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A primer on digital productivity

An introduction to some of the basic concepts of how digitisation affects productivity growth

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This Bureau of Communications Research (BCR) report is published under the authority of the Department of Communications Chief Economist and Head of the BCR, Dr Paul Paterson. BCR Specialist Economic Advisor Mr Dean Parham authored the report with input from BCR staff.

The BCR thanks Mr Parham for this important contribution to its research program.

Bureau of Communications Research

The BCR is a professional, independent, economic and statistical research unit in the Department of Communications. With a digital focus, it supports the development of good public policy through sound, fact-based policy development and advice based on economic and statistical research and analysis.

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1. Introduction

Computers and digital technologies are everywhere.

In our day-to-day lives, many of us carry around a powerful computer. It's the smart phone. It has far more computing power than the Apollo Guidance Computer that took the first three astronauts to the moon.

If you choose to shop the old-fashioned way and drive to your local shopping centre, you could be driving a car managed by several on-board computers. Once there, you can choose from merchandise that has been monitored and restocked from point-of-sale information. The barcode on your chosen item calls up prices from centralised data storage and you pay the total due electronically, direct from your bank account.

Digitisation has had profound effects on our social interactions, our schooling and work lives, how we entertain ourselves and how we transact with businesses and government agencies.

In this paper, however, we look at the supply-side of the economy—the production of goods and services. This is just one of the perspectives the Bureau of Communications Research (BCR) is taking in its research program.

There is no doubt digitisation has had profound effects on the production, delivery and sale of goods and services. Here are just a few examples:

- Farmers can use GPS devices to guide the precise use of machinery to deliver fertiliser.
- Miners can carry out mining operations in the Pilbara, including the use of driverless trucks, by remote control from Perth.
- Construction companies can identify potential problems before building starts by rehearsing the project virtually.
- Health service providers use many digital technologies such as MRI scanners.
- Robots are used routinely in advanced manufacturing.
- Companies use data networks to coordinate design, production, marketing and delivery of products in global supply chains.
- Service companies develop and use customer databases to provide targeted marketing and customised products.
- Smart meters can help customers spread energy over the day, reducing peak demand, so there is less need to expand generating capacity.

The specific focus of this BCR project is whether, beyond the undeniable widespread and deep changes, digitisation has continued to boost productivity growth in the Australian economy.

Transformational change does not necessarily translate into widespread or major productivity growth. But there is more than a suspicion that it does, based on a large body of research.

The productivity boost from computers was a hot topic more than a decade ago. While there were some extravagant claims (especially in the U.S.), which in part led to the tech bubble, there was solid evidence that information and communications technologies (ICTs) were indeed good for productivity growth.

There was evidence that Australia had benefited in the 1990s. In fact, ours was one of the first countries to show productivity gains from putting ICTs to innovative uses.

More than a decade on, it is time to look again at the links between productivity and ICTs, or digitisation more broadly. Australia's productivity growth has slowed dramatically since the 1990s, while digitisation has steamed ahead. The three questions it seems pertinent to ask are:

- Was the productivity boost from ICTs in the 90s a one-off phenomenon, with few or no further opportunities for productivity improvements?
- Have productivity opportunities continued to grow, but not been taken?
- Have productivity gains from digitisation been realised but been swamped by other factors that have held back Australia's productivity growth? Or have we missed the gains in our productivity measures?

Answering these questions could allow governments to better address relevant policy issues. To lift Australia's productivity growth has become imperative, and it may be that an important source exists but is hidden, or just needs to be tweaked with some appropriate policy attention.

This paper explains key concepts and issues integral to the BCR's Digital Productivity project, with a summary of key points to conclude. It is intended to inform those with an interest in digital productivity, stimulate discussion and assist external engagement with the project.

2. Productivity matters

An important starting point is to clarify what productivity is and why it matters.

