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Digital productivity: key issues from the literature

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¹ The Stakeholder Workshop comprised representatives from the Bureau of Communications and Arts Research and the Market Analysis teams in the Department of Communications and the Arts, the Commonwealth Treasury, the Department of the Prime Minister and Cabinet, the Productivity Commission, the Australian Bureau of Statistics, the Department of Industry, Innovation and Science and the Australian Bureau of Agricultural and Resource Economics and Sciences, within government; and the University of New South Wales Centre for Applied Economic Research (Professor Kevin Fox), Queensland University of Technology PwC Chair in Digital Economy (Dr Shahid Muhammad) and McKinsey & Company (Simon Blackburne).

Executive summary

Context

- Australia has enjoyed strong and steady economic growth for the past 25 years, but (similar to the United States of America (US) and other developed countries) the last decade of this strong performance has not been underpinned by good productivity growth.
- As productivity growth is fundamental to long-term prosperity, there is strong interest in better understanding this productivity malaise—in particular why the seemingly all-pervasive ‘digital revolution’ is not driving better economy-wide productivity performance, and whether we can rely on new digital technologies to lift future productivity growth.
- With the Department of Communications and the Arts’ role in the provision of enabling services and regulation of inputs critical to resource allocation in the economy it is interested in the role digitalisation can play in renewing aggregate productivity growth. This paper draws together recent research findings on digital productivity by critically reviewing the burgeoning literature in this priority area.
- The analysis is structured around: Australia’s productivity performance to date (Part II); the role digital technologies have played in past productivity growth and the prospects of doing so going forward (Part III); and structural blockers to productivity growth and the potential role of governments (Part IV).

Australia’s productivity performance to date—the modern-day productivity paradox

- There have been three distinct eras of productivity growth over the past 30 years: modest growth to 1994, a productivity growth spike from 1994 to 2004, and near-zero growth for the past decade.

Box 1: Three eras of Australian productivity growth

From 1989–90 to 1993–94: **0.41** per cent p.a.

From 1993–94 to 2003–04: **1.55** per cent p.a.

From 2003–04 to 2015–16: **0.16** per cent p.a.

Note: 12 industry multifactor productivity index. Log growth rates.

- While there is wide agreement that then-new digital technologies—business computerisation and the internet—contributed to the 1994–2004 growth spike, there is vigorous debate about the causes and meaning of the apparent disjuncture between more recent digitalisation and near-zero aggregate productivity growth.
- From our review of the main competing hypotheses—mismeasurement, transient cyclical and industry specific factors masking underlying digitally-driven productivity growth and digital impotency—we conclude that:
 - Neither mismeasurement nor the GFC-induced output slump are behind the observed productivity slowdown Australia over the past 10 years, although research in this area is ongoing.
 - Temporary productivity reversals in mining and utilities from long lead time investments have masked significant productivity growth elsewhere in the Australian economy.
 - While claims of complete digital impotence to lift productivity performance need to be tempered, the picture of weak productivity growth in the face of rapid digitalisation remains.

The role of digital technologies in past and future productivity growth

- Our review of in-depth statistical and commercially-focussed studies reveals significant digitally-driven productivity benefit over the past decade, although less than that during the 1995–2005 growth surge, consistent with our earlier conclusion that the near-zero aggregate productivity growth observed in part reflects transient productivity reversals in just two sectors. We conclude that the widespread use of emerging digital technologies has at least selectively lifted productivity over the past decade.
- As to the future of digitally-driven productivity, of the two camps (the digital ‘optimists’ and ‘pessimists’) the optimists consider that digital technologies have the potential to drive future productivity growth because of the fundamental disruptive impact these technologies are having on industries across the economy. The digital pessimists, by contrast, conclude that digitalisation is more entertainment-focused and has not materially raised the capacity of business to use capital and labour in new ways.

Structural impediments

- There are potential structural impediments to the realisation of these latent digital productivity gains. The literature points to long technology impact lags, digital diffusion stickiness, skills mismatching and digital infrastructure limitations.
- We find that:
 - While there have been very long lags from invention to widespread impact for past technologies, the very nature of digital technologies would be expected to result in much faster commercialisation and economic impact than in the past.
 - However, diffusion stickiness is likely to continue to be a pernicious retardant of economic benefit from new technologies. There is clear evidence that early adopter firms enjoy substantially higher productivity growth than the rest of industry, but an inability or reluctance of others to follow.
 - The evidence on skills shortage is mixed, with claims that IT graduates are in short supply contrasting with the evidence of difficulties of these graduates finding jobs. What is evident is that practical problem-solving, communication, collaboration and adaptability worker skills are required across the economy.
 - Digital infrastructure is not a material barrier to digitally-driven productivity growth now, nor in the foreseeable future as it continues to evolve to meet demand.

Background

Context

Australia has enjoyed two and a half decades of continuous economic growth. The first 15 years were underpinned by productivity growth and favourable international conditions, but for the past 10 years economy-wide productivity growth has slumped.

Reflecting the fundamental importance of productivity growth to ongoing prosperity, there is strong interest in better understanding the causes of a productivity malaise. Many see potential for significant productivity growth from digital technologies, given their seemingly profound effects on how we live and work. The use of computers has become the norm in all sectors of the economy, and businesses increasingly interact with each other and their customers using digital platforms enabled by ubiquitous high speed internet access. The long-anticipated Internet of Things (IoT) is emerging as a reality, and cloud storage and computing, big data analytics, artificial intelligence and advanced robotics have progressed rapidly in recent years.

Digital technologies have led to economic gains in the past, contributing to the productivity growth spurt of the late 1990s and early 2000s in Australia and the US. Recent research findings indicate that continued digitalisation is paying productivity dividends in leading firms and some industries. More generally, there is a widespread intuition that, with so much fundamental change occurring in the digital arena, this must have an impact on the basic ‘outputs relative to inputs’ productivity identity.

However, such an impact is not apparent in the aggregate productivity statistics for the past decade, with little growth in multifactor productivity (MFP) in many developed countries, including Australia. Rather, a modern-day version of Robert Solow’s 1980s ‘productivity paradox’—“you can see the computer age everywhere but in the productivity statistics”—appears to be playing out (Solow, 1987).

Views are divided on the potency of widespread digitalisation to drive sustained productivity growth over coming decades. Reflecting recent performance, some believe the digital revolution is a pale shadow of the earlier industrial revolutions emanating from the great inventions of the 18th and 19th centuries and will not deliver substantial productivity growth over coming decades, citing the current prolonged productivity slow-down as evidence of this. Others see a world experiencing a new, digitally-based technology revolution that will fuel unprecedented productivity and prosperity, with the apparent productivity slow-down explained by mismeasurement, the global financial crisis (GFC) and the focus to date of digital technologies in consumer entertainment rather than economic production.

With the Department’s role in policy-making and regulation of inputs critical to resource allocation in the economy, it is interested in the role digitalisation can play in reviving productivity growth. This paper gives an overview of current knowledge from a review of the burgeoning research literature in this area. It follows initial work on digital productivity by the Bureau of Communications Research (2015, 2016). The following *digital productivity basics* section draws on those earlier publications.

Report overview

In the face of the apparent productivity slowdown, the potential for digital technologies to drive future growth and ongoing prosperity through innovation is of vital interest and has stimulated a burgeoning body of economic research in this area. This research paper presents an overview of current knowledge on digital productivity from a review of recent published research, covering:

- recent productivity performance in Australia
- the role of digital technologies in past and future productivity growth, and
- structural blockers to productivity growth.

It also provides a brief overview of some recent discussion of the potential role for government in fostering digital productivity.

Digital productivity basics

What is productivity and how is it measured?

Productivity, at its simplest, is the ratio of outputs produced to inputs used. Output is measured as constant price economic value added (real gross domestic product (GDP)). Inputs are measured by total hours worked, and the flow of services from the stock of productive capital. It shows “the capacity of a business, government or economy to convert its resources into a valued output” (Productivity Commission, 2016a).

Productivity is expressed in a number of ways:

- **Multifactor productivity:** the ratio of output produced to labour and capital used
- **Labour productivity:** the ratio of output produced to the amount of labour used
- **Capital productivity:** the ratio of output to capital used.

While labour productivity is relevant in particular circumstances—such as the potential for sustainable wage growth—MFP is considered to be a more comprehensive measure as it takes into account both labour and capital inputs, and reflects the impact of innovation without the confounding effects of capital deepening. Unless otherwise indicated, MFP is the measure of productivity referred to in this report.

Why is productivity important?

Productivity matters as it reflects the efficiency of production in the economy—the rate at which inputs are turned into final goods and services. Productivity *growth* matters as it reflects a nation's ability to harness its physical and human resources to produce more goods and services, improve incomes and raise the standard of living of its citizens. As famously quipped by the economist Paul Krugman: "productivity isn't everything, but in the long run it is almost everything" (Krugman, 1997).

How does productivity growth occur?

A key driver of MFP growth is innovation—the development and adoption of new technologies, and implementation of new management techniques and production processes. The importance of innovation in economic growth was highlighted by Joseph Schumpeter: "innovation is the outstanding fact in the economic history of capitalist society" (Schumpeter, 1934), and more recently by Erik Brynjolfsson and Andrew McAfee (2014): "innovation is how productivity growth happens." Other factors include workforce skills, the quality of infrastructure, openness to trade and investment, and responsiveness in the allocation of resources between firms and industries to technological change.

Productivity growth at the firm level is not a matter of simply reducing costs. Innovation is doing something different—introducing a new and better way to produce firms' outputs, or producing new and better-quality products. Furthermore, it is not necessary to invent to innovate, firms can innovate by adopting existing inventions pioneered by others. Economy-wide productivity growth can also occur by more-productive firms replacing less-productive ones—the playing out of Schumpeterian 'creative destruction'. Conversely, stickiness in this occurring can restrict productivity growth.

