y_t - \sum_{X=L,K,N^{PRV}} s_X \ln X_t. \tag{17}$$

By substituting (14) and (15), and allowing for the effect of other factors, Z_t, which are not accounted for in the calculation of MFP, (17) can be rewritten as:[23]

$$\ln MFP_t = \alpha_o + \sum_{X=L,K,N^{PRV}} d_X \ln X_t + \varepsilon_{N^{PUB}} \ln N_t^{PUB} + \alpha_1 Z_t + \upsilon_t, \tag{18}$$

where α_1 is a vector of coefficients. Equation (18) is used to examine two issues of interest: First, the existence of any spillovers from the market sector investment in intangibles. This issue can be addressed by estimating the coefficient on private intangible capital. Further, by breaking intangible capital into classes (software, innovative property and economic competencies), individual effects of these classes can be estimated. Second, (18) is used to examine the impact of public support for R&D through the estimation of the elasticity parameter $\varepsilon_{N^{PUB}}$. In addition, N^{PUB} can be broken into components to assess the impact of direct versus indirect public support for R&D.

Equation (18) involves the use of time-series data in (log) levels. Thus, there is a risk that some of these series show non-stationary behaviour. Previous studies of productivity analysis have extensively discussed the issue of spurious regression which might emerge when non-stationary series are used (e.g., Tatom 1993). Often, the best practice to address the issue of spurious regression is to formally test for unit roots and cointegration. Performing these tests,

[22] Solow's (1957) approach is based on two simplifying assumptions: (i) competitive markets in which factors are rewarded according to their marginal products — so that the output elasticities can be represented by factor shares in total factor income, and (ii) constant returns to scale — so that factor shares sum to unity.

[23] Note that there is an important difference between the regression model of this paper represented by (17) and that of HW. Instead of using the stock of public sector R&D as in this paper, HW lagged the ratio of public sector R&D expenditure to GDP and used it as a regressor, assuming a zero depreciation rate of public sector R&D.

we find evidence of cointegration; however, the result of this test may not be legitimate due to the small size of the sample.[24] When the series is suspected to be non-stationary, a possible solution suggested in literature is to estimate the production function using first differences. Generally speaking, estimation in first differences is problematic in that it may destroy the long-run relationship between the variables of interest, since any common long-run stochastic trends in the data are removed by differencing. However, as with HW, we are also interested in the determinants of productivity growth, so (18) is rewritten in first differences (i.e. growth terms) as follows:

$$\Delta \ln MFP_t = \tilde{\alpha}_o + \sum_{X=L,K,N^{PRV}} \tilde{d}_X \Delta \ln X_t + \tilde{\varepsilon}_{N^{PUB}} \Delta \ln N_t^{PUB} + \tilde{\alpha}_1 Z_t + \eta_t. \tag{19}$$

7.2 Control variables

A number of studies suggest some external factors as possible determinants of Australia's productivity growth (e.g., Connolly and Fox 2006, Shanks and Zheng 2006). This paper focuses on a group of factors that are generally seen as important in explaining productivity. For some of these factors there is no consensus on either the size or the direction of the effects on productivity.

Public infrastructure

The significant role of public infrastructure on productivity in Australia has been cited in a number of studies such as Otto and Voss (1994) and Shanks and Barnes (2008). The majority of these studies have used the official measure of the public net capital stock published by the ABS as a measure of public infrastructure. This paper constructs a more suitable measure for public economic infrastructure by utilising the engineering construction data published by the ABS. These data better represent the spending on economic infrastructure in comparison to other available data (Elnasri 2013).

Business cycle

Connolly and Fox (2006) and Shanks and Zheng (2006), among others, have included a business cycle variable to control for the pro-cyclical nature of MFP. An output gap measure provides one of the methods for controlling for the effects of the business cycle. Here, following a standard approach, the output gap is measured as the difference between the natural logarithm of output and its trend. The trend is calculated using the Hodrick-Prescott filter (Hodrick and Prescott 1997) with the smoothing parameter equal to 1,600.

Trade openness

Some evidence suggests that in relatively unregulated economies, such as Australia, an increase

[24] The augmented Dickey-Fuller (ADF) test (Dickey and Fuller (1979)) is applied to the OLS residuals to test for the null hypothesis of no cointegration. However, a major and widely cited setback with the ADF test is the inherent low power when it is applied to short data series. The power of the test is the ability to reject the null of non-stationarity when it is false; because the ADF test has low power, it may suggest that a series has a unit root while it is stationary.

in trade openness is associated with an increase in GDP per capita (Bolaky and Freund 2004). Thus, a measure of trade openness is constructed as the sum of imports and exports over GDP.

Energy prices

Connolly and Fox (2006) included the West Texas crude oil prices in regressions to control for the three oil price shocks when they examined the impact of high-tech capital on the Australia's productivity. These crude oil prices are used here as a proxy to control for price shocks that might have a direct impact on the world energy market.

Terms of trade

Similarly to Madden and Savage (1998), a terms of trade variable (the ratio of export prices to import prices) is used to represent international competitiveness.

