Picking up speed: Does ultrafast broadband increase firm productivity?

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Abstract

We estimate whether there are productivity gains from ultrafast broadband (UFB) adoption and whether any gains are higher when firms undertake complementary organisational investments. Using an IV strategy based on proximity to schools (that were targeted in the UFB roll-out), we find that the average effect of UFB adoption on employment and (labour and multifactor) productivity is insignificantly different from zero, even for firms in industries where we might expect the returns to UFB to be relatively high. Conversely, we find that firms making concurrent investments in organisational capital specifically for the purpose of getting more from their ICTs appear to experience higher productivity growth, at least in first-difference specifications. Firms making these joint (UFB-organisational) investment decisions are significantly more likely to report other positive outcomes from their ICT investments, consistent with the identified relationship with productivity being causal.

JEL codes

D22, L23, O33

Keywords

Ultrafast broadband adoption, fibre-to-the-door, productivity, organisational change, complementary investments

Summary haiku

UFB alone
is not the path to success.
Organise, you must.

1 Motivation

Since the turn of the millennium, analysts and policy agencies have stressed the importance of the internet as a factor that can improve the performance of individual firms (Choi and Whinston 2000; OECD 2003). Furthermore, as internet speeds have increased through technological advances, arguments have been made for the importance of investment in fast broadband infrastructure to enable beneficial economic spillovers (Enck and Reynolds 2009). A result has been the emergence of government initiatives to promote investment in ultrafast broadband (UFB) infrastructure to complement or enhance private sector roll out initiatives (Howell and Grimes 2010).[1]

One example of such support is the New Zealand Government's Ultra-fast Broadband Initiative. This initiative is designed to roll out fibre optic cable across the country to make UFB available to 80 percent of the population by 2022.[2] The roll out was specifically prioritised so that all schools and hospitals would be connected by the end of 2015 (MBIE 2016). In a statement to the Commerce Commission (competition regulator) in 2011, the Government outlined key aspects of its policy programme and expected benefits as follows (New Zealand Government 2011):

> *The Government believes that faster and better broadband services are critical to improving productivity in the economy, New Zealand's global competitiveness and the lives of New Zealanders. To this end it has put in place the Ultra-fast Broadband Initiative to assist and encourage the private sector to invest in early deployment of fibre... The Government has the following objective for ultra-fast broadband: "To accelerate the roll-out of ultra-fast broadband to 75 percent of New Zealanders over 10 years, concentrating in the first six years on priority broadband users such as businesses, schools and health services"... Through the Rural Broadband Initiative (RBI), the Government has also subsidised ultra-fast broadband infrastructure in the rural sector... The RBI will provide fibre connections to schools and hospitals, as well as businesses and households that are located on new fibre routes.*

Figure 1 shows the usage of UFB by New Zealand firms over the period

[1] We use UFB, fibre and fibre-to-the-door synonymously. Our analysis makes use of survey responses where the broadband connection type is described as "fibre-to-the-premise."

[2] In the New Zealand context, UFB can typically provide download speeds of up to 100Mbps (megabits per second), and in some areas up to 1000Mbps, with upload speeds of at least 50 Mbps (New Zealand Government 2011; MBIE 2016).

2010 to 2014, which has been enabled by this government-funded investment in fibre infrastructure.[3] Over this four year period, UFB usage has more than doubled from 9 percent to 22 percent of all private sector firms with 6 or more employees. The majority of large (100+ employment) firms had fibre-to-the-door by 2012, rising to 62 percent by 2014. In contrast, standard broadband adoption has largely reached saturation point, with non-use of a broadband connection mainly associated with firms that don't use the internet or computers at all.

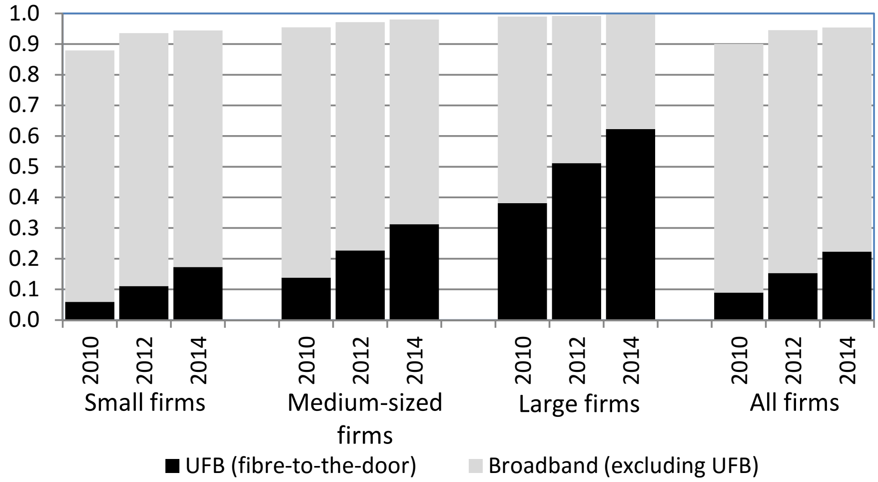
Of those firms that didn't have UFB in 2014, 36 percent intended to adopt in the future implying strong future growth in UFB penetration. For those firms that did not intend to adopt in the future, 37 percent cited unavailability in the local area as a reason for non-adoption, compared with 24 percent who believed that their needs were met by other (standard broadband) technologies. The fact that some firms have been constrained by the availability of the necessary infrastructure demonstrates the importance of the UFB roll-out to adoption, and provides us with the necessary data to identify whether there are causal effects of adoption in our empirical analysis. This question is important in light of previous literature which indicates that *ex post* returns to certain ICT investments have often not matched *ex ante* expected returns (Howell and Grimes 2010).

This paper contributes to two Information and Communication Technology (ICT)-related literatures. Firstly, we add to the nascent literature assessing the direct impact of broadband adoption on firm productivity (Grimes et al. 2012; Bertschek et al. 2013; Colombo et al. 2013; De Stefano et al. 2014; Akerman et al. 2015; Haller and Lyons 2015). To the best of our knowledge, our paper is the first to examine the effect of adoption of UFB (fibre-to-the-door), with the prior work focussing on standard broadband (largely DSL/ADSL) adoption. With the exception of Grimes et al. (2012) for New Zealand and Akerman et al. (2015) for Norway, prior studies have largely concluded that, while firms with standard broadband connections tend to have relatively high productivity, broadband adoption has no identifiable causal impact on firm productivity.

Grimes et al. (2012) used propensity score matching to control for selection effects in their cross-sectional study, showing that such controls reduced the implied contribution of broadband adoption to firm productivity relative to a raw estimate of productivity differences. Their work indicated that while there were some estimated firm level benefits to broadband adop-

[3] The data section of the paper describes the survey source of these statistics. Unfortunately fibre usage is not identified in earlier years.

Figure 1: Firm broadband and UFB penetration rates



Population-weighted statistics derived from Statistics New Zealand (NZ.Stat) tables. Firm size categorisation follows the Business Operations Survey (BOS) stratification: small firms (6-19 employment strata); medium-sized firms (20-49 and 50-99 employment strata pooled); large firms (100+ employment strata). Denominator includes firms not using the internet, but excludes firms with "don't know" responses to either of the connection type questions, which is similar to Statistics NZ's method for imputing non-response. Non-response/"don't know" response rates are discussed in the main text.

tion, the size of the benefits were such as to leave the firm broadly in the same part of the productivity spectrum within its own sector. They detected no significant differences in productivity impacts of broadband adoption for firms in urban versus rural locations or for firms in high versus low knowledge intensive industries. In addition they found no difference in effect according to the type of broadband connection (e.g. ADSL versus cable).[4]

Akerman et al. (2015) also use cross-sectional broadband and productivity data, coupled with an instrumental variables (IV) approach, to show that broadband raises productivity in Norwegian firms, and that productivity gains are achieved through an increase in the relative productivity of skilled labour (measured using formal qualifications), which has a subsequent impact on the wage distribution.

The second literature we add to focuses on complementarities between investment in ICT and organisational capital (Bresnahan et al. 2002; Hempell 2005; Bartel et al. 2007; Crespi et al. 2007; Bloom et al. 2012; Tambe et al. 2012; Aral et al. 2012; Bloom et al. 2013). Draca et al. (2009) review this literature, as well as the broader literature estimating the relationship be-

[4]Fibre connection was not included as a separate broadband connection category within their dataset.

tween productivity and ICT use. The general consensus of this literature is that any productivity gains from ICT investments are higher in better managed firms and/or when firms also change their strategies and management practices to exploit the potential gains that new technologies create. If ICTs are potentially transformative technologies, how they are adopted can make a major difference to aggregate productivity growth. For example, Bloom et al. (2012) attribute much of the post-1995 productivity gains experienced by the US relative to Europe to superior "people-management practices" allowing American firms to extract more benefit from their IT investments.

Our unique contribution in this context, is to estimate whether there are productivity gains from UFB adoption and whether any gains are higher when firms undertake complementary organisational investments.[5] Our data are ideally designed to answer this question, specifically asking respondents to identify the activities they have undertaken to get more benefit from their ICTs.

