Australian Government
Department of Infrastructure, Transport, Regional Development, Communications and the Arts

Bureau of Communications, Arts and Regional Research

Productivity impacts from improved broadband

Firm-level analysis

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Key Findings

- **There is some evidence of a link between a firm's productivity growth and their use of high-speed broadband. Businesses that switch from exchange-based digital subscriber line to fibre/cable-based broadband experience higher productivity growth than before making the switch**. More generally, high-speed broadband tends to have a positive relationship with productivity growth, while other characteristics such as business size, location and industry are also important to a firm's productivity growth.
- **Businesses with fibre-based broadband report the highest productivity growth** when compared with all other broadband types. Based on self-assessment, businesses using fibre broadband had the highest share of respondents saying their productivity had increased: 37 per cent of fibre users in 2018–19, above the 29 per cent for all businesses.
- **More productive firms tend to have high-speed broadband connections**. In particular, businesses that use fibre or cable-based broadband have higher productivity than firms using older technologies like exchange-based digital subscriber line (DSL).
- **The National Broadband Network has transformed Australia's fixed-line broadband infrastructure**. Broadband has shifted from copper to fibre-based connections, with exchange-based DSL connections decreasing from 73 per cent of Australian premises in June 2011 to only 2 per cent in June 2022. Over the same period, fibre-based connections (including partial and full-fibre) increased from 0.5 per cent to 70 per cent of premises.
- **Businesses with better broadband connections are generally large, urban-based and in internet-intensive industries**. These businesses have better access to broadband infrastructure, as well as the capital required for infrastructure upgrades. Industries with better broadband connections include information media and telecommunications and financial services.
- **Businesses are increasingly carrying out core activities online**. Online technology is now a widespread part of business practice, with 92 per cent of businesses relying on digital/online payment technologies in 2021. The proportion of businesses receiving online orders increased from 30 per cent in 2012–13 to 50 per cent in 2019–20. Total online retail sales have also increased from $3 billion in 2014 to $42 billion in 2021.
- **Businesses recognise the importance of high-speed broadband**. More than 4 out of 5 businesses (84 per cent) indicated that high-speed broadband is an important digital technology in 2017–18. Demand for broadband-reliant technology is high, with 55 per cent of businesses making use of paid cloud computing services in 2019–20.
- **Limited research is available on firm-level productivity and its relationship with broadband**. More robust datasets which contain detailed broadband metrics are needed to better identify whether broadband directly improves business productivity as well as whether this relationship persists over time and with improved broadband technologies. The growing availability of firm-level datasets will assist future studies of this relationship.

Introduction

The last 10 years have seen the National Broadband Network (NBN) roll out improve broadband technologies across Australia. The enduring purpose of the NBN is to provide fast, reliable and affordable connectivity to enable Australia to seize the economic and social opportunities and drive productivity and economic growth.[1] Improved access to high-speed broadband has coincided with much greater use of business activities online.

Improved broadband access can lead to greater use of data-intensive software applications such as digital communications, cloud-based technology, online orders and machine to machine technologies.[2] These technologies have a wide number of use cases across industries, such as in education, retail trade and agriculture.[3] Greater business use of broadband-enabled applications has the potential to lead to productivity growth, an important driver of economic growth. Internationally, there is evidence that broadband is positively related to productivity.[4] However, most studies look at this relationship from an economy-wide level (see Appendix G: Economy-wide impacts of broadband (literature review)). In Australia, there is some evidence of a positive relationship between high-tech capital use and productivity growth, where high-tech capital includes computers, software, and electronics.[5]

To date, very little evidence is available in Australia to link broadband and productivity at the individual business or firm level. This paper addresses this gap by analysing the impact of broadband improvements on business productivity using large scale administrative data. The main advantage of a firm-level analysis is that it can be used to examine changes in business productivity due to the use of high-speed broadband, which allows for a more direct estimate of impacts that may have arisen from broadband uptake.

The approach is experimental, using firm-level data from the Australian Business Register and taxation records from the Business Longitudinal Analysis Data Environment (BLADE). Firm-level productivity growth is constructed using business financial information contained in these datasets. This is then combined with survey data on broadband usage (which includes a sample of around 7,000 firms annually). This analysis focuses on broadband connections rather than broadband speed due to data limitations.[i] For this paper, **high-speed broadband is defined as fixed-line connections which rely on fibre or cable-based technology (including partial and full-fibre)** as opposed to traditional copper lines (e.g. exchange-based DSL). Many other factors affect the scale and timing of productivity growth, such as business size, location and industry. The analysis presented in this report account for these factors where possible, using statistical techniques such as fixed-effects regression. The analysis focuses on 10 years of data from 2009–10 to 2018–19 and so does not include the impacts of COVID-19.

This paper is set out as follows. The first section discusses changes in how businesses use broadband and how broadband can relate to productivity growth. The second section explores broadband's role in influencing firm-level productivity growth, and discusses the impact of this relationship using a variety of statistical approaches. Further detail on statistical methods is described in Appendix D: Broadband technology and productivity growth relationship.

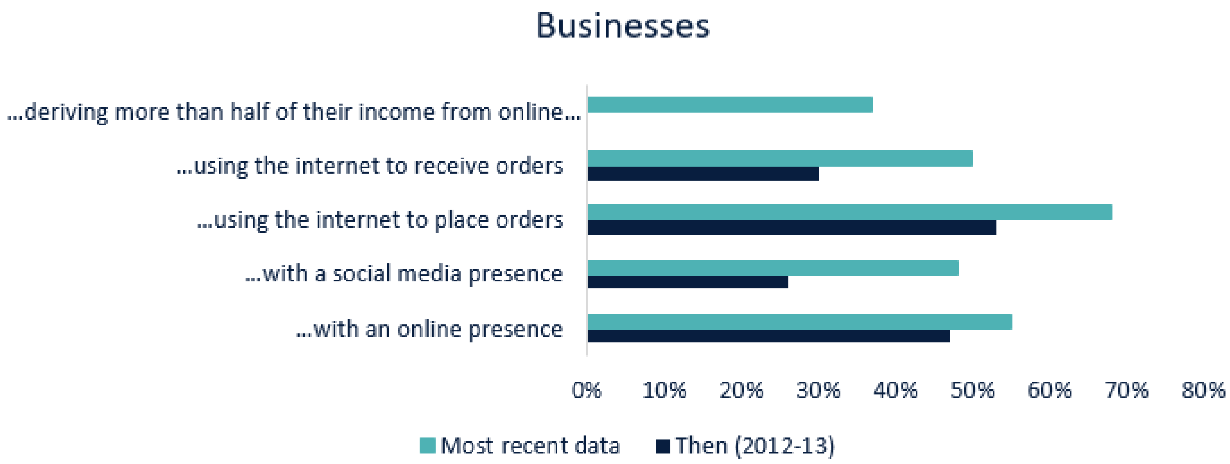
[i] Broadband usage is best measured either through the amount of data or bandwidth that can be accessed or used at a premises. However, there is no reliable survey information on these attributes for this analysis.

Changes in business use of broadband

Businesses are carrying out more of their activities online

Businesses are increasingly carrying out core activities online. This is shown by trends in web presence, social media and online orders for businesses across the economy. In 2018–19, over 54 per cent of Australian businesses had a web presence, up from 47 per cent in 2012–13 (Figure 1).[6] It is now increasingly commonplace for businesses to place and receive orders over the internet, with 37 per cent of businesses in 2019–20 deriving more than half of their income from online orders.[7]

Figure 1. Internet use by businesses activity type



Source: ABS Characteristics of Australian Businesses, various years. Most recent data refers to years 2018–19 or 2019–20.

Online business activity has substantially increased in customer-facing services industries. Total online retail sales expanded from $0.45 billion in 2012 to $3.58 billion in 2022.[8] Online technology is now a widespread part of business practice, with 92 per cent of businesses relying on digital/online payment technologies in 2021.[9]

Business demand for data-intensive applications has also increased. In 2019–20, 55 per cent of Australian businesses made use of paid cloud computing services, an increase of 36 percentage points from 2013-14.[10] Of these businesses, more than half used cloud computing for storage capacity services and over 80 per cent for finance or accounting software. Additionally, 58 per cent of Australian businesses believed that cloud technology was important for their business in 2017–18.[11] Survey findings indicate that businesses understand the importance of high-speed broadband to their work, with more than 4 out of 5 businesses (84 per cent) in 2017–18 indicating that high-speed broadband is an important digital technology.

Shift from DSL to fibre broadband

To support the rise in online activity, the technologies used to deliver internet services have shifted. Internet connections for businesses have moved from exchange-based DSL which uses existing telephone lines, to fibre-based and cable technologies (sometimes referred to as hybrid fibre coaxial or HFC). Table 1 outlines the 5 main broadband technologies used to deliver broadband in Australia.

Table 1. Broadband technology types in Australia, all premises (businesses and households)

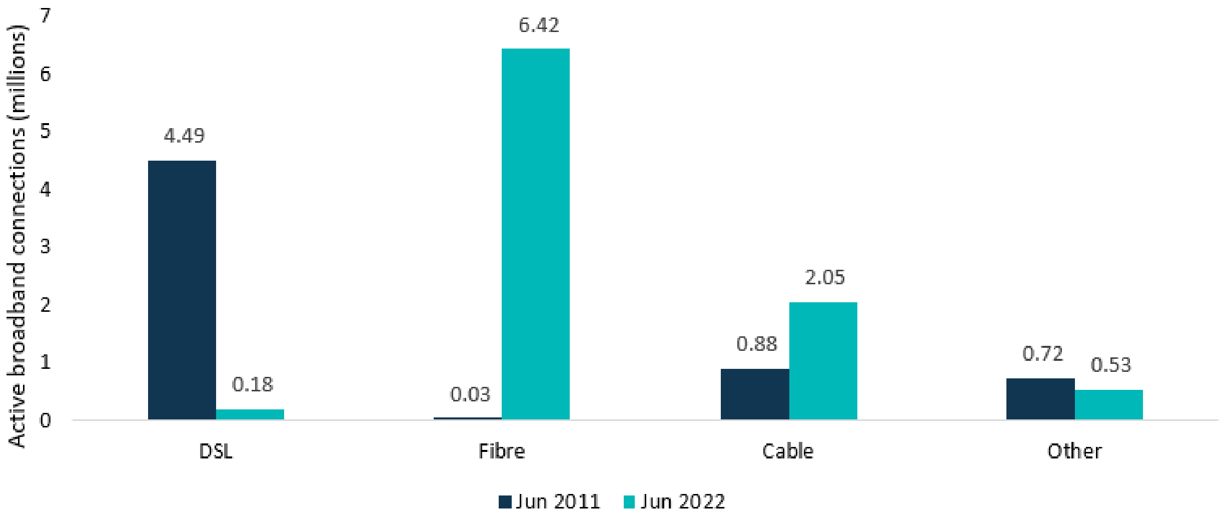
Broadband technology	Share of Australian premises in 2022	Explanation
DSL	2%	A family of technologies (including ADSL, ADSL2 and ADSL2+) that provides digital data transmission over the local telephone network.
Fibre-based	70%	Includes any type of fibre-based connection e.g. fibre-to-the-premises (FTTP), fibre-to-the-basement (FTTB), fibre-to-the-curb (FTTC), fibre-to-the-node (FTTN). Mainly used in urban/suburban areas.
Cable	22%	Cable television infrastructure which uses coaxial cable or Hybrid-Fibre Coaxial (HFC). Mainly used in suburban areas.
Fixed wireless	4%	Broadband transmitted using radio signals over a dedicated fixed wireless network. Uses technology similar to mobile networks. Mainly used in regional areas.
Satellite	2%	Broadband delivered using satellite transmitters and satellite receivers attached to premises. Mainly used in regional and remote areas.

Source: BCARR analysis of ACCC Internet Activity RKR data and NBN Wholesale Market Indicators report, June 2022. Data does not provide an estimate for the number of premises with mobile wireless broadband. Data includes both residential and business connections.

While improvements to bandwidth capabilities have been made over the decade regardless of technology type, some types of broadband perform better than others. Fibre and cable-based broadband typically have the highest bandwidth capacity, being able to deliver speeds of at least 25 megabits per second (Mbps) and often speeds above 100 Mbps. By contrast, DSL provides much slower speeds (typically around 1–7 Mbps). Wireless-based technologies (such as fixed-wireless and satellite) have the potential for high speeds (25–75 Mbps) but performance on these networks can be constrained by the physical limits of available spectrum, particularly during peak times.

While enterprise-level solutions have been available for businesses located in CBDs, the rollout of the NBN has transformed the wider fixed-broadband market in Australia with a marked increase in fibre-based technologies in place of DSL. In June 2011, only 31,000 connections (0.5 per cent) were fibre-based (Figure 2). In the decade or so since, this has grown to 6.4 million fibre-based connections (70 per cent). In the same time, DSL connections decreased from around 4.5 million connections (73 per cent) to 180,000 connections (2 per cent) in June 2022.

Figure 2. Connection by broadband technology type, June 2011 and June 2022



Source: BCARR analysis of the ABS Internet Activity Survey and ACCC Internet Activity RKR data and NBN Wholesale Market Indicators report. Other includes dial-up (in June 2011), fixed wireless, satellite and other broadband connections. Data includes both residential and business connections.

Broadband use depends on business characteristics

Broadband use in Australia varies based on the size, location and industry the business works in. For example, smaller businesses may have less choice on broadband connections as it may require significant capital investment to upgrade this technology. Remote regions tend to have less infrastructure available to support fixed-line broadband than urban areas, while industry use of broadband also differs by how important broadband is to carry out the core business functions of the industry. For example, businesses in the finance sector rely on ultra-low latency connections for trading (latency being the lag between transmission and receipt of data), while information media services rely on high data throughput to transfer and broadcast content.

Evidence from the ABS Business Characteristics Survey (BCS) pooled from 2009–10 to 2018–19 shows that businesses with greater turnover have higher broadband adoption rates than businesses with a turnover of less than $200,000 (Table 2). A similar relationship is found when analysing businesses by headcount. Over the 10-year period, 6 per cent of businesses with a headcount under 20 had no broadband compared with only 1 per cent of businesses with 20 or more employees.

Large CBD-based businesses also tend to use better broadband technologies than smaller businesses with enterprise-based solutions being available in CBDs for many years. Over the decade to 2018–19, 20 per cent of businesses with turnover over $2 million used a fibre connection, which was much higher than the 5 per cent of businesses with a turnover of less than $2 million.[12] During the same period, 31 per cent of businesses with turnover less than $200,000 had higher rates of fixed wireless and mobile wireless broadband connections, compared to 22 per cent for businesses with turnover over $200,000.