7.3 Results

Spillovers from market sector intangible investment

The first column of results in Table 5 presents the effects of the aggregate market sector's intangible capital on MFP. Results are reported for both the (log) levels and growth of MFP from estimating (18) and (19), with the exclusion of the public sector R&D terms, i.e. $\varepsilon_{N^{PUB}} \ln N_t^{PUB}$ and $\tilde{\varepsilon}_{N^{PUB}} \Delta \ln N_t^{PUB}$ from these two equations respectively. Focusing first on the (log) levels model, there is strong evidence for the positive impact of intangible capital on the market sector MFP. In particular, the elasticity of MFP relative to intangibles is 0.64 which means an increase of 1% of intangible capital can increase MFP by 0.64%. Bearing in mind that the intangibles variable is an aggregate measure that includes all types of intangible assets, the magnitude of the estimated elasticity is not entirely surprising. As mentioned earlier, the direct effects of the primary inputs (labour, tangible and intangible capital) are accounted for in the calculation of the MFP index. Thus, the estimated coefficients on these variables, presented in (18) and (19), represent indirect effects that may arise due to deviations from perfect competition and CRS assumptions, imposed on the construction of MFP, or spillovers due to those factors.

While intangible capital has positive spillovers, the negatively signed and highly statistically significant coefficients on the tangible capital and labour inputs suggest negative spillovers or decreasing returns. This is not an unusual result for the Australian market sector, as previous studies such as Shanks and Zheng (2006) and Industry Commission (1995) have also found evidence on decreasing returns to labour and capital.

Results on the coefficients of the control variables (business cycle, public infrastructure and trade openness) are broadly acceptable and consistent with theory and prior empirical findings. In particular, they suggest positive and statistically significant impacts for these three variables on productivity. The overall fit of the model is good with the $\bar{R}^2$ being equal to 0.99. Because there is evidence of serial correlations detected by the Durbin-Watson statistic test, Newey-West standard errors are applied in drawing statistical inferences.

Table 5 Spillovers from intangible investment (1993-2012)

	$\ln MFP$	$\Delta \ln MFP^a$	$\ln MFP$	$\Delta \ln MFP^a$
Tangible capital	-0.481***	-0.545***	-0.175**	-0.117
	(0.060)	(0.137)	(0.067)	(0.084)
Labour	-0.631***	-0.127	-0.555***	-0.122*
	(0.094)	(0.115)	(0.054)	(0.065)
Intangible capital	0.644***	0.418*		
	(0.073)	(0.191)		
Software			0.141***	0.059
			(0.007)	(0.058)
Innovative property			0.099*	-0.112
			(0.049)	(0.130)
Economic competencies			0.114***	0.277***
			(0.025)	(0.029)
Business cycle	0.628***	0.046	0.806***	0.121
	(0.193)	(0.129	(0.110)	(0.067)
Public infrastructure	0.391*	-0.151	0.057	-0.138
	(0.220)	(0.325)	(0.122)	(0.209)
Openness	0.012*	-0.001	0.002*	0.003*
	(0.005)	(0.001)	(0.001)	(0.002)
$\bar{R}^2$	0.99	0.75	0.99	0.91
Durbin-Watson	1.28	1.17	2.51	2.74
Jarque-Bera normality	(0.447)	(0.507)	(0.627)	(0.971)

[a] $\Delta \ln MFP$ smoothed by three-year moving average. Terms in brackets are heteroskedasticity and autocorrelation robust Newey-West standard errors.

The second model describes the effects on MFP growth which is, as in HW (2013), smoothed by a three-year moving average. The result on the intangibles remains positive and statistically significant. While the coefficient on tangible capital growth is negative and statistically significant, the effects of the remaining variables are statistically insignificant.

To explore which components of intangible capital are the major drivers of the positive relationship found above, the second column of Table 5 presents the breakdown of intangibles into its three components, i.e. computerised information (software), innovative property, and economic competencies. When the (log) levels model is estimated, the three components of intangibles have positive and significant coefficients with reasonable magnitudes. However, in the differences model, only the result for economic competencies remains robust while the impacts of software and innovative property appear insignificant.

Including the three components of intangibles simultaneously in the same model may raise a problem of multicollinearity which can produce large standard errors and hence have an impact on the statistical inferences. To address this problem, three individual regressions are performed to separately examine the effects of software, innovative property and economic competencies and the results are reported in Tables 6, 7 and 8 respectively. A further robustness check for the results is made by changing the specification of the model. Specifically, the terms of trade and energy prices control variables are included in the model while openness is dropped.[25]

While in the (log) levels model the three components of intangibles have positive and stat-

[25] Due to the small number of observations, not all control variables were included simultaneously.

Table 6 Spillovers from software (1993-2012)

	$\ln MFP$	$\Delta \ln MFP^a$
Tangible capital	-0.226**	-0.511**
	(0.076)	(0.222)
Labour	-0.629***	-0.027
	(0.055)	(0.144)
Software	0.199***	0.013
	(0.010)	(0.118)
Business cycle	1.232***	0.038
	(0.086)	(0.102)
Public infrastructure	0.266*	-0.482
	(0.145)	(0.305)
Terms of trade	0.057	-0.019
	(0.029)	(0.036)
Energy prices	-0.010**	-0.003
	(0.003)	(0.006)
Number of Observations	20	19
$\bar{R}^2$	0.99	0.63
Durbin-Watson	1.39	1.12
Jarque-Bera normality	(0.477)	(0.284)

[a] $\Delta \ln MFP$ smoothed by three-year moving average.
Terms in brackets are heteroskedasticity and autocorrelation robust Newey-West standard errors.