2.1 What is productivity?

Although productivity is a straightforward concept, it tends to get mired in confusion and misunderstanding in public discussions. One reason is that productivity can be defined and measured in different ways. Businesspeople, for example, tend to take a financial view based on revenue, profit or cost per unit of input. Engineers, on the other hand, might take a technical view of the capacity of plant or machinery to generate output. Economists tend to think of productivity growth as advances in technology or production knowledge.

For policy purposes—and the view taken in this project—productivity is best thought of as the efficiency of production, as measured by the rate at which quantities of inputs to production are turned into quantities of outputs of goods and services. Put simply, productivity is the ratio of output produced to inputs used over a period of time.

Production inputs can be provided by labour and capital (assets such as buildings, machinery and equipment and land) and can include purchased materials and components, energy and services.

2.2 Why does productivity matter?

Productivity growth means that a nation generates more output. Importantly, however, more output also means more income. And so productivity growth matters because it determines a nation's ability to harness its physical and human resources not only to produce goods and services, but also to generate income and improve its standard of living.

2.3 How is productivity measured?

Productivity measures, such as those published by the Australian Bureau of Statistics (ABS) and used in policy discussions, are quantity or volume based. This means any effects of price inflation are stripped out.

Productivity is measured by taking the ratio of the volume of output to the volume of inputs used to generate the output. There are several productivity measures, which differ according to the input(s) chosen:

- Labour productivity is the ratio of output produced to the amount of labour used (usually the total number of hours worked).
- Capital productivity is the ratio of output to capital used.
- Multifactor productivity (MFP) is the ratio of output produced to the amount of both labour and capital used.

These different efficiency measures are all useful in different contexts. MFP, however, is usually considered to be more comprehensive because it takes into account the use of both the major inputs—labour and capital.

2.4 The nature of productivity growth

Productivity growth at the firm level comes from innovation. It is not a matter of simply reducing costs. Innovation is doing something different—introducing a new and better way to produce the firm's outputs or producing new and better-quality products. It is not necessary to invent in order to innovate. Firms can adopt existing innovations invented by others.

Some think of productivity as making do with less or working harder. That can happen in some situations in the short term. But working smarter, rather than working harder, does much more to improve productivity over the long term. The use of computers and more-sophisticated equipment, for example, mean today's workers produce a lot more output in a day than those a decade or a generation ago.

Productivity in industries depends on more than the rate of innovation in firms. It also depends on firm dynamics—the entry and exit of firms in an industry and the relative growth and decline of firms. There is a range in productivity levels across firms, even within the same industry. If higher-productivity firms grow or enter more rapidly than lower-productivity firms decline or exit, the average productivity of the industry will increase.

The same applies to the relative growth and decline of industries. National productivity can increase or decrease depending on the relative growth of higher- and lower-productivity industries.

2.5 Influences on productivity

Productivity is affected by a wide range of factors that operate in complex and interdependent ways. There is no single silver bullet.

Factors that affect the magnitude of MFP growth include advances in and dispersion of technologies, new management techniques and production processes, as well as additional workforce skills. Deeper factors include the nature and quality of infrastructure, openness to trade and investment, and how responsive the allocation of resources is across firms and industries is to changes in market conditions.

MFP growth is influenced by everything apart from the amount of labour and capital used, because they are taken into account as inputs in the MFP measure. To put it another way, MFP growth reflects the influence of all the other factors—technologies and so on—that determine how effectively labour and capital combine to produce output.

Labour productivity growth is affected by all the same factors that affect MFP growth, *plus* the amount of capital that is available per worker (because capital is not included in the measure of inputs). This means labour productivity growth is often portrayed as a combination of capital deepening (essentially increases in the capital-labour ratio) and MFP growth (improvements in general production efficiency).

For example, labour productivity improves if workers are given machinery and equipment over hand tools (capital deepening) and if the capital tied up in a plant or factory is more fully utilised through the introduction of work shifts (MFP growth).

Labour productivity growth is an indicator of a lot more than just how hard and effectively workers are applying themselves to their appointed tasks.