How can digitalisation lift productivity growth?

The Productivity Commission (2016a) identifies the following ways digital technologies can affect the economy:

- Reducing the cost of information transmission—fostering the emergence of products with both goods and services components.
- Enabling the collection, processing and application of data—a new and valuable resource for which almost boundless accumulation is possible and use by one party does not reduce availability to others.
- Allowing automation of tasks and the replacement of workers with capital.
- Creating new business models.
- Bringing new labour and capital resources into the economy by allowing more workers to participate and utilise their personal assets (e.g. Uber drivers and Airbnb hosts).

There are a number of recent technological developments and promising digital technologies that are expected to deliver substantial productivity benefits (Box 2). These can boost productivity because:

- Businesses can invest in more powerful, lower cost information technology and communications equipment as a substitute for labour in routine tasks. Advanced digital technologies—cloud storage and computing, IoT, big data analytics and artificial intelligence—are beginning to replace humans for judgement-based tasks such as identifying legal precedents, preparing financial reports, and synthesising research findings.
- Digital services provide an infrastructure underpinning business innovation in products and processes—a general purpose infrastructure that enables firms to produce new things and produce the same things in different ways.

Box 2: Promising technologies

Machine learning and artificial intelligence

Artificial intelligence (AI) aims to make programs react to human input in more natural and intuitive ways. The technology includes ‘bots’, which use natural language processing and cognitive computing to interact with humans and provide relevant information and services on request. IBM’s Watson, for example, can search for and analyse information on specific topics at human direction (IBM, 2016). This technology has been used to create digital assistants such as the iPhone’s Siri verbal query function, and adapted to specific circumstances such as banking (Newman, 2016), government service delivery (Dilmegani et al, 2014), and healthcare. AI and machine learning will increasingly allow innovative firms to reduce costs and improve yields (Oldfield, 2016).

More fundamentally, there are signs that AI, supported by expanding data collection, storage and sophisticated analysis, is beginning to replace lower-level judgement-based professional jobs. Examples include identifying and contextualising legal case law precedent, and assessing credit-worthiness and insurance risks (Vanian, 2016). Compliance and regulation efficiencies can also be substantially increased using AI (Frost, 2016).

Blockchain

Blockchain technology allows reliable and trustworthy exchanges between parties by providing a means of verifying by all parties’ ledger order entries without a central authority. Tapscott and Wilson (2016) characterise blockchain as addressing a fundamental information asymmetry, improving efficiency. While blockchain technology is being considered most actively for use in the finance industry, it is anticipated to have wider-ranging relevance, for example Australia Post has proposed use of the technology to provide online identity management services (Gray, 2016).

Advanced robotics

Advanced robotics can significantly reduce labour costs. In fields as diverse as the garment industry, cooking, health care and transport, robots are being deployed to fill labour supply shortages or reduce costs (The Economist, 2016). With the support of AI and machine learning, an emerging field of robotics concerns autonomous vehicles, such as Uber’s self-driving truck (Newcomer & Webb, 2016). The increasing automation of everyday tasks will have a significant impact on the future economy, and is predicted to boost productivity.

Part I: Recent productivity performance

Productivity growth in Australia can be divided into three periods:

- From 1989–90 to 1993–94: 0.41 per cent p.a. average MFP growth
- From 1993–94 to 2004–95: 1.55 per cent p.a.
- From 2004–95 to 2015–16: **0.16 per cent p.a.**²

This pattern—modest productivity growth over the early 1990s, a productivity surge in the second half of the 1990s and the early 2000s, and near-zero productivity growth over the past decade—broadly mirrors that of the US. Below the aggregate level, differences between industries in productivity growth have been substantial—see Appendix A for details.

Productivity surge: mid-1990s to mid-2000s

The productivity growth surge spanning the late-1990s and early-2000s is widely attributed to the major economic policy reforms of that time and, to a lesser extent, early digitalisation of the economy. The Productivity Commission (2004) concluded that: “For Australia, major policy reforms (opening the economy, privatisation and National Competition Policy) played a major role, but ICT has been estimated to have contributed around one to two tenths of the total acceleration.” A similar finding is reported by Parham (2004), also noting that the contribution of ICT to US productivity growth over this period was around 0.3 percentage points, similar to that in Australia.

Productivity slump: mid-2000s onwards

Over the past decade, ongoing digitalisation has dramatically changed how people live and work through near-ubiquitous access through fixed and mobile connections to the internet and a plethora of online entertainment, networking and business services. To varying degrees IoT, big data analytics, advanced robotics and artificial intelligence have also begun to play a role in business and government. However, in the face of these seemingly far-reaching digital advances, aggregate productivity growth has languished in Australia, the US and other developed countries, presenting a modern-day ‘digital productivity puzzle’.

Does the current prolonged period of flat productivity growth suggest digital impotency in improving the basic ‘outputs-to-inputs’ ratio of the economy? Some conclude this is the case. Others dispute it, claiming ‘the numbers are wrong’—that digital productivity growth has in fact occurred but due to mismeasurement is not being reflected in official productivity statistics. Yet others point to productivity gains at the firm and industry level and posit that aggregate productivity growth has been temporarily swamped by transient cyclical and sectoral factors—in particular the post-GFC economic slowdown, and (for Australia) an investment spike in long lead-time assets in the mining and utility sectors.

Insights into the 2005+ productivity slump

Research findings on these competing views on the causes of Australia’s productivity performance over the past decade as digital technologies have advanced apace. Mismeasurement, the post-GFC

² MFP is measured at a number of levels by the Australian Bureau of Statistics (ABS), including 12- and 16-industry market sector aggregate indexes, and indexes for individual sectors. We focus in particular on the 12-industry market sector index in this report, noting the 16-industry measure follows the same general behaviour. The average annual rate of growth in a series, y , between year t and year $t+i$, can be measured in terms of natural logs as $\frac{1}{i} \ln \left(\frac{y_{t+i}}{y_t} \right)$. This approach is used in this paper.

slowdown, large sector-specific investments in long lead-time assets and (failing these) digital impotency—are presented below. We conclude that:

- Mismeasurement is unlikely to account for any more than a small part of the observed productivity slump, although research in this area is ongoing.
- The post-GFC output slowdown was not of sufficient magnitude in Australia to materially impact productivity performance.
- Large investments in long lead-time assets in mining and utilities have in fact masked significant productivity growth in other sectors in the aggregate productivity statistics.
- Digital impotency over this period—that is, marginal impact of digitalisation on productivity growth—cannot be dismissed.

Digital productivity mismeasurement

There is strong interest in whether digital productivity mismeasurement has masked actual productivity growth from digitalisation.³ Reflecting this, the G20's Digital Economy Task Force requested the International Monetary Fund (IMF) and the OECD to address measurement of the digital economy, including whether the current measurement framework adequately accounts for productivity growth driven by digital innovation. More broadly, there is a large and growing research literature on productivity mismeasurement, spanning a range of possible output (GDP) and factor input (capital and labour) causes:

- Output mismeasurement:
 - free online services
 - the online sharing economy
 - digitally-enabled 'home' production
 - the informal economy
 - quality adjustment of output price movements for digital goods and services
- Capital mismeasurement:
 - knowledge-based assets
 - profit shifting and globalisation
- Labour mismeasurement:
 - digital skills mismatch.

Output mismeasurement

Free online services

The thesis here is that output growth, and accordingly productivity growth, is seriously underestimated as the value of the many digital services provided free on the internet is not captured in GDP. While this view is postulated by many commentators and technologists, Ahmad and Schreyer (2016) argue that, while improvements in consumer wellbeing from free digital services should be recognised in some way, adding it to GDP (and hence productivity) is not economically sound. They explain that GDP measurement is carefully designed to reflect only the level of market economy activity (value added) in the exchange economy which does not include consumer surplus (value to consumers beyond what they pay), including that from free digital services. The authors conclude that, while substantial practical challenges in measuring GDP and productivity do exist, the underlying GDP (and productivity) statistical framework remains sound in the digital age.

³ Productivity measurement per se has also been raised as a broader issue.

The IMF-OECD issues paper on national accounts mismeasurement prepared for the 2016 Digital Economy Task Force concluded:

- The conceptual basis (the 2008 System of National Accounts (SNA)) for GDP is robust for the digital economy, with remaining grey areas recognised in the SNA research agenda.
- National accounts measurement problems posed by the digital economy, including measurement of productivity growth, are not new but do require further work, in particular price and output volume measurement and where digitalisation meets internationalisation.
- Misunderstanding about the scope of GDP—which is not designed to extend beyond market sectors to include consumer surplus or more broadly measure consumer wellbeing—is often at the heart of current mismeasurement confusion.
- G20 support for the development of complementary accounting frameworks and data that capture these wider aspects of the digital economy is warranted, to capitalise on the opportunities arising from digitalisation.

Bean (2016), a former senior national accounts statistician engaged by the UK Government to lead a recent major review of UK economic statistics, presents a contrary view. Bean explored a number of methods for covering the consumption of free digital products in GDP measurement.

Online sharing economy

The issue here is whether economic activity in the internet-based sharing economy is not fully captured in official statistics, biasing productivity measurement. Bean (2016) describes two key elements of the sharing economy measurement challenge: first, whether the established statistical framework correctly identifies, measures and classifies these increasingly more important types of transactions; and second, the blurred line between work and leisure—what outputs and inputs should be in and what should be out when measuring productivity. The likely direction of bias in productivity measurement from growth in the sharing economy is not apparent as it impacts measurement of both outputs and inputs, meaning the possibility of under- or over-estimation of productivity growth—or little net impact from offsetting effects.

Box 3: Definition of the sharing economy

The sharing economy is described as: “... the use of digital technologies to unlock online marketplaces and social networks to facilitate the purchase, hire and sharing of assets and skills” (Bean, 2016, p. 91).