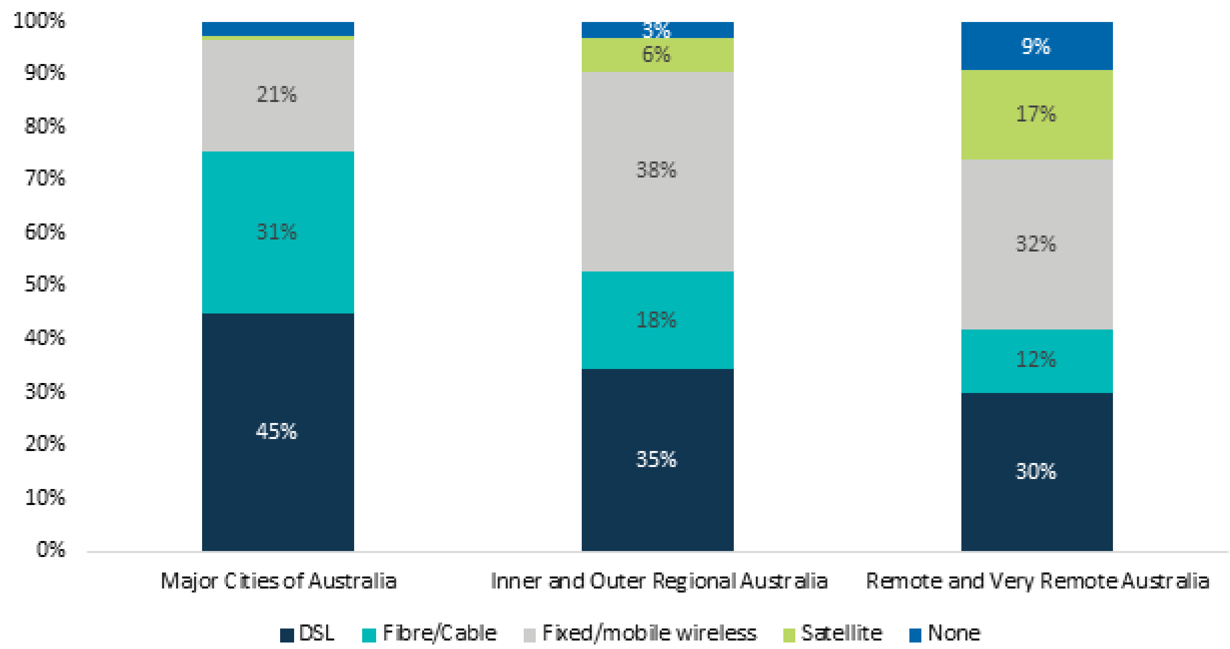
Table 2. Broadband connection technology types, pooled data from 2009–10 to 2018–19

Technology	% of businesses Turnover Less than $200,000	% of businesses Turnover $200,000 or more	% of businesses Turnover Less than 200	% of businesses Turnover 200 or more
No broadband	12	3	5	0
DSL	52	61	63	48
Fibre	4	13	8	29
Cable	7	7	6	13
Fixed wireless	10	8	9	5
Mobile wireless	12	5	7	2
Satellite	3	2	2	0
Other	0	1	0	2

Source: BCARR analysis of Business Characteristics Survey and BLADE data in DataLab, pooled data from 2009–10 to 2018–19.

Businesses in regional and remote areas have lower rates of broadband adoption than those in major cities. Figure 3 shows businesses located outside of major cities have higher proportions of fixed wireless, mobile wireless and satellite broadband usage relative to major cities. In contrast, broadband connections in major cities are more often fibre or cable-based.

Figure 3. Business broadband technology types by region, 2017–18 to 2018–19

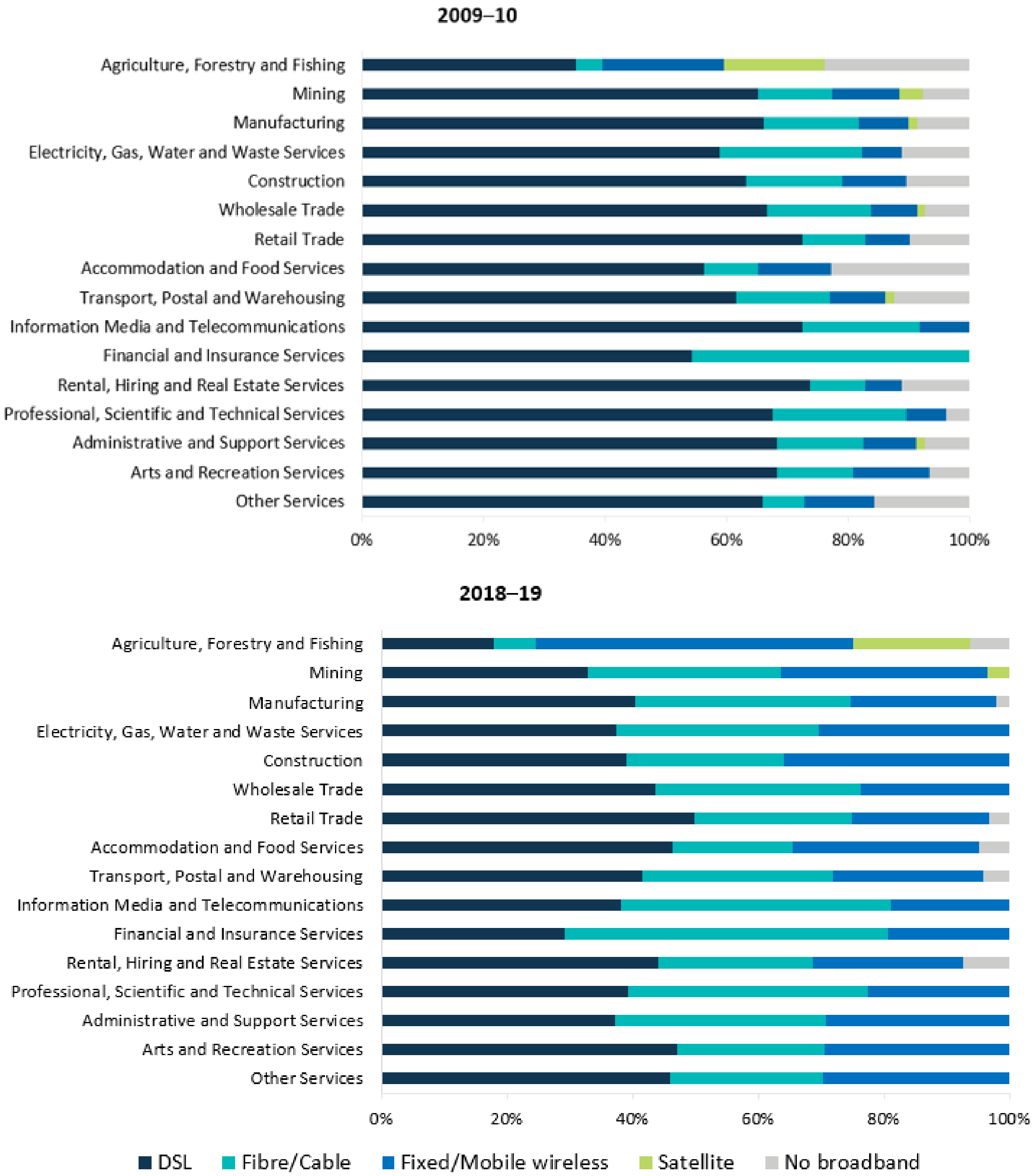


Source: BCARR analysis of Business Characteristics Survey data and experimental location data from BLADE. Two year-average of broadband connection types between 2017–18 and 2018–19.

Survey data also confirms that broadband adoption depends on industry type. In 2018–19, urban-based technology-reliant industries such as telecommunications and financial services have the greatest share of fibre and cable-based connections, while agriculture, which is comprised of businesses that are generally located outside of the major cities, has the largest proportion of wireless and satellite services (Figure 4).

Over the decade, the transition from exchange-based DSL to fibre-based broadband technologies was greatest for manufacturing and financial services industries with a decrease of around 40 percentage points in DSL connections between 2010–11 and 2019–20 (Figure 4).[13] These industries tend to involve operations that require automation and low broadband latency. At the other end of the scale, the share of DSL connections in agriculture decreased by only 11 percentage points between 2010–11 and 2019–20, although far fewer businesses in the sector reported having no broadband in 2019–20.

Figure 4. Connection type by industry



Source: BCARR analysis of BLADE. 2018–19 data relies on imputation of a main broadband connection from a multiple response.

Firms using fibre and cable-based connections are making better use of high-growth digital technologies. Table 3 shows that 71 per cent of firms using fibre-based connections and 65 per cent of firms using cable made use of cloud-based technologies either to a moderate or major extent. This is the highest amongst all broadband types, with DSL at 53 per cent. Cloud-based technologies generally require real-time data streaming, which has higher bandwidth requirements than other standard internet applications. This high use of cloud technology indicates that firms are taking advantage of the capabilities offered by high-speed broadband.

Table 3. Firm use of cloud-based technology, 2017–18

Technology	not at all/small extent (%)	moderate/major extent (%)
Fibre	29	71
Cable	35	65
Fixed wireless	44	56
DSL	47	53
Mobile wireless	56	44
Satellite	60	40

Source: BCARR analysis of Business Characteristics Survey data from BLADE, BLADE experimental location data.

Broadband and productivity growth

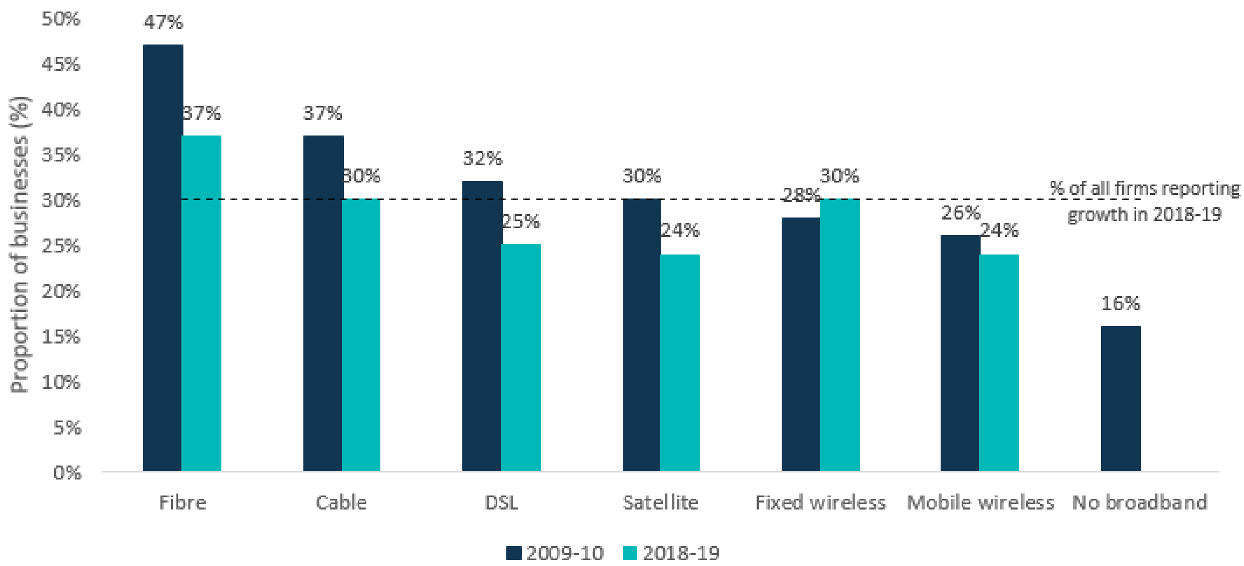
This section examines the potential relationship between broadband use and productivity growth at the firm level. It uses statistical analysis to compare productivity growth measures by broadband technology type and focuses on comparing fibre and cable-based connections with DSL connections. Several regression models are used to examine this relationship, controlling for firm and time-based factors which may also influence business productivity growth.

The analysis uses Australian Business Register data and the taxation records of firms from 2009–10 to 2018–19 from BLADE. To capture information on broadband usage, the analysis is restricted to firms which have responded to the BCS (around 7,000 firms annually). More information on data issues is outlined in Appendix F: Limitations to the analysis.

Firms with better broadband report higher productivity growth

Analysis of the BCS data shows that 47 per cent of businesses in 2009–10 and 37 per cent of businesses in 2018–19 with fibre or cable-based broadband self-reported having higher productivity growth (Figure 5). In contrast, businesses with no broadband had the lowest rate of firms reporting productivity growth improvements (16 per cent in 2009–10).

Figure 5. Proportion of businesses reporting increased productivity by technology type



Source: BCARR analysis of the Businesses Characteristics Survey from BLADE. Businesses were surveyed on their level of productivity compared with the previous year, based on self-assessment.

Figure 5 also highlights that the overall share of firms which reported improved productivity in 2018–19 was lower than the share of firms reporting this in 2009–10, which broadly aligns with trends observed in official ABS estimates for business productivity.[14] While a firm's own assessment of productivity is only indicative of actual productivity, these findings do support the analysis of key productivity measures shown in the sections that follow.

Productivity growth by broadband technology

Productivity growth can be quantified in several ways.[15] BCARR has analysed firm-level information from BLADE to assess the relationship between productivity growth and broadband technology. Productivity growth is measured by the change in both outputs and inputs. Output is measured through business turnover, while inputs are a combination of labour utilisation, capital stock and use of intermediate goods or services (further details on calculating firm-level productivity growth are in Appendix B: Firm-level productivity growth measures). Non-market industries, including public administration, education and health sectors, were excluded because reliable measures for output could not be constructed for this analysis.

The analysis focuses on two key productivity growth measures:

- Labour productivity growth (LP growth): the ratio of output growth to the growth in labour usage
- Multifactor productivity growth (MFP growth): the ratio of output growth to the growth in labour, capital and intermediate inputs.