2.6 Productivity trends

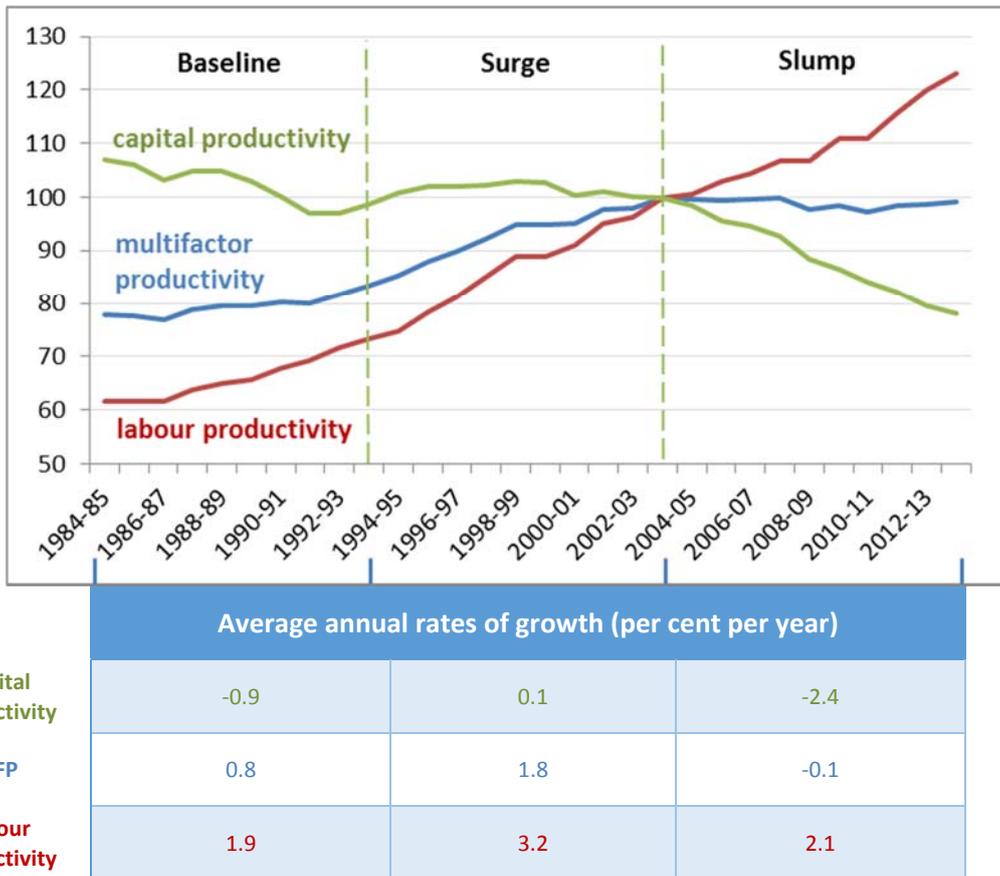
There have been big changes in Australia's productivity trends over the past three decades (Figure 1).

The period since the mid-1980s can be divided into three:

- Baseline productivity growth between 1984–85 and 1993–94.
 - Surge in productivity growth between 1993–94 and 2003–04, which saw MFP more than double to 1.8 per cent a year. The combination of microeconomic reforms and the ICT revolution are widely considered to be behind this.
 - Slump in productivity growth since 2003–04, which saw MFP growth flatline—a highly unusual outcome over such a long period. The major development has been a protracted fall in capital productivity, which has dragged MFP growth down. (MFP can be viewed as a weighted average of capital productivity and labour productivity.) The very rapid growth in capital ahead of output growth, in particular with the investment boom in the mining sector, is a key explanation for the fall in capital productivity.
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Figure 1: Three phases of Australia's productivity performance

Indexes, 2003–04 = 100



Sourced from ABS data

This brief overview shows that while digital productivity was part of Australia’s productivity surge, we need to look beyond the mining boom to see whether digitisation has continued to boost productivity growth, and if so, to what extent.