Table 7 Spillovers from innovative property (1993-2012)

	$\ln MFP$	$\Delta \ln MFP^a$
Tangible capital	-0.951***	-0.480**
	(0.186)	(0.198)
Labour	-1.001***	-0.005
	(0.242)	(0.155)
Innovative property	0.757***	-0.110
	(0.126)	(0.201)
Business cycle	1.313***	0.057
	(0.277)	(0.099)
Public infrastructure	1.297***	-0.540
	(0.291)	(0.389)
Terms of trade	-0.060	-0.017
	(0.066)	(0.030)
Energy prices	0.025**	-0.0041
	(0.011)	(0.006)
Number of Observations	20	19
$\bar{R}^2$	0.98	0.63
Durbin-Watson	2.01	1.72
Jarque-Bera normality	(0.957)	(0.306)

[a] $\Delta \ln MFP$ smoothed by three-year moving average.
Terms in brackets are heteroskedasticity and autocorrelation robust Newey-West standard errors.

Table 8 Spillovers from economic competencies (1993-2012)

	$\ln MFP$	$\Delta \ln MFP^a$
Tangible capital	-0.094	-0.273***
	(0.127)	(0.078)
Labour	-0.555***	-0.161*
	(0.141)	(0.076)
Economic competencies	0.422***	0.276***
	(0.052)	(0.035)
Business cycle	0.293	0.083
	(0.281)	(0.075)
Public infrastructure	0.187	-0.143
	(0.385)	(0.221)
Energy prices	0.034***	0.006
	(0.007)	(0.004)
Number of Observations	20	19
$\bar{R}^2$	99	90
Durbin-Watson	1.23	1.78
Jarque-Bera normality	(0.777)	(0.941)

[a] $\Delta \ln MFP$ smoothed by three-year moving average.
Terms in brackets are heteroskedasticity and autocorrelation robust Newey-West standard errors.

ically significant effects on productivity, in the differences model, only economic competencies persists in having a significant result. This finding is consistent with the one reported in Table 5. Nevertheless, there is a noticeable increase in the magnitude of the coefficients of innovative property and economic competencies which show a higher impact on productivity. The significant increase of these coefficients may result from bias due to the omission of some variables or a specification problem caused by the small number of observations. In terms of the goodness of the fit, the values of $\bar{R}^2$ remain large. Again due to the presence of serial correlation, Newey-West standard errors are reported.

To summarise, the interpretation of the results obtained from the above regression analysis is that there is strong evidence of a positive impact from private sector investment in intangibles on MFP at the market sector level. In line with the findings of the New Growth Theory literature, the significant coefficient on intangibles can be interpreted as productivity gains from increasing returns due to the development of 'know-how' to do business, or knowledge spillovers beyond firms' borders. Because the MFP index used in the regressions takes into account of the treatment of intangibles as capital assets (a necessary adjustment to ensure that the private return to intangibles is not captured in MFP) the obtained estimates of the intangible coefficients may only reflect knowledge spillovers or increasing returns. These results contrast with those of HW, who did not find evidence for significant spillovers from private sector intangibles.

Spillovers from public support for R&D

This part discusses the impact of public support for R&D on the market sector MFP, measured by the coefficients ε_{NPUB} in (18) and $\tilde{\varepsilon}_{NPUB}$ in (19). Because public R&D is not included in the construction of MFP, the estimates of these coefficients will reflect social returns from public R&D. Results from regressing both the level and growth of MFP on an aggregate measure of the public sector stock of R&D are presented in the first column of Table 9. To avoid possible omitted variable bias, the two models include the business cycle and public infrastructure control variables.

As indicated by the results from the levels model, there are significant spillovers from total public R&D stock to private MFP, with an estimated elasticity of 0.46. While this result suggests a beneficial effect from governmental involvement in the area of research and innovation, it is not informative whether all, or only some, types of the public support are effective as the estimated coefficient is associated with an aggregate measure of public R&D. Before looking into this issue in more detail, it is noted that the model has good fit, as suggested by the large value of $\bar{R}^2$, the coefficients of the two control variables possess the expected signs and they are statistically significant. The estimated coefficient for the private sector intangibles supports the findings of Table 5 of positive spillovers on productivity. Moreover, there is again evidence of decreasing returns from labour and tangible capital. However, the findings of the levels model are not robust to first differencing.

As outlined in Section 5, public sector R&D is divided into four classes: research agencies, higher education sector, business enterprise sector, and multisector. Breaking down the aggregate stock of public sector R&D into four classes and running the two regressions results in the estimates in the second column of Table 9. They suggest that the observed positive spillovers from public sector R&D are mainly driven by the spending on research agencies and higher education sectors, while the insignificant coefficients on business enterprise sector and multisector variables suggest no impact on productivity.