Using an IV strategy, we find that the average effect of UFB adoption on employment and (labour and multifactor) productivity is insignificantly different from zero. Even focussing on industries where we might expect these effects to be more likely to be positive – ie, industries where UFB uptake is high, more firms say connection speed is important, or with higher average computer capital intensity – we fail to find any impact on firm performance. Conversely, and consistent with the complementary investments literature, we find that firms making concurrent investments in organisational capital *specifically* for the purpose of getting more from their ICTs appear to experience higher (labour and multifactor) productivity growth. Unfortunately, we cannot empirically confirm that this is a causal relationship because the available instruments only weakly identify the joint (UFB-organisational) investment decision. However, supplemental summary statistics suggest that firms making concurrent organisational investments are significantly more likely to report other positive outcomes from their ICT investments, consistent with the identified relationship with productivity being causal.

Section 2 outlines the empirical method and the data used. Results are discussed in section 3 before we summarise the findings in section 4.

[5] Colombo et al. (2013) also address this issue in the context of broadband adoption, though much of their analysis is in the context of specific "broadband applications." Where they interact adoption of these applications with their binary measure of management variables they exclude main effects, making it hard to interpret their findings as necessarily implying complementarities.

2 Data and estimation approach

All data are drawn from Statistics New Zealand's Longitudinal Business Database (LBD), which brings together survey and administrative data on business practices and performance (Fabling and Sanderson 2016). We utilise two central components of the LBD: the Fabling-Maré labour and productivity datasets; and the Business Operations Survey (BOS) which contains data relating to firm-level ICT use.

2.1 Productivity data

The construction of the productivity and labour datasets is described in detail in Fabling and Maré (2015a) and Fabling and Maré (2015b) respectively. Labour data is derived from monthly mandatory pay-as-you-earn (PAYE) tax filings for employees combined with personal tax returns for working proprietors. We use the Fabling-Maré method to adjust employee labour input to an approximate full-time equivalent (FTE) measure and add this to the working proprietor count to derive total employment (l, where lower case production function variables denote natural logs). The productivity dataset provides firm-level production function components consisting of real gross output (y), intermediate consumption (m), and capital services (k), derived from a mix of survey and tax-filed administrative data.[6]

Unfortunately the underlying data does not contain a separate estimate of computer capital or computer capital investment for most of the sample.[7] In addition, the tax form underlying most of the productivity data changed substantially in 2013, meaning that the productivity dataset currently covers the years 2001-2012.

From the productivity components we derive labour productivity (LP $= \ln([Y - M]/L)$) and multifactor productivity which, together with total employment, are the three outcomes of interest in the analysis. Total employment growth is included as an outcome because UFB adoption could raise aggregate productivity growth, even in the absence of firm-level productivity improvements, if adoption led to more productive firms expanding

[6] The survey data used corresponds to the main input into National Accounts aggregates. Fabling & Maré exploit the robust conceptual underpinnings of the survey data to improve the alignment of the administrative data to these standards via a series of industry- and firm-level adjustments (Fabling and Maré 2015a).

[7] Data on computer capital was collected as part of the BOS until 2008 and we make use of that data to define high computer capital intensity industries.

their labour share. Examining employment outcomes provides an indication of whether reallocation effects are likely to be important.

2.2 Ultrafast broadband data

The BOS is an annual survey of approximately 7,500 private sector firms with six or more employees, which, in even years, asks questions about firms' use of ICTs. The survey has an 80 percent response rate yielding around 6,000 responses a year from a population of around 35,000-36,000 firms.[8] The survey is sampled in a way that generates a substantial panel element allowing firms to be tracked over time. For example, Fabling and Sanderson (2016) report an average 69% chance that a BOS ICT respondent also responds to the subsequent (two years later) BOS ICT module.

The specific survey questions that we use from the BOS are shown in the appendix. These cover outcomes of ICT use (question 7), complementary investments (question 8), connection type (questions 9, 11 & 12), and factors affecting the decision between connection types (question 13). The last of these variables is used to aid our understanding of why firms choose UFB over competing technologies.[9]

Unfortunately the fibre connection type category on which the analysis relies was only introduced in the 2010 survey form. As Grimes et al. (2012) note, there was undoubtedly some UFB use prior to this date and respondents potentially selected cable access as the best alternative in the BOS. Since our unique contribution is to look at *ultrafast* broadband uptake, the analysis is restricted to 2010 and 2012 – the two years where both firm-level UFB connection and productivity data exist.

Despite being able to answer most questions in the BOS, some respondents have trouble identifying their connection type. Table 1 demonstrates the scale of this issue by reporting the sample loss as we add data quality requirements. We start with 11,775 BOS observations pooling 2010 and 2012 data, from which there are 4,059 firms that appear in both years. Firstly, we drop the 4.1% of observations that are associated with firms that aren't computer or internet users. We do this so that all firms in the sample have

[8] The survey is stratified by industry and firm size, so that large firms are closer to full coverage than small firms. Statistics NZ achieves at least an 80% response rate in each industry-size stratum.

[9] The BOS questions discussed in the motivation section regarding future UFB uptake were not introduced until 2012.

some basic pre-existing usage of the internet, so that we avoid confounding any effect of UFB adoption with that of computer adoption.

The next three steps correspond to eliminating inadequate responses relating to connection type, either non-response or a "don't know" response, resulting in a combined loss of 13.5% of the original sample. This is predominantly due to respondents who believe that they have a broadband connection but who are not able to identify what type of connection it is (8.2% of observations), but also due to some respondents having trouble identifying whether they are on a dial-up or broadband connection (3.9%). The resulting sample of firms – labelled sample (a) – is used to motivate the instruments (discussed in section 2.4), since we can tell for these firms whether they have UFB and what factors they considered important in choosing their connection type.[10]

The next cleaning step excludes firms that are ever only using dial-up. As in the initial step of dropping non-computer/internet users, removing these observations ensures that firms which change connection type are only moving between standard and ultrafast broadband.

The final two steps relate to the coverage of the productivity dataset, which is not complete. The first of these two steps restricts the analysis to the measured sector, identified by Statistics New Zealand (2014) as "...industries [that] mainly contain enterprises that are market producers," which is also an industry restriction applied to the productivity dataset.[11] The final step links the broadband data to the productivity data, resulting in a loss of 18.1% of the initial sample corresponding to having productivity dataset components for 75% (0.545/0.726) of the potential in-scope industry BOS observations with suitably high quality survey responses. Overall, we lose half of the initial number of balanced panel responses, yielding a final dataset of 2,031 firms that have broadband and productivity data in both 2010 and 2012.

[10]The outcomes of ICT use and complementary investments question have low non-response rates – 0.7% and 1.1% respectively. When we use these data, we assume that non-response implies that the outcome (activity) was not achieved (undertaken) by the firm, allowing us to maintain consistent samples throughout the analysis.

[11]The resulting sample (sample b) is used to confirm the robustness of employment-related results to the inclusion of observations that do not have productivity data, since the Fabling-Maré labour dataset is full coverage.

2.3 Methodology

To investigate the relationship between UFB and productivity, we estimate the following equations for firm i in industry j and location(s) k:

$$X_{it} = \beta\text{Fibre-to-the-door}_{it} + \sum_j \lambda_{jt}\delta_j(I_i) + \sum_k \theta_{kt}\frac{L_{kt}}{L_t} + \xi_{it}, \quad (1)$$

$$\Delta X_{it} = \beta\text{Fibre-to-the-door}_{it-2} + \sum_j \lambda_j\delta_j(I_i) + \sum_k \theta_k\frac{L_{kt-2}}{L_{t-2}} + \xi_{it}, \quad (2)$$

$$\Delta X_{it} = \beta\Delta\text{Fibre-to-the-door}_{it} + \sum_j \lambda_j\delta_j(I_i) + \sum_k \theta_k\Delta\left[\frac{L_{kt}}{L_t}\right] + \xi_{it}. \quad (3)$$

X_{it} is one of the three performance metrics (total employment, labour productivity or MFP), β is the coefficient of interest, and ξ_{it} is the residual. The first summation reflects industry controls, where $\delta_j(I_i)$ is an indicator variable set to one for firms in industry j, and zero otherwise. The second summation reflects location controls, defined as the share of firm employment in each Territorial Authority (TA, indexed by k).[12]

Equation 1 is a levels regression and, in this case, β indicates whether UFB usage is *correlated* with firm performance, controlling for industry and location. Such a correlation might arise simply from a selection effect, because better performing or larger firms may be more likely to adopt fibre. Equations 2 and 3 focus on the relationship between UFB and changes in outcomes, which begins to address the selection issues associated with identifying causal estimates of β. These two equations differ in their assumptions about the timing of potential productivity gains from adoption. Equation 2 is a difference-level regression, which allows for the possibility that prior (2010 or earlier) adoption may have a permanent or delayed effect on subsequent productivity growth, whereas 3 is in first-differences and assumes that any effect on productivity growth is contemporaneous to adoption. Equation 3 has the added econometric benefit of eliminating any permanent unobserved differences between firms.