This includes the global sharing platforms of Airbnb, Uber, and the many national and local digital sharing platforms, which have expanded dramatically over the past decade.

Home production

Another potential source of productivity mismeasurement is a shift to household self-provision of what were previously market economy services, including disintermediation facilitated by digital connectivity. Examples are consumers making their own travel arrangements rather than using a travel agency, or online share trading. While growth of this phenomenon has the potential for underestimation of productivity growth by reducing measured output, this bias would be tempered by lower capital and labour inputs. Furthermore, it is not apparent whether digitalisation will drive an overall increase or decrease in home production, as digital platforms also facilitate the contracting out of erstwhile home production tasks.

Informal economy

Informal economic activity is by nature not recorded in the national accounts and hence not reflected in GDP. The direction of bias this causes in productivity measurement is clear when outputs are not reported while inputs are (e.g. from a tradesman not reporting income from 'jobs on the side' that use inputs that are reported)—there will be underestimation. However, the net impact is not apparent where both outputs and inputs are not captured (e.g. from cash payments for casual window cleaning services). Whether digitalisation is likely to encourage or discourage informal production is not yet apparent. While digitalisation makes it easier to work within the system (simpler recording and reporting) and the risk of detection greater, it also provides greater scope for informal production using digital platforms which may not record and report the transactions taking place.

Quality adjustment for digital goods and services

In measuring productivity, nominal GDP (GDP measured in current dollar terms) is adjusted for inflation to get the real amount of value added for the year. In doing this, statisticians attempt to take account of changes in the quality of goods (e.g. improvements in the processing power of a personal computer), by deducting the increase in quality from the nominal price change. Mismeasurement can arise from year-on-year quality changes, which are often substantial for final digital goods and services (e.g. increased functionality of a smart phone) and may not be fully captured, thereby *underestimating* the actual increase in output. For example, if the market price rises by 5 percent from one year to the next, but the quality rises by 15 percent, there has been an increase in the value of that good or service which is not reflected in GDP.

A related issue identified by Byrne et al. (2016) is the treatment of new products as usually they are not added to the price index for a number of years, missing often-large price reductions early in their life cycle: *"The price index [for estimating real output] for any class of products is computed by looking at the subset of products that are on the market in two consecutive periods. In practice that means that new products do not enter into price index estimates for a while, often for a few years. This then means that the period of rapid price decline that often occurs with new products can be missed."*

However, quality adjustment for input measures also affects value added and therefore productivity. Under-adjusting for improvements in the quality of inputs to production will overstate the aggregate productivity outcome (see labour mismeasurement issues, below).

Capital mismeasurement issues

Knowledge-based assets

The OECD (2016a) identifies the treatment of knowledge-based assets in the national accounts as a potential source of productivity mismeasurement, as follows. The national accounts recognise a number of intellectual property assets, including research and development (R&D) expenditure, software and databases, mineral exploration costs, and artistic and literary originals. However, these are not the only knowledge-based assets that can contribute to growth—assets such as organisational capital, brand equity, training and product-specific design competence can all play an important role. Bean (2016) notes that the growing value and volume of data in the digital age also may not be adequately captured in national accounts. As these unmeasured intangible investments are likely to be rising as a share of total investment with digitalisation, overestimation of productivity growth is likely.

Profit-shifting and globalisation

The OECD (2016a) has highlighted the challenge for productivity measurement presented by multinational enterprise (MNE) global supply chains and international profit-shifting which result in jurisdictional disconnection between the reported location of intangible assets and profits. According to Google's Chief Economist Professor Hal Varian (Byrne et al. 2016) much of the design and innovation built into today's digital products comes from the US, they are manufactured in lower-cost countries and then sold globally—with this geographic fragmentation of the supply chain dissipating their contribution to US productivity growth.

Labour mismeasurement issues

Digital skills mismatch

The mismeasurement issue here is that, if relevant skills are not included in the labour input measure, labour input will be understated, resulting in productivity overstatement. In particular, productivity *growth* will be overestimated from year-to-year increases in the value of human capital provided in an hour's work—as occurred in the 1990s from rising tertiary education levels, and may occur in the future from better-focussed vocational training.

The most recent *OECD Compendium of Productivity Indicators* (OECD 2016a) notes that many National Statistical Offices have now computed estimates of labour quality, providing the basis for a better understanding of conventional productivity measurement and executing better measurement practices. In Australia, the ABS now weights different worker characteristics (age, gender education) by compensation shares in its Quality Adjusted Labour Inputs (QALI) index, using 5-yearly household census data, as discussed in *Quality Adjusted Labour Inputs* (Australian Bureau of Statistics, 2005). To the extent this approach adequately captures key worker attributes, productivity mismeasurement from this source can be diminished. In practice the ABS publishes a labour quality-adjusted MFP and an unadjusted MFP indexes. To date researchers and commentators have in general continued to use MFP derived from the original (unadjusted) labour input measure. For consistency with this practice, unadjusted productivity indexes are used in this paper.

Empirical findings on mismeasurement

A number of studies that attempt to assess the magnitude of productivity mismeasurement have been published in the past five years. Nakamura, Samuels and Soloveichik (2016) use an experimental approach to estimate the uplift in GDP and MFP growth from free and under-priced internet services. The value of unpriced media services is approximated by its production cost, a methodology often used to value unpriced public sector services. They conclude that free media services make little difference to US GDP and MFP growth rates. This result is unsurprising and of limited value, as valuing output at its input cost does not capture productivity movements in the associated activity, a well-known limitation of using this methodology for unpriced public services.

Hatzius (2015) casts a wider net in sizing the impact of mismeasurement on US GDP and productivity, covering unpriced digital services, quality adjustment error, and shifts over time in the type of digital services consumed. He finds the US annual GDP growth rate would be 0.7 percentage points higher were these factors taken into account, and labour productivity growth 0.9 percentage points higher—the impact on MFP growth is not reported. Hatzius concludes “an increase in measurement error might explain a sizable share of if the slowdown in ... the underlying productivity trend in the mid-2000s.” However methodological details are not provided, limiting the weight accorded these findings.

Bean's (2016) preferred method for covering consumption of free digital services is to tie their value to the rapidly-rising volume of internet traffic, calculating that including free digital services would increase annual UK GDP growth by 0.7 percentage points (similar to Hatzius for the US). Bean does not, however, translate the 0.7 percentage points uplift to annual GDP growth into an associated uplift to productivity growth, and does not take account of other sources of mismeasurement.

A number of other studies are cited as evidence of substantial mismeasurement. Brynjolfsson and Oh (2012) found that the consumer surplus from free internet services was in excess of \$100 million per annum for the US in the second half of the 2000s, and if included would add around 0.75 percentage points per annum to annual GDP growth. Burhin and Manyika (2014) have estimated the net value that European and US consumers derive from free access to the world wide web as €100 billion in 2010 and €250 billion in 2013, a 150 percent rise in three years. AlphaBeta (2016) estimated the gross benefits of four free Google services (YouTube, Google Search, Google Maps and Google Apps) to Australia consumers, businesses and society to be A\$14.8 billion, A\$15.1 billion and "large but difficult to quantify" respectively. However, the value of this group of findings is limited as only Brynjolfsson and Oh estimate the impact on GDP, and none report an impact on productivity growth, nor address the validity of including it in productivity metrics.

Two recent US studies, Syverson (2016) and Byrne et al. (2016), take a different approach to testing the veracity of mismeasurement as an explanation of low productivity growth in the face of rapid digital development. Their methodology is to test, from a variety of perspectives, the hypothesis that under-measured digitalisation benefits could reasonably account for the slowdown in measured productivity. Both these studies go beyond uncounted consumer surplus from unpriced digital services, embracing ICT quality-adjustment issue and other potential distortions.

Details of these studies are provided below. Significantly, each of the studies fails to find evidence that mismeasurement accounts for a significant part of the productivity growth slowdown recorded in official statistics. We place significant weight on these findings, based on the robust scientific approach used—carefully testing a formulated hypothesis in a variety ways.

Syverson (2016) conducted four complementary tests of the mismeasurement hypothesis, concluding that the mismeasurement argument "faces real hurdles when confronted with the data" and that mismeasurement is unlikely to account for all, or significant part, of the productivity downturn. The tests applied are:

1. Whether the extent of measured productivity slowdown in different countries correlates with ICT consumption or production intensity. No such relationship is found.
2. Whether estimates of the surpluses created by internet-linked technologies reported in the research literature are sufficient to account for the 'missing output' necessary to explain the productivity slowdown. Available estimates of unmeasured value to users of these technologies are found to fall far short of the notional 'missing output'.
3. Whether feasible upward revisions to measured productivity growth rates in industries that produce and service ICTs would be sufficient to account for even a modest share of the slowdown. They find that the output and productivity growth rates of these industries would need to be multiples of their officially recorded growth rates for this to be the case.
4. Whether measured gross domestic income exceeding measured gross domestic product in the US over the productivity slowdown period is sufficient to support workers being paid to make products that can be given away free or at highly discounted prices. They find that US gross domestic income was exceeding gross domestic product well before the productivity slowdown

began in the mid-2000s, associated with unusually high capital income (profits) rather than employing staff to make free services.

Byrne et al. (2016) test the mismeasurement hypothesis in two other ways, finding that:

1. Whether quality adjustment mismeasurement of IT hardware is confined to the productivity slowdown period or of longer duration, mismeasurement was significant well before the slowdown. Rather, such mismeasurement was of greater significance in the 1995—2004 period of higher productivity growth when IT investment was higher. Paradoxically, adjusting for this effect would worsen the post-2005 productivity slowdown.
2. Given their link to leisure time, it is questionable whether the consumer benefits from free or under-priced digital services should, on conceptual grounds, rightly be included in the measured market sector. Inclusion is rejected as the free services by-and-large raise consumer well-being through more productive use of their leisure time, rather than shifting market sector production functions outwards.