Table 4 provides a preliminary analysis of productivity growth by broadband technology, but does not control for other factors that affect productivity growth. It shows that the median firms with fibre-based and cable broadband have higher than average productivity growth, while firms with DSL have lower median productivity growth. The median firm using a fibre-based connection has 0.88 per cent annual MFP growth compared with 0.77 per cent for the median firm using DSL. Similarly, for LP growth, fibre has 0.8 per cent LP growth compared with 0.54 per cent for DSL. The median firm using cable has considerably high productivity growth (1.08 per cent MFP growth; 1.2 per cent LP growth) while the median firm without a broadband connection has much lower productivity growth (0.37 per cent MFP growth; -0.71 per cent LP growth).

Satellite has the highest median MFP growth of all broadband types, at 1.25 per cent. High median MFP growth for satellite firms is likely driven by industry and firm-size based characteristics. This is because firms with satellite tend to be small firms based in the agricultural sector, both factors which are correlated with higher productivity growth over the 10-year period analysed.

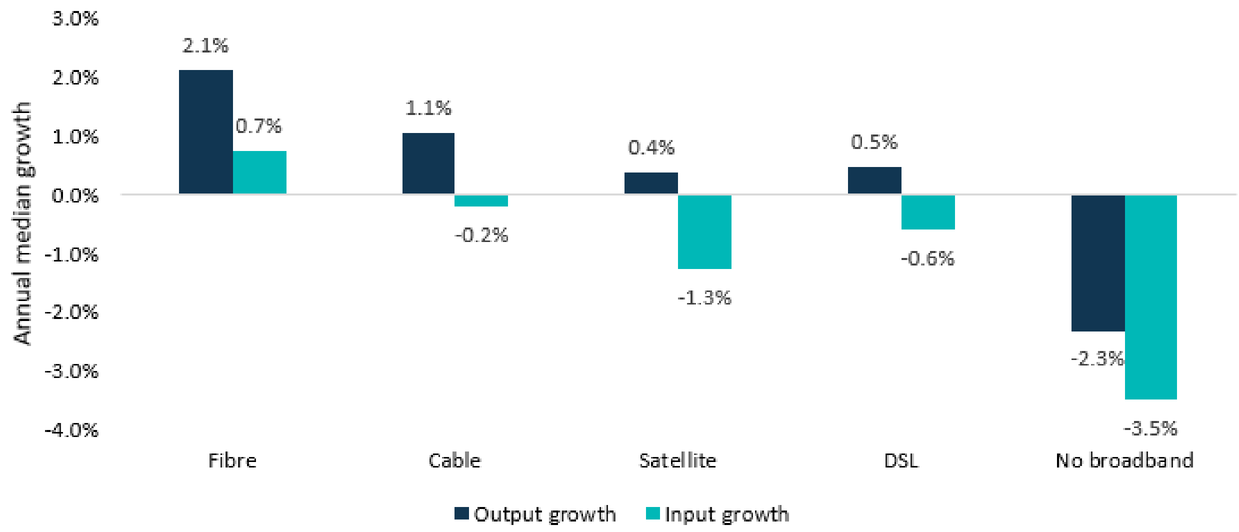
Table 4. Productivity growth by broadband technology

Broadband technology	Median annual MFP growth (%)	Median annual LP growth (%)
DSL	0.77	0.54
Fibre-based	0.88	0.80
Cable	1.08	1.20
Satellite	1.25	0.86
No broadband	0.37	-0.71
All businesses	**0.83**	**0.57**

Source: BCARR analysis of the Businesses Characteristics Survey from BLADE, based on data from 2009–10 to 2018–19.

As MFP and LP are ratios of outputs to inputs, examining input and output growth by broadband type yields some insight into why firms with satellite, fibre and cable connections have higher median productivity growth. Figure 6 shows that high productivity growth for fibre and cable is largely attributable to growth in outputs, while productivity growth for satellite users is due mainly to reductions in the growth of inputs. This negative input growth for satellite firms suggests inputs are decreasing due to efficiency savings, lower broadband costs, or perhaps due to a stagnation in their inputs. Conversely, satellite firms may also be more likely to experience accelerated benefits from broadband connectivity, as some firms on satellite in remote areas previously had no or very limited internet connectivity.

Figure 6. Annual input and output growth by broadband technology, 2009–10 to 2018–19



Source: BCARR analysis of BLADE data from 2009–10 to 2018–19.

While these descriptive results indicate a possible relationship between broadband and productivity growth, they do not indicate whether broadband is a driver of productivity growth. This is because productivity growth differences may be due to other factors that affect the business, such as its geography, business size and industry.

BCARR has used regression analysis to identify whether broadband technology influences productivity, after controlling for these business characteristics, as well as other factors that are specific to the business but not directly observable. The effects of different broadband technology types on productivity can be measured by testing the relationship of productivity measures (MFP growth and LP growth) with broadband technology types as well as other variables.

Broadband type can be linked with productivity growth

BCARR's regression analysis shows a relationship between broadband technology type and productivity growth at the firm level. In particular, firms with fibre-based or cable broadband have higher MFP growth than firms with DSL connections, while firms without broadband have lower productivity growth. The statistical significance of this relationship varies depending on the regression model being tested.

Two main types of regression were developed: using broadband technology type as a predictor of productivity growth; and using a firm's switch from DSL to fibre or cable-based broadband as a predictor of productivity growth. Regression models were tested with different sets of controls as well as testing time lags on the impacts of broadband on productivity growth.

Other firm-based factors were found to affect productivity growth. These include the size of a business (with a negative relationship with productivity growth as business size increases), time-effects (with specific increases in productivity in 2017–18 onwards, driven by data issues outlined in Appendix F: Limitations to the analysis), as well as industry and geographic effects. Appendix D: Broadband technology and productivity growth relationship details these regression results.

Table 5 shows that using a pooled ordinary least squares (OLS) model, firms with fibre and cable-based broadband are estimated to have 0.8 per cent higher annual MFP growth than firms using DSL. This model accounts for the age of the firm, time, industry and geography effects. Under a two-way fixed-effects model, which controls for firm-specific effects (one-way fixed-effects) as well as time-specific effects, there are no statistically significant results. The pooled OLS regressions suggest there is a small likelihood that businesses with fibre and cable-based connections have higher productivity growth when compared with firms on DSL. However, this difference is not observable in the fixed-effects regressions. This suggests that other idiosyncratic factors specific to a firm, which are captured in the variation of fixed-effects regressions, may account for the higher productivity growth found in the pooled OLS model. Another possibility is that the statistical variance of broadband technology type at the firm-level is not large enough to identify a statistically significant relationship.

Table 5. Productivity growth for firms on fibre or cable broadband compared with DSL – Regression results

Productivity measure	Model	Annual productivity growth of Fibre/cable (compared with DSL)	P-value	Statistical significance
MFP growth	**Pooled OLS**	**0.8%**	**0.077**	**Weak significance**
MFP growth	Two-way fixed-effects	0.8%	0.228	No significance
LP growth	Pooled OLS	0.7%	0.621	No significance
LP growth	Two-way fixed-effects	2.4%	0.240	No significance

Source: BCARR analysis of BLADE data from 2009–10 to 2018–19. For full regression results, see Appendix D: Broadband technology and productivity growth relationship. High significance is indicated by $p \leq 0.05$, weak significance is indicated by $0.05 < p \leq 0.10$. For Pooled OLS, controls were based on firm industry, year, geography, firm size and firm age.

There is also some evidence that firms without a broadband connection have lower labour productivity growth when compared with firms on DSL. Table 6 shows under a pooled OLS model, firms with no broadband are estimated to have 1.5 per cent lower annual LP growth. This estimate is highly statistically significant. Despite this finding, no significant relationship is observed for LP growth under a two-way fixed-effects model, nor for MFP growth under either pooled OLS or fixed-effects models. The lack of a relationship with MFP growth could mean that the significance of LP growth is driven by firm choices to invest in capital inputs (which are not captured by the metric for LP growth).

Table 6. Productivity growth for firms without broadband, compared with DSL – Regression results

Productivity measure	Model	Annual productivity growth of No broadband (compared with DSL)	P-value	Statistical significance
MFP growth	Pooled OLS	-0.9%	0.252	No significance
MFP growth	Two-way fixed-effects	-1.7%	0.265	No significance
LP growth	**Pooled OLS**	**-1.5%**	**< 0.001**	**High significance**
LP growth	Two-way fixed-effects	5.5%	0.217	No significance

Source: BCARR analysis of BLADE data from 2009–10 to 2018–19. For full regression results, see Appendix D: Broadband technology and productivity growth relationship. High significance is indicated by $p \leq 0.05$, weak significance is indicated by $0.05 < p \leq 0.10$. For Pooled OLS, controls were based on firm industry, year, geography, firm size and firm age.

Regression analysis indicates that firms with satellite broadband have higher MFP growth than when on DSL. This relationship is not evident in the pooled OLS model but is significant in the fixed-effects model. The observed benefits for satellite broadband are high, with firms that adopt satellite broadband with 5.6 per cent higher annual MFP growth over DSL. These results suggest that firms that adopt satellite is associated with increasing MFP within that firm. Despite the statistical significance, caution must be taken when interpreting the results for satellite broadband due to the small number of firms in the BCS with satellite-based connections (around 180 firms annually).[16]

Table 7. Productivity growth for firms on satellite broadband, compared with DSL – Regression results

Productivity measure	Model	Annual productivity growth of Satellite (compared with DSL)	P-value	Statistical significance
MFP growth	Pooled OLS	0.7%	0.57	No significance
MFP growth	**Two-way fixed-effects**	**5.6%**	**0.02**	**High significance**
LP growth	Pooled OLS	-5.2%	0.17	No significance
LP growth	Two-way fixed-effects	7.1%	0.32	No significance

Source: BCARR analysis of BLADE data from 2009–10 to 2018–19. For full regression results, see Appendix D: Broadband technology and productivity growth relationship. High significance is indicated by $p \leq 0.05$, weak significance is indicated by $0.05 < p \leq 0.10$. For Pooled OLS, controls were based on firm industry, year, geography, firm size and firm age.

The above regression results provide some support for the hypothesis that better broadband leads to higher productivity growth. High-speed broadband technologies appear to have higher productivity growth than lower speed technologies, while firms without broadband do worst of all. The results are also in line with the median productivity growth levels by different broadband technologies, presented in Table 4.

Improved broadband has a positive impact on productivity growth

Limiting the sample only to firms that switch from DSL to fibre or cable-based broadband is a way of implementing experimental design without having to conduct a randomised controlled trial. This allows for the estimation of a firm's productivity growth based on their adoption of better broadband, which more likely reflects the impact of a change in broadband technology.

There is stronger evidence that firms switching from DSL to fibre or cable-based broadband experience higher productivity growth after switching. This relationship is strongest in the year immediately following adoption, with no observable effect of continual growth in future years. Multiple models shown in Table 8 suggest a positive impact on productivity growth when firms switch from DSL to fibre or cable-based broadband.

Under a pooled OLS regression, the effect of switching from DSL to fibre or cable-based broadband is an increase in annual MFP growth of 4.2 per cent in the immediate year following switching. In a separate estimation using fixed-effects regression, the effect of switching from DSL to fibre or cable-based broadband is a 13.5 per cent increase in LP growth. The significance and consistency of these results indicates that there is some positive productivity growth effect of broadband, even once controlling for industry, time, geography and business size characteristics. However, differences in MFP growth are no longer observable when a fixed-effects model is estimated.

Table 8. Productivity growth for firms that switch from DSL to fibre or cable broadband – Regression results

Productivity measure	Model	Annual productivity growth switching from DSL to Fibre/cable	P-value	Statistical significance
MFP growth	**Pooled OLS**	**4.2%**	**0.008**	**High significance**
MFP growth	One-way fixed-effects	3.2%	0.21	No significance
LP growth	**Pooled OLS**	**14.8%**	**0.002**	**High significance**
LP growth	**One-way fixed-effects**	**13.5%**	**0.037**	**High significance**

Source: BCARR analysis of BLADE data from 2009–10 to 2018–19. For full regression results, see Appendix D: Broadband technology and productivity growth relationship. High significance is indicated by $p \leq 0.05$, weak significance is indicated by $0.05 < p \leq 0.10$. For Pooled OLS, controls were based on firm industry, year, geography, firm size and firm age.

Lagged productivity growth benefits were tested and found to be insignificant (Appendix D: Broadband technology and productivity growth relationship). These results suggest that any improvements in productivity growth from broadband are absorbed by firms in the immediate year of adoption and no lagged benefits are observable.

While productivity growth does not show significant additional benefits in the years beyond the immediate year of broadband adoption, there is some evidence to suggest that fibre or cable-based broadband does have a longer lasting impact on productivity growth. Table 9 compares multiple years-worth of data before and after the adoption of fibre or cable-based broadband. It shows that the adoption of fibre or cable-based broadband results in an observable difference in productivity growth. This is in contrast to single year lags, which examine productivity in comparison to a single pre-broadband baseline year and single post-broadband year.

Table 9. Sustained annual productivity growth for firms that switch from DSL to fibre or cable broadband - regression results

Productivity measure	Model	Sustained annual productivity growth switching from DSL to Fibre/cable	P-value	Statistical significance
MFP growth	Pooled OLS	2.1%	0.102	No significance
MFP growth	**Two-way fixed-effects**	**5.1%**	**0.008**	**High significance**
LP growth	**Pooled OLS**	**11%**	**0.002**	**High significance**
LP growth	**Two-way fixed-effects**	**9.1%**	**0.042**	**High significance**

Source: BCARR analysis of BLADE data from 2009–10 to 2018–19. For full regression results, see Appendix D: Broadband technology and productivity growth relationship. High significance is indicated by $p \leq 0.05$, weak significance is indicated by $0.05 < p \leq 0.10$. For Pooled OLS, controls were based on firm industry, year, geography, firm size and firm age.

A similar model was also developed to examine longer term effects, which constructed 2 groups of firms that stayed on DSL for the full analysis period of 2010–11 to 2018–19 against firms that switched to fibre/cable-based broadband. Once controlling for other factors using pooled OLS, the results indicate a positive relationship for firms in the group that switched, compared to those that remained on DSL. This relationship was only weakly significant for MFP growth, and not significant under various lags. Appendix D: Broadband technology and productivity growth relationship provides details of the full regression outputs.

As is common for estimates of firm-level productivity growth analysis, overall model fit for the regressions was generally quite poor. Studies show that the link between positive (or negative) variance in productivity growth and changes in broadband technology can be tenuous[17] and can be driven by the high randomness, unpredictability and noise of data at the firm-level, when compared with aggregate macroeconomic data. This creates high variance in productivity growth estimates and affects the precision of predicting firm-level productivity growth. Despite these limitations, there appears to be a positive and statistically-significant relationship between broadband and firm-level productivity in many of the regression models estimated.