3. How can digitisation affect productivity?

In the early years of analysing ICT and productivity, ICT was defined as hardware and software in information and communications equipment—what was often referred to as computers—because it was just after desktop computers became widely available and were connected through the internet. ICT did not include communications networks and services, computer services, various embedded digital technologies (like the on-board computers in motor vehicles) and the internet of things (machines communicating with machines).

There are three ways in which ICT—as defined in this early sense—can affect productivity:

1. Producers of ICT equipment can add product enhancements such as more-powerful processors and more on-board storage in computers. In so doing, they make higher-quality products (increase their output) without increasing their use of inputs by much, if at all. That is an MFP gain.

2. Business users of ICT are presented with more opportunities (more-powerful and cheaper equipment) to invest in ICT as a substitute for labour in routine tasks. For example, computers can perform routine account-keeping tasks that used to be performed by staff. And because computers can carry out such tasks more accurately, less supervision is needed.
3. ICTs provide a platform for businesses using these technologies to innovate in their products and processes, which show up as MFP gains in the ICT-using industries. For example, using ICTs, businesses can sell goods or services such as accommodation and flight bookings over the internet.

Since Australia produces very little ICT equipment, which would generate productivity gains of the first type, the last two mechanisms are the most relevant to the Australian case—and to this project.

The two mechanisms are captured by labour productivity growth which, as discussed earlier, combines the elements of capital deepening or labour-substitution and MFP growth. Box 1 discusses these mechanisms from an economics perspective.

The key points are these.

The capital-deepening mechanism—ICTs substitute for labour—comes about because ICTs provide a cheaper way of doing essentially the same things. As computers and related technologies have become more powerful, cheaper and easier to use, businesses have chosen to use more of them, relative to the amount of labour they use, to produce their goods and services.

ICT-based innovations that generate MFP gains in using industries come about from producing new things or producing the same things in different ways. For example:

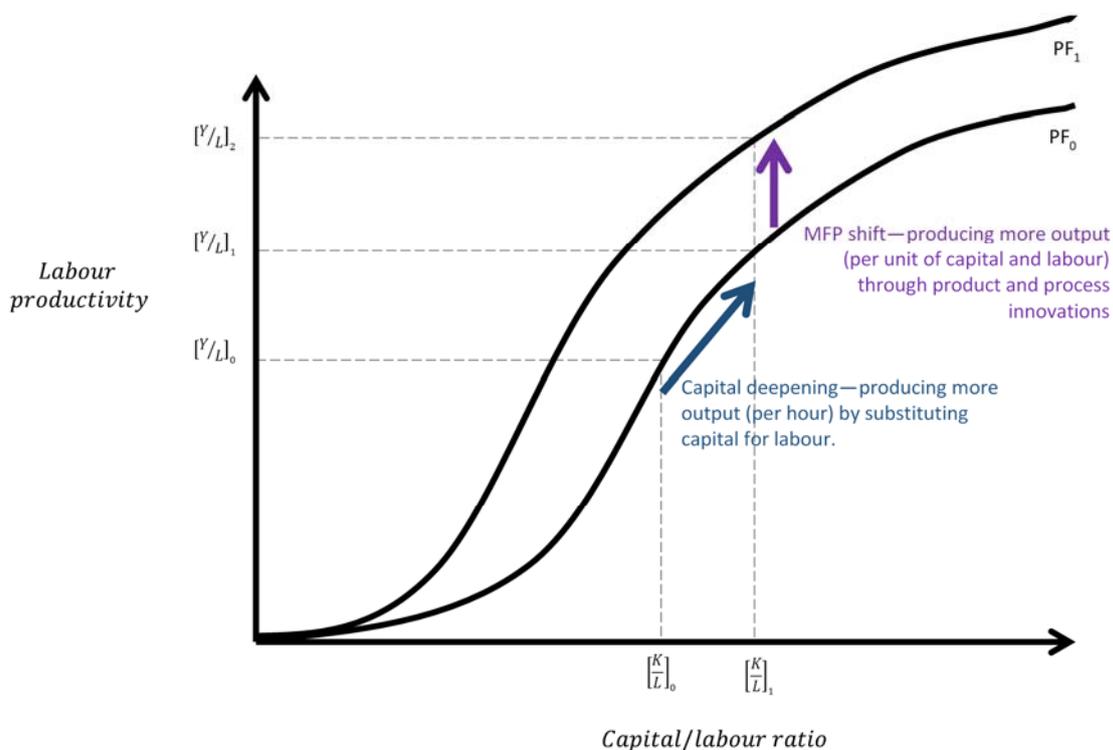
- New products—businesses have used ICTs to produce information-hungry hedging products, provide the convenience of automatic teller machines and coordinate real-time back-loading of transport vehicles.
 - New processes—businesses have used ICTs to better coordinate activities in different locations, streamline business processes, remote sensing, gathering more information and carrying out more analysis to improve efficiency and reduce waste.
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Box 1