In all three equations, X is assumed to be known. For MFP, this means that estimation of the impact of UFB adoption on MFP is done in a two-step procedure, rather than a single regression where adoption is included directly in the estimated production function. MFP is first derived from an industry-specific gross output Cobb-Douglas production function estimated

[12] Territorial Authorities are city or district councils. Excluding the Chatham Islands, there are 66 TAs.

separately for each industry:[13]

$$y_{it} = \alpha_t + \beta_1 m_{it} + \beta_2 l_{it} + \beta_3 k_{it} + \epsilon_{it}. \tag{4}$$

Estimation of this first-stage production function is done in a way that is consistent with the second-stage. In levels regressions (equation 1), MFP is defined as the estimated residual (ϵ_{it}) as shown in equation 4. For difference-level and first-differences (equations 2 and 3), we modify equation 4 by assuming the residual takes the form $\epsilon_{it} = \mu_i + \upsilon_{it}$ where μ_i is a firm fixed effect. The advantage of a two-step estimation procedure is to maximise sample size, enabling separate production function estimation at a reasonably detailed industry level, and to substantially improve the identification of the firm fixed effects (μ_i) by including up to twelve annual observations per firm.

While equations 2 and 3 address some of the selection issues associated with identifying β, they don't adequately address reverse causality from productivity to investment nor anticipation effects where firms, eg, have future expansion plans and invest with that future growth in mind. To address these issues, we use instrumental variables to identify causal estimates of β derived from equations 2 and 3.

2.4 Instruments

With the exception of Grimes et al. (2012) and Colombo et al. (2013), studies of broadband and firm performance rely primarily on instruments derived from broadband infrastructure availability to identify causal effects on productivity. The use of broadband availability as an instrument is an inherently appealing approach, particularly when the roll-out of infrastructure is not driven by a profit motive (De Stefano et al. 2014). In this case, broadband infrastructure availability satisfies the joint instrument requirements of predicting adoption and not determining firm performance, except via any adoption effect. Even in cases where instruments of this type are not central, similarly motivated variables are included.[14]

[13] There are 39 productivity industries (generally aligned to subdivisions of the Australian & New Zealand Standard Industrial Classification 2006), which are determined by sample size and the availability of industry-specific input and output price deflators (Fabling and Maré 2015a).

[14] Grimes et al. (2012) include a qualitative firm-level assessment of local ICT infrastructure adequacy in their instrument set, while Colombo et al. (2013) follow a standard GMM approach of using lagged inputs as instruments, but also supplement these with a general measure of provincial telecommunications infrastructure investment.

We also rely on UFB availability to construct instruments, exploiting the fact that, in New Zealand, the roll-out was primarily funded by central government with a key goal being to provide UFB access to all primary and secondary school students. The school roll-out was staggered over time, creating differential access to firms depending on geographic proximity to a school, since the creation of UFB infrastructure to the school provided a basis for expanding access to nearby households and businesses. Instruments based on school proximity are conceptually superior to instruments that exploit the timing of commercial or "business-oriented" public investment, since these latter investment strategies may be prioritised towards regions with, eg, high growth prospects, which would undermine the validity of the instrument. Furthermore, school proximity is unlikely to directly affect firm performance and firms are unlikely to have sorted into locations on the basis of school proximity.[15]

Figure 2 uses BOS data to identify firms that were constrained away from their ideal connection type prior to the fibre roll-out. The figure shows that a large proportion of firms in 2010 and 2012 operated in locations (Area Units or AUs) where UFB was not apparently available for other firms "needing fibre."[16] "Needing fibre" is defined as having fibre or responding that speed is a consideration in choosing between internet connection types (see appendix question 13). The figure shows that in 2010 approximately 28% of firms were located in areas in which less than 10% of other firms who "needed fibre" actually had fibre.[17] Ninety percent of firms within that category are in areas where none of the other firms "needing fibre" had fibre. Over time, the relaxation of this geographic constraint – ie, the rightward shift in the distribution – due to the roll-out of UFB infrastructure provides the exogenous variation necessary for good instruments.

To construct instruments, we separately identify the (log) distance between each BOS firm and the nearest primary or secondary school.[18] Regression estimates of the correlates of UFB adoption presented in section 3.1 confirm the expected negative relationship between adoption and nearest

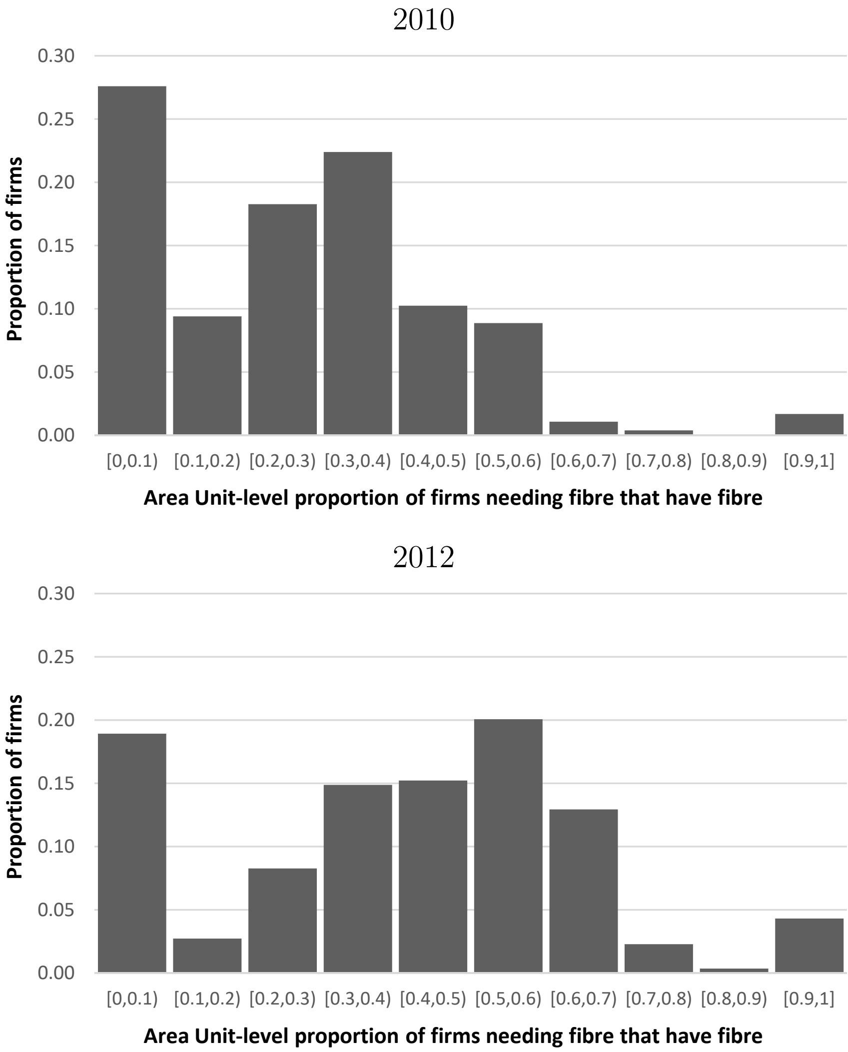
[15] We include firm TA employment shares as regression controls to account for any systematic differences in regional economic performance.

[16] There are 2,020 Area Units classified by Statistics NZ. They are non-administrative geographic areas that, within urban areas, can be characterised as "suburbs," normally contain a population of three to five thousand people.

[17] All counts of firms are random-rounded (base 3), in compliance with Statistics NZ confidentiality rules.

[18] Distance is meshblock centroid to meshblock centroid, where a meshblock corresponds approximately to a city block in urban areas. For firms located in a meshblock with a school, we set the log distance to zero.

Figure 2: Distribution of firms by Area Unit-level proportion of other firms "needing fibre" that have fibre



Firms "needing fibre" have fibre and/or responded that speed is a consideration in choosing between internet connection types. The AU-level measure excludes multi-AU firms and, therefore, the distribution excludes firms exclusively located in Area Units that don't have any single-AU other firms "needing fibre" (13% of firms in 2010, and 16% of firms in 2012).

school distance. For robustness, we also construct a third measure based on nearest distance to any (primary or secondary) school. We additionally interact these distance variables with whether the firm reported being speed-dependent, that is whether speed was a consideration in choosing between connection types. This interaction captures the likelihood that firms with speed requirements are more constrained in the absence of UFB. Overall, we have six potential instruments for the main IV estimates:[19]

$$\begin{aligned}
IV_P &= \ln(\text{distance to nearest primary school}) \\
IV_S &= \ln(\text{distance to nearest secondary school}) \\
IV_A &= \ln(\text{distance to nearest school}) \\
IV_{P\times} &= \delta(\text{speed-dependent}) \times \ln(\text{distance to nearest primary school}) \\
IV_{S\times} &= \delta(\text{speed-dependent}) \times \ln(\text{distance to nearest secondary school}) \\
IV_{A\times} &= \delta(\text{speed-dependent}) \times \ln(\text{distance to nearest school}).
\end{aligned}$$

In first-difference regressions (equation 3), speed-dependence is based on 2012 responses, since lagged values of the considerations variables do not appear to predict future adoption (see section 3.1). In difference-level regressions (equation 2), speed-dependence is based on 2010 responses, consistent with this being the year the fibre variable is measured in. Distance to school is always 2010 values, though in practice this choice is largely irrelevant given that most firms and schools have the same locations in both 2010 and 2012.[20] We are agnostic as to which of these instruments may perform best and search across all permutations of the six instruments using the weak identification F-statistic as the criteria for choosing the strongest instrument set.