Conclusion

The analysis generally finds a positive relationship between the adoption of fibre and cable-based broadband and firm-level productivity growth. This relationship is strongest immediately after the adoption of broadband technology. Additionally, the prevalence of broadband varies based on size, geography and industry which can also influence firm-level productivity growth. This experimental analysis also found some signs of a positive relationship between firms on satellite broadband and productivity growth, however the small sample of firms with satellite connections limited the robustness of these estimates.

The findings in this paper establish a foundation to progress research on the relationship between broadband and firm-level productivity growth within Australia. However, data limitations constrain this analysis. While the emergence of administrative datasets such as BLADE can be used to construct estimates of firm-level productivity growth, limited data is available on broadband connections or the speeds attainable by businesses (Appendix F: Limitations to the analysis). Where businesses are able to provide more robust datasets that can be combined with BLADE to address these limitations, the analysis and subsequent findings in this paper may be enhanced.

Appendix A: Data sources and preparation

Data was obtained from BLADE, a longitudinal dataset provided by the ABS that links firm-level tax data, ABS survey information, and administrative data collected by various government agencies. BLADE was supplemented with public ABS datasets for deflation and depreciation purposes.

The key datasets and variables used for estimating firm-level productivity growth and broadband usage were:

- **Business Activity Statements (BAS):** output (turnover), wages, capital and operating expenditure data for businesses registered for GST purposes. Around 2.5 million businesses report each year.[18]
- **Business Income Tax (BIT)**: assets, liabilities and expenditure data reported for income taxation purposes. Around 2.5 million businesses report each year.[19]
- **Pay As You Go (PAYG)**: employment levels data, collected for employee taxation purposes. Around 700,000 businesses report each year.[20]
- **Business Characteristics Survey (BCS)**: data on business use of IT, innovation, internet and broadband usage. Around 7,000 businesses respond per year.[21]
- **Experimental BLADE locations data**: location information on BLADE businesses for the 2018–19 financial year including Statistical Area levels.

Data treatment steps were taken before analysing productivity growth. All financial values were converted into real (inflation-adjusted) terms before analysis using 2002 (the starting year of BLADE) as the base year. Implicit price deflators were constructed to deflate output and intermediate inputs, using industry-based economic activity. Cost-shares data were used to deflate output indexes.[22] Capital expenditure was deflated using the deflator for national accounts industry-based gross fixed capital formation,[23] while wages were deflated using CPI data.[24] Next, GST in capital and operational expenditure data was factored out to avoid inconsistent tax treatment across different years of BLADE. Finally, asset disposals were subtracted from turnover and capital stock data to ensure the sale of large assets was not influencing MFP results. Outlier firms with extremely high or low levels of productivity growth were treated by removing observations beyond the first and 99th percentile. This treatment was applied separately to MFP growth and LP growth variables.

Methodology summary

Figure 7. Estimating firm-level productivity growth

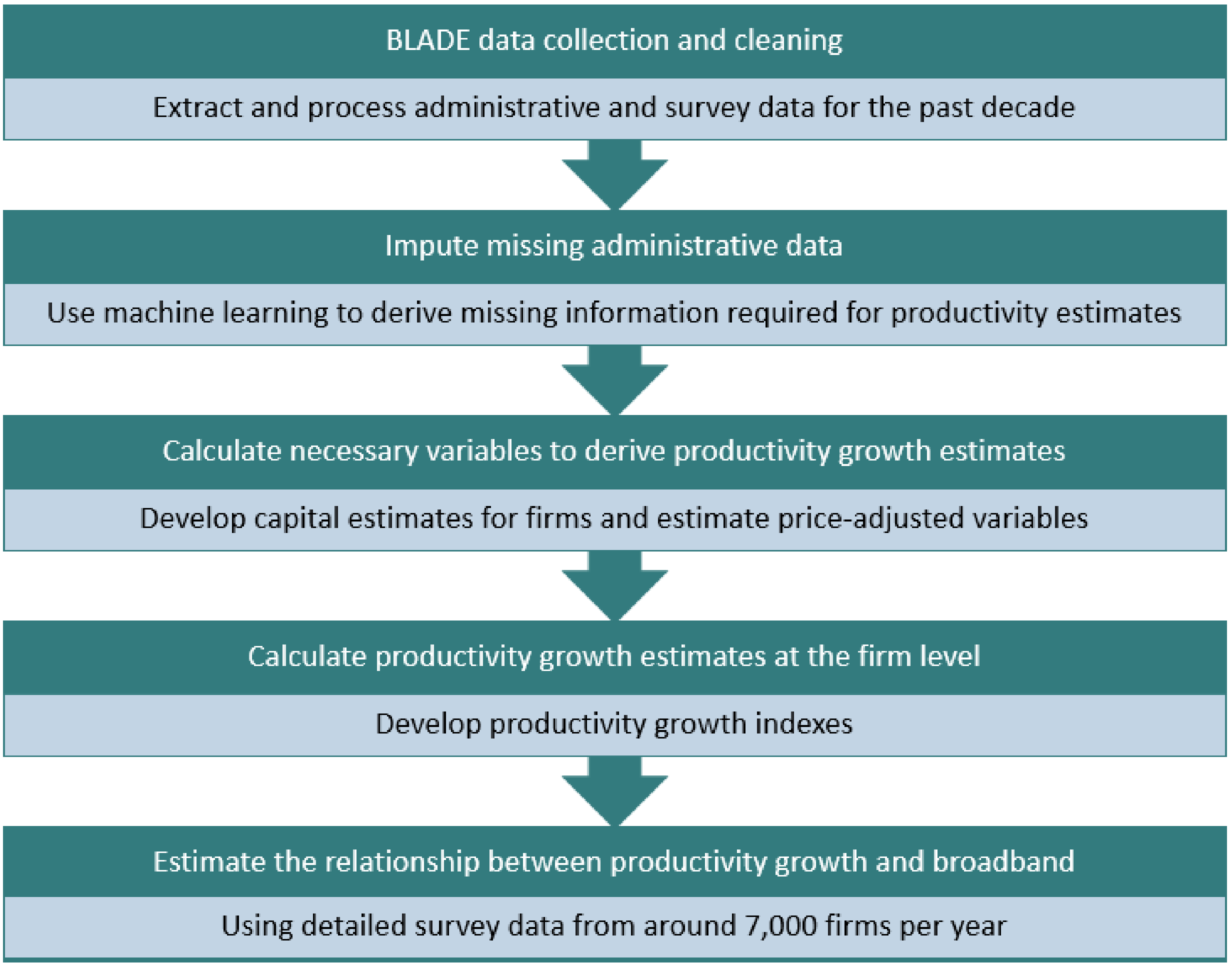


Figure 8. Estimating the relationship between productivity growth and broadband

Appendix B: Firm-level productivity growth measures

Productivity growth can be quantified in several ways.[25] This analysis focuses on 2 key productivity measures:

- Labour productivity growth (LP growth): the ratio of output growth to the growth in labour usage
- Multifactor productivity growth (MFP growth): the ratio of output growth to the growth in labour, capital and intermediate inputs.

Each measure was calculated at the firm level using an index-numbers approach. Due to the challenging nature of creating a firm-level capital stock index, a proxy approach was used that is in line with the Organisation for Economic Co-operation and Development (OECD) recommendations. To determine a firm's MFP growth, its labour inputs, capital inputs and intermediate inputs were aggregated using a bilateral Törnqvist quantity index (a weighted geometric average of input components, where the weights are the arithmetic average of the expenditure shares in the 2 periods being compared).[26] This is the same index formula that is used by the Australian Bureau of Statistics in calculating estimates of industry MFP.[27] To make the best use of the breadth of data in BLADE, missing output and input data was imputed using machine-learning methods.

Deriving productivity growth using index numbers

BCARR's productivity growth measures were estimated using an index-numbers approach.[28] This approach creates an index for the change in each firm's inputs and outputs. Productivity growth can be measured by chaining changes in the ratio of output and input indexes over time. At the firm level, MFP and LP growth was measured using the following formula:

$$\text{MFP growth}_{it} = \frac{\text{Output growth}_{it}}{\text{Input growth}_{it}} = \frac{\text{Y growth}_{it}}{L, K, I\ growth_{it}}$$

$$\text{LP growth}_{it} = \frac{\text{Output growth}_{it}}{\text{Input growth}_{it}} = \frac{\text{Y growth}_{it}}{L\ growth_{it}}$$

where growth refers to the change between year *t* and the previous year *t-1,* for firm *i* (where *t* is between years 2009–10 and 2019–20). For each, the growth rate is the respective formula minus 1. Indexes for output, labour and intermediate inputs are calculated using data readily available in BLADE. For MFP growth, output growth (Y) is measured using deflated business turnover, while input growth is measured using a combination of labour inputs (*L*), deflated capital inputs (*K*) and deflated intermediate inputs (*I*). Real output growth is calculated at the firm level as the yearly growth in deflated total sales; labour growth is the growth in full-time equivalent (FTE) employees; and real intermediate input growth is the growth in deflated operational expenditure. In contrast, a capital index is more difficult to construct as there is no widely available measure of capital stock in BLADE.[ii] Capital stock levels at the firm level were estimated using a proxy method, shown below.

These individual input variables cannot be simply added together to find a total input value as they use different units of measurement. Instead, the input variables are weighted by their share of a firm's total costs. Using this approach, the previous formula can be disaggregated using the following logged form:

$$\ln\left(\frac{MFP_{it}}{MFP_{i(t-1)}}\right) = \ln\left(\frac{Y_{it}}{Y_{i(t-1)}}\right) - W_L \ln\left(\frac{L_{it}}{L_{i(t-1)}}\right) - W_K \ln\left(\frac{K_{it}}{K_{i(t-1)}}\right) - W_I \ln\left(\frac{I_{it}}{I_{i(t-1)}}\right)$$

where W_L, W_K and W_I are the weights associated with labour, capital and intermediate inputs (see *Input index weighting* for further information). Firm-level productivity growth $\left(\frac{MFP_t}{MFP_{t-1}}\right)$ is estimated by first

[ii] The BIT does collect capital stock information, but this is only available for around 5% of all BLADE observations.

solving the right-hand side of this formula and then taking the exponent of both sides. Solving the right-hand side of this formula requires constructing input and output growth indexes using the data available in BLADE. In summary, this formula shows that MFP growth for a firm is a function of logged output growth less logged input growth.

Creating a capital index

Capital stock was constructed using the Perpetual Inventory Method (PIM), which is in line with the methodology favoured by the ABS and the OECD.[29] This is expressed by the following formula:

$$K_{it} = (1 - \delta_{jt})K_{it-1} + I_{it}$$

where *K* is the capital stock level; *i* is the firm; *t* is the year; δ is the industry capital depreciation rate,[iii] and *I* is the level of capital expenditure. The intuition behind this formula is that the level of capital stock is based on the previous year's capital stock level (K_{it-1}) multiplied by some depreciation rate (to represent the diminishing value of assets) with the addition of the current year's capital investments. Where capital expenditure is missing from BLADE, the average capital expenditure across all years for a given firm is used.

One problem that arises from the PIM method is that calculating any year's capital stock requires knowing the initial capital stock level for a business (K_0), which may not be available.[30] Even where initial capital stock data is available, this information is not necessarily reliable (e.g. a business could use pre-existing assets owned by a household). Finding a reasonable estimate for K_0 is therefore difficult. BCARR has set K_0 using the following average investment proxy:

$$K_{i,t=0} = \frac{mean(I_i)}{\delta_{jt} + \gamma_j}$$

This represents the average capital expenditure across all years of operation for a firm, divided by the industry capital depreciation rate plus the industry investment growth rate. This approach deviates from OECD recommendations,[31] which simply use average investment divided by capital depreciation rate. However, using the industry investment growth rate is the same approach used by the ABS when producing industry capital stock estimates,[32] and other firm-level research using BLADE.[33]

Input index weighting

Creating an input index for a firm requires weighting capital, labour and intermediate inputs based on their respective importance for each firm. This is challenging as the 3 inputs differ in their units of measurement and so are not directly comparable. The inputs are a mix of stocks (measured at a specific point in time) and flows (measured over an interval of time) and these are a mix of monetary values and people as units of employment. To address this, a two-step approach is taken:

- financial flow measures are estimated for each input
- a weight (or input share) is calculated by dividing the value of an input by the total inputs value.

Table 10 shows how different inputs are weighted in the index. Capital input weights are calculated based on the user cost of capital (defined as the yearly cost for a firm to hold its capital stock).[34] Labour input weights are estimated using wage costs from the BAS. Intermediate input weights are directly based on the operational expenditure variable in BAS. As productivity growth represents a change of 2 years (*t* and *t-1*), input weights are calculated for a given firm using the average weight shares between years *t* and *t-1*.

[iii] Industry level depreciation rates are derived by dividing consumption of fixed capital by net capital stock for each industry division using data found in the ABS System of National Accounts.

Table 10. Index weights used for firm inputs

Input index	Weight
Capital input	$\frac{\text{user cost of capital} \times \text{capital stock}}{\text{total inputs}}$
Labour input	$\frac{\text{wages}}{\text{total inputs}}$
Intermediate input	$\frac{\text{operational expenditure}}{\text{total inputs}}$
Total inputs (denominator)	$(\text{User cost of capital} \times \text{capital stock}) + \text{wages} + \text{operational expenditure}$

The cost for firms of holding capital is not observable in BLADE and must be derived using economic theory. A common approach to weighting capital stock for measuring multifactor productivity is the user costs of capital method.[35] The user cost of capital equation estimates the yearly cost of holding capital using 3 elements: depreciation of assets, financing costs, and a capital gain/loss component.[36] At the firm level, the user cost of capital is calculated using the following formula:

$$uc_{tn} = (r_i - i_t + (1 + i_t)\delta_{jt})P_{tn}$$

where *r* = interest rate for small business borrowing, *i* = inflation rate, *δ* = industry capital depreciation rate, and *P* = capital deflator.[iv] Depreciation of assets is represented by *δ*, while financing costs are represented by *r*, and capital gains/losses are represented by *i* (under the assumption that businesses base their asset price inflation expectations on the ex-post inflation rate).