Figure 2 shows the relationship between a firm's inputs and outputs—a production function to economists. It relates output (per unit of labour) to capital (per unit of labour).

The initial curve, PF_0 , shows that increasing the capital-labour ratio from $(K/L)_0$ to $(K/L)_1$ increases output per unit of labour, or labour productivity, from $(Y/L)_0$ to $(Y/L)_1$. This is the capital-deepening contribution ICT can make through substituting ICT capital for labour. It is a shift *around* the production function; the same products are produced but with a different combination of labour and capital. It happens because capital has become cheaper.

Figure 2: How ICT affects labour productivity through capital deepening and MFP growth



3.1 Gains need complementary investments

The productivity gains from ICTs do not come like manna from heaven. One of the lessons from the early research is that other investments—complementary investments—are needed to successfully introduce productivity improvements. Complementary investments could be in: research and development to develop suitable software systems; gathering customer information and setting up databases; training staff in the use of new information systems; restructuring an organisation and reassigning tasks and responsibilities consistent with the introduction of new business models.

3.2 ICT as a disruptive general-purpose technology

As noted at the beginning, ICT has become pervasive throughout the economy. It has been widely used by firms as a platform to change the way they go about business.

The fact it provides a platform for disruptive effects on production throughout the economy has led many to class it as a general-purpose technology. Examples of general technologies include the steam engine, electricity and the car.

There are three key characteristics of general-purpose technologies:

- they enable deep and wide restructuring of businesses and economic activity
- time and complementary investments are needed to use them successfully
- they enable widespread spillover productivity gains (that is, secondary benefits).

The importance of complementary investments has been put forward as one reason to Robert Solow's lament, 'You can see the computer age everywhere but in the productivity statistics'. Many think productivity payoffs from ICTs took a long time to be realised because it took time to identify the opportunities and carry out the complementary investments, and to iterate between the two.

3.3 Beyond the traditional scope

Moving beyond the traditional view of ICT, there are other potential productivity gains associated with communications infrastructure. These are network effects and stem from the fact the value to a user of a network increases as the number of users expands. For example, the value of a web presence to a retailer increases as market reach expands with more people connecting to the internet.

There can also be productivity gains associated with the nature of the communications infrastructure. For example, the ability to carry out various forms of business has expanded in going from dial-up to broadband to mobile broadband.

3.4 Have opportunities been exhausted?

It is possible that at least some of the productivity gains associated with ICTs and communications infrastructure have been exhausted, for example, in using computers in the place of clerks to carry out routine tasks. Once they are replaced, there is no opportunity for further replacement. (However, using computers to carry out additional and more-complex tasks would improve the labour productivity of those who have remained.)

On the other hand, there is the argument that ICTs have a dynamic effect on business. The technologies keep changing (from desktop to mobile to cloud computing), new applications are developed and new business models are continually introduced.

4. Tools for investigating digital productivity

Unfortunately, there is no single definitive way to pinpoint the magnitude of productivity effects associated with ICTs. Four main approaches have been used and each has its strengths and weaknesses. These include growth accounting, macro-econometric analysis, longitudinal firm-level econometric analysis and case studies.