We do not include δ(speed-dependent) directly as an instrument because we are concerned that being speed-dependent may affect productivity through channels other than fibre adoption, which would violate the requirements for a valid instrument. Main IV estimates have fewer endogenous variables than instruments, enabling an overidentification test of whether the interacted instruments ($IV_{P\times}, IV_{S\times}, IV_{A\times}$) are valid, conditional on the assumption that the other instruments are valid.

We turn now to the question of which firms adopt UFB, particularly whether this is correlated with initial firm performance (selection effects) and with the variables underlying the instruments (instrument validity).

[19] The delta notation represents an indicator function set to one if the clause holds and zero otherwise.

[20] Choosing 2010 values minimises the risk that distance changes over time as a consequence of the UFB roll-out (ie, because firms move closer to schools in order to access the infrastructure).

3 Results

3.1 UFB adoption

Table 2 shows transition rates into and out of the six broadband connection types between 2010 and 2012. Transition rates for the sample reinforce the aggregate picture presented in figure 1, with 15.1% of firms adopting fibre over the period, and a net gain in fibre usage of 9.7% of firms.[21]

Fibre is the third most commonly adopted technology, after DSL/ADSL and cellular connections, when we only consider firms that did not already have a technology (column 4). However, in contrast to fibre, DSL/ADSL is initially used by 78.1% of firms, but 14.3% of firms no longer have a DSL/ADSL connection by 2012. Cellular connections continue to grow in a net sense, presumably reflecting the fact that this technology provides mobile connectivity and, therefore, is not directly substitutable for fibre. Other technologies – cable, wireless and satellite – start from relatively low bases and all are in net decline by 2012.

As table 2 shows, the total proportion of firms retaining connection types exceeds one, which is due to many firms having multiple broadband connection types. Table 3 shows the incidence rate of multiple connection types by whether the firm uses fibre and by the geographic span of their operations. Firms that are limited to a single AU are less likely than firms in multiple AUs to have multiple connection types, consistent with infrastructural differences across locations, but also consistent with geographic dispersion being associated with separation of economic activities – for example, the separation of head office and manufacturing divisions.

A significant proportion of multi-connection type firms have a cellular connection, with cellular being the most prevalent other technology employed by firms with fibre. Excluding cellular connections, the proportion of firms with multiple connection types drops substantially, but is still high for firms with a fibre connection (second from bottom row of table 3). We ignore these

[21]Figure 1 implies an equivalent net adoption rate of 7.8% from 2010 to 2012 as a percentage of broadband-connected firms in 2010 (recall that, by construction firms in the sample have a broadband connection in each period). The difference between this adoption rate and that in our sample is due to the weighting applied to official statistics to make them representative of the population as a whole. Since larger firms are sampled at a higher rate than smaller firms, and larger firms have a higher net adoption rate, an unweighted estimate of fibre adoption will exceed the population-weighted estimate. We do not use official population weights as these are only appropriate for cross-sectional statistics.

other connection types in the analysis of the impact of UFB adoption. We believe this exclusive focus is reasonable given the substantially faster upload and download speeds fibre provides over the other technologies that firms may already use. Insofar as firms' other connection types are persistent, as is often the case with DSL/ADSL (table 2), first-difference regressions account for the use of these other technologies.

Table 3 also shows the proportion of firms that have fibre, by geographic span. Firms located in multiple Area Units are over twice as likely to have fibre than firms in a single AU. This could due to a number of factors, for example, multiple AU firms: are larger, which may require different technological requirements such as a need to service international clients (or size may reflect the benefits of new technology adoption); are more likely to have at least one plant in a densely populated urban area with better infrastructure availability; or may have higher demands for data transfer between business locations because of their geographic dispersion. We explore these possibilities by examining the correlates of fibre adoption in a multivariate setting.

Table 4 shows marginal effects probit estimates of the correlates of fibre adoption using lagged (2010) values of independent variables. Column 1 starts with lagged production function variables, and confirms the picture from the aggregate statistics that adoption is more likely amongst large firms. It is also more prevalent in more capital-intensive firms, even after controlling for (unreported) industry differences in capital intensity.[22] Across all specifications, there is no evidence that initially higher multifactor productivity firms are more likely to adopt UFB.

Controlling for firm size, the apparent relationship between geographic span and fibre adoption from table 3 remains. Firms operating from a single physical location in 2010 are 8.1 percentage points less likely to have adopted fibre between 2010 and 2012 than multi-location firms (column 2).[23] This relationship is partly due to the fact that smaller (single location) firms are less likely to be in places with good fibre access, as evidenced by the reduced magnitude of the coefficient on this variable when the school distance variables are introduced in column 5.

Fibre adopters are more likely to have had cable or wireless technologies in place in 2010 (columns 3-5). Column 4 adds self-reported considerations

[22] All regressions also include initial (2010) TA employment shares.

[23] This variable is based on physical plant locations, rather than AU span. A small proportion of single AU firms have multiple physical locations within that AU.

in choosing connection type. These variables are contemporaneous, rather than lagged, since the BOS question is specifically about determining factors of the *current* connections the firm has. In (unreported) robustness tests, we find that lagged considerations are not significant if substituted for contemporaneous ones, implying that firms technology requirements may change materially over a two year period, or that the importance of the underlying factors change over time, eg due to infrastructure development or relative price shifts across the various technologies.[24]

Availability in the business location has a negative relationship with fibre adoption implying that respondents select this option when the technology is *unavailable* in the business location. As expected, connection speed requirements have a positive relationship with adoption (column 4). Start-up costs also appear to inhibit adoption, which may reflect the direct start-up costs associated with getting a connection, but which may also reflect the additional cost of adopting business practices to maximise the return from adoption. In contrast, the cost of adapting current business technologies is presumably captured by the "compatibility with existing technology" category, with coefficients insignificantly different from zero.

Column 5 adds distance to the nearest primary and secondary school. The secondary school variable has the anticipated (negative) sign since we expect firms further from schools to be less likely to have good UFB infrastructure available in 2010. In unreported robustness tests, the primary school variable is significantly different from zero at the 5% level when only the two school variables are included along with industry and TA employment share controls (coefficient of -0.009 on primary school distance, and -0.028 on secondary school distance, significant at the 1% level).[25] Overall, the strength of the estimated relationships for the variables underlying the instruments – school distance and (connection) speed-dependence – supports their intended use. We now implement the IV strategy to examine the causal effect of UFB adoption on productivity.

3.2 Impact of UFB adoption on productivity

Tables 5-7 show OLS and IV results estimating the relationship between having a fibre connection and employment, labour productivity and MFP

[24]We have no price data on the alternatives other than the qualitative "ongoing connection and usage costs" indicator variable included in columns 4 and 5.

[25]If we substitute the two schools variables for the minimum distance to any school (IV_A), the coefficient is -0.006, significantly different from zero at the 10% level.

respectively. Each of the three tables follows the same format.

Column 1-3 present OLS estimates of the relationship between fibre usage and firm performance, following equations 1-3 respectively. Columns 4 and 5 present IV estimates of equations 2 and 3 respectively. The levels specification (column 1) includes industry-year dummies and TA employment shares. Other specifications include industry dummies, and either initial (2010) TA employment shares (columns 2 & 4) or changes in TA employment shares (columns 3 & 5). As indicated in equation 2, the fibre-to-the door variable in the difference-level specification (columns 2 & 4) is the initial (2010) value. For IV estimates, we report Kleibergen-Paap F-statistics for tests of underidentification and weak identification, together with the Hansen J statistic overidentification test.

Levels estimates (column 1, tables 5-7) are consistent with the selection effect that we observe in the adoption regressions, showing that larger firms and firms with higher labour productivity are more likely to have fibre-to-the-door, whereas firms with higher MFP are no more likely to have fibre-to-the-door.[26] First-differencing removes the selection effect by relating the change in connection type to changes in firm performance. OLS estimates in first differences (column 3, tables 5-7) show no significant relationship between fibre use and firm performance.

Potentially, first-difference coefficients could be zero because of lags between adoption and performance gains. In this case, the fact that effects are identified from firms that adopted within (at most) a two year period may be problematic. Column 2 accounts for this by regressing performance growth on initial (2010) fibre use, which is an appropriate specification if fibre use causes a change in the growth rate of firm performance with lags after adoption, either through a permanent increase in the growth rate or through a transition to a higher level. Difference-level estimates (column 2) again show no relationship between adoption and subsequent employment or productivity growth.