The robustness of the findings presented in Table 9 is examined by performing several additional regressions to examine the individual effects of each of the four classes. Accordingly, eight models are developed by replacing aggregate public sector R&D in (18) and (19) by a measure of each of these four classes. The first column of Table 10 shows that the result of the impact of spending on research agencies remains robust in the levels model. However, one concern with the contemporaneous relationship presented above is that the significance of the results is sensitive to the dating of the public sector R&D variable. Even though our capital measure is constructed using all previous investments, there might be some lagged effects of public sector R&D that are not captured in the contemporaneous model, which mask the relationship between MFP and public R&D. Thus, to allow for these lagged effects, another set of regressions is performed by replacing the contemporaneous research agencies stock variable by a one-lag stock measure. Results presented in the second column of Table 10 provide support for all the findings of the contemporaneous model.[26] It can be noted that this strong positive relationship between MFP and government spending on research agencies is consistent with the

[26] With a small number of available observations, only one lag is used. HW did not use capital stock of public sector R&D in their regressions. Instead, they used two and three lags of the ratio of spending on public R&D relative to output, assuming by this a zero depreciation rate. Recalling that the PIM employed in this paper for constructing public knowledge capital includes all previous investment expenditures in the accumulation process, it is somewhat equivalent to the model of HW but with more lags.

what is observed in Figure 12.

Table 9 Spillovers from total public support (1993-2012)

	$\ln MFP$	$\Delta \ln MFP^a$	$\ln MFP$	$\Delta \ln MFP^a$
Tangible capital	-0.576***	-0.545***	-0.309**	-0.235**
	(0.084)	(0.136)	(0.107)	(0.090)
Labour	-0.811***	-0.092	-0.509***	-0.027
	(0.127)	(0.115)	(0.088)	(0.062)
Intangible capital	0.484***	0.377*	0.470***	0.358**
	(0.080)	(0.200)	(0.050)	(0.136)
Total public support	0.456 **	-0.148		
	(0.175)	(0.201)		
Research agencies			0.301***	0.011
			(0.047)	(0.119)
Higher education			0.226**	0.357**
			(0.091)	(0.134)
Business enterprise			0.001	-0.039
			(0.038)	(0.059)
Multisector			-0.041	-0.024
			(0.030)	(0.048)
Business cycle	1.184***	0.015	0.872***	0.118
	(0.183)	(0.130)	(0.134)	(0.097)
Public infrastructure	0.609***	-0.166	0.363	-0.382
	(0.188)	(0.303)	(0.257)	(0.321)
$\bar{R}^2$	0.99	0.75	0.99	0.89
Durbin-Watson	1.02	1.25	2.22	2.52
Jarque-Bera normality	(0.263)	(0.714)	(0.943)	(0.459)
Number of Observations	20	19	20	19

[a] $\Delta \ln MFP$ smoothed by three-year moving average.
Terms in brackets are heteroskedasticity and autocorrelation robust Newey-West standard errors.

An extra investigation is made to examine the source of positive spillovers from research agencies. A replication of the above regressions is performed using a breakdown of research agencies capital stock into defence (i.e., DSTO) and non-defence research agencies (i.e., other R&D agencies such as CSIRO, ANSTO, AIMS and so forth). Results of the breakdown, shown in Table 11, indicate that the source of the spillovers is driven mainly by non-defence R&D agencies.

Similar regressions to those presented above (but adding energy prices as an extra control variable) are performed to examine the impact of public support for higher education. The results, presented in Table 12, suggest significant positive spillovers from higher education R&D, which remain robust across both the levels model, growth model and the incorporation of the lagged effects. This finding is consistent with the relationship shown in Figure 12.

Next, market sector MFP is regressed on a stock measure of government support for business sector science and innovation to assess whether or not there were benefits to the business enterprise sector from the R&D Tax Concession and other sources of innovation and R&D support. Results for the four models are reported in Table 13. There is no evidence of contemporaneous gains from government indirect spending on R&D to the market sector MFP. These findings are consistent in both the levels and growth models. When a lagged effect is allowed for, some evi-

Table 10 Spillovers from public support (1993-2012): Research agencies

	$\ln MFP$	$\Delta \ln MFP^a$	$\ln MFP$	$\Delta \ln MFP^a$
Tangible capital	-0.601***	-0.556***	-0.701***	-0.454**
	(0.031)	(0.138)	(0.062)	(0.172)
Labour	-0.731***	-0.111	-0.793***	-0.025
	(0.061)	(0.110)	(0.103)	(0.084)
Intangible capital	0.508***	0.368	0.500***	0.312*
	(0.061)	(0.235)	(0.086)	(0.163)
Research agencies	0.303***	-0.079		
	(0.062)	(0.183)		
Research agencies (t-1)			0.360***	-0.323
			(0.113)	(0.190)
Business cycle	1.098***	0.005	1.177***	-0.011
	(0.159)	(0.147)	(0.219)	(0.122)
Public infrastructure	0.961***	0.199	1.230***	-0.609
	(0.126)	(0.329)	(0.319)	(0.410)
$\bar{R}^2$	0.99	0.74	0.99	0.86
Durbin-Watson	1.72	1.13	1.54	1.62
Jarque-Bera normality	(0.748)	(0.653)	(0.757)	(0.528)
Number of Observations	20	19	20	19

[a] $\Delta \ln MFP$ smoothed by three-year moving average.
Terms in brackets are heteroskedasticity and autocorrelation robust Newey-West standard errors.

dence of negative spillovers from public funding appears, as the coefficients are negatively signed and statistically significant. Note that this negative relationship between MFP and government spending on the business enterprise sector was observed earlier in Figure 12.