Imputing missing data using XGBoost

A common issue with research using BLADE is the large amount of missing data.[37] This is especially a problem when estimating firm-level productivity growth because calculating productivity growth requires the inclusion of all input and output variables. Productivity growth compounds these requirements as it uses data for both the current and previous year for a given firm. Table 11 shows how this issue can lead to a significant loss of information in the BLADE dataset. The wide scope of BLADE makes it possible to impute missing values using other data available for the firm. Imputing missing data increases the sample size available to compute productivity growth which improves the robustness of the analysis.

Table 11. Share of BLADE observations missing in dataset, by selected variables

Productivity variable	Proportion of missing observations in the Business Characteristics Survey
Turnover (used for Y)	8%
FTE (used for L)	25%
Capital expenditure (used for K)	16%
Operational expenditure (I)	16%

Source: BCARR analysis of BLADE data.

[iv] Small business borrowing interest rate derived from the RBA (Lenders' Interest Rates | RBA). Inflation rate defined from CPI (Measures of Consumer Price Inflation | RBA). Gamma, or depreciation of assets, is derived from ABS information (Australian National Accounts: Capital Stock (abs.gov.au)).

BCARR has adopted a supervised machine learning approach to impute missing values. This is in line with research by the Department of Industry, Science, and Resources (DISR), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Productivity Commission. Extreme Gradient Boosting (XGBoost)[v] was the algorithm used to impute key productivity variables. XGBoost is a flexible and robust method for regression using big data. This involves creating and sequentially adding decision trees to the model to reduce error. XGBoost was the preferred approach over a more parametric approach (such as linear regression) because the complexity of BLADE makes it difficult to predict the underlying distribution of the data, which is necessary for parametric approaches. XGBoost was also preferred over other decision tree-based methods as it is regularised,[vi] an advantage to prevent overfitting (a common problem in large datasets like BLADE).

XGBoost was used to impute 4 variables: turnover, FTE, capital expenditure and operational expenditure. Table 12 shows the performance of these XGBoost models. Relative absolute error compares model performance to a simple model which simply predicts the mean (where values closer to zero indicate perfect predictive power, and values above one are worse than predicting the mean). All models outperform predicting the mean, but vary in their efficiency. Turnover has the highest accuracy, while capital expenditure is less accurate. This is likely a result of unpredictable nature of capital expenses, comprising largely of one-off businesses purchases.

Table 12. XGBoost evaluation metrics

XGBoost model	Relative absolute error	Root relative squared error	Root mean squared error	Mean absolute error
log(turnover)	0.122	0.299	1.356	0.442
log(FTE)	0.238	0.314	0.204	0.116
log(operational expenditure)	0.280	0.494	2.336	1.130
log(capital expenditure)	0.611	0.754	3.573	2.667

Source: BCARR analysis of BLADE data. Note: capital expenditure and operational expenditure were not imputed for years 2018 onwards. This was due to an underlying change in the reporting obligations to the ATO which has made capital and operational expenditure optional for many businesses to report. With no feasible way to determine which businesses are impacted by the change, the years 2018 onwards have not been imputed to avoid exacerbating data issues.

[v] Open source library available in R.

[vi] Regularisation is the process of introducing bias into a model to prevent a model from overfitting to a training dataset. Often this involves penalising reliance on complex terms within a model, in favour of simpler (and more general) terms within a model.

Appendix C: Scope of the analysis

BCARR has focused on the most recent decade of data from 2009–10 to 2019–20 (with 2018–19 as the most recent BCS release within BLADE 2019–20) to analyse productivity growth. All firms with a GST turnover of more than $75,000 appear in BLADE. This analysis was further restricted to firms which respond to the BCS (around 7,000 firms annually).

Since 2017–18, businesses with a goods and services tax (GST) turnover of less than $10 million are no longer obligated to report capital and operational expenditure.[38] The change has caused many businesses to discontinue reporting information necessary to compute firm-level productivity growth. This means that a large number of firms report either zero or lower capital and operational expenditure amounts after the reporting change, which causes issues for computing capital and intermediate inputs for productivity growth. BCARR has accounted for this change by using time dummies in its pooled OLS regression estimations, and two-way fixed effects regressions (which factors in both time and individual firm effects).

Non-market industries (public administration and safety, education and training and health care and social assistance) were excluded from the analysis. Non-market industries are industries where output is provided either free of charge or at prices not reflective of market value.[39] Consequently, reliable measures for output and deflating nominal values are unavailable in BLADE for these industries. More information is included in Appendix F: Limitations to the analysis.

Table 13 shows the characteristics of the firms analysed and the differences between the Business Characteristics Survey (BCS) and Australian Business Register (ABR) samples. As mentioned earlier, firms in the BCS sample are a subset of the ABR and tend to have more employees and higher turnover. The BCS sample also has a higher share of firms registered as companies and non-financial corporations.

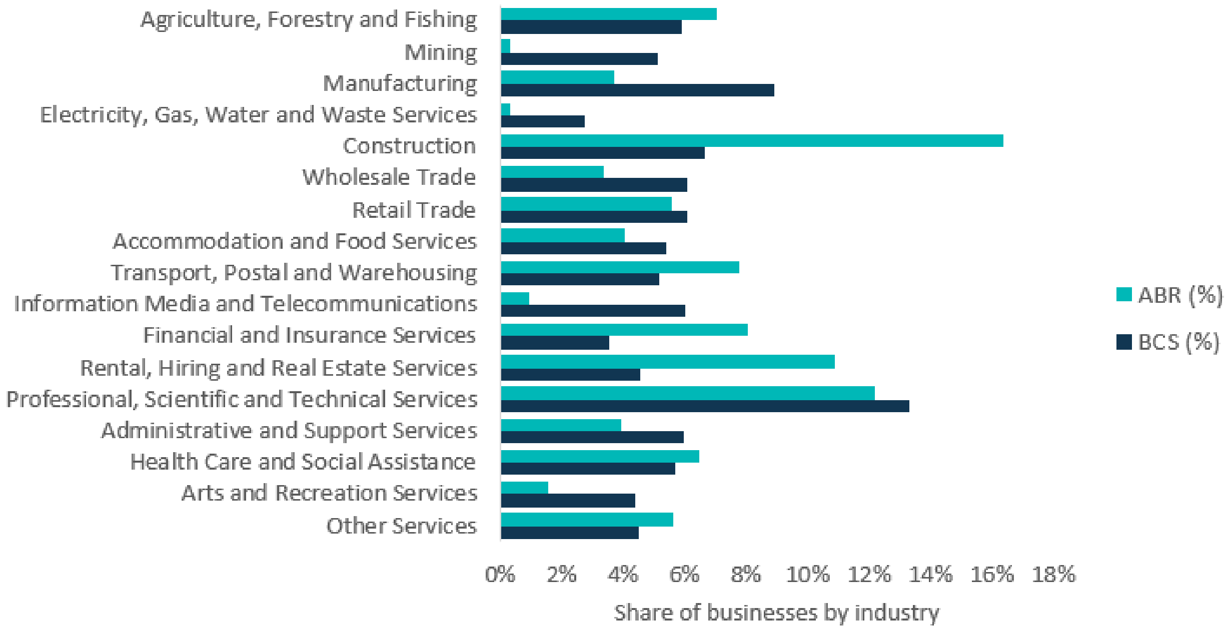
Table 13. Firm characteristics—Business Characteristics Survey (BCS) and Australian Business Register (ABR)

Variable	Category	Share of sampled BCS businesses (%)	Share of ABR businesses (%)
Firm size or headcount	0 to 4 employees	31	52
Firm size or headcount	5 to 19 employees	26	33
Firm size or headcount	20 to 199 employees	22	13
Firm size or headcount	200 or more employees	21	1
Turnover size	Less than $50,000	5	26
Turnover size	Less than $200,000	15	32
Turnover size	Less than $2,000,000	41	34
Turnover size	More than $2,000,000	40	8
Type of legal organisation	Companies	71	39
Type of legal organisation	Sole proprietors	6	27
Type of legal organisation	Partnerships	6	11
Type of legal organisation	Trusts	17	23
Institutional sector	Non-financial corporations	93	79
Institutional sector	Financial corporations	5	18
Institutional sector	Households	3	3

Source: BLADE and ABS counts of Australian businesses, entries and exits. All data is for 2018–19 (to not be impacted by any structural changes due to COVID-19). Turnover data is in nominal terms and does not contain imputed information.

Figure 9 also shows significant industry differences between the BCS and the ABR. Businesses in mining; manufacturing; electricity, gas, water and waste services; wholesale trade; information media and telecommunications; and arts and recreation services were over-represented in the BCS compared with the ABR. In comparison, a lower share of BCS businesses came from construction; and rental, hiring and real estate services – industries characterised by small firms and sole proprietors. In practice, this means that median productivity across the BCS sample is biased towards these overrepresented industries.

Figure 9. Share of businesses by industry from the Business Characteristics Survey (BCS) and Australian Business Register (ABR)



Source: BLADE and ABS counts of Australian businesses, entries and exits. All data is for 2018–19.

Appendix D: Broadband technology and productivity growth relationship

Multiple models were used to assess the impacts of broadband technology on firm-level productivity growth. Regression models are of the following form:

$$Y = \beta_0 + \beta_i X_i + \mu_j Controls_j$$

where the terms β, μ are the set of coefficients which are estimated using pooled OLS. The dependent variable Y represents MFP growth or LP growth, depending on the model estimated. These dependent variables are constructed to give a holistic view of firm-level performance and is consistent with other studies that have examined the relationship between connection technology and productivity growth.[40] Fixed-effects regressions were also used.

X_i represents a selection of broadband identifier dummy variables that were tested. This is analogous to the approach taken by Canzian et al.[41] The coefficients β_i and their statistical significance show the magnitude and certainty of the influence of broadband on productivity growth. Table 14 gives an overview of the different broadband identifier dummies that were used.

Table 14. Broadband variables used in regression models

Broadband variable (X_i)	Sample	Interpretation
X_1 Broadband technology	BCS respondents	6 dummy variables, indicating the presence of either: no Broadband, DSL, Fibre, HFC, Mobile Wireless, fixed wireless or satellite.
X_2 Stayed on DSL vs. switched to fibre or cable-based broadband	BCS respondents that either had DSL, or had DSL and switched to fibre or cable-based broadband	Single dummy variable, where 0 = firms on DSL for the entire period 1 = firms after switching from DSL to fibre or cable-based broadband
X_3 Pre-fibre/cable vs. switched to fibre or cable-based broadband	BCS respondents that had DSL and switched to fibre or cable-based broadband	Single dummy variable, where 0 = firms before switching from DSL to fibre or cable-based broadband 1 = firms after switching from DSL to fibre or cable-based broadband

Additionally, 5 control variables have been included:

- *age* is how many years the firm has been in operation
- *year* is a set of dummy variables for financial years
- *industry* is a set of dummy variables for Australian and New Zealand Standard Industrial Classification (ANZSIC) industry division
- *size* is the FTE size of the business
- *location* is the Greater Capital City Statistical Areas of the business.

Control variables aim to reduce the impact of other factors that may influence the relationship. The firm-specific control variables used in this analysis are consistent with other studies that have examined the relationship between broadband technology and productivity growth.[42]

There is the potential for lags between broadband adoption and productivity growth benefits.[43] To test the impact of lags from broadband adoption on productivity growth, BCARR has investigated adding time lags to the regression models in multiple ways.

- Values where X_i = 1 were lagged by one and 2 years to test delayed productivity growth impacts from broadband.
- Longitudinal dummy variables were developed to test the permanent effects of broadband adoption on productivity growth. In practice, comparing the data for all the years a given firm was in BLADE after changing broadband type against their pre-broadband (or pre-NBN) baseline.

Both pooled OLS and fixed effects methods are used for this analysis. Pooled OLS is a simple linear regression method that does not recognise the panel structure of the data. As a result, it tends to suffer from heterogeneity bias due to firm-specific characteristics that are not controlled for (for example, idiosyncratic characteristics of the firm such as management skill that is not captured in the dataset but may influence MFP growth). A fixed effects model is used to capture firm-specific characteristics. The mean of each variable in each firm is subtracted from the initial value (or first-differenced). While this overcomes some forms of heterogeneity bias, it can mean that there is not sufficient variation for the estimation. The results of the regressions are shown in the tables below.

Table 15. Regression results for X_1 – effect of broadband technology types (compared with DSL)

Dependent variable	Pooled ordinary lease squares MFP growth	Pooled ordinary lease squares LP growth	Two-way fixed-effects MFP growth	Two-way fixed-effects LP growth
Fibre-based	0.009* (0.006)	0.018 (0.018)	0.005 (0.008)	0.011 (0.024)
Cable	0.006 (0.006)	-0.007 (0.02)	0.012 (0.009)	0.042 (0.028)
Fixed wireless	-0.006 (0.006)	-0.019 (0.019)	-0.011 (0.009)	0.024 (0.025)
Mobile wireless	-0.013* (0.007)	-0.066*** (0.021)	-0.001 (0.011)	-0.027 (0.032)
Satellite	0.007 (0.012)	-0.052 (0.038)	0.056** (0.024)	0.071 (0.071)
No broadband	-0.009 (0.008)	-0.153*** (0.024)	-0.017 (0.015)	0.055 (0.045)
R^2	0.023	0.045	0.011	0.054
N (observations)	67,447	89,154	67,447	89,154

Source: BCARR analysis of BLADE data from 2009–10 to 2018–19. Numbers indicate impact on productivity, *, **, *** indicates statistical significance at the 10%, 5%, 1% levels respectively. Controls and intercept coefficients are not shown. Baseline for comparison (where all dummies are equal to zero) represents DSL-connections. Robust standard errors in parentheses.

Table 16. Regression results for X3 – effect of fibre and cable-based broadband adoption

Dependent variable	Pooled ordinary least squares MFP growth	Pooled ordinary least squares LP growth	Two-way fixed-effects MFP growth	Two-way fixed-effects LP growth
Post-adoption	0.042*** (0.016)	0.148*** (0.047)	0.032 (0.025)	0.135** (0.064)
R^2	0.049	0.057	0.026	0.053
N (observations)	2,325	3,214	2,325	3,214
Post-adoption (lagged)	0.008 (0.018)	-0.013 (0.035)	-0.001 (0.029)	0.036 (0.044)
R^2	0.041	0.046	0.042	0.039
N (observations)	1,906	2,510	1,906	2,510
Post-adoption (2-year lag)	-0.019 (0.022)	0.01 (0.042)	-0.01 (0.034)	-0.139 (0.12)
R^2	0.045	0.045	0.09	0.203
N (observations)	1,626	1,626	1,626	2,068
Post-adoption (sustained impact)	0.021 (0.013)	0.11*** (0.035)	0.051*** (0.019)	0.091** (0.045)
R^2	0.030	0.056	0.024	0.046
N (observations)	3,794	5,076	3,794	5,076

Source: BCARR analysis of BLADE data from 2009–10 to 2018–19. Numbers indicate impact on productivity, *, **, *** indicates statistical significance at the 10%, 5%, 1% levels respectively. Controls and intercept coefficients are not shown. 1: Individual fixed-effects regressions are used for all models, with the exception of post adoption sustained impacts, where the multiple number of periods per firm allows for two-way fixed effects. Robust standard errors in parentheses.