Columns 4 & 5 control for the endogeneity of fibre connection decisions by using instruments based on UFB infrastructure availability. Searching all permutations of the available instruments, the preferred instrument set is $\{IV_S, IV_{S\times}\}$ for difference-level specifications and $\{IV_A, IV_{P\times}\}$ for first-differences (instruments defined in section 2.4). Underidentification F-statistics,

[26] Adoption regressions include the capital-labour ratio rather than labour productivity because this makes interpretation easier when MFP is also included. Labour productivity and capital intensity are positively correlated.

Hansen J statistic, and the weak instrument F-statistic all support the instrument choices.[27] In particular, on the assumption that school distance is truly exogenous, school distance interacted with speed-dependence is also a valid instrument. Across all six IV results, we fail to find any effect of UFB adoption on firm performance.

It could be that effects are positive for subgroups of firms. We test this hypothesis by restricting estimation to firms in industries where fibre usage may have particularly high returns, namely industries with relatively high: average fibre use; consideration of speed in determining connection type; and computer capital intensity. Industries that fall into these categories are listed in table 8, together with their contribution to the size of the subsample. Businesses in wholesale trade are a major contributor to all three subsamples, while professional, scientific and technical services are the largest component of the high fibre use and consideration of speed subsamples, and administrative and support services is an important component of the high computer capital subsample.

Table 9 reports OLS results from both difference-level (odd columns) and first-difference specifications (even columns). As with the whole sample estimates, all fibre coefficients are insignificantly different from zero. Corresponding IV estimates are also insignificantly different from zero, though these suffer from weak identification issues and are not reported for that reason.

Overall, these results do not support the hypothesis that fibre adoption has an effect on productivity, at least when adopted in isolation. We now consider whether fibre adoption raises productivity when combined with other investments by the firm.

3.3 Complementary investments and UFB adoption

The BOS asks respondents to identify activities the firm has undertaken during the previous two years to extract more benefit from ICTs (see appendix, question 8). Table 10 shows the reported incidence rate of these activities distinguished by whether or not the firm adopted fibre over the same two year period. Across every activity, firms that adopted fibre were more likely to

[27] That is, we reject the null hypothesis of underidentification, while we do not reject the null hypothesis of identification in the overidentification test. For the weak identification F-stat, Staiger and Stock's (1997) rule of thumb is to reject weak instruments if F $\geq$ 10.

have made complementary investments than non-adopters of fibre (all means significantly different from each other at the 1% level).

Shifts in production towards more ICT-intensive products, and physical relocation of business activities are over twice as likely amongst fibre adopters than non-adopters (column 3). Even activities, such as specific employee training, which are performed by many employers have a 20 percentage point higher incidence rate in fibre adopters compared to non-adopters. Having said that, aside from employee training the majority of fibre adopters do not undertake each of the complementary investments, raising the possibility that this lack of co-investment with adoption explains the estimated zero average effect of UFB on productivity.

To explore this further, we estimate:

$$\Delta X_{it} = \alpha \text{Investment}_{it} + \beta \Delta \text{Fibre-to-the-door}_{it} + \gamma \text{Investment}_{it} \times \Delta \text{Fibre-to-the-door}_{it} + \sum_j \lambda_j \delta_j(I_i) + \sum_k \theta_k \Delta \left[\frac{L_{kt}}{L_t} \right] + \xi_{it} \quad (5)$$

where Investment_{it} is an indicator variable set to one if a particular complementary investment was made during the two year period over which the first differences of the other variables are calculated. The investment variable appears in (2012) levels because investment is already, by its nature, a change variable. We only estimate this model in first-differences – rather than also in difference-levels – because aligning the investment timeframe with the adoption timeframe seems most consistent with the interpretation of these potentially being complementary investments.

We estimate equation 5 for each of the three performance metrics paired with each of the ten complementary investment categories, yielding 30 interaction terms. To demonstrate complementarity between fibre adoption and any particular investment activity we require a positive coefficient on the interaction term, ie, $\gamma > 0$. We also report the p-value of a statistical test of whether $\beta + \gamma$ is zero, where $\beta + \gamma$ is the effect of fibre adoption holding constant the assumption that a firm is investing in the complementary investment.

Regression results are presented in table 11, where the investment variables are denoted by their question number (see table 10 or the appendix for the corresponding wording) and, initially, we report OLS (first-difference) estimates. These results are exploratory, in the sense that we initially aim to uncover which, if any, interaction terms are significant without imposing much structure on the analysis.

Firstly, aside from two coefficients – on organisational restructuring (b0804) and investments in non-ICT capital (b0807), both where the outcome is employment growth – the investment variable main effect (α) is never significantly different from zero, perhaps reflecting the fact that the variable is specifically about ICT-enhancing investments rather than overall investments.[28] Secondly, consistent with the results in tables 5-7, the main effect of fibre adoption (β) is almost always insignificantly different from zero. There is one instance where the main effect is estimated to be negative – new business strategies or management techniques (b0805), where MFP growth is the outcome of interest. However, in this case, the interaction term and combined ($\beta + \gamma$) coefficients are significant and positive.

The interaction terms associated with three investment variables – organisational restructuring (b0804), new strategies or management techniques (b0805), and redesigned processes (b0809) – are consistently positively related to each of the productivity measures at the 10% level of significance or better, as are the associated combined ($\beta+\gamma$) coefficients. Not only are these estimates consistently positive, but they are also economically significant implying increases in multifactor productivity of 11-13 percentage points from joint implementation.

These investment variables all represent forms of "organisational investment." To test for causal effects of complementary investments, we take a more structured approach by combining these variables together. This approach acknowledges that there is some overlap in their implementation and that they may, in fact, be implemented as a suite of practices (as in, eg, Fabling and Grimes 2014). We also include in this group shifting production towards more ICT-intensive products (b0810), for which there is weaker evidence of a positive relationship with MFP.[29]

The only remaining significant interaction term relates to new work practices (b0803), where the outcome is employment growth. In addition, for employment, two further investments have insignificant positive interaction term coefficients where the combined ($\beta + \gamma$) coefficients are significantly different from zero at the 10% level – physical relocation (b0806) and

[28] Furthermore, in one of these cases – organisational restructuring (b0804) – the estimated coefficient is negative.

[29] This relationship is weaker in the sense that the interaction term coefficient is positive and significant at the 10% level, but the combined coefficient is not quite significant at the 10% level (p = 0.104).

shifting production towards more ICT-intensive products (b0810). Other complementary investment variables – changing staff level or mix (b0801), training (b0802) and R&D (b0808) – do not appear to be related to any of the performance metrics, either independently or in conjunction with fibre adoption. For the remainder of the paper, we focus exclusively on the four organisational investment variables that appear to be related to (labour and multifactor) productivity growth.

Table 12 shows the pattern of cumulative activity across the four complementary organisational investments. Consistent with the hypothesis that these investments may be introduced as a coordinated suite of practices, the largest proportionate differences between fibre adopters and non-adopters relate to undertaking all four investments (followed by undertaking three of the investments). Specifically, ignoring non-investors, making all four investments represents the category with both the largest absolute (5.8 percentage points) and proportionate (4.46 times more likely) difference between fibre adopters and non-adopters (means different at the 1% significance level). In this context, it makes sense to consider the effects of a combination of investments. We calculate a combined complementary organisational investment variable as the total number of investments made (ie, zero to four). The final column of table 12 shows the proportion of firms in the first-difference OLS sample with each total number of investments. We then normalise this count so that the variable is mean zero, standard deviation one (ie, a z-score).

Table 13 (column 1) shows the equivalent estimates of equation 5 for the combined organisational investment variable. As with the earlier activity-by-activity estimates (table 11), there is a significant relationship between (labour and multifactor) productivity and adopting fibre together with organisational investment. We now test whether this relationship is causal.

Our earlier instruments were constructed to predict fibre usage, rather than complementary organisational investments, and do not adequately predict complementary investment, particularly the main effect of investment alone. To account for this issue we take two steps. First, in column 2, we drop the insignificant main effects to show that the interaction term (in an OLS setting) is largely unaffected by this change. On the assumption that IV estimates of the interaction term would be similarly robust to the exclusion of main effects, this allows us to focus on instrumenting a single variable related to the joint investment decision (ie, Investment$\times\Delta$Fibre-to-the-door).

We then apply IV using the same six instruments as earlier, but interacted with a predicted complementary investment variable derived by regressing investment on firm-level industry-region employment shares.[30] The logic for this approach is that firms may learn about good management techniques from other similar firms. Since the variable is predominantly predicted from other firms' behaviour, it should be unlikely to directly affect firm performance. We interact predicted investment with the current instruments to mimic the functional form of the variable we are instrumenting, and search across all permutations of the six instruments to find the strongest instrument set, maximising the weak identification F-statistic.

In this case, we identify a single best instrument, $IV_{A\times} \times$ [predicted investment]. Column 3 of table 13 shows the results of using this instrument. The coefficient on the joint investment decision variable remains positive. However, while the instrument passes the underidentification test, it is a weak instrument ($F < 10$) inflating both the coefficients and standard errors on the interaction term, implying caution in interpreting the results.[31]

To provide additional insights on the relationship between fibre adoption, complementary investments and firm performance, we consider a range of self-reported firm-level outcomes. Table 14 shows mean responses to the outcomes of ICT use question for 2012, based on whether firms adopted fibre and by the number of complementary organisational investments made (0, 1 or 2+). This question asks respondents to directly assess the impact of their ICT use on a wide range of business outcomes. Almost without exception, the incidence of better firm outcomes increases with the number of complementary investments made in conjunction with adopting fibre.