Taken together, the empirical studies reviewed suggest there are substantial consumer benefits from free internet services, with the potential for these effects to raise the rate of growth of GDP and productivity significantly *if these benefits alone are included in these measures*. The case for doing this, however, is questionable as many economists see the role of GDP and productivity metrics as measures of exchange economy activity, preferring to capture consumer surplus benefits from digitalisation in a separate accounting framework.

Based on the preceding discussion, there is currently a range of views regarding the contribution of digitalisation (and the related substitution of non-market for market-based production) to the observed decline in measured productivity growth since 2004.

However, given the research program underway within international organisations and research institutions, it would be premature to conclude that mismeasurement has not materially contributed to the observed productivity slowdown over this period. It is clearer that mismeasurement cannot explain the entire productivity slowdown over this period. However it is also true that the process of digitalisation did not begin in 2004 and consideration should be given to the contribution of digitalisation to the broader productivity slowdown observed in developed economies beginning in the 1970s.

Although indicative, existing studies of digital mismeasurement have not been able to comprehensively assess all forms of potential digital mismeasurement. The fact that digital mismeasurement involves the accumulation of many small forms of mismeasurement makes assessing the aggregate impact on productivity growth challenging.

Transient factors masking productivity growth

The thesis here is that digitalisation over the past decade has resulted in productivity gains, but these gains have been masked or offset in aggregate productivity statistics by cyclical and/or other transient factors—specifically, the post-GFC economic slow-down (internationally), and a spike in long lead-time investments in the mining and utilities sectors (Australia).

Post-GFC cyclical downturn

This argument rests on the historically observed relationship between recession and productivity growth—as the economy slows down, productivity growth falls—observed by de Long (2002), the OECD (2016a) and others. Asset disposal may be time-consuming, non-remunerative or impractical, and incur significant opportunity costs from limited productivity capacity when the economy picks up.

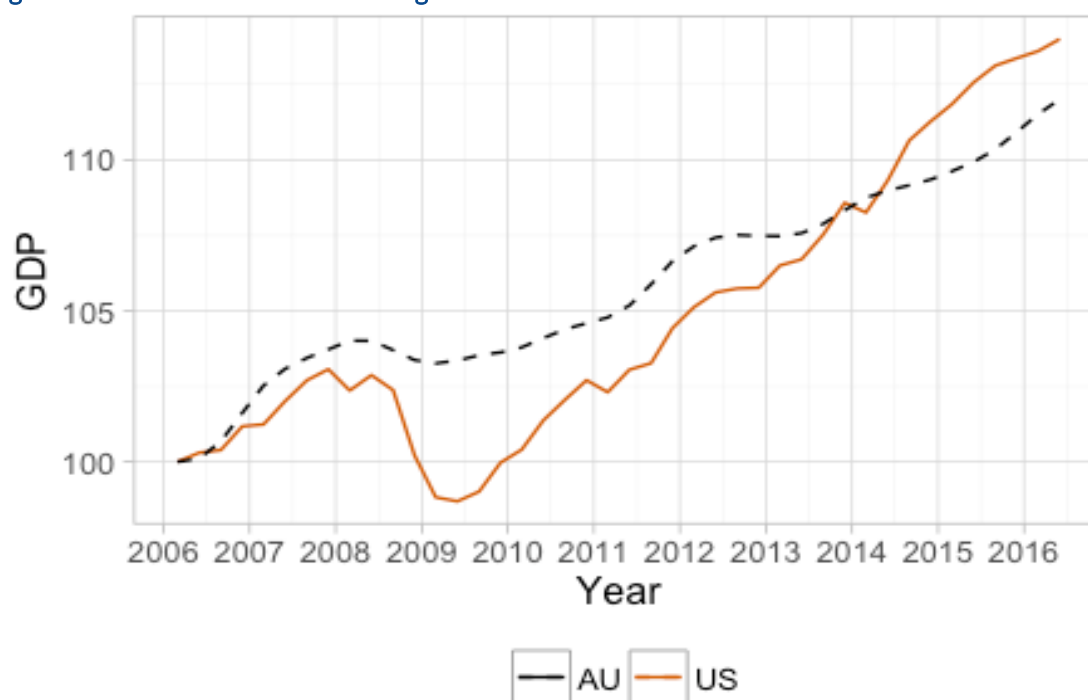
Reducing labour costs is a common approach to a downturn, but has its own opportunity, and regulatory, costs. The loss of specialist human capital to competitors may also be a consideration. Rather, firms may reduce labour costs by reducing training and other skill development activities. Cassidy (2016) argues that productivity growth falls in periods of low demand from degraded worker skills and by reducing firm incentives to invest in technology.

However, Fernald and Wang (2016) find that MFP in the US has become less pro-cyclical than in the past, with reduced variation in factor utilisation rates the key driver of this change. They find that increased flexibility in employment and asset holdings, changes in the structure of the economy, and the shrinking share of manufacturing relative to services in the economy appear to have played a role.

Our preliminary examination of GDP data for Australia and the US suggests a post-GFC slowdown in productivity growth from this cyclical relationship is more likely for the US than Australia, as there was a sharper and more prolonged downturn in US GDP growth. This is shown in Figure 1. While GDP growth in the US has improved in recent years, the period 2007–10 showed substantial downturn—although the timing of the economic slowdown does not coincide with the levelling off of US productivity growth, with the start of the productivity slump preceding the GFC.

Overall, there is not strong empirical support for cyclical effects offsetting digitally-induced productivity growth in Australia.

Figure 1: Australian and US real GDP growth 2006–16



Source: Australian Bureau of Statistics, 2016a; US Bureau of Economic Analysis (2016)

Uneven gains

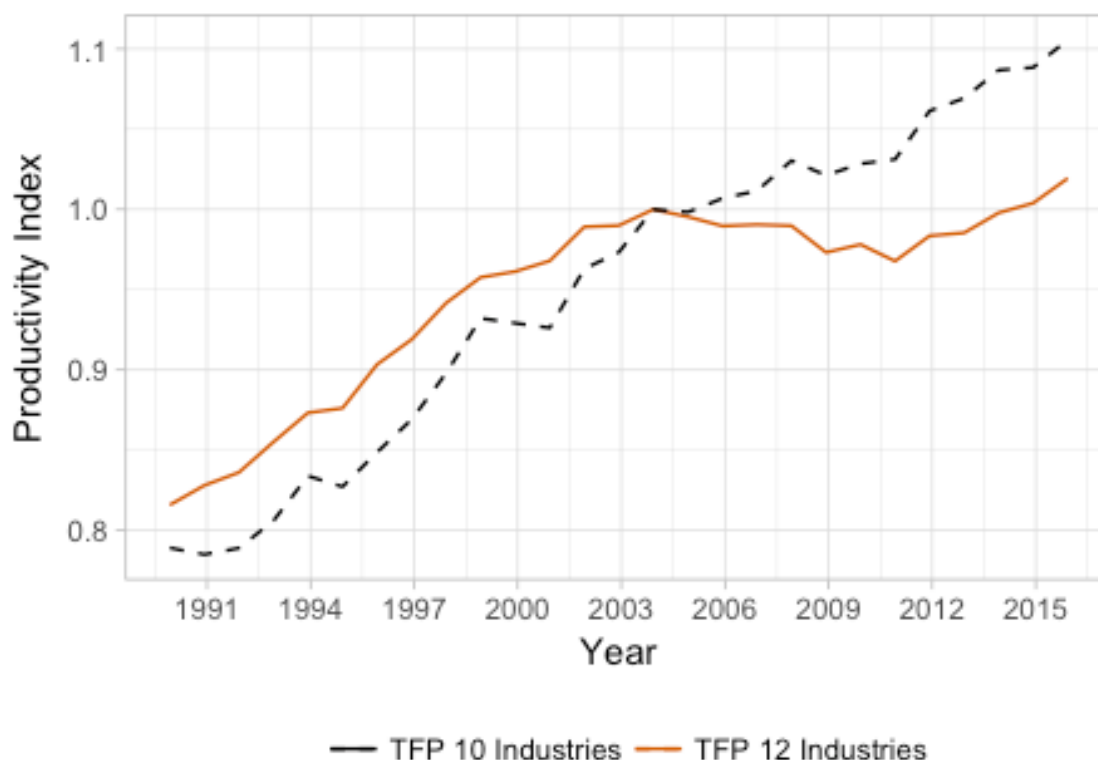
The mining boom investment surge, coupled with mining companies exploiting less efficient ore bodies in response to high prices, led to a significant productivity downturn in this sector, with -3.08 per cent p.a. MFP growth on average for the period 2004–05 to 2015–16 (see Topp et al (2008), Productivity Commission (2015)). In the same timeframe, underutilised investment in power utility infrastructure resulted in a similar MFP fall in this sector, with -2.83 per cent average annual growth over the past decade. Taken together, these falls in productivity may have been of sufficient

magnitude to pull down aggregate productivity performance—see Topp, et al. (2008) and Productivity Commission (2015).

Analysis by the International Monetary Fund (2015) found that the Australian mining investment boom and the exploitation of more marginal ore deposits, coupled with the impact of drought on the agriculture and utilities sectors, resulted in a significant drop in aggregate MFP growth earlier this decade. Our preliminary analysis supports these IMF findings. We compared growth in the ABS 12-industry MFP index with a comparable 10-industry MFP index we constructed by excluding mining and utilities.⁴ Average annual growth for the 10-industry MFP index was 0.84 per cent for the past decade, compared to 0.16 per cent for the 12 industry index (see Figure 2)—without the influence of the mining and utilities sectors, aggregate productivity growth would be higher. The Productivity Commission (2016b) recently reached a similar conclusion.