The results should be treated with caution, as endogeneity has not been accounted for. Endogeneity in this analysis involves wrongly attributing productivity growth increases to broadband adoption, when the causal effect may be the other way around (i.e. higher productivity businesses being more likely to self-select better broadband technologies). Despite this limitation, some endogeneity is avoided by the introduction of the NBN. During the NBN rollout, many firms may have been forced to switch from DSL-based connections to fibre-based connections, mitigating some of the causality issues that arises from firms self-selecting better broadband technologies.

Table 17. MFP Regression results – Division controls, effect of fibre/cable broadband adoption

Division	A	B	C	D	E	F
Mining	0.045*** (0.01)	0.045*** (0.01)	0.016 (0.069)	0.066 (0.073)	0.022 (0.073)	0.014 (0.054)
Manufacturing	-0.033 (0.008)	-0.033 (0.008)	-0.052 (0.065)	0.049 (0.069)	-0.015 (0.068)	-0.025 (0.052)
Electricity, Gas, Water and Waste Services	-0.018*** (0.013)	-0.018*** (0.013)	-0.071 (0.077)	0.035 (0.083)	-0.022 (0.083)	-0.053 (0.061)
Construction	-0.048*** (0.009)	-0.048*** (0.009)	0.007 (0.067)	0.053 (0.072)	0.006 (0.071)	0.01 (0.055)
Wholesale Trade	-0.034*** (0.009)	-0.034*** (0.009)	-0.02 (0.065)	0.101 (0.07)	0.037 (0.068)	0.007 (0.053)
Retail Trade	-0.04*** (0.009)	-0.04*** (0.009)	0 (0.069)	0.026 (0.073)	0.003 (0.072)	0.003 (0.056)
Accommodation and Food Services	-0.056*** (0.009)	-0.056*** (0.009)	-0.04 (0.072)	-0.017 (0.077)	-0.019 (0.077)	0.008 (0.06)
Transport, Postal and Warehousing	-0.029*** (0.009)	-0.029*** (0.009)	0.017 (0.066)	0.103 (0.071)	0.079 (0.07)	0.007 (0.054)
Information Media and Telecommunications	-0.026** (0.01)	-0.026** (0.01)	0.016 (0.067)	0.089 (0.072)	0.025 (0.071)	0.006 (0.054)
Financial and Insurance Services	-0.023* (0.012)	-0.023* (0.012)	-0.034 (0.071)	0.084 (0.075)	0.063 (0.075)	0.025 (0.057)
Rental, Hiring and Real Estate Services	-0.017*** (0.009)	-0.017*** (0.009)	-0.001 (0.069)	0.081 (0.073)	0.02 (0.073)	0.02 (0.057)
Professional, Scientific and Technical Services	-0.033*** (0.008)	-0.033*** (0.008)	-0.009 (0.064)	0.081 (0.069)	0.041 (0.068)	0.013 (0.052)
Administrative and Support Services	-0.063*** (0.009)	-0.063*** (0.009)	-0.071 (0.066)	0.018* (0.071)	-0.016 (0.071)	-0.049 (0.054)
Arts and Recreation Services	-0.04*** (0.009)	-0.04*** (0.009)	0.02 (0.07)	0.138* (0.075)	0.108 (0.074)	0.067 (0.057)
Other Services	-0.059*** (0.009)	-0.059*** (0.009)	-0.004*** (0.071)	0.137*** (0.077)	0.101*** (0.076)	-0.019*** (0.06)

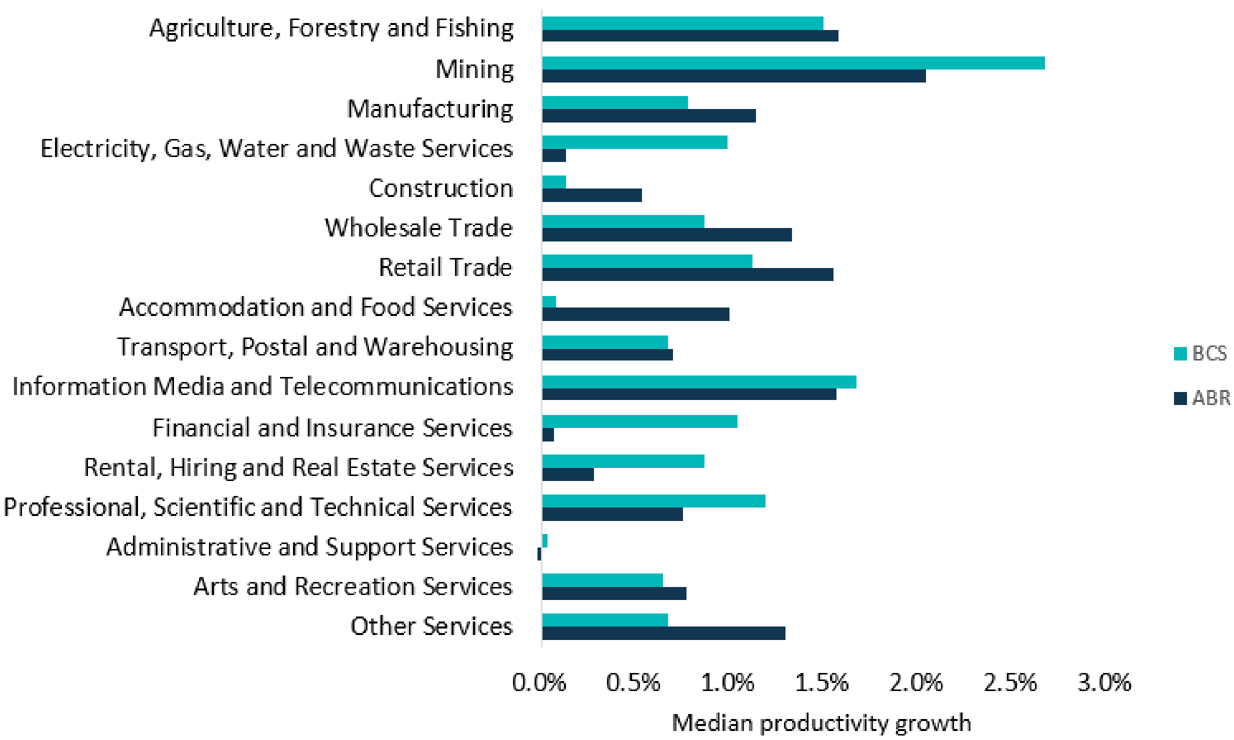
Source: BCARR analysis of BLADE data from 2009–10 to 2018–19. Numbers indicate impact on productivity *, **, *** indicates statistical significance at the 10%, 5%, 1% levels respectively. Controls and intercept coefficients are not shown. Models A-F are all pooled OLS regression models, but differ in the choice of explanatory variable of interest, where (A): regression using broadband type (with HFC/Cable aggregated), (B): regression using broadband type, (C): regression using broadband adoption (pre-post), (D): regression using lagged broadband adoption (pre-post), where productivity growth is measured one year after adopting broadband, (E): regression using lagged broadband adoption (pre-post), where productivity growth is measured one year after adopting broadband, (F): regression using broadband adoption (pre-post), where productivity growth is measured using an equal number of years pre and post-broadband adoption at the firm-level. Robust standard errors in parentheses.

Table 18. LP Regression results – Division controls, effect of fibre/cable broadband adoption

Division	A	B	C	D	E	F
Mining	0.144	0.144	0.055	-0.101	-0.249	0.089
	(0.031)	(0.031)	(0.204)	(0.137)	(0.189)	(0.142)
Manufacturing	-0.037	-0.037	0.135	-0.123	-0.159	0.112
	(0.026)	(0.026)	(0.188)	(0.127)	(0.175)	(0.134)
Electricity, Gas, Water and Waste Services	-0.067	-0.067	-0.096	-0.137	-0.213	-0.06
	(0.041)	(0.041)	(0.228)	(0.16)	(0.215)	(0.161)
Construction	-0.025***	-0.025***	-0.131	-0.219	-0.284	-0.085
	(0.028)	(0.028)	(0.195)	(0.133)	(0.183)	(0.141)
Wholesale Trade	-0.073***	-0.073***	-0.015	-0.118	-0.209*	0.043
	(0.028)	(0.028)	(0.19)	(0.129)	(0.176)	(0.136)
Retail Trade	-0.144***	-0.144***	-0.171	-0.186	-0.334	-0.105
	(0.028)	(0.028)	(0.2)	(0.134)	(0.185)	(0.143)
Accommodation and Food Services	-0.118**	-0.117**	0.072	-0.209	-0.177	0.137
	(0.029)	(0.029)	(0.213)	(0.145)	(0.199)	(0.156)
Transport, Postal and Warehousing	-0.072	-0.072	-0.059	-0.114	-0.22	-0.032
	(0.029)	(0.029)	(0.195)	(0.132)	(0.182)	(0.14)
Information Media and Telecommunications	0.02	0.02	0.133	-0.023	-0.181*	0.121
	(0.03)	(0.03)	(0.192)	(0.131)	(0.181)	(0.138)
Financial and Insurance Services	-0.058**	-0.058**	-0.093	-0.226*	-0.339**	-0.017
	(0.037)	(0.037)	(0.209)	(0.142)	(0.195)	(0.149)
Rental, Hiring and Real Estate Services	-0.064***	-0.063***	-0.063	-0.251	-0.394**	-0.053
	(0.03)	(0.03)	(0.197)	(0.135)	(0.185)	(0.143)
Professional, Scientific and Technical Services	-0.119***	-0.119***	-0.046	-0.197*	-0.354*	-0.038
	(0.027)	(0.027)	(0.185)	(0.126)	(0.174)	(0.133)
Administrative and Support Services	-0.126***	-0.125***	-0.136	-0.24	-0.306	-0.085
	(0.028)	(0.028)	(0.193)	(0.131)	(0.18)	(0.139)
Arts and Recreation Services	-0.165***	-0.165***	0.099	-0.116	-0.213	0.057
	(0.03)	(0.03)	(0.202)	(0.138)	(0.189)	(0.146)
Other Services	-0.209***	-0.209***	-0.153***	-0.12***	-0.105***	-0.08***
	(0.029)	(0.029)	(0.204)	(0.142)	(0.194)	(0.151)

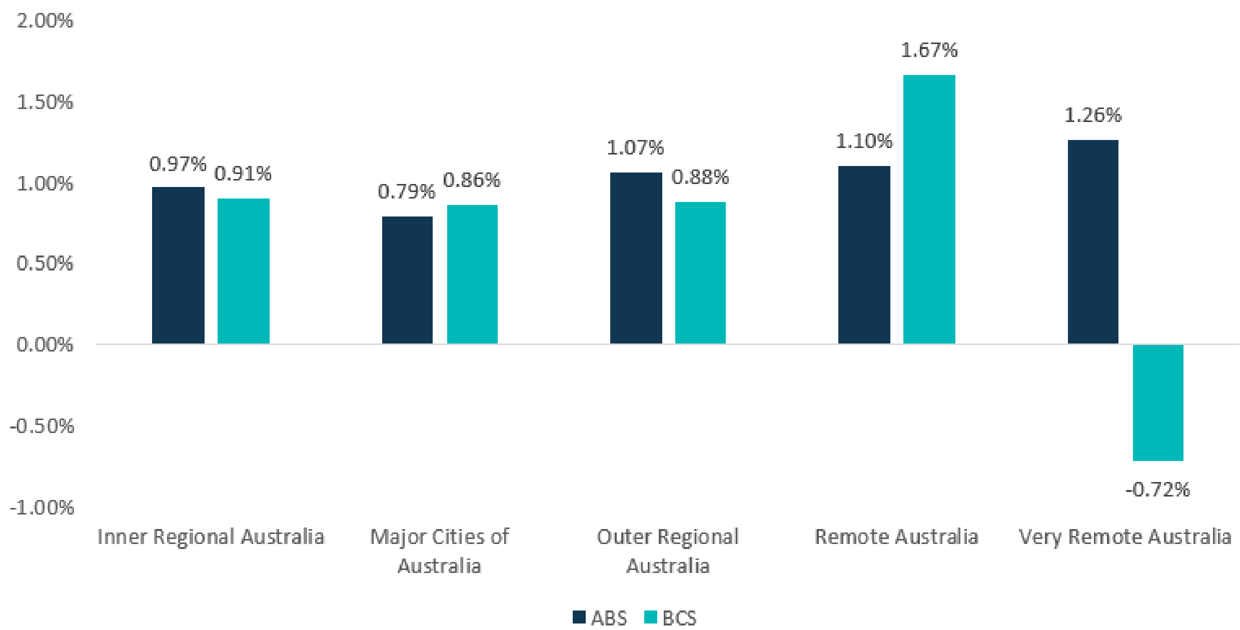
Source: BCARR analysis of BLADE data from 2009–10 to 2018–19. Numbers indicate impact on productivity, standard error, and *, **, *** indicates statistical significance at the 10%, 5%, 1% levels respectively. Controls and intercept coefficients are not shown. Models A-F are all pooled OLS regression models, but differ in the choice of explanatory variable of interest, where (A): regression using broadband type (with HFC/Cable aggregated), (B): regression using broadband type, (C): regression using broadband adoption (pre-post), (D): regression using lagged broadband adoption (pre-post), where productivity growth is measured one year after adopting broadband, (E): regression using lagged broadband adoption (pre-post), where productivity growth is measured one year after adopting broadband, (F): regression using broadband adoption (pre-post), where productivity growth is measured using an equal number of years pre and post-broadband adoption at the firm-level. Robust standard errors in parentheses.

Figure 10. Median Multifactor Productivity Growth, 2009–10 to 2018–19



Source: BCARR analysis of BLADE data.