Growth accounting uses national accounts data to apportion labour productivity growth in large sectors of the economy into components associated with ICT capital and non-ICT capital.

The advantages of this approach include it provides ready indications of the penetration of ICT equipment and software across industries and the contribution ICT makes to capital deepening. Disadvantages include it does not provide any indication of the size of the MFP growth effects of any ICT-based innovations; and it does not provide any insight into how any productivity gains come about, for example, through complementary investments.

Macro-econometric analysis is quantitative analysis at the broad industry or economy-wide level. It seeks to relate variations in productivity to variations in the amount of ICT used. Other variables that capture elements of complementary investments can be included. The problem is that by the time these other variables are included to isolate the effects of ICTs, there are generally too few observations to get clear or robust estimates.

Longitudinal firm-level econometric analysis involves quantitative analysis of firm behaviour and performance using very large databases with observations on a large number of firms over a period of years.

The idea is to explain why some firms have better productivity performance than others. Productivity can be related to ICT use and other variables, lags can be considered by relating investments in one year to productivity in a subsequent year and the complementarities between investments or between ICT use and skills can be tested.

Since there are usually thousands and thousands of observations, obtaining precise estimates is not such a problem. However, the ability to specify variables in a desired way is often compromised by the way original survey questions were posed. For example, data may be available for broad categories of ICT use ('connected to the Internet', 'have a website' or 'have online sales capability'), rather than indicating the intensity with which these features are used.

Case studies of firms and industries can provide a lot of qualitative information and, in some cases, allow some quantitative analysis. They provide scope for gaining insights into a range of factors that get in the way of productivity improvement and others that facilitate productivity improvement. The problems can be finding the right person(s) who can articulate the full story and then illustrating it with hard evidence. Then there is the issue of the extent to which case study evidence can be extrapolated to suggest what applies more generally.

4.1 Are we measuring digital productivity properly?

These days, there are additional measurement challenges in exploring the relationship between ICTs, digital technologies and productivity.

First, the scope of digital technologies is now so much broader than it was a decade or more ago. Back then digital technology was pretty well associated with computers and communications equipment. Now, very many things that were analogue are now digital and have considerable computing power. The smart phone is a good example. And many things now have digital technologies embedded within them, for example the modern car.

It therefore seems appropriate to broaden the scope of the technologies considered beyond the boundaries of traditional ICTs. That is why we have referred to digital productivity in the project title. However, that then raises the difficult questions of where to draw the boundaries around the digital technologies that are considered, and to what extent are data on the use of these technologies available.

A second issue concerns measuring output. For many decades, measuring output and GDP has been based on the premise that the price of a good or service reflects its value. That is how statisticians

are able to add apples and oranges to get a combined measure of output of different goods and services. You measure output according to its value.

Measurement of output is fundamental to the measurement of productivity. All productivity measures involve the amount of output produced divided by one or more inputs.

But these days not everything that happens in the digital sphere is priced—either fully or at all. There are hundreds of apps on smart phones that provide services for free—getting the temperature and a weather forecast for your current locale, for example. Users are able to use at least some cloud storage for free.

These free services create value to users. But they are not counted in output measures because they do not have a price.

The conundrum for productivity measurement is clear: these digital services consume resource inputs but don't generate measured output.

5. What do we already know?

The analysis and estimates currently around are mostly dated. The lingering message is that traditional ICTs have enabled some productivity improvements, both through ICT-capital deepening and through ICT-based innovations. There have also been a number of studies that have demonstrated productivity benefits associated with various forms of communications infrastructure.

The BCR commissioned the Centre for International Economics (CIE) to carry out a literature review of quantitative analyses of the productivity implications of ICTs and related technologies and to recommend useful options for further analytical work.

Based on the CIE review and our own investigations, the work carried out for Australia includes the following:

- Growth accounting studies from a decade ago showed ICT capital deepening was much greater in the productivity surge period of the mid-to-late 1990s and contributed 1 percentage point (around one third) of the annual average growth in labour productivity.
- A small number of econometric analyses of industry sectors or the broader economy have found positive productivity effects, but have failed to distinguish all relevant mechanisms (such as complementary investments). Questions about the robustness of results remain.
- One or two econometric analyses of large datasets of firms have used data from the mid-1990s and found ICTs enabled a few tenths of a percentage point of annual MFP growth.