Finally, the fourth category of public sector spending on R&D — multisector — is examined. Results reported in Table 14 suggest no significant contemporaneous spillovers to market sector MFP. As in the case of the business enterprise sector, when a lagged effect is allowed for there is some evidence of negative spillovers.

As seen from the above results, Australian government support for research and innovation has different impacts on market sector productivity depending on the spending component. Specifically, spending on Government research agencies - other than defence - and higher education institutions yields productivity gains, while no evidence of gains are observed from spending on business enterprise and civil sectors. These findings are consistent with those of HW who find strong evidence of market sector productivity benefits from public spending on research councils and no evidence of market sector spillovers from public spending on civil or defence R&D.

8 Conclusion

In a world defined by a finite endowment of resources, the contribution to economic growth through resources utilisation is limited; therefore, sustained economic growth in the long term will have to come from productivity enhancements. Investments in research and innovation (such as information technology, R&D, skills development, design and organisational improvements and other types of intangible assets) are central drivers of productivity. They create more

Table 11 Spillovers from public support (1993-2012): Research agencies - breakdown

	$\ln MFP$	$\Delta \ln MFP^a$	$\ln MFP$	$\Delta \ln MFP^a$
Tangible capital	-0.465***	-0.519**	-0.362***	-0.451**
	(0.050)	(0.186)	(0.050)	(0.177)
Labour	-0.610***	-0.086	-0.575***	0.099
	(0.067)	(0.131)	(0.084)	(0.128)
Intangible capital	0.407***	0.385	0.247***	0.383*
	(0.054)	(0.227)	(0.027)	(0.179)
Research agencies (x defence)	0.269***	-0.007		
	(0.038)	(0.141)		
Defence	-0.125*	-0.107		
	(0.064)	(0.163)		
Research agencies (x defence)			0.292***	-0.125
(t-1)			(0.034)	(0.134)
Defence (t-1)			-0.349	-0.271
			(0.038)	(0.184)
Business cycle	1.058***	0.042	1.225***	-0.054
	(0.114)	(0.152)	(0.091)	(0.136)
Public infrastructure	0.773***	-0.140	0.856***	-0.368
	(0.107)	(0.328)	(0.110)	(0.512)
$\bar{R}^2$	0.99	0.73	0.99	0.85
Durbin-Watson	1.62	1.107	2.59	1.70
Jarque-Bera normality	(0.789)	(0.863)	(0.726)	(0.426)
Number of Observations	20	19	20	19

[a] $\Delta \ln MFP$ smoothed by three-year moving average.
Terms in brackets are heteroskedasticity and autocorrelation robust Newey-West standard errors.

Table 12 Spillovers from public support (1993-2012): Higher education sector

	$\ln MFP$	$\Delta \ln MFP^a$	$\ln MFP$	$\Delta \ln MFP^a$
Tangible capital	-0.324*	-0.246**	-0.246*	-0.300**
	(0.151)	(0.108)	(0.116)	(0.104)
Labour	-0.587***	-0.066	-0.515***	-0.021
	(0.096)	(0.082)	(0.106)	(0.061)
Intangible capital	0.543***	0.380***	0.455***	0.385***
	(0.041)	(0.116)	(0.065)	(0.119)
Higher education	0.225**	0.415***		
	(0.096)	(0.116)		
Higher education (t-1)			0.311***	0.395***
			(0.065)	(0.087)
Business cycle	0.668***	0.153**	0.602***	0.088
	(0.091)	(0.053)	(0.084)	(0.066)
Public infrastructure	0.061	-0.368	0.072	-0.160
	(0.317)	(0.299)	(0.182)	(0.204)
Energy prices	0.018***	0.001	0.010	-0.005
	(0.005)	(0.003)	(0.005)	(0.005)
$\bar{R}^2$	0.99	0.90	0.99	0.89
Durbin-Watson	1.52	2.45	1.65	2.57
Jarque-Bera normality	(0.219)	(0.495)	(0.978)	(0.420)
Number of Observations	20	19	19	18

[a] $\Delta \ln MFP$ smoothed by three-year moving average.
Terms in brackets are heteroskedasticity and autocorrelation robust Newey-West standard errors.

Table 13 Spillovers from public support (1993-2012): Business enterprise sector

	$\ln MFP$	$\Delta \ln MFP^a$	$\ln MFP$	$\Delta \ln MFP^a$
Tangible capital	-0.620***	-0.393***	-0.352***	-0.409***
	(0.125)	(0.100)	(0.065)	(0.116)
Labour	-0.809***	0.029	-0.680***	-0.054
	(0.198)	(0.090)	(0.108)	(0.093)
Intangible capital	0.665***	0.253	0.586***	0.419**
	(0.076)	(0.171)	(0.034)	(0.151)
Business enterprise	0.089	-0.157		
	(0.088)	(0.058)		
Business enterprise (t-1)			-0.146***	-0.158**
			(0.038)	(0.066)
Business cycle	0.970***	-0.031	0.607***	-0.075
	(0.255)	(0.086)	(0.147)	(0.091)
Public infrastructure	0.595*	-0.361	0.284*	-0.206
	(0.285)	(0.307)	(0.144)	(0.317)
Energy prices			0.024***	0.006
			(0.005)	(0.007)
$\bar{R}^2$	0.99	0.82	0.99	0.82
Durbin-Watson	0.82	1.94	2.43	1.85
Jarque-Bera normality	(0.691)	(0.810)	(0.737)	(0.899)
Number of Observations	20	19	19	18

[a] $\Delta \ln MFP$ smoothed by three-year moving average.
Terms in brackets are heteroskedasticity and autocorrelation robust Newey-West standard errors.