Figure 11. Productivity growth rates by Accessibility and Remoteness Index of Australia (ARIA)



Source: BCARR analysis of BLADE data.

Appendix E: Integrating location data with firm-level data

Location data longitudinally

The locations of businesses for financial years 2009–10 to 2019–20 were based on extrapolating point in time 2018–19 experimental BLADE location data estimates, however it is likely that some businesses may have moved over the decade. As there is only SA1 information in BLADE, it is not possible to assess how mobile businesses were over the study period. International evidence shows that around 30 per cent of businesses moved over a 5-year period but that they do not tend to move that far when they do relocate with a median relocation distance of less than 5 kilometres.[44]

BLADE also has postcode information for businesses and includes this data over time. Over the period, 26 per cent of businesses in the business register that were active in both 2009–10 and 2018–19 had changed postcodes. Nonetheless, this information is likely to be less reflective of a business location as it is a contact address derived from tax return information, and therefore may be the postcode for their accountant.

Working with businesses that have multiple locations

There were approximately 2.2 million actively trading businesses in Australia in June 2019.[vii] Of these, approximately 450,000 businesses (or 21 per cent) had multiple locations in 2018–19. These were more likely to be larger businesses. For example, 30 per cent of businesses with turnover of at least $2 million had multiple premises compared with 16 per cent for businesses with turnover under $50,000. Businesses with multiple premises tended to be bigger and on average had much higher turnover and full-time equivalent staff (Table 19).

Table 19. Characteristics of businesses with single and multiple premises, 2018–19

Business with…	Average turnover ($)	Median turnover ($)	Average full-time equivalent	Median full-time equivalent
Single premises	1,930,400	131,800	7	2
Multiple premises	7,427,400	200,800	33	3

Source: BCARR analysis of BLADE data. Turnover data is in nominal terms and does not include any imputed information from XGBoost.[viii]

Particular industries also had higher rates of multiple premises businesses than others such as accommodation and food services with almost one in every 3 businesses having multiple premises (32 per cent) as at 2018–19. Retail trade and health care and social assistance services also had higher rates of multiple premises businesses (28 per cent) compared to the average (21 per cent). The financial and insurance services industry had the lowest rate of multiple premises (16 per cent) followed by construction (17 per cent).

[vii] This figure is from BLADE and is slightly lower than the published count of 2.3 million from ABS business counts due to variances in scope.

[viii] The corresponding information including imputed data from XGBoost is $2.9 million and $131,700 average and median turnover for single premises compared to $7.5 million and $215,700 for multiple premises businesses. Average and median FTE equivalent was 2 and 0.2 respectively for single premises business compared to 11 and 0.3 for multiple premises businesses in 2018–19.

While there is no practical way to consider the impacts of broadband on productivity growth for these businesses, it is important to note that a significant share of economic activity in Australia is from multiple premises businesses and so these estimates of productivity growth impacts of broadband should be treated with caution. Table 20 shows that these businesses account for 40 per cent of revenue and over half of employment in the economy based on BLADE.

Table 20. Turnover and employment by single and multiple premises businesses

Businesses with…	Share of turnover (%)	Share of employment (%)	Share of full-time equivalent employment (%)
Single premises	59.8	42.7	41.4
Multiple premises	40.2	57.3	58.6

Source: BCARR analysis of BLADE data. Turnover data is in real terms and turnover and full-time equivalent employment include imputed information from XGBoost.

Appendix F: Limitations to the analysis

The main advantage of firm-level analysis is that it can be used to examine changes in business productivity growth and broadband rollout in Australia over the past decade. This approach allows for a direct estimate of the potential productivity growth impacts that have may have arisen from access to better broadband from the rollout of the NBN. However, the main disadvantage of this analytical approach is the extensive data requirements. It is also important to note that the analysis does not distinguish between NBN residential grade services and business-specific services (not all fibre-based connections are provided over the NBN).

Firm-level productivity growth estimates are experimental

Computing firm-level productivity growth using BLADE is challenging for a variety of reasons.[45] Firstly, BLADE contains no price and quantity measures, which are preferable for calculating productivity growth using index numbers particularly when firms may produce many outputs and use multiple inputs.[46] In the absence of this, firm turnover and cost information (adjusted for inflation) is used, an approach which produces estimates broadly in line with productivity growth based on detailed price and quantity information.[47]

Secondly, measuring inputs and outputs can be difficult, due to lack of available data (such as capital stock measures). Even where these measures exist in BLADE, they may appear for only a small subsample of businesses.[48] To address these concerns, BCARR has used established methods for estimating capital stock levels, in line with the OECD.[49] BCARR has also taken advantage of the wide range of datasets available in BLADE, by imputing missing values for key productivity variables (as outlined in imputed missing values section).

Thirdly, it is not possible to calculate firm-level productivity growth for non-market sectors. Furthermore, estimates for some market-based industries are less reliable than others, particularly for service-based industries where outputs and quality differences are less easy to understand and quantify.[50] While this does limit the scope of the analysis, this problem is not unique to firm-level analysis, as calculating macroeconomic-level productivity growth for these sectors is similarly challenging.

Survey design impacts the reliability of the Business Characteristics Survey results

Productivity growth and broadband data from the BCS should be treated with caution, as the BCS sample is not representative of all businesses. The BCS is a subset of the ABR that is stratified by business and employment size, but oversamples large businesses and certain industries (see Appendix C: Scope of the analysis). In practice, this means median productivity growth estimates that are aggregated across industries and employment sizes may bias large businesses and certain industries. These issues are largely addressed by controlling for time and industry effects in the pooled OLS and fixed-effects models, or examining productivity growth by industry and employment size.

Survey questions on business use of technology can also be unreliable and suffer from measurement quality issues.[51] This is because firms may not have a detailed understanding of the technology used within their organisation. Within the context of this analysis, respondents may not be aware of the broadband connection technology for the business, which can impact the reliability of broadband connection data. Furthermore, survey questions tend to focus on gaining information than can be easily answered by a broad range of respondents rather than more specific information that may be irrelevant or too difficult to answer. For the BCS, the survey asks questions on whether firms have a website, sell services online or use cloud computing, but do not ask further questions about the volume of the firm’s usage of these features, which would be useful for understanding activities enabled by broadband.

Other technological factors can affect business productivity growth

Technological advancements provide further challenges to quantifying productivity improvements. Productivity measures often do not capture the intangible nature of output that has been produced by technology.[52] Furthermore, some digital outputs are increasingly available 'for free' to consumers. For example, mobile phone users have access to many applications that provide them with access to information and entertainment that they can download without payment. These products create value for users (or 'consumer surplus') but because they do not have a price they are not counted in output measures.[53] Caution must therefore be taken when interpreting firm-level productivity growth results, particularly for digitally-intensive industries such as information media and telecommunications, as productivity growth in recent years may be underestimated as a result of these factors that are difficult to measure.

Productivity growth can also be impacted by time lags of innovation that stem from the slow uptake and usage of new digital technologies.[54] Technology can take time to diffuse and become mainstream in the economy, and some new technologies require time for businesses to learn how to use them.[55] This means initial costs in capital inputs may not be captured at the same time as the gains from the inputs. Measured productivity growth impacts may therefore initially understate the importance of technology because capital inputs were counted in this earlier period, and later overstate the impact as fewer capital inputs are counted and more output is produced. This phenomenon is referred to as the productivity J-curve (referring to the shape of the productivity effect) which can adversely dip during the initial period of disruption and improve sharply over time when the benefits of the innovation become more tangible.[56] Results from this analysis may not capture the productivity J-curve for broadband adoption, particularly NBN technologies which have been rolled out in recent years.

Structural break in BLADE data

As noted in the scope for the analysis section, the BAS reporting change in 2017–18 meant that a large number of firms ceased reporting information necessary to compute capital and intermediate inputs for MFP. The structural break means that the sample size of the ABR 2017–18 onwards is heavily restricted (see Table 21). It is worth noting that the BCS results are impacted by the reporting change less than the ABR results, as the change mostly affects small businesses that do not appear in the BCS. Furthermore, the change only affects MFP growth estimates, as LP growth does not rely on the impacted capital and operational expenditure data.

Table 21. Number of businesses for which firm-level productivity can be calculated

Measure	2010–11 to 2016–17 average (millions)	2017–18 (millions)	2018–19 (millions)	2019–20 (millions)
MFP growth	1.1	0.4	0.2	0.1
LP growth	1.6	1.7	1.7	1.6

Source: BCARR analysis of BLADE

Appendix G: Economy-wide impacts of broadband (literature review)

Many econometric studies have used an economy-wide analysis to examine the impact of broadband adoption and a well-established methodology developed over the last 2 decades. This approach uses data from a large sample of countries which is necessary to provide robust results. For this reason, estimates of the impact of broadband are generally presented as an average figure across all of the countries studied – or if the sample size is large enough, provided for a particular region or group, such as the Asia-Pacific region or for high income countries.

This appendix reviews the rich literature available on the economy-wide impacts of broadband and aims to unpack the different types of approaches taken. The studies largely point to positive effects—in a 2015 survey of the literature Bertschek et al. concluded that broadband penetration[ix] has a positive impact on economic growth, employment and productivity.[57] The magnitude of this impact differs across studies, owing to differences in the approaches taken, time periods covered and regions studied. The relationship between broadband and economic growth and the main findings from the literature are discussed below.

In addition to the economy-wide impacts of broadband, this appendix briefly discusses studies on the firm-level impacts of broadband. Unlike the economy-wide literature, firm-level studies show mixed results with some finding a positive impact, others finding positive impacts in limited circumstances, or no impacts.

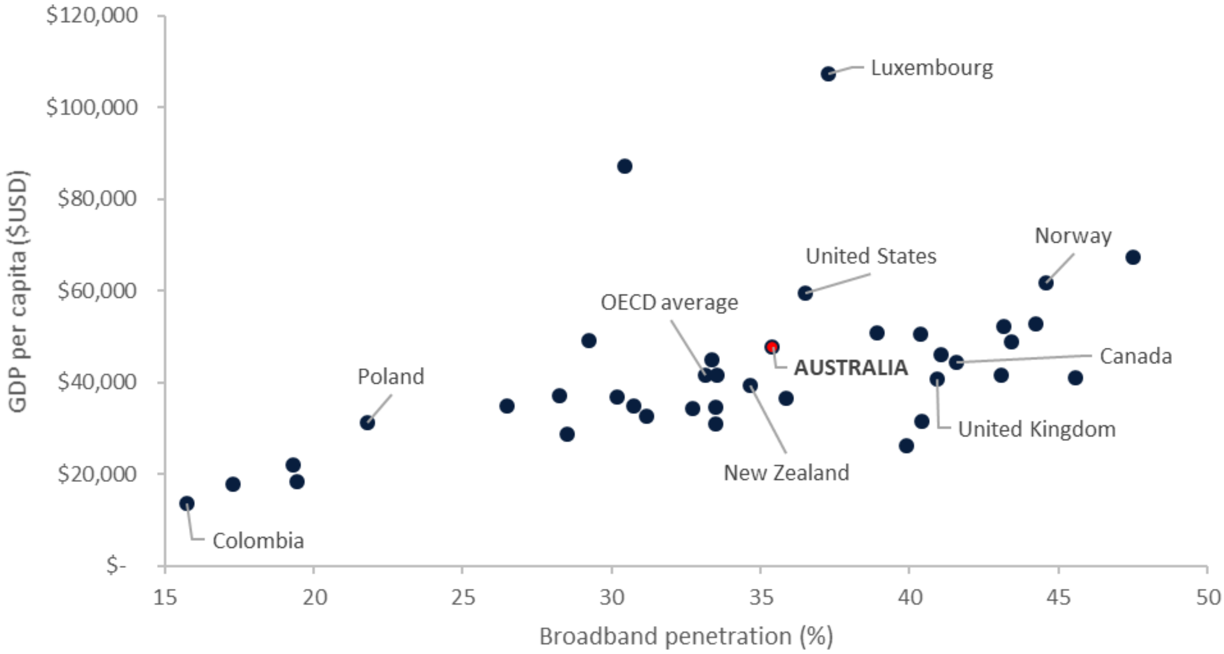
The economy-wide relationship between broadband and growth

Economy-wide studies estimate the effects of broadband on the economy through the use of a production function. This approach makes it possible to estimate how much change in an economy's output is determined by changes in inputs. An economy-wide production function shows the country's total output, or gross domestic product (GDP), achieved by its inputs – usually represented by the economy's use of capital (machinery and equipment) and labour resources (hours worked). As these studies aim to measure the impact of broadband penetration in the economy, a specific broadband penetration variable is included as an input in the production function. The relationship and value that broadband penetration has on economic growth can then be isolated using a variety of statistical techniques.

A preliminary look at the relationship between levels of broadband penetration and GDP per capita ($US) is shown in Figure 12. It shows that for OECD countries there is a positive relationship where higher income countries tend to have higher levels of broadband penetration. Australia ranks slightly above average in both broadband penetration and GDP per capita – in 2020 Australia had 35 broadband subscriptions per 100 people (the OECD average was 33 subscriptions); while GDP per capita was $USD 48,000 (the OECD average was $USD 42,000).

[ix] Broadband penetration (or adoption) generally refers to the number of fixed broadband subscriptions per 100 people. In this definition, one subscription can provide broadband to multiple people in a household.

Figure 12. Broadband penetration and GDP per capita in OECD countries, quarter 4 2020



Source: OECD Quarterly National Accounts: GDP per capita (extracted on 23 August 2021) and OECD Broadband Portal.

Despite the positive relationship, it is not clear from the information above whether broadband penetration raises GDP per capita, or if high income countries simply invest more in broadband infrastructure – an issue known as 'reverse causality'.[x] Many studies attempt to untangle these complex relationships using advanced statistical methods (Box 1). While these methods allow for more reliable estimates of the impact of broadband on growth, the statistical bias can never be fully addressed and results should be interpreted with caution.

Box 1: Statistical methods used to address reverse causality

- **Simultaneous equations** of demand and supply as used by Koutroumpis and the International Telecommunication Union.[58] The models are made up of a system of equations representing the economy's production function and three demand, supply and output functions – the last 3 equations solve for the component of broadband that is actually demanded and provided to consumers, controlling for reverse causality.
- **Instrumental variables** as used by Czernich et al. (2011) where estimation of a third variable (the instrument) is applied to mitigate the potential bias of the explanatory variable (broadband).[59] Using instruments of supply, broadband deployment is modelled by the authors based on the diffusion of existing broadband infrastructure. This approach rules out demand-side effects that arise from wealth, economic growth and government policy.