For example, 64.1% of non-fibre adopters report improved responsiveness to customer needs (first row, b0701), while 72.1% of fibre adopters report improved responsiveness. The latter average hides substantial variation. Adopters who make no organisational investments are worse than non-adopters (57.4% reported improvement), compared with single investment adopters (78.4%) and multiple organisational investment adopters (92.7%). As in this example, adopters with no organisational investments have significantly worse average outcomes (at the 10% level or better) than non-adopters of UFB for seven out of the thirteen outcomes, and never have significantly better average self-reported outcomes.

If the observed relationships between productivity and complementary organisational investments were spurious or due to reverse causation – ie, if

[30] For this analysis, regions are defined as Regional Councils to limit the number of firms that are in unique industry-region cells. There are 16 Regional Councils.

[31] The overidentification test is not possible because a single instrument is being used.

firms adopt fibre because their productivity improved – then it seems unlikely that respondents would attribute improvements across a wide range of outcomes to their ICT use. The strength and consistency of the OLS first-difference results coupled with the systematic patterns in the self-reported outcomes suggest that there is a causal relationship between joint adoption of fibre and complementary organisational investments. However, we cannot confirm that finding using an IV approach because we lack a sufficiently compelling exogenous variable that predicts joint investment.

4 Conclusions

Using an IV strategy based on proximity to primary and secondary schools, we find that the average effect of UFB adoption on employment and productivity growth is insignificantly different from zero. This finding holds even when we restrict the analysis to industries where we might expect the returns to UFB adoption to be relatively high – industries with relatively high: average fibre use; consideration of speed in determining connection type; and computer capital intensity. Our results are consistent with much of the current literature on standard broadband, though our study is the first (to our knowledge) to examine the effect of ultrafast broadband.

Following the guidance of the literature on management capability, complementary investments, and ICT use, we also examine the effect of concurrent organisational capital investments on the returns to fibre adoption. The data we use are unique in this regard, in that they explicitly ask respondents about investments made specifically for the purpose of getting more benefits from ICTs. We find that firms making concurrent investments in organisational capital experience higher (labour and multifactor) productivity growth. While the associated IV estimates suffer from a weak identification problem (making causal inference difficult), we find that firms making these joint (UFB-organisational) investment decisions are significantly more likely to report other positive outcomes from their ICT investments. Furthermore, the finding that UFB adoption in the absence of complementary investments yields no better (and frequently worse) outcomes than non-adoption of UFB, implies that it is the presence of complementary investments that is leveraging the benefits of UFB adoption for firm performance.

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Tables

Table 1: Effect of data availability and cleaning on sample size

		N(observations)		BOS proportion	
Cumulative sample restrictions		levels	first-diff	levels	first-diff
Business Operations Survey responses		11,775	4,059	1.000	1.000
+ Firm always uses computers/the internet to some extent		11,295	3,900	0.959	0.961
+ Respondents can always tell:					
whether they are on dial-up or broadband		10,830	3,729	0.920	0.919
what type of broadband they are on		9,864	3,363	0.838	0.829
which factors affected their connection choice	(a)	9,708	3,303	0.824	0.814
+ Firm isn't ever dial-up only		9,630	3,276	0.818	0.807
+ Industry included in productivity dataset	(b)	8,553	2,916	0.726	0.718
+ Firm-year is in the productivity dataset	(c)	6,417	2,031	0.545	0.500

Sample (a) is used to determine Area Unit characteristics of UFB uptake. Sample (b) is used for summary statistics that do no rely on the presence of productivity data (eg, broadband connection type adoption patterns), and to confirm the robustness of employment-related results to the inclusion of observations that do not have productivity data. Sample (c) is the sample used in OLS regressions.

Table 2: Broadband connection type transitions (2010 to 2012)

	Proportion of total Adopt	Drop	Retain	Net Adopt	Proportion of potential Adopt	Drop
DSL/ADSL	0.088	0.143	0.638	-0.055	0.404	0.183
Cable	0.038	0.047	0.025	-0.009	0.041	0.657
Fibre-to-the-door	0.151	0.054	0.181	0.098	0.198	0.228
Cellular	0.175	0.140	0.245	0.035	0.285	0.364
Wireless	0.141	0.110	0.100	0.031	0.178	0.525
Satellite	0.024	0.019	0.021	0.005	0.025	0.474

Sample includes firms that aren't present in the productivity dataset (ie, sample (b) in table 1). Net adopt is $A - D$ where A is Adopt (column 1), and D is Drop (column 2). The "proportion of potential" denominators differ by connection type and only consider firms that could potentially adopt (drop) each connection. Adopt as a proportion of potential is, therefore, $A/(1 - D - R)$ where R is Retain (column 3). Drop as a proportion of potential is $D/(D + R)$.

Table 3: Multiple broadband connection types by fibre usage and geographic span

	Single Area Unit		Multiple Area Unit	
	Has fibre		Has fibre	
N(broadband connection types)	No	Yes	No	Yes
One	3,048	396	780	225
Two	1,296	339	600	267
Three	324	249	228	378
Four or more	30	120	36	237
Total	**4,698**	**1,104**	**1,644**	**1,107**
Proportion with multiple types	0.351	0.641	0.526	0.797
+ excluding cellular	0.158	0.478	0.245	0.675
Proportion of single/multi AU with fibre	0.190		0.402	

Both years (2010; 2012) pooled, including firms that aren't present in the productivity dataset (ie, sample (b) in table 1). There are six listed broadband connection types: DSL/ADSL; cable; fibre-to-the-premise; cellular; wireless; satellite. Respondents are instructed to "mark all that apply" (see appendix).

Table 4: Correlates of fibre adoption – marginal effects probit regression

Independent variable (2010 value except where noted)	Dependent variable: Adoption of fibre-to-the-door in 2012 (1)	(2)	(3)	(4)	(5)
Total employment, ln(L)	0.093***	0.077***	0.074***	0.067***	0.065***
	[0.008]	[0.009]	[0.009]	[0.009]	[0.009]
Capital-to-labour ratio, ln(K/L)	0.030***	0.026***	0.028***	0.029***	0.029***
	[0.010]	[0.010]	[0.010]	[0.009]	[0.009]
Multifactor productivity (MFP)	0.007	0.008	0.008	0.002	0.002
	[0.021]	[0.020]	[0.020]	[0.018]	[0.018]
Firm with single business location		-0.081***	-0.075***	-0.076***	-0.062***
		[0.023]	[0.023]	[0.022]	[0.022]
Connection type(s):					
Dial-up			0.002	0.004	0.002
			[0.025]	[0.023]	[0.023]
DSL/ADSL			0.018	0.008	0.008
			[0.026]	[0.026]	[0.025]
Cable			0.103**	0.081*	0.083*
			[0.049]	[0.046]	[0.046]
Cellular			0.005	-0.001	0.000
			[0.018]	[0.016]	[0.017]
Wireless			0.085***	0.073***	0.074***
			[0.027]	[0.025]	[0.025]
Satellite			-0.017	-0.018	-0.015
			[0.044]	[0.044]	[0.046]
Considerations in choosing (2012 values):					
Availability in business location				-0.053***	-0.052***
				[0.020]	[0.020]
Startup costs				-0.043**	-0.041**
				[0.017]	[0.017]
Ongoing connection and usage costs				-0.026	-0.028
				[0.018]	[0.018]
Connection speed				0.135***	0.135***
				[0.018]	[0.018]
Mobile access				-0.009	-0.008
				[0.019]	[0.019]
Compatibility with existing technology				0.005	0.004
				[0.018]	[0.018]
Availability of technical support				-0.005	-0.008
				[0.019]	[0.019]
ln(distance to nearest primary school)					-0.001
					[0.004]
ln(distance to nearest secondary school)					-0.011**
					[0.005]
N(observations)	1,662	1,662	1,662	1,662	1,662
Pseudo-R^2	0.226	0.235	0.246	0.290	0.293
Mean(dependent variable)	0.202	0.202	0.202	0.202	0.202

Probit regression where the dependent variable is an indicator variable set to one if the firm has fibre-to-the-door in 2012 and zero otherwise (marginal effects shown). Sample restricted to firms that did not have fibre in 2010. All independent variables are 2010 values, except the considerations in choosing indicators. MFP is derived from estimating equation 4 with firm fixed effects. All regressions include industry dummies and initial (2010) TA employment shares. Robust standard errors shown in square brackets. ***;**;* indicates coefficient significantly different from zero at the 1%;5%;10% level respectively.