Table 14 Spillovers from public support (1993-2012): Multisector/Civil

	$\ln MFP$	$\Delta \ln MFP^a$	$\ln MFP$	$\Delta \ln MFP^a$
Tangible capital	-0.490***	-0.481***	-0.360***	-0.547***
	(0.074)	(0.133)	(0.117)	(0.173)
Labour	-0.963***	-0.168	-0.758***	-0.058
	(0.074)	(0.098)	(0.136)	(0.112)
Intangible capital	0.737***	0.582***	0.692***	0.445*
	(0.068)	(0.150)	(0.055)	(0.209)
Multisector	-0.079	-0.106		
	(0.047)	(0.080)		
Multisector (t-1)			-0.123*	-0.049
			(0.106)	(0.061)
Business cycle	0.626***	-0.009	0.828***	-0.027
	(0.123)	(0.086)	(0.149)	(0.121)
Public infrastructure	0.320*	-0.188	0.392**	-0.217
	(0.165)	(0.256)	(0.177)	(0.344)
Energy prices	0.025***	0.008	0.024	0.002
	(0.005)	(0.005)	(0.006)	(0.007)
$\bar{R}^2$	0.99	0.79	0.99	0.74
Durbin-Watson	1.88	1.55	2.08	1.21
Jarque-Bera normality	(0.574)	(0.435)	(0.515)	(0.671)
Number of Observations	20	19	19	18

[a] $\Delta \ln MFP$ smoothed by three-year moving average
Terms in brackets are heteroskedasticity and autocorrelation robust Newey-West standard errors.

efficient services and production processes, more effective workplace organisation and open up new markets.

Despite the prospects of research and innovation in boosting productivity and economic growth, they remain an area that is surrounded by many complexities and challenges, such as difficulties in measurement and inefficiency of provision.

To better understand and improve the functioning of the innovation systems of an economy, it is essential to track, or benchmark, performance. However, developing robust and relevant measures of research and innovation is hard. The intangible nature of research and innovation poses problems for the measurement of spending and the depreciation of spending in defining capital stocks. As such, research and innovation are largely ignored in the National Accounts and corporate financial reports of many countries where they have been only treated as intermediate expenditure. However, excluding investment in these intangible assets means that investment is underestimated, and this may distort measures of growth in capital services and consequently, productivity.

Another complication is the provision of a socially optimal level of research and innovation. It is commonly argued that there are major market failures in the provision of a sufficient amount of knowledge capital because knowledge diffuses beyond the control of the inventor, which implies that the private rate of return for research and innovation is lower than its social return. Additionally the high risks involved discourage firms from engaging in such activities. For both reasons, the amount invested by firms in research activities in a competitive framework is likely to be below the socially optimal level. This justifies intervention by governments to directly make their own investments in knowledge capital or to indirectly support the private sector to reduce its costs. However, governments face the stumbling block of a large number of projects competing for tight budgets. This study has attempted to make a contribution to the advancement of knowledge about spillovers from innovation through the explicit inclusion of both privately and publically funded intangibles in the analysis.

Recent literature defines a range of private sector intangible assets. This paper extends, and makes more current, Australian studies on three classes of intangible assets (computerised information, innovative property and economic competencies). Next, the paper incorporates these intangibles in the National Accounts to examine their effects on growth accounting components. The paper finds that: (i) investment in intangibles has increased at a faster rate than investment in tangibles over time. (ii) The share of labour income in GDP has declined while the share of capital income has increased due to the expanded total capital stock. (iii) A comparison of the new estimates of MFP (adjusted for the capitalisation of all intangible assets) with the traditional MFP, reveals a noticeable reduction in MFP growth.

Further, the paper utilises the new estimates of MFP in performing a range of regressions for investigating possible spillovers from private and public sectors' knowledge capital. Unlike estimates of the traditional MFP, adjusted estimates have the advantage of isolating social from private returns to knowledge capital. Insufficient attention has been paid to this refinement in the measured rates of return in past studies.

The results provide some policy-relevant insights. First, measuring research and innovation by only focusing on the set of assets which are currently capitalised in the System of National Accounts seems unreliable. Total investment has been found to be under-reported and this has distorted measures of growth in capital services and consequently, productivity. Second, accumulation of private sector knowledge capital is a source of positive spillovers to market sector productivity. Third, given the pressures on public finances, it is appealing to direct the innovation budget to areas with higher social benefits. The empirical findings suggest that government research agencies and higher education are areas with more potential gains.