[x] Reverse causality refers to a form of potential statistical bias where the dependent (y) variable causes changes in the independent (x) variable.

Findings from the literature

Telecommunications infrastructure and growth

Most studies show that broadband penetration is causally related to economic growth by applying the statistical methods mentioned above. Röller and Waverman (2001) first applied this framework to telecommunications by analysing the relationship between telecommunications investment and economic growth.[60] The authors found a strong causal relationship but noticed that this occurs only when telecommunications services reach a certain threshold. The results of selected studies are shown in Table 22.

Adapting this framework to broadband

Koutroumpis (2009) adapted the Röller and Waverman framework to focus on broadband adoption.[61] Using data from 15 European Union (EU) countries, the author found a significant positive impact of broadband adoption, with a one per cent increase producing a 0.0026–0.038 per cent increase in GDP growth. The results are found by solving the demand and supply equations that determine broadband investment, controlling for reverse causality. In 2018, Koutroumpis updated this research to examine broadband penetration and GDP growth for 35 OECD countries from 2002 to 2016.[62] The author found a significant positive impact of broadband penetration on GDP, with a cumulative GDP increase of 4.34 per cent during this period. This increase in GDP is a result of the average penetration within the OECD sample growing from 3.8 connections per 100 people in 2002 to 31.3 connections per 100 people in 2016. This equates to an average GDP increase of 0.30 per cent per year.

The International Telecommunication Union (ITU 2018), in their series on the 'The impact of broadband on the economy' applied a similar framework and found that a one per cent increase in broadband penetration yielded a GDP increase of 0.08 per cent.[63] The research used a comprehensive dataset consisting of 139 countries from 2010 to 2017. The dataset was also split by region and income to focus on different outcomes. This approach provided estimates for groups of countries that are more comparable to Australia. For high-income countries (with a GDP per capita of over $USD 22,000) the effect of a one per cent increase in broadband penetration resulted in a 0.14 per cent increase in GDP growth. For Asia-Pacific countries the results were even more pronounced, with a one per cent increase in broadband penetration resulting in a 0.16 per cent increase in GDP growth.[64]

Other studies using similar demand and supply approaches have found similar results. The World Bank (2009) using a sample of 120 countries from 1980 to 2006 found that a 10 per cent increase in broadband penetration[xi] resulted in a 1.21 per cent increase in GDP per capita growth for developed countries, and a 1.38 per cent increase in GDP per capita growth for developing countries.[65] The authors caution that while it would appear that the scope for economic growth is greater in developing countries, these results were less statistically significant.[xii] They suggested this was due to how broadband was a recent phenomenon in developing countries at the time and broadband penetration levels had not yet reached critical mass to generate aggregate impacts.

A study by Gruber et al. (2013) of EU countries in 2013 focused on the economic value that broadband provides and found that use of these networks contributed 1.36 per cent to GDP annually.[66] In addition to the initial results, the authors also undertook a cost-benefit analysis of achieving the Digital Agenda for Europe (DAE) policy objective. The agenda targets 100 per cent broadband penetration and availability of at least 30 megabits per second (Mbps) speeds for all households by 2013, as well as the adoption of 100 Mbps speeds by at least 50 per cent of European households by 2020. The authors found that in their base case scenario, the overall benefits of achieving the policy would outweigh the costs associated with

[xi] Measured by subscribers per 100 people – equivalent to a 10-line increase.

[xii] Developing countries were statistically significant at the 10 per cent level while developed countries were statistically significant at the 5 per cent level.

the infrastructure build by 32 per cent for the European Union. Several other scenarios were tested under different economic conditions which also found positive returns.

Alternative approaches have also been undertaken. Czernich et al. (2011) applied an instrumental variable approach using data for 25 OECD countries from 1996 to 2007 to calculate GDP per capita growth from changes in broadband penetration.[67] The authors found that a 10 per cent increase in broadband penetration equates to a 0.9–1.5 per cent increase in annual GDP per capita growth. Data from this study was collected at a time when broadband had not yet been deployed in several countries. As a result, the authors were also interested in whether the introduction of broadband in the first instance had an effect on GDP at all. The authors found that GDP per capita was 2.7–3.9 per cent higher on average than before the introduction of broadband in a particular country.

Table 22. Selected studies showing GDP per capita impacts from a 10 per cent increase in fixed-broadband penetration

Study	Impact on GDP per capita growth	Sample
Koutroumpis (2009)	0.26–0.38%	22 OECD countries (2002–2007)
World Bank (2009) - Developing countries	1.38%	120 countries (1980–2006)
World Bank (2009) - Developed countries	1.21%	as above
Czernich et al. (2011)	0.9–1.5%	25 OECD countries (1996–2007)
Koutroumpis (2018)	1.4% from an increase of 10 to 20 subscriptions	35 OECD countries (2002–2016)
	0.82% from an increase of 20 to 30 subscriptions	as above
ITU (2018) - All countries	0.77%	139 countries (2010–2017)
ITU (2019) - Asia-Pacific region	1.63%	18 countries (2010–2017)
ITU (2018) - High-income countries	1.40%	50 countries (2010–2017)

Source: BCARR analysis of various sources. Penetration is defined as subscribers per 100 people. Koutroumpis (2018) uses aggregate GDP growth rather than GDP per capita growth.

Box 2: Firm-level impacts of broadband

At a firm level, studies provide mixed findings in relation to the impact of broadband on productivity. Studies done by Canzian et al. (2019)[68] in Italy and Ipsos MORI (2018)[69] in the UK indicate that firms adopting high speed broadband experience an overall increase in productivity. This reaffirms the findings of older studies which suggest that productivity gains of up to 10 per cent may result from the adoption of broadband.[70] However, other studies do not find a link between broadband adoption and productivity,[71] or that the impacts are selective – boosting productivity only for firms that also invest in their management capability,[72] or benefiting firms using skilled labour but having no impact for firms using unskilled labour.[73]

Impacts depend on the level of broadband penetration

While these studies show a positive impact of broadband penetration on economic growth, the nature of the relationship varies depending on just how widespread broadband is within a region. Generally, there is a curve whereby very low levels of broadband penetration have a small impact on economic growth. This impact gets larger as broadband penetration expands, with improvements diminishing as broadband penetration nears saturation.[74]

By splitting the sample of countries by income or region, the econometric studies show that the impacts of broadband will be different in each country, as demonstrated by the ITU and World Bank studies. Czernich et al. (2011) also noted this by including dummy variables in their model for when a country has reached 10 per cent and 20 per cent broadband penetration. The results showed that a significant broadband effect emerges only when the 10 per cent threshold is passed but that no additional benefits emerge beyond 20 per cent. Koutroumpis (2018) also found diminished benefits from broadband penetration beyond a certain level. An increase in subscriptions per 100 people from 10 to 20 results in GDP growth of 1.40 per cent, whereas an increase from 20 to 30 subscriptions results in GDP growth of only 0.82 per cent.

The inclusion of speed

More recent studies have also examined the impact of faster broadband speeds on economic growth. Speed represents a broadband quality indicator in the country's production function. If 2 regions have comparable levels of broadband penetration but one region has a much faster average broadband speed, it is expected that this region will be able to better utilise some technologies which could increase economic output. While speed alone does not address all the quality aspects of broadband it is a key feature that enables activities that enhance economic outcomes such as information sharing, e-commerce, worker mobility, data analytics and cloud computing, as well as reduced firm costs. The inclusion of speed in these studies means that the economic benefits provided by such activities can still be captured even when broadband penetration approaches near complete diffusion. Economic studies which examine speed are shown in Table 23.

Few studies so far have focused on broadband speed as a driver of economic growth. Speed has been applied using different forms – from including a speed variable in the production function, to splitting the dataset using different speed tiers, to applying the adoption of different broadband technologies (such as fibre) as a proxy for improved broadband speed and quality over copper-based technologies.

One of the first attempts to measure the impact on broadband speed on economic growth was by Rohman and Bohlin (2012) using OECD data from 33 countries over the period 2008 to 2010 and a proprietary speed testing dataset. Their findings suggest that doubling the broadband speed would contribute an additional 0.3 per cent to annual GDP growth (the average speed in the sample was 8.3 Mbps).[75] Kongaut and Bohlin (2014) performed a similar study but also compare the relationship between high- and low-income countries. The authors found that a one per cent increase in speeds resulted in an additional 0.09 per cent GDP per capita for low income countries and a 0.06 per cent increase for high income countries.[76] In contrast, Gruber et al. (2013), in an update of their initial model, split their sample by speed rather than by income and grouped countries using dummy variables as either having high or low broadband speed.[xiii] The authors found that the high speed broadband sample had an annual GDP increase of 0.032 per cent over the low speed sample.[77]

Koutroumpis (2018) found that faster broadband speeds led to a 1.32 per cent additional GDP increase over the period studied (2002 to 2016) or 0.09 per cent annually when speed was included in the production function.[78] The author observed that across the regions, average broadband speeds grew from 0.75 Mbps in 2002 to 12.85 Mbps in 2016. Accordingly, when interpreting the results alongside broadband adoption the effects become a 5.66 per cent increase in GDP. Much like broadband adoption, the evidence suggests that there is a point at which there are diminishing marginal returns to speed. Koutroumpis estimated this level to be 9.8 Mbps after which the additional economic benefits are negligible. However, both the overall economic benefits and saturation point will differ from country to country and speed-related gains are moving higher as a result of the readiness of the economy to make productive use of broadband. Katz and Callorda (2019) used an extensive dataset of 159 countries and

[xiii] The lower speed threshold was considered to be less than 2Mbps and the higher threshold was greater than 2Mbps.

found that the impact on GDP of fixed broadband speeds only became positive when the average speed was between 10 and 40 Mbps. This effect became even greater for speeds in excess of 40 Mbps.[79]

Broadband impacts by technology type

Briglauer and Gugler (2018) examined the impacts of broadband by the type of technology used. The authors analysed 27 EU countries between 2003 and 2015 and found that a one per cent increase in end-to-end fibre broadband adoption led to a GDP increase that was 0.002 to 0.005 per cent higher than basic broadband.[xiv,80] The authors used an instrumental variable approach to account for statistical bias using specific variables related to regulation and competition as factors that influence broadband adoption. The results also showed that the benefits of adopting hybrid-fibre broadband over basic broadband were slightly lower, with a 0.002 to 0.003 per cent increase in GDP.[xv]

Applying a similar framework to an intra-country study, Briglauer et al (2021) focused on high-speed broadband adoption in German counties over the period 2010 to 2015, finding an increase in average speeds by one Mbps resulted in a GDP increase of 0.18 per cent in that region.[81] Frontier Economics applied these results to Australia, finding a 10 per cent increase in average speeds could lead to a 0.23 per cent GDP increase by 2024.[82] They found consistent speeds nationwide with the GDP impact equating to $4.5 billion in 2024, with $1.2 billion in gains coming from rural areas.[xvi]

Table 23. Selected studies showing GDP per capita impacts from changes in broadband speeds

Study	Speed changes	Impact on GDP per capita growth	Sample
Rohman and Bohlin (2012)	Doubling the sample average speed from 8.3 Mbps to 16.6 Mbps	0.3 per cent increase in GDP	33 OECD countries (2008–2010)
Gruber et al (2013)	For countries with broadband speeds greater than 2 Mbps	Experienced additional annual GDP effects of 0.032 per cent due to speed	27 EU countries (2005–2011)
Kongaut and Bohlin (2014)	Results from a 10 per cent increase in broadband speed	All countries: 0.80 per cent increase in GDP per capita	33 OECD countries (2008–2012)
Kongaut and Bohlin (2014)	Results from a 10 per cent increase in broadband speed	Low-income countries: 0.97 per cent increase in GDP per capita	33 OECD countries (2008–2012)
Kongaut and Bohlin (2014)	Results from a 10 per cent increase in broadband speed	High-income countries: 0.59 per cent increase in GDP per capita	33 OECD countries (2008–2012)
Briglauer and Gugler (2018)	one per cent increase in fibre adoption	0.002–0.005 per cent increase in GDP per annum	27 EU countries (2003–2015)
Briglauer and Gugler (2018)	one per cent increase hybrid-fibre adoption	0.002–0.003 per cent increase in GDP per annum	27 EU countries (2003–2015)

[xiv] Basic broadband refers to digital subscriber line and coaxial cable modem technologies.
[xv] Hybrid-fibre broadband refers to where there is a mix of basic and end-to-end fibre technology.
[xvi] Rural areas were defined as populations of less than 100,000 people.

Study	Speed changes	Impact on GDP per capita growth	Sample
Koutroumpis (2018)	Increase in average speeds from 0.75 Mbps to 12.85 Mbps across the sample period	0.09 per cent increase in GDP annually. Combined with adoption, the impact was 0.39 per cent annually	35 OECD countries (2002–2016)
Katz and Callorda (2019)	one per cent increase in download speeds	No impact on GDP for countries with download speeds less than 10 Mbps	159 countries (2008–2019)
Katz and Callorda (2019)	one per cent increase in download speeds	0.00264 per cent increase in GDP for countries with download speeds between 10 Mbps and 40 Mbps	159 countries (2008–2019)
Katz and Callorda (2019)	one per cent increase in download speeds	0.0073 per cent increase in GDP for countries with download speeds greater than 40 Mbps	159 countries (2008–2019)
Frontier Economics (2021)	10 per cent increase in average speeds	0.23 per cent increase in GDP	Australian forecast (2024)

Source: BCARR analysis of various sources.

These economy-wide studies indicate that both broadband penetration and speed have a positive impact on growth. The magnitude of this impact varies depending on the countries studied and the initial level of broadband adoption and speeds available in the country. While broadband penetration and speed are key indicators of broadband use and quality, it will become more important in coming years to expand this approach to include other indicators of broadband quality. These indicators include connection reliability (the consistent high quality of the broadband service) and latency (the lag between transmission and receipt of data) which can affect the utility of certain applications that are of growing importance in service-based economies, such as video-conferencing, cloud computing and financial transactions.

While there is now an extensive number of studies and a well-established methodology, economy-wide studies can be a blunt tool for examining the economic impacts of broadband as it relies on data collected from a large sample of countries. The country-level data therefore limits the studies to allow only an aggregate assessment to be made on the economic impacts from broadband penetration and speed. The approach also requires a wide time window for analysis which limits the ability to capture more recent advances in broadband or the impact of specific policy interventions.

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