In summary, there has been a significant dampening of aggregate productivity growth over the past decade from transient productivity falls in mining and utilities from long lead time investments.

Figure 2: MFP (total factor productivity) growth, 12 and 10 industry MFP indexes: 1989–2014



Source: Australian Bureau of Statistics, 2016a.

Note: The ABS 12 Industry Index includes Agriculture, Mining, Manufacturing, Utilities, Construction, Wholesale, Retail, Accommodation, Transport, IMT, Finance, Arts and recreation. The Approximate 10 Industry Index excludes Mining and Utilities.

⁴ The 10 industry index is constructed by weighting each individual industry MFP index by its contribution to aggregate output of the ten industries. MFP growth is measured in log form, as described earlier in the report.

From this evidence we conclude that:

- Neither mismeasurement nor the GFC-induced output slump are behind the observed productivity slowdown Australia over the past 10 years, although research in this area is ongoing.
- Temporary productivity reversals in mining and utilities from long lead time investments have masked significant productivity growth elsewhere in the Australian economy.
- While claims of complete digital impotence to lift productivity performance need to be tempered, the picture of weak productivity growth in the face of rapid digitalisation remains.

PART II: Past and future impact of digitalisation

Having concluded that, while (for Australia) the near-zero aggregate productivity growth performance of the past decade in part reflects the transient influence of long lead time capacity expansion investment-in just two sectors, the possibility of digital impotency remains. In Part II we review the evidence from recent statistical and commercially-focussed studies that more directly address the effect of digitalisation on productivity growth to date and going forward.⁵ This 'below the surface' research suggests that the widespread use of emerging digital technologies has boosted productivity growth over the past decade and has the potential to drive future productivity growth.

Digital productivity impact to date

A number of in-depth statistical and commercial studies have shown that there have been digitally-driven productivity benefits over the past decade, albeit less substantial than those during the 1995–2005 growth surge. This is consistent with our earlier conclusion that the near-zero aggregate productivity growth observed in part reflects transient productivity reversals in just two sectors.

Aggregate impacts

For Australia, detailed growth accounting analysis by the Bureau of Communication Research (2016) showed that investment in ICT capital has continued to provide a significant contribution to labour productivity growth since the mid-2000s, but the role of IT investment on labour productivity growth has reduced relative to the previous decade. Specifically, IT capital deepening—essentially the substitution of computers for people—contributed about 0.5 percentage points to annual labour productivity growth in the decade from 2003–04 (about one-third of the total annual growth), compared with the stronger 0.8 percentage points contribution in the decade from 1993–94 (although also around one-third of the higher total annual growth).

An unpublished literature review by the Centre for International Economics (described in Bureau of Communications Research (2015)) found that a small number of econometric analyses of industry sectors or the broader economy revealed positive productivity effects, but questioned the robustness of the results.

The Bureau of Communications Research concluded the use of ICT is still having labour productivity effects in Australia, and for some industries IT assets complement skilled labour and reduces the need for land and building assets. However, there is some uncertainty as to the magnitude of these

⁵ Surveys of earlier digital productivity studies have been published by the OECD (Kretschmer, 2012) and European Commission (Biagi, 2013).

linkages, and the role of complementary intangible investments including computerised information (software and databases) and organisational capital.

Shahiduzzaman and Alam (2014) found that in recent years the contribution of IT capital on output and labour productivity has slowed due to lower IT investment (with industries with above-average ICT investment experiencing positive MFP growth during 2005–14). They also found a higher elasticity of (labour) productivity to digitalisation in recent years relative to the 1990s, possibly due to rising investment in complementary intangible assets such as databases, software and organisational capital, and better policy and regulatory frameworks. Subsequent research by Shahiduzzaman, Layton and Alam (2015) for the period 1965 to 2013 found evidence of long run productivity impacts of ICT capital as a general purpose technology.

Basu et al. (2003) investigated the role of ICT as a general purpose technology in productivity growth in the US and UK, concluding ICT use contributed significantly to US productivity growth. Connolly and Fox (2006) found that *“the relationship is significant and positive for only some industries [with] the benefits of investment in high-tech capital are not spread evenly across the economy.”* Shahiduzzaman and Alam (2014) cite US studies that demonstrate a significant contribution from IT capital to productivity growth in the 1990s.

The role of ICT in boosting productivity growth in the late 1990s is recognised both by the ‘digital optimists’ Brynjolfsson and McAfee in *The Second Machine Age* (2014), and the more pessimistic Gordon in *The Rise and Fall of American Growth* (2016) who (after initial scepticism) attributes a significant role to ICT in the late 1990s productivity growth from the marriage of computing and communications empowering the internet as a general purpose technology.

Industry and firm-level analysis

There is also a body of Australian and international analysis at the enterprise and industry level.

The Centre for International Economics (2014) found that productivity in the Australian mobile communications industry increased on average by more than 10 per cent per year in the period 2006-13 and that these efficiency gains were passed onto businesses and households by means of lower costs. A survey of 1002 businesses conducted by the Centre for International Economics in 2013 for this study indicated that substantive pathways of change in business productivity mediated by mobile broadband technologies were reported, including faster document review and decision making, more productive use of downtime, and the ability to use the internet anywhere. Of the businesses surveyed, 25 per cent indicated that mobile broadband reduced costs and 75 per cent indicated the technology saved employees time.

Barrett et al. (Barrett, Kowalkiewicz, & Shahiduzzaman, 2016) found that high growth firms in Queensland were not necessarily high-tech, but technically creative. These firms built technology usage and application by developing critical complementary capabilities, mirroring research into the uptake of digital technologies.

AlphaBeta (2016) found that the Google product *Apps for Work* supported \$450 million in business benefits in Australia in 2015, with the product suite enabling 50,000 businesses mobile access to documents and collaborative projects across multiple devices, increasing cross-location productivity. AlphaBeta also confirmed that digitalisation has been a powerful tool for businesses to be discoverable by customers and more efficiently achieve sales on a wide scale. AlphaBeta note that both paid and free search and AdSense products from Google provide benefits estimated at \$14.5 billion to around 840,000 businesses in Australia.

A number of global management consulting firms have also examined the process, benefits and extent of digitalisation at the enterprise and industry level in various countries. These studies primarily take a commercial focus (revenue and profitability gains), although a number also draw out the link to productivity growth. While these studies are rich in ideas and examples, the methodologies employed and assumptions are often not discernible from the published reports.

The McKinsey Global Institute (MGI) has recently published *Digital America* (Manyika, et al., 2015) and *Digital Europe* (Bughin, et al., 2016), focussing on the extent of digitalisation of different enterprises and industries relative to the 'digital frontier', the benefits to firms and the economy of closing this gap (including MFP growth), and the role government can play in this process. The *Digital America* study concludes that as digitalisation picks up speed "... *the United States has a major opportunity to boost productivity growth*", including from digitalisation as an innovation-enabling general purpose technology. This study describes the key drivers of productivity growth as:

- **Labour productivity:** from working with digital assets, and better and faster matching of workers with employers.
- **Capital productivity:** Improved asset efficiency through reduced downtime from preventive maintenance, and increased utilisation of assets.
- **Multifactor productivity:** digitally-enabled R&D and faster product development cycles from data analytics; operations and supply chain optimisation including better logistics routing through path optimisation and prioritisation; and enhanced resource management capability such as increased energy efficiency and reduced waste of raw materials.

Box 4: Defining digitalisation

"Digitalisation, like electricity, is a general-purpose technology that underpins a huge share of economic activity beyond the sector that supplies it" (p.2) and "Digitalisation has advanced in a series of accelerating waves that touch more and more participants. As each one builds on and amplifies what has come before, the waves are hitting in faster succession and with greater impact ... For decades, digital innovation was focussed on expanding business usage through enterprise software for managing operations. But beginning in the 1990s and over the past decade, the US digital transformation moved in new directions. The internet, mobile connectivity, social media and smartphone apps created a massive spike in consumer adoption. Meanwhile, businesses have continued to invest ... stepping into the age of analytics ... to analyse enormous troves of data, the Internet-of-Things to improve utilisation and efficiency of machinery, potentially delivering a significant boost to productivity in the decade ahead. Even bigger possibilities are on the horizon with advances in artificial intelligence and new applications in fields such as synthetic biology." (Digital America, p.3)

In *Digital Europe*, MGI finds Europe's economy is already seeing the early impact of digitalisation, with some correlation between productivity growth and digital intensity across sectors. Chui et al. (2015) present McKinsey analysis which suggests that the potential for artificial intelligence and robots to perform tasks is no longer the realm of demonstration, but a common occurrence in the workplace. They suggest that up to 45 per cent of activities individuals are paid to perform could be automated by adapting currently demonstrated technologies.

BCG analysis (Sander & Wolfgang, 2014) highlights the importance of advances in robotics and artificial intelligence, finding falling prices and increasing quality is allowing these machines to increase productivity across multiple industries. Accenture (2016) quantifies the potential value from boosting digital skills, digital technologies and digital accelerators (the environmental, cultural and behavioral aspects of the economy that support digital entrepreneurship). It concludes that Australia would benefit from a relatively even focus on all three elements, whereas the United States should focus

most on skills and accelerators. It estimates that digital density optimisation could lead to a boost to GDP of 2.4 per cent in Australia by 2020.

The economic consultancy arms of some of the major accounting firms in Australia have published studies quantifying the contribution to GDP of certain aspects of digital development, finding significant positive effects—see for example (Deloitte, 2016) and Price Waterhouse Coopers (2014). However, in general these studies do not specifically examine the link between digital development and productivity growth and the extent to which it displaces existing economic activity.