Specifically, the paper examines the impact of four classes of public support for research and innovation — Commonwealth research agencies, higher education sector, business enterprise sector and multisector — on market sector MFP growth. The paper finds strong evidence of productivity benefits from public spending on Commonwealth research agencies and higher education. However, the results suggest no evidence of spillover effects on private productivity from public support to the business enterprise sector, multisector or defence R&D. Some reasons for this can be postulated. Health research funding makes up almost 50% of the public expenditure on the multisector in 2012-13; see Figure 8. Its output is not part of market sector value added, and any productivity effects are likely to be very long-run, through improvements in the health of the workforce and population more generally; hence there is a bias against finding a positive significant result. Similarly, it is expected that while some select components of the expenditure on defence may result in innovations with commercial value that appear in the market sector, defence services will not, again biasing the results against finding a positive relationship. The main public support for the business enterprise sector research and innovation is the industry R&D tax concession, comprising 81% of support to the sector in 2012-13. Unlike much of the funding to higher education and research agencies, allocation of support is based on expenditure rather than being performance based. Obviously there are strong financial incentives for firms to maximise the expenditures classified as being related to R&D, potentially biasing the results. In addition, there may be other policy goals of the R&D tax concession than raising productivity. Indeed, providing incentives for the establishment of small innovative firms may actually lower productivity as new entrants often initially have lower productivity compared with incumbents; see e.g. Baldwin (1995) and Aw et al. (2001).

There remain several areas of improvement for future research. The main source of the data on intangibles used in this paper is from the PC report (Barnes and McClure 2009). As indicated by the authors of that report, due to data limitations and measurement challenges these estimates need further refinements and improvement. In addition, a longer time series is important for having more confidence in the regression analysis and the precision of the results. For example, a longer time series can allow for appropriate lag structures for the purpose of forming knowledge stocks. Another issue not taken into account, but one able to provide further insights, is to allow for heterogeneity and variability by modelling for firm or sector behaviour. However, this requires appropriate data at the level of firms or industry. Flexible functional forms are widely recommended to address the complex relationship between output, primary inputs and external factors. With more observations, a more flexible form for modelling the production technology, such as the translog functional form can be adopted. Last but not least, an interesting extension to the presented analysis would be to assess excess returns to private and public sectors' knowledge capital, a useful technique for identifying areas where there is either an excess of, or lack of provision.

Appendix

Description and data sources for intangibles data

Data on investment in 'national accounts' intangibles covering the period 1974-75 to 2012-13 is sourced from the ABS website. Data on 'new' intangibles is taken from the PC report and de Rassenfosse (2012). A brief description of the data sources, methodologies and assumptions made by these two studies to construct complete time series over the period 1974-75 to 2010-11 is provided below. A more detailed description is provided in the appendixes of these studies. This paper has extended these series to 2012-2103 by assuming linear growth rates in the recent years.

National accounts intangibles:

Computerised information Time series for gross fixed capital formation and capital stock are available for the full period 1974-75 to 2012-13 (ABS, Cat. no. 5204.0). The ABS defines computer software as: '... computer programs, program descriptions and supporting materials for both systems and applications software. Included are purchased software and, if the expenditure is large, software developed on own-account. It also includes the purchase or development of large databases that the enterprise expects to use in production over a period of more than one year. The ASNA does not separately identify databases from computer software as recommended by the 2008 SNA' (ABS 2013, p.653).

Business expenditure on R&D (BERD) Shanks and Zheng (2006) have constructed series for Australian BERD for the market sector (excluding Agriculture, forestry & fishing) covering the period 1968-69 to 2002-03. The PC report has updated and extended their series to 2005-06. For this paper it is extended to 2012-13 using revised and updated data from the ABS Research and Experimental Development, Businesses. The ABS survey of BERD covers scientific R&D and R&D in social sciences and humanities. It also covers some aspects of product development costs in the financial industry and new architectural and engineering designs. The ABS defines R&D activity as 'creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications' (ABS 2011, p.33). It should be noted that CHS (2005) have included R&D related to financial services and architectural/engineering services in sperate broader categories. Thus, as this paper abides by their methodology in defining and categorising intangibles, R&D related to these services are deducted from the ABS estimates of BERD to avoid double counting.

Mineral exploration Time series for gross fixed capital formation and capital stock are available for the full period 1974-75 to 2012-13 (ABS, Cat. no. 5204.0). The ABS defines mineral exploration as: '... the value of expenditures on exploration for petroleum and natural gas and for non-petroleum mineral deposits. These expenditures include prelicence costs, licence and acquisition costs, appraisal costs and the costs of actual test drilling and boring, as well as the costs of aerial and other surveys, transportation costs etc., incurred to make it possible to carry out the tests' (ABS 2013, p.662).

Artistic originals Time series for gross fixed capital formation and capital stock are available for the full period 1974-75 to 2012-13 (ABS, Cat. no. 5204.0). The ABS defines entertainment, literary or artistic originals as: 'original films, sound recordings, manuscripts, tapes, models, etc., on which drama performances, radio and television programming, musical performances, sporting events, literary and artistic output, etc. are recorded or embodied. Included are works produced on own-account. In some cases there may be multiple originals (e.g. films)'(ABS 2013, p.655).