Table 5: Effect of UFB adoption on total employment

	OLS	OLS	OLS	IV	IV
Dependent variable	$\ln(L)$	$\Delta\ln(L)$	$\Delta\ln(L)$	$\Delta\ln(L)$	$\Delta\ln(L)$
	(1)	(2)	(3)	(4)	(5)
Fibre-to-the-door	1.067***	0.014		-0.032	
	[0.044]	[0.017]		[0.087]	
ΔFibre-to-the-door			0.007		-0.102
			[0.013]		[0.106]
N(observations)	6,417	2,832	2,031	2,832	2,031
R^2	0.247	0.063	0.080		
Underidentification F-stat (p)				128.48 (0.00)	30.31 (0.00)
Weak identification F-stat				68.76	15.20
Overidentification Hansen J-stat (p)				0.16 (0.69)	1.85 (0.17)

Specification (1) includes industry-year dummies and TA employment shares. Specifications (2)-(5) include industry dummies, and either initial (2010) TA employment shares (specs 2 & 4) or changes in TA employment shares (specs 3 & 5). In specifications (2) & (4), the fibre-to-the door variable is the initial (2010) value. Robust standard errors shown in square brackets. ***;**;* indicates coefficient significantly different from zero at the 1%;5%;10% level respectively. Instruments used for spec (4) are: initial log distance to nearest secondary school (IV_S); and that variable interacted with a firm-level indicator for whether speed is a consideration in choosing connection type in 2010 ($IV_{S\times}$). Instruments used for spec (5) are: initial log distance to nearest school (IV_A); and initial log distance to nearest primary school interacted with a firm-level indicator for whether speed is a consideration in choosing connection type in 2012 ($IV_{P\times}$). Kleibergen-Paap F-statistics for tests of underidentification and weak identification reported, together with Hansen J statistic overidentification test.

Table 6: Effect of UFB adoption on labour productivity (LP)

	OLS	OLS	OLS	IV	IV
Dependent variable	LP	ΔLP	ΔLP	ΔLP	ΔLP
	(1)	(2)	(3)	(4)	(5)
Fibre-to-the-door	0.177***	-0.010		0.017	
	[0.025]	[0.025]		[0.127]	
ΔFibre-to-the-door			0.023		-0.046
			[0.029]		[0.208]
N(observations)	6,306	2,757	1,986	2,757	1,986
R^2	0.232	0.073	0.100		
Underidentification F-stat (p)				120.68 (0.00)	32.92 (0.00)
Weak identification F-stat				64.29	16.58
Overidentification Hansen J-stat (p)				0.20 (0.65)	0.21 (0.65)

Specification (1) includes industry-year dummies and TA employment shares. Specifications (2)-(5) include industry dummies, and either initial (2010) TA employment shares (specs 2 & 4) or changes in TA employment shares (specs 3 & 5). In specifications (2) & (4), the fibre-to-the door variable is the initial (2010) value. Robust standard errors shown in square brackets. ***;**;* indicates coefficient significantly different from zero at the 1%;5%;10% level respectively. Instruments used for spec (4) are: initial log distance to nearest secondary school (IV_S); and that variable interacted with a firm-level indicator for whether speed is a consideration in choosing connection type in 2010 ($IV_{S\times}$). Instruments used for spec (5) are: initial log distance to nearest school (IV_A); and initial log distance to nearest primary school interacted with a firm-level indicator for whether speed is a consideration in choosing connection type in 2012 ($IV_{P\times}$). Kleibergen-Paap F-statistics for tests of underidentification and weak identification reported, together with Hansen J statistic overidentification test.

Table 7: Effect of UFB adoption on multifactor productivity (MFP)

	OLS	OLS	OLS	IV	IV
Dependent variable	MFP	ΔMFP	ΔMFP	ΔMFP	ΔMFP
	(1)	(2)	(3)	(4)	(5)
Fibre-to-the-door	0.002	0.015		-0.073	
	[0.016]	[0.016]		[0.081]	
ΔFibre-to-the-door			0.000		0.006
			[0.020]		[0.134]
N(observations)	6,417	2,832	2,031	2,832	2,031
R^2	0.059	0.034	0.060		
Underidentification F-stat (p)				128.48 (0.00)	30.31 (0.00)
Weak identification F-stat				68.76	15.20
Overidentification Hansen J-stat (p)				0.03 (0.86)	0.06 (0.81)

Specification (1) includes industry-year dummies and TA employment shares. Specifications (2)-(5) include industry dummies, and either initial (2010) TA employment shares (specs 2 & 4) or changes in TA employment shares (specs 3 & 5). In specifications (2) & (4), the fibre-to-the door variable is the initial (2010) value. Robust standard errors shown in square brackets. ***;**;* indicates coefficient significantly different from zero at the 1%;5%;10% level respectively. Instruments used for spec (4) are: initial log distance to nearest secondary school (IV_S); and that variable interacted with a firm-level indicator for whether speed is a consideration in choosing connection type in 2010 ($IV_{S\times}$). Instruments used for spec (5) are: initial log distance to nearest school (IV_A); and initial log distance to nearest primary school interacted with a firm-level indicator for whether speed is a consideration in choosing connection type in 2012 ($IV_{P\times}$). Kleibergen-Paap F-statistics for tests of underidentification and weak identification reported, together with Hansen J statistic overidentification test.

Table 8: Composition of potentially high-return industries

	High (top third of) industries with			
Productivity dataset industry	Fibre-to-the-door	Consideration of speed	Computer K/L	N(obs)
Poultry, deer & other (non-sheep/beef/dairy) livestock farming		X		6
Mining			X	30
Printing		X	X	48
Electricity, gas, water & waste services			X	30
Wholesale trade	X	X	X	192
Rail, water, air & other (non-road) transport	X	X		21
Postal, courier transport support & warehousing services	X	X		48
Information media services	X		X	54
Telecommunications, internet & library services	X	X	X	24
Auxiliary finance & insurance services	X	X	X	42
Finance, insurance & superannuation funds	X	X	X	60
Rental & hiring services (except real estate)			X	33
Professional, scientific & technical services	X	X		222
Administrative & support services			X	147
Arts & recreation services			X	36

"X" denotes industries included in the potentially high-return subsamples of table 9. In each case the high threshold is set so that as close to one third of first-difference firm observations are included in the subsample. The industry contribution to the number of firms in each of these subsamples is shown in the rightmost column. The "fibre-to-the-door" sample is firms in industries with the highest fibre penetration rates. The "consideration of speed" sample is firms in industries with the highest rates of connection speed being a consideration in choosing between connection types. The "computer K/L" sample is firms in industries with the highest average computer (hardware and software) capital per full-time equivalent. The first two industry classifications are determined using responses in the levels dataset. The last category uses computer-specific fixed capital from the 2008 BOS, which was the last year that this data was collected in the BOS. The cut-off value for being a high computer capital industry is $2,500/FTE (2008 NZ dollars).

Table 9: UFB adoption and firm performance in potentially high-return industries – OLS estimates

	High fibre		High speed		High K_c/L	
	(1)	(2)	(3)	(4)	(5)	(6)
			Dependent variable: $\Delta \ln(L)$			
Fibre-to-the-door	0.026		0.032		0.012	
	[0.026]		[0.024]		[0.032]	
ΔFibre-to-the-door		0.005		0.011		0.031
		[0.023]		[0.023]		[0.025]
N(observations)	939	666	936	666	927	702
R^2	0.182	0.088	0.198	0.089	0.148	0.129
			Dependent variable: ΔLP			
Fibre-to-the-door	0.030		0.016		-0.045	
	[0.041]		[0.040]		[0.050]	
ΔFibre-to-the-door		-0.051		-0.045		0.028
		[0.053]		[0.053]		[0.060]
N(observations)	897	639	897	642	894	678
R^2	0.113	0.104	0.112	0.098	0.128	0.139
			Dependent variable: ΔMFP			
Fibre-to-the-door	0.001		-0.006		-0.013	
	[0.030]		[0.031]		[0.033]	
ΔFibre-to-the-door		0.001		0.015		0.021
		[0.038]		[0.038]		[0.048]
N(observations)	939	666	936	666	927	702
R^2	0.050	0.115	0.054	0.123	0.063	0.067

High fibre, high speed, and high K_c/L samples refer to, respectively, firms in industries with relatively high average fibre use, consideration of speed in determining connection type, and computer capital per FTE (as defined in table 8). All specifications include industry dummies, and either initial (2010) TA employment shares (specs 1, 3 & 5) or changes in TA employment shares (specs 2, 4 & 6). In specs (1), (3) & (5), the fibre-to-the door variable is the initial (2010) value. Robust standard errors shown in square brackets. ***;**;* indicates coefficient significantly different from zero at the 1%;5%;10% level respectively.

Table 10: Complementary investments to get more benefits from ICTs by whether fibre-to-the-door was adopted between 2010 and 2012

		Fibre adopter			Ratio
		No	Yes		[Yes/No]
b0801	Changed staff levels or skills mix	0.211	0.381	***	1.80
b0802	Trained employees	0.456	0.653	***	1.43
b0803	Introduced new work practices	0.227	0.354	***	1.56
b0804	Restructured the organisation	0.153	0.279	***	1.83
b0805	Implemented new business strategies/management techniques	0.220	0.327	***	1.49
b0806	Physically relocated any business activities	0.067	0.156	***	2.33
b0807	Invested in capital other than ICT	0.128	0.204	***	1.60
b0808	Performed research and development	0.086	0.163	***	1.91
b0809	Redesigned processes for producing or distributing products	0.146	0.286	***	1.96
b0810	Shifted production towards more ICT-intensive products	0.069	0.163	***	2.37

Sample restricted to firms that did not have fibre in 2010 (ie, the probit adoption sample in table 4). Complementary investment responses are 2012 values, corresponding to the same two year period during which UFB was potentially adopted. b080X in leftmost column corresponds to the BOS 2010 survey question number. Some response categories have been shortened for presentation purposes (see the appendix for complete response categories, which are identical in 2010 and 2012). *** indicates mean investment rates significantly different from each other at the 1% level.