Future prospects for digitally-driven productivity growth

Whether digital productivity will drive future growth has been debated between two camps —the digital pessimists, and the digital optimists. Studies shaping the debate are in general inferential and qualitative rather than detailed statistical analyses, addressing the core question of whether limited digital impact over the past decade suggests little hope of digitalisation lifting productivity growth going forward. Robert Gordon, Tyler Cowen and other ‘digital pessimists’ believe so. Yet the ‘digital optimists’ such as Erik Brynjolfsson and Andrew McAfee, and Joel Mokyr, conclude the world is on the eve of a powerful digital revolution that will result in unprecedented prosperity.

Digital pessimists

The main proponents of the digital impotency view are Gordon (2016), Cowen (2011) and Erixon and Weigel (2016). They conclude that digitalisation has not materially raised the capacity of business to use capital and labour in new ways that give increased output as most recent digital applications are entertainment-focussed—“more fun than fundamental” (Krugman 2015)— with business uses of marginal economic relevance.

Gordon’s view that recent digital developments have little productivity potency is based on his analysis of productivity growth and living standards in the US over the past century, confirmed in Gordon’s view by the collapse of productivity growth over the past decade (Gordon, 2016). Gordon argues that, compared to the ‘great inventions’ of the 18th and 19th centuries which subsequently drove strong and sustained productivity growth for the half-century from 1920 to the 1970, recent digital technologies have driven only a temporary rather than permanent pick-up in productivity growth.

In Gordon’s view it is not that there is a lack of recent digital innovations, rather they are having little fundamental impact on how things are done and what is done.

Gordon points out that (for the US) total spending on all electronic communications and computer devices, entertainment, and internet and telephone services comprise only seven per cent of the economy, with the remaining 93 per cent of the economy not deeply affected by the digital revolution. Looking forward, Gordon predicts that:

“the major technology breakthroughs comparable to those of the past 150 years are not and will not be repeated—including digital technologies. The post 1870 economic revolution was unique and is impossible to repeat.”

Cowen (2011) came to the same conclusions as Gordon. He similarly argued that the productivity growth effects from earlier industrial inventions have now run their course as engines of productivity growth, and this growth engine role is not being taken up by internet-based developments, in part because much of the new output is provided free.

A similar diagnosis and outlook to that of Gordon is also espoused by Erixon and Weigel (2016), who offer their own underlying explanation for the current innovation impotency malaise—a fundamental change in the nature of capitalism to favouring certainty over Schumpeterian entrepreneurialism. This change, it is posited, has occurred from four related developments:

- ‘Grey’ capital: the primacy of debt over equity financing, resulting in corporations favouring certainty at the expense of calculated risk, the defence of incumbency rather than robust entrepreneurial competition, and a low appetite for disruptive innovation.
- Corporate managerialism: aligned with the risk-averse ‘custodian’ culture demanded by debt finance, a corporate focus on tight control and risk minimisation through hierarchical structures and tightly-managed processes—also dampening pursuit of disruptive innovation.
- Globalisation: as companies redraw firm boundaries and build global production and distribution networks, their focus is on market position and their ability to influence their end-customer market rather than disrupting markets through innovation
- Regulatory complexity: regulators have responded to an increasingly complex world by making regulation more complex.

Digital optimists

The digital optimists anticipate that digitalisation will drive a return to robust economic growth and productivity improvement in the future, based on the transformational characteristics of digital developments. The most prominent digital optimists are Brynjolfsson and McAfee, with a number of others holding similar views, including the economic historian Joel Mokyr.

Brynjolfsson and McAfee (2014) and in a recent Harvard Business Review interview (Bernstein & Raman, 2015), espouse that the digital revolution we are now experiencing is presently driving productivity growth and will continue to do this with ever-increasing force. They see the slowdown in US productivity growth post-2005 as a transitory cyclical aberration caused by the post-GFC recession rather than digital productivity impotency over the past decade. Brynjolfsson and McAfee posit that technological progress is improving exponentially from ubiquitous digitalisation in the economy and our personal lives, with imminent scope for enormous productivity and human wellbeing benefits.

These advances include big data analytics, robotics breakthroughs, artificial intelligence and machine learning. In their view the market economy and society is and will be fundamentally and favourably transformed, albeit with substantial adjustment challenges. Furthermore, this ‘second machine age’ will boost productivity growth across the economy for a long period, driven by the interaction of the following characteristics of the new technologies:

- **Exponential**—Moore’s Law is playing out for many aspects of digital technology, not just computing power⁶.
- **Digital**—All knowledge is being converted to a common 0–1 language which can be readily communicated and analysed, with exploitation of these data across the economy enabled by ubiquitous connectivity and access to supercomputing and artificial intelligence (the general purpose technology aspect of ICTs).
- **Combinatorial**—large-scale digitally-based advances occurring from different combinations of existing as well as new inventions and innovations, based on the premise that the true work of innovation is not coming up with something big and new, instead *recombining* things that already exist.

⁶ Opposed to this view, there is a fairly strong belief in the computer science community that Moore’s Law will not hold up much longer, citing for example Intel’s decision to increase the time between new generations of chip technology (Simonite, 2016).

Overall, Brynjolfsson and McAfee conclude that innovation and productivity will grow at healthy rates in the future. They believe that the essential building blocks are already in place, with these continually being recombined in new and better ways.

Brynjolfsson and McAfee believe that ICT general purpose technology has given birth to radically new ways to combine and recombine ideas, with the global digital network fostering recombinant innovation. In support of this view, Brynjolfsson and McAfee cite the examples of Google's *Chauffeur* service, and *Waze*, which combine information on user location, destination and traffic conditions from other users to calculate the fastest possible routes. They also cite the internet itself and platforms utilising it such as Instagram and Facebook. It is this combining of existing technologies that will allow artificial intelligence, machine learning and IoT (discussed below) to have substantial future potential for productivity.

Joel Mokyr in (Nathan, 2015) is similarly optimistic, founded on the positive history of inventions and innovation boosting economic growth, the poor track record of past pessimists, and the specifics of the digital revolution—super-fast computing as a new tool opening the way to new inventions and innovations in the future, with these shared faster than ever. He believes the race to be the global leader in science and technology will spur innovation worldwide, from the combined forces of the globalisation of business and associated heightened international competition:

Moreover, Mokyr considers scientific progress in the past decade "as exciting as ever," and that as technology improves the tools—including digital tools—that scientists use for research, the result will be achievements in laser technology, medical science, genetic engineering and other areas that look out of reach today.

Klaus Schwab in *The Fourth Industrial Revolution (2016)* makes a succinct case for optimism, identifying three unique characteristics of the current technological revolution:

- **Velocity**—contrary to the previous industrial revolutions, the digital revolution is evolving at an exponential, not linear, pace.
- **Breadth and depth**—it combines multiple technologies that are leading to unprecedented paradigm shifts in the economy, business, society, and for individuals.
- **Systems impact**—it involves the transformation of entire systems, across (and within) countries, companies, industries and society as a whole.

The OECD internationally, and the Productivity Commission in Australia, are also (reservedly) positive about the capacity of advanced digital services to drive future productivity growth (OECD 2016b and Productivity Commission 2016a). However, they acknowledge that the creation and initial commercialisation of digital technologies alone are not necessarily sufficient to ensure sustained productivity growth. Potentially serious structural impediments to the realisation of latent digital productivity gains have been raised in the literature, in particular:

- a repeat of historical long lags between invention and sustained productivity uplift
- tardiness in innovation diffusion from leading firms to the rest of the market
- shortages of right-skilled workers, and
- inadequate digital infrastructure.

While both sides of the debate agree on the fundamental growth process of invention of powerful technologies, their initial narrow application and subsequent innovation enabling wider use, they differ on four key points:

1. First, the extent to which digital technologies will fundamentally impact the business environment. Gordon sees the ‘third industrial revolution’ as primarily about entertainment and media. Contrary to that view, Brynjolfsson and McAfee see recent digital technologies infusing the business world—cloud storage and computing, data analytics, artificial intelligence and advanced robotics—and now disrupting many industries. *We find the latter position the more convincing.*
2. Second, the depth of these disruption effects. Gordon expects superficial change only in most industries, while Brynjolfsson and McAfee anticipate deep, fundamental changes in how and what is produced—reflecting the general purpose technology nature of digital technologies. *Here also we find the optimists’ position the more compelling.*
3. Third, the speed at which diffusion will occur, with Brynjolfsson and McAfee believing this will occur much faster than in the past due to the core characteristics of digital services themselves (zero-one and combinative) while Gordon thinks any substantial impacts that might occur will be a long time in coming. *While it is too early for clear evidence either way, again we judge the latter view to be the more likely.*
4. Finally, the parties differ in their interpretation of recent history. Gordon sees the poor productivity growth of the past decade as evidence of the failure of (earlier) digital technologies to have long-lasting pervasive effects from ongoing powerful innovations. Brynjolfsson and McAfee, on the other hand, see the productivity slowdown as a temporary aberration from immediate technology impact lags and the GFC-induced economic slump in the US. *The evidence furnished by the statistical and commercial studies on the impact of digitalisation reviewed earlier incline us to the optimists’ position.*

PART III: Productivity growth and the role of government

Structural blockers to digital productivity

Four potential impediments (blockers) to digital productivity are frequently raised in the research literature and general commentary:

1. normal technology impact lags
2. diffusion tardiness
3. skills mismatch, and
4. inadequate digital infrastructure.

Technology impact lags

New technologies typically have a long impact lag as commercial innovation and widespread application takes place. If these lags are substantial for digital technologies, there may be no material uplift to productivity growth from digitalisation for some time even if it has the inherent potential to do this, a point highlighted by the Productivity Commission (2016a). While the digital technologies seen by some as the productivity game-changers—cloud storage, data analytics, IoT, artificial intelligence, advanced robotics—are now being adopted by leading businesses., but questions remain as to when they will have a material impact.