'New' intangibles:

New product development in the financial industry The PC report has constructed expenditure series for total intermediate purchases by the financial services industries covering the period 1974-75 to 2005-2006 using the ABS data from input-output (IO) and supply use (SU) tables. The SU industry codes equivalent to ANZSIC 73 and 75 are 380 Finance and 400 Services to finance, investment and insurance. The PC report estimated the investment series as 20% of total intermediate purchases.[27] To extend the series, de Rassenfosse (2012) has collected investment data for the period 2004-08 from Input-Output Tables (ABS Cat. no. 5215.0.55.001). The series is then used to estimate a growth rate in investment, which is applied to the 2004-05 data point from the PC series to obtain an investment series for 2005-06 to 2010-11.[28]

New architectural and engineering designs The PC report has constructed expenditure series of the revenue of architectural and engineering industries using different data sources, this includes data on the ANZSIC 7821 Architectural services industry and ANZSIC 7823 Consulting engineering industry which are sourced from the ABS Industry survey (Cat. no. 8155.0), the ABS data from input-output (IO) and supply use (SU) tables in addition to unpublished data. Several assumption were made to estimate data for the missing years and backcast the aggregate series so that to cover the period 1974-75 to 2005-06. Investment is estimated by the PC report as 50% of the revenue of architectural and engineering industries. de Rassenfosse (2012) has extended the series by using turnover data from the ABS Counts of Australian Businesses including Entries and Exits (Cat. no. 8165.0) for the classes of Architectural Services and

[27]Refer to Appendix A of the PC reports for more details on the assumptions made to backcast and forecast sections of the data series.

[28]Refer to de Rassenfosse (2012) for a discussion on how a beak in the series caused by the change in ANZSIC classification is treated.

Engineering Design and Engineering Consulting Services.

Advertising Annual data on Australian advertising expenditure is available from Commercial Economic Advisory Service of Australia (CEASA). Based on data for the United States and United Kingdom about the proportion of production costs in total advertising costs, the PC report suggests doubling CEASA series to account for production costs.[29]

Market research Following CHS who estimate this intangible as twice the revenue of the market and consumer research industry, the PC report has constructed a series as the double of the revenue of the market research industry using different data sources, mainly the ANZSIC 7853 Market research services (ABS, Cat. no. 8155.0). Interpolation and backcast were made by the PC report to complete the series.

Firm-specific human capital CHS suggest that spending on firm-specific human capital can be measured by the costs of employer-provided workforce training, which consists of two types: direct firm expenses (outlays on in house and external training courses) and wage and salary costs of employee time spent in informal and formal training. Unfortunately, there is no single data source provides a time series of Australian employer-provided training expenditure. The PC report emphasises that the estimated series of firm-specific human capital is only 'indicative' because several data sources were used and a number of assumptions were made to construct this series. The main data source used by the report was from the ABS (Cat. no. 6278.0) Education and Training Experience, which has been updated only once since 2005 (in 2009). Because the ABS has made a significant definitional changes to the work-related training module in 2007, the data on work-related training became not comparable over time. To overcome this problem, de Rassenfosse (2012) has used the share of investment in firm-specific human capital to to forecast observations over the period 2006-07 to 2010-11.

Purchased The PC report has constructed a series as 77% of the revenue for ANZSIC 7855 Business management services available from Australian Industry (ABS Cat. no. 8155.0) by using a few available data sources (1998-99 to 2004-05). To backcast the series from 1998-99 to 1974-75, the report uses the growth in Market and business consultancy services from the product details of the ABS IO tables (Cat. no. 5215.0). de Rassenfosse (2012) has extended the series to 2010-11 by using turnover data from the ABS (Cat. no. 8165.0) Counts of Australian Businesses, including Entries and Exits for the class 6962 Management Advice and Related Consulting Services.

Own account The PC report constructed the series to cover the period 1974-75 to 2005-06 as 20 % of salaries of Managers and Administrators (excluding farm managers and IT managers) using the ABS data on average weekly earnings and number of Managers & administrators,

[29] Refer to the PC report explanation on how these estimates for the total Australian economy have been scaled down to market sector estimates.

available from the Employee Earnings, Benefits and Trade Union Membership (EEBTUM) survey (Cat. no. 6310.0). de Rassenfosse (2012) has extended the series to 2010-11 by using the ABS data on employee earnings, benefits and trade union membership (Cat. no. 6310.0).

Growth accounting data

Output Gross value-added (ABS, Cat. no. 5204.0).

Labour Total hours worked (ABS, Cat. no 6291.0.55.003).

Tangible capital Stocks on machinery and equipment and non-dwelling construction sourced from the ABS (Cat. no. 5204.0).

Labour's income share (compensation of employees + labour component in mixed income)/total income (ABS, Cat. no. 5204.0).

All tangibles and intangibles capital's income share (gross operating surplus + the capital component in mixed income+all investment in new intangibles)/total income (ABS, Cat. no. 5204.0).

National Accounts capital's income share (gross operating surplus + the capital component in mixed income)/total income (ABS, Cat. no. 5204.0).

Tangibles capital's income share (gross operating surplus + the capital component in mixed income - GFCF in the national accounts intangible assets)/total income (ABS, Cat. no. 5204.0).

MFP Indexes are constructed as the ratio of output index, Y, over input index, $Q_{L,K}$, where L is labour input, K is capital stock (with three different defintions: including all tangible assets and all intangible assets, including all tangible assets and National Accounts intangible assets, or including tangible assets only). $Q_{L,K}$ is constructed using the Tornqvist index number approach described by the following formula:

$$Q_{L,K}^{0,1} = \prod_{i=l,k} \left(\frac{q_i^1}{q_i^0} \right)^{\frac{1}{2}(s_i^0 + s_i^1)},$$

where q_i^t is the quantity of labour and capital input at period t; s_i^t is the labour and capital income share at period t; and $t = 0, 1$.

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