It would be fair to say that empirical analysis has established the existence of the capital deepening and MFP channels in Australia. However, some doubt remains about the magnitudes of the links, the role of complementary investments and whether the magnitudes have changed over the last decade.

The scope of analysis has broadened a little. There have been a number of studies of the potential productivity effects of different elements of communications infrastructure, for example, broadband and mobile technologies. They have found positive productivity links.

As far as policy implications go, it was clear from analysis carried out that it was a sensible strategy for Australia to concentrate on accessing the productivity gains from using ICTs. There has been very strong international competition in the production of ICTs and Australia could effectively import the

spillover gains (productivity gains from ICT use) generated by overseas manufacturers. Moving into the production of ICTs in any substantial way was neither necessary nor a sensible way to access productivity gains from ICTs.

International research showed the productive uptake of ICTs was driven by competitive pressures, which encouraged producers to look for opportunities to improve productivity. Another key factor was the need for flexibility to introduce new business models by changing organisational structures quickly and by giving start-ups the chance to experiment.

6. The BCR's current Digital Productivity project

Based on the view there is no single appropriate way forward, our approach in the Digital Productivity project is multifaceted: we want to build up a clearer picture from various angles.

Following the CIE review and the release of this project primer, we intend to carry out the following things:

- Update labour productivity growth accounting estimates, including analysis of a range of individual industries.
- Analyse longitudinal micro-data for systematic patterns in ICT use and productivity payoffs.
- Generate firm or industry case studies to gather intelligence on how digitisation affects productivity, the complementary factors that facilitate gains and the things that get in the way.

Looking further down the track, we want to investigate ways to improve measurement, beyond the scope of the current ICT Statistics Review that is being carried out in conjunction with the ABS. This would likely include:

- Expanding the scope and measurement of digitisation included in productivity analysis.
 - Exploring non-traditional methods of output measurement to include the value that is generated in the digital world, but is unpriced.
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Key points

- Productivity is the efficiency of production of goods and services, as reflected in the rate at which quantities of inputs are turned into quantities of outputs.
- Productivity growth matters because it determines a nation's ability to harness its physical and human resources to generate income and improve its standards of living.
- There are three common productivity measures:
 - labour productivity is the output produced per unit of labour input
 - capital productivity is the output produced per unit capital input
 - multifactor productivity (MFP) is the output produced from the combined inputs of labour and capital.
- Productivity growth comes from:
 - firm-level innovation—firms doing something different in what they produce or how they produce it; and
 - firm and industry dynamics—entry and exit of firms and the relative growth of high-productivity and low-productivity firms and industries.
- Labour productivity growth comes from a combination of:
 - capital deepening—essentially, increases in the ratio of capital to labour; and
 - improvements in (MFP) production efficiency.
- Information and communications technologies (ICTs) can affect both these elements of labour productivity growth by:
 - allowing substitution of capital (ICTs) for labour; and
 - enabling business users of ICTs to develop and introduce their own innovations in products and processes.
- Realising productivity gains, however, requires other complementary investments.
- ICTs and digital technologies have become widespread and 'disruptive' in their applications.
- There is a strong case for further empirical analysis of digital productivity as a general guide to policy.
 - While available estimates have shown productivity gains from ICT use in Australia, they are mostly dated. Digitisation has steamed ahead with widespread and profound transformational effects.
 - On the other hand, some opportunities for productivity gain may have been exhausted.
 - Obvious signs of productivity gains at the macro level would have been swamped by the negative effects on measured productivity of the mining boom and other developments.
- Estimation of digital productivity faces a number of definitional, measurement and empirical challenges.
- In its Digital Productivity project, the BCR proposes to take a multi-pronged approach in order to build up a clearer picture.