The existence of long impact lags for new inventions is documented at length by Gordon (2016), who sees the origins of the prolonged 20th century period of productivity growth from the 1920s to the 1970s in the ‘great inventions’ of the 18th and 19th centuries. The prevalence of such lags for breakthrough digital productivities is also referenced by Cowen (2011), and Brynjolfsson and McAfee (2014). Reasons cited for substantial lags until productivity gains from invention and innovation

include the co-existence of new and old technologies acting to the detriment of each system's performance, and the costs of disruption offsetting the gains for early adopters (David, 1990).

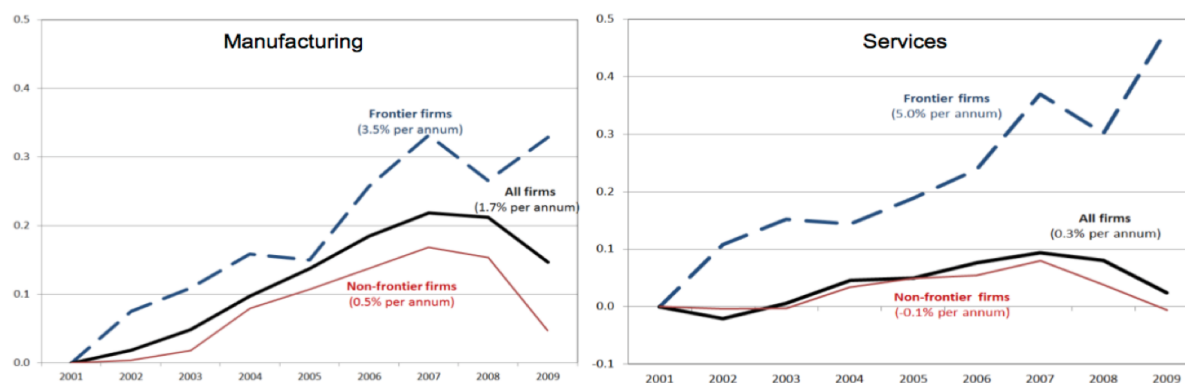
Brynjolfsson and McAfee expect these lags to be shorter than in the past given the speed of communications enabled by the internet and other communications networks—the inherent readily-communicated nature of many digital services and the presence of enabling digital infrastructure. As examples, they point to the explosive take-up of the iPhone, and the commercial development of autonomous vehicles. They also cite the growing capability of artificial intelligence systems in mastering unfamiliar tasks now being deployed Andrew McAfee is quoted (Bernstein & Raman, 2015) as emphasising not-so-distant future gains from recent technological breakthroughs.

Diffusion stickiness

Driving the widespread uptake of innovation, including digital innovation, has long been known to be difficult in practice—with entrenched social and enterprise-level practices slow to yield to new technologies. Walker and Maqsood (2007) noted that the gap between innovation best practice and practical outcomes is often large; some firms innovate rapidly, others are slow to adopt new digital technologies. The enormous disparities in performance at the firm level can be missed in aggregate productivity data (Productivity Commission 2016b).

OECD analysis indicates a growing gap between the growth of MFP for frontier firms and others contributing to the global slowdown (Andrews, Criscuolo and Gal 2015)—a failure in the 'diffusion mechanism' through which firms learn about frontier practices, and constraints on the forces that lead to the exit of inefficient firms. Differing diffusion behaviour between firms is documented by the OECD, reproduced in Figure 3 below. For the 2001–09 period frontier firms in manufacturing have labour productivity growth of 3.5 per cent p.a., substantially exceeding 0.5 per cent for all other firms in that sector. In the services industry, the frontier firms experienced labour productivity growth of 5 per cent p.a. compared to 0.1 per cent p.a. for other firms.

Figure 3: Frontier vs non frontier firm productivity growth



Note: Labour productivity average annual growth 2001–09 in parentheses

Source: OECD 2016b

Technology diffusion has been attributed to location and finance effects. The OECD (2016b) found that poor diffusion of digital technologies had both a regional and remoteness bias, and that good access to digital infrastructure had significant potential to promote economic development in regional and remote communities. In Australia, Gretzel et al. (2014) also found that firm location in the tourism industry was related to the uptake of digital technologies.

Meanwhile, Eidhoff et al. (2016) found that the adoption of new digital technologies was hindered by a lack of financial resources with more financially stable firms more likely to adopt new technologies.

Other factors cited as underlying causes of diffusion stickiness in Australia, although empirical evidence is often lacking, include:

- **Management quality**—Andrews, Criscuolo and Gal (2015) point to Australian management shortcomings as a key cause of technology diffusion tardiness. The Macquarie Graduate School of Management (2009) found that while Australia has a group of firms with high-performing management, it also has a long tail of firms with poor management quality. High quality management was found to be associated with higher productivity.
- **Oligopolistic or monopolistic markets**—As a small, open economy, local conditions may favour these kinds of outcomes as small markets cannot scale to support large numbers of firms (Productivity Commission 2016b). While digitally-enabled global product supply may mean market concentration is reduced in the future, the Productivity Commission notes that new digital technologies are also changing the source of market power. Control over data (for example, banking data) and supplier and customer networks, are potential new means for incumbent firms to hinder entry. For new digital platform services such as Facebook and Google search, the combination of near-limitless scalability and steep economies of scale are fostering ‘winner-takes-all’ markets—as described in Paul McCarthy’s *Online gravity* (2015).
- **Reduction in Business Dynamism**—Andrews et al. (2015) note that this may be part of a reason for diffusion stickiness. Risk averse firm behaviour may be contributory.
- **Skill mismatch and capital misallocation**—If the necessary skills are not available to utilise new innovation or capital is misallocated in uneconomic ways, it may not be possible for firms to achieve the digital innovation frontier. Studies that address this issue are discussed below.
- **Poor or inadequate complementary asset investment**—Complementary investments are also an important part of the diffusion story. The OECD (2016b) found that effective use of ICTs generally requires a complimentary knowledge base and that without this (and wider complementary intangible investments) full utilisation cannot be attained. That is, in order to utilize the productive benefits of ICT and digital technologies, a level of technical competence in the specific technology and other complimentary technologies must be present within the economy. As Draca et al. (2007) put it:
 - “Successful implementation of an ICT project requires reorganisation of the firm around the new technology. Reorganisation incurs costs, whether in the shape of paid fees to consultants, management time, or expenditure on the retraining of workers. There is much anecdotal evidence supporting this view, and it has been claimed that the total cost of an ICT project can be four or more times the amount paid for the equipment and software.”

Gretzel et al. (2014) found larger firms more likely to be early adopters of technology, with smaller firms less likely to do so due to capability and awareness limitations. “Leap frogging” behaviours, where a firm avoids adoption of one innovation, but then bypasses it in favour of a newer innovation was observed in larger SMEs more than smaller ones.

Some technologies with the potential to offer large productivity gains do not experience wide and fast take up due to concerns about security and sovereignty. For example, Kennedy (2016) found slow acceptance by firms and governments for these reasons.

More generally, investment in new technologies may “cannibalise” parts of the currently successful business (OECD, 2016b) as the competitive environment of a firm may work against a company’s desire to digitise. Lack of trust in the digital economy was also cited as a reason for poor take up of digital technologies amongst enterprises.

Other potential barriers identified to the take up of new ideas include (Parkinson 2016):

- Intellectual property rights that impose restrictive rules on the use of ideas
- Tax and regulatory settings that penalise risk taking
- Risk aversion rather than risk neutrality by regulatory authorities
- Tolerance of anti-competitive behaviour
- Uncontested government services
- Policies that shield unprofitable companies from international market pressure
- Sub-par management vision and acumen.

Overall, the following findings emerge for diffusion stickiness:

- It is a significant retardant of innovation-driven productivity growth—in general and for digital technologies. Leading technology-adoption firms routinely enjoy much stronger productivity growth than their lagging counterparts, and the gap between leaders and laggards is growing.
- Australia is worse afflicted in this area than other advanced developed countries.
- There is a wide range of contributing factors—lack of management acumen, weak competition, regulator risk aversion, lack of awareness of new technologies, inadequate investment in complementary assets, and firm size and location (remoteness).

Skills mismatch

Skills mismatch does not appear to be a major barrier to digitally-driven productivity improvement. Despite estimates that it has a large cost in potential production foregone (Evenstad, 2016), Burtless concluded in a Brookings study (2014) that most credible studies do not find a bigger mismatch than seen in past cyclical recoveries, and questions why there has not been evidence of soaring pay for workers whose skills are in short supply.

In Australia, Deloitte (2016) found that there has been growth in the number of ICT professionals, with an increase to 600,000 workers in 2014, and an estimated demand for a further 100,000 workers over the subsequent six years. In spite of strong demand, graduates with ICT qualifications have declined significantly since the early 2000s. At the firm level, a 2015 survey of 150 Australian organisations commissioned by the Slade Group (Slade Group, 2015) emphasised the ongoing digital skills shortage in Australia, with Slade reporting that 70 per cent of businesses thought a digital skills gap was taking a moderate or heavy toll on their business.

On the other hand, The Productivity Commission (2016a) found that, except for those with specialised skills, STEM graduates fare poorly on the job market, with 20 per cent of graduates with generalist skills without a job. Skills shortage data from the Department of Employment also does not appear to support the view of a wide-ranging digital skill shortage across the entire economy. Rather, available data indicates that a key feature of the IT labour market is the large number of candidates competing for available vacancies (Department of Employment, 2016).

Nonetheless the Department of Employment (2016) indicates that there are some difficulties in the labour market with skills shortages in specific subsections of the IT industry. For example, vacancies for analyst/programmers are only filled 56 per cent of the time while ICT security specialist vacancies are currently filled only 58 per cent of the time. However, in other parts of the IT labour market, large numbers of candidates are competing for available vacancies; on average around 29 applicants per surveyed vacancy (Department of Employment, 2015). The Department notes that, as a consequence of this mismatch:

- IT university graduates are facing increasing difficulty securing employment in the sector as graduate and junior positions are particularly competitive.

- Filling positions for senior ICT security specialists, senior web and front-end developers, senior analysts and developer programmers is difficult.

Several reasons for this uneven distribution of demand in the industry have been posited by the Department, including the possibility that offshoring of IT functions tends to be lower-level, more routine roles and this has reduced the volume of entry-level opportunities for graduates and juniors. The Department noted that the emerging areas of demand commonly mentioned were data scientists, data miners (a subset of the former), cyber security, cloud computing, and infrastructure specialists. The lack of appropriate and highly specific human capital may slow both technological diffusion and productive deployment of it.

Overall, the evidence on skills shortage is mixed, with research indicating IT graduates are in short supply contrasting with the evidence of difficulties of such graduates finding jobs. What is evident is that practical digital skills of workers will be needed across the economy going forward, coupled with adaptability. While gaps in this area in some firms may be limiting digital diffusion, overall, skills shortages and mismatching do not appear to be a major barrier to digitally-driven productivity growth.

Infrastructure

The diffusion of digital technology through an economy is more rapid when the underlying infrastructure is in place, making diffusion over years rather than decades possible (Productivity Commission 2016a). The rapid take-up of the smartphone was underpinned by existing infrastructure, and software, unlike hardware, can be easily and often remotely upgraded. Where new products are delivered, the pace of change is dependent on the accessibility, speed, and reliability of communications infrastructure.

The Centre for International Economics (2014) found that businesses with greater access to mobile broadband for their employees reported an increased impact on their business in terms of both cost and time saving metrics. Bertschek and Niebel (2015) show there are statistically significant gains in productivity to firms whose employees use mobile broadband technologies, with a one percentage point higher share of employees with mobile internet access associated with a 0.2 per cent higher labour productivity.

In Australia, the rollout of the National Broadband Network which is scheduled to be complete by 2020, will provide all homes and businesses in Australia with access to ubiquitous high speed broadband.

The role of government in the digital age

Two recent studies provide an overview of the possible role for government in fostering digitally-driven productivity growth by addressing diffusion stickiness. Long technology impact lags are viewed as essentially a 'speed of innovation' issue and as such, likely to be implicitly addressed through policies to stimulate digital innovation.

A recent study by the OECD (2016b) on the role of government policies for the successful diffusion of digital technology identified the following areas for particular government attention:

- Access to cost effective and interoperable digital infrastructures:
 - broadband networks
 - new emerging ICTs
 - data, including public sector data
 - open interoperability standards

- Trust in the digital economy:
 - cybersecurity risks
 - privacy in a data-driven economy
- Investments in complementary knowledge-based assets:
 - organisation change and business model transformation
 - skills and awareness
- Regulatory frameworks and market conditions:
 - competition and product market regulation
 - labour market regulation
 - bankruptcy legislation
 - access to finance.

The Productivity Commission's Digital Disruption research paper (2016a) identifies key roles for governments as enablers of innovation diffusion including:

- establishing interoperability standards
- setting regulations that permit risk-taking
- facilitating firm-to-firm and firm-to-researchers collaboration
- supporting the provision of necessary infrastructure
- reskilling workers
- improving the availability of government data
- ensuring innovation policies are evolutionary, and
- adopting innovative technologies themselves as exemplars for the wider economy.

Through optimal regulatory frameworks, improving accessibility of data and adopting innovative technology itself, government can influence the development and pace of adoption of new technologies. Regulation can also mitigate the risks of adverse economic and environmental impacts from digital disruption.

The *World Bank Digital Dividends* (Pena-Lopez, 2016) reports that for countries pursuing transition to a digital economy (such as Australia), the main task is to address the issues that arise for the business sector, for consumers and for society and government. For the business sector this includes ensuring that digital platforms do not abuse their dominant position and promoting fair competition between the online and offline services. For consumers, privacy and personal data security concerns are paramount. For society as a whole, key priorities are digital inclusiveness and the need for lifetime learning that matches the pace of digital development. And for the public sector, where basic e-government functions are already effective, using digital tools to facilitate closer collaboration between all parts of government, enabling the full integration of public and private services, and greater citizen involvement in truly participatory policy making are key imperatives.

Appendix A: Industry-level productivity growth

Industries have displayed diverse changes in productivity over recent decades. Table A1 gives the detailed data, and Figure A1 shows MFP industry-level growth, divided into three groups:

1. High MFP growth: agriculture, finance and wholesale.
2. Moderate MFP growth: accommodation, construction, IMT, manufacturing, retail and transport.
3. Low and negative MFP growth: arts, mining and utilities.

Table A1: Mean log MFP growth by industry: 1989–90 to 2015–16

	1989–90 to 1993–94 (Per cent p.a.)	1993–94 to 2003–04 (Per cent p.a.)	2003–04 to 2015–16 (Per cent p.a.)
Agriculture	1.18	3.02	0.72
Mining	0.73	-0.03	-2.87
Manufacturing	0.34	0.98	-0.3
Utilities	1.04	0.28	-2.83
Construction	-0.15	1.25	0.62
Wholesale	-0.5	3.96	1.66
Retail	0.63	1.69	0.76
Accommodation	-0.3	1.08	0.13
Transport	0.71	1.71	-0.17
IMT*	1.53	0.57	1.01
Finance	1.56	1.41	2.09
Rental	NA	NA	-0.6
Professional	NA	NA	-0.83
Administration	NA	NA	-0.68
Arts & rec.**	-0.2	-0.38	-0.89
Other	NA	NA	-0.62
ABS 16 Industry Index***	NA	NA	0.06
ABS 12 Industry Index***	0.41	1.55	0.16
Approximate 10 Industry Index***	0.46	1.51	0.84

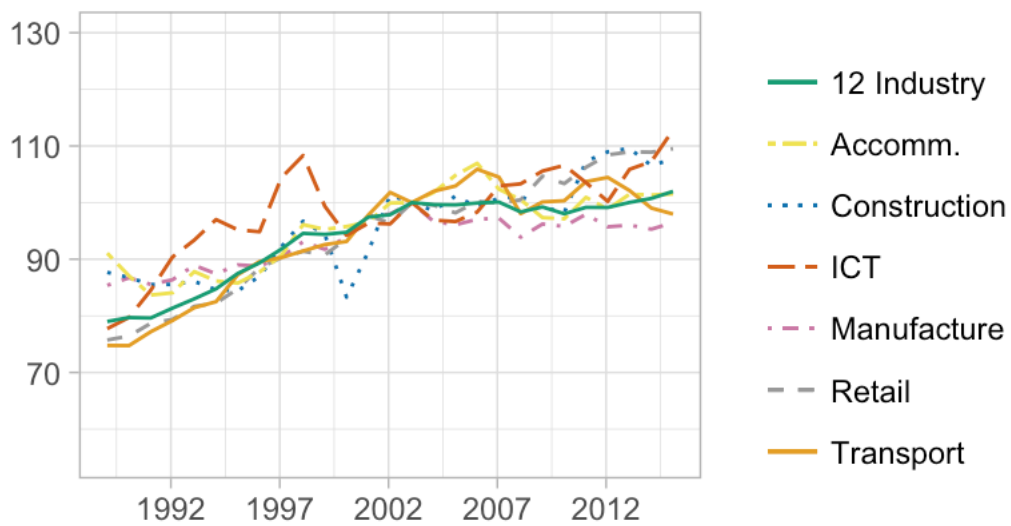
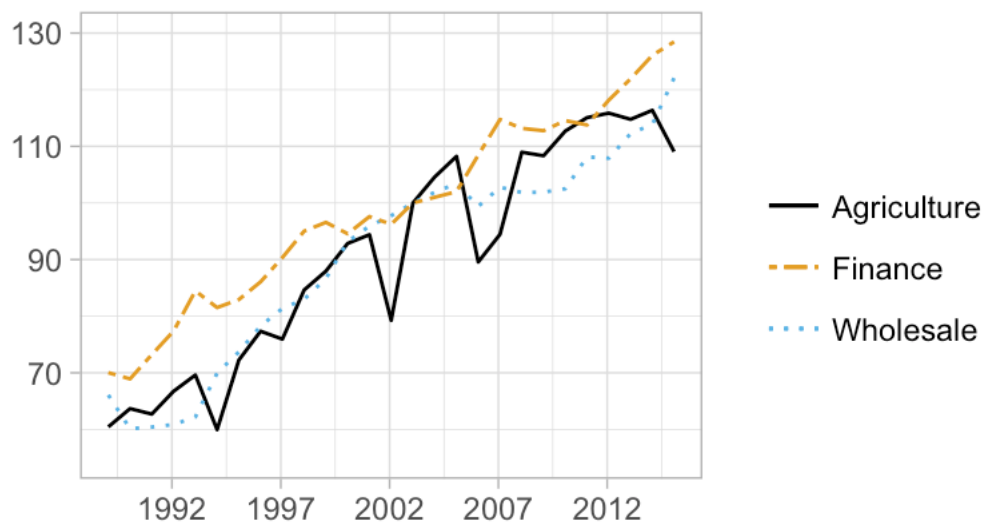
*Information technology, media and telecommunications

** The Arts and Recreation Services Division includes units mainly engaged in the preservation and exhibition of objects and sites of historical, cultural or educational interest; the production of original artistic works and/or participation in live performances, events, or exhibits intended for public viewing; and the operation of facilities or the provision of services that enable patrons to participate in sporting or recreational activities, or to pursue amusement interests.

*** The ABS 16 Industry Index includes all industry categories outlined in the table above. The 12 Industry Index excludes Rental, Professional, Administration and Other. The Approximate 10 Industry Index also excludes Mining and Utilities.

Source: Australian Bureau of Statistics, 2016b

Figure A2: Multifactor productivity by industry: 1989-90–2015-16. Base year 2003-04 = 100



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