Table 11: Complementary investment, UFB adoption and firm performance – OLS first differences

	Complementary investment variable (2012 value)									
	b0801	b0802	b0803	b0804	b0805	b0806	b0807	b0808	b0809	b0810
	Dependent variable: $\Delta \ln(L)$									
Investment	0.012	0.005	0.013	-0.023*	0.006	-0.002	0.040***	0.022	0.020	-0.029
	[0.012]	[0.011]	[0.012]	[0.014]	[0.012]	[0.018]	[0.015]	[0.015]	[0.014]	[0.018]
ΔFibre-to-the-door	0.005	0.001	-0.012	0.009	0.006	-0.001	0.010	0.008	0.012	-0.001
	[0.017]	[0.021]	[0.015]	[0.014]	[0.015]	[0.014]	[0.014]	[0.014]	[0.015]	[0.013]
Investment×ΔFibre-to-the-door	0.003	0.009	0.051*	-0.005	0.000	0.052	-0.018	-0.012	-0.021	0.062
	[0.025]	[0.027]	[0.027]	[0.031]	[0.027]	[0.033]	[0.030]	[0.035]	[0.028]	[0.038]
p(ΔFibre+Invest×ΔFibre= 0)	0.700	0.559	**0.083**	0.877	0.775	**0.085**	0.749	0.898	0.696	**0.088**
	Dependent variable: ΔLP									
Investment	0.036	0.030	0.035	0.007	0.034	0.039	0.023	0.017	0.006	-0.013
	[0.025]	[0.022]	[0.025]	[0.028]	[0.025]	[0.038]	[0.030]	[0.036]	[0.027]	[0.038]
ΔFibre-to-the-door	0.011	0.037	-0.003	-0.018	-0.022	0.018	0.009	0.008	-0.009	0.013
	[0.036]	[0.040]	[0.035]	[0.032]	[0.035]	[0.031]	[0.034]	[0.032]	[0.033]	[0.030]
Investment×ΔFibre-to-the-door	0.025	-0.025	0.069	0.168**	0.134**	0.027	0.062	0.101	0.107*	0.070
	[0.060]	[0.055]	[0.060]	[0.071]	[0.061]	[0.083]	[0.062]	[0.077]	[0.065]	[0.094]
p(ΔFibre+Invest×ΔFibre= 0)	0.453	0.741	0.179	**0.019**	**0.024**	0.557	0.170	0.123	**0.076**	0.352
	Dependent variable: ΔMFP									
Investment	0.005	0.001	0.007	-0.017	-0.017	-0.003	-0.006	-0.010	0.009	-0.001
	[0.016]	[0.015]	[0.018]	[0.019]	[0.017]	[0.031]	[0.018]	[0.025]	[0.019]	[0.029]
ΔFibre-to-the-door	-0.006	-0.018	-0.022	-0.024	-0.041*	-0.008	-0.011	-0.012	-0.033	-0.020
	[0.024]	[0.032]	[0.022]	[0.022]	[0.024]	[0.021]	[0.024]	[0.022]	[0.023]	[0.020]
Investment×ΔFibre-to-the-door	0.015	0.028	0.065	0.107**	0.127***	0.054	0.055	0.086	0.116**	0.141*
	[0.044]	[0.041]	[0.047]	[0.053]	[0.044]	[0.071]	[0.044]	[0.058]	[0.047]	[0.076]
p(ΔFibre+Invest×ΔFibre= 0)	0.791	0.698	0.307	**0.083**	**0.017**	0.492	0.236	0.173	**0.045**	0.104

Each performance variable-specific panel represents a separate set of ten regressions with the b080X column header showing each of the specific survey question used as the "Investment" variable (see table 10 or the appendix for the related response categories). All regressions include industry dummies and changes in TA employment shares. Robust standard errors shown in square brackets. ***;**;* indicates coefficient significantly different from zero at the 1%;5%;10% level respectively. The bottom row of each panel reports the p-value on a test that the combined (main plus interaction) effect of fibre adoption on performance is zero (p-values less than 0.10 shown in bold).

Table 12: Number of complementary organisational investments made

N(investments)	Fibre adopter No	Fibre adopter Yes		Ratio [Yes/No]	First-diff sample
None	0.643	0.463	***	0.720	0.548
One	0.198	0.252	**	1.271	0.230
Two	0.102	0.122		1.196	0.114
Three	0.039	0.088	***	2.292	0.064
All four	0.017	0.075	***	4.460	0.044
Total	1.000	1.000			1.000

"Fibre adopter" sample restricted to firms that did not have fibre in 2010 (ie, the probit adoption sample). "First-diff" sample is the first-difference (OLS) sample used in tables 11 and 13. The four complementary organisational investments are: "restructured the organisation" (b0804); "implemented new business strategies or management techniques" (b0805); "redesigned processes for producing or distributing products" (b0809); and "shifted production towards products that use ICT more intensively" (b0810). ***;**;* indicates mean investment rates significantly different from zero at the 1%;5%;10% level respectively.

Table 13: The effect of UFB adoption and complementary organisational investment on firm performance

	OLS	OLS	IV
	(1)	(2)	(3)
	Dependent variable: $\Delta \ln(L)$		
Investment	-0.002		
	[0.006]		
ΔFibre-to-the-door	0.007		
	[0.013]		
Investment×ΔFibre-to-the-door	0.002	0.001	0.047
	[0.012]	[0.012]	[0.111]
R^2	0.080	0.080	
p(ΔFibre+Invest×ΔFibre= 0)	0.634		
Underidentification F-stat (p)			6.75 (0.01)
Weak identification F-stat			6.47
	Dependent variable: ΔLP		
Investment	0.007		
	[0.013]		
ΔFibre-to-the-door	0.011		
	[0.029]		
Investment×ΔFibre-to-the-door	0.066**	0.071**	0.358
	[0.033]	[0.033]	[0.311]
R^2	0.105	0.105	
p(ΔFibre+Invest×ΔFibre= 0)	0.059		
Underidentification F-stat (p)			5.89 (0.02)
Weak identification F-stat			5.65
	Dependent variable: ΔMFP		
Investment	-0.005		
	[0.009]		
ΔFibre-to-the-door	-0.009		
	[0.020]		
Investment×ΔFibre-to-the-door	0.066***	0.063***	0.180
	[0.024]	[0.024]	[0.167]
R^2	0.070	0.069	
p(ΔFibre+Invest×ΔFibre= 0)	0.065		
Underidentification F-stat (p)			6.75 (0.01)
Weak identification F-stat			6.47

The "Investment" variable is the sum of the four complementary organisational investment binary variables normalised to be mean zero with standard deviation of one in the column (1) sample. All regressions include industry dummies and change in TA employment shares. Each performance variable-specific panel represents a separate set of regressions, and reports the p-value on a test that the combined (main plus interaction) effect of fibre-to-the-door adoption on performance is zero (spec 1). Robust standard errors shown in square brackets. ***;**;* indicates coefficient significantly different from zero at the 1%;5%;10% level respectively. Instrument used for IV is $IV_{A\times} \times$ [industry-regional council predicted investment]. IV is estimated by 2SLS. Kleibergen-Paap F-statistics for tests of underidentification and weak identification reported. Hansen J statistic overidentification test not possible because single instrument used.

Table 14: Mean of self-reported outcomes by fibre adoption and the number of complementary organisational investments made

		Fibre adopter			Adopter by n(invest)					
		No	Yes	N=Y	0	1	2+	N= 0	0 = 1	1 = 2+
b0701	Improved responsiveness to customer needs	0.641	0.721	***	0.574	0.784	0.927	**	***	***
b0702	Greater understanding of markets	0.332	0.415	***	0.250	0.405	0.732	**	**	***
b0703	Better sales or marketing methods	0.466	0.531	***	0.382	0.568	0.780	**	***	***
b0704	Introduced products not possible without ICT	0.230	0.367	***	0.250	0.324	0.610			***
b0705	Reduced prices from suppliers	0.220	0.252		0.162	0.189	0.488	**		***
b0706	Improved efficiency of work flow, etc (eg, just-in-time)	0.597	0.646	**	0.515	0.730	0.805	**	***	*
b0707	Better coordination of staff and business activities	0.569	0.667	***	0.485	0.784	0.878	*	***	**
b0708	Improved efficiency of production processes	0.361	0.463	***	0.324	0.541	0.634		***	*
b0709	Improved management of quality	0.372	0.483	***	0.324	0.541	0.683		***	**
b0710	Improved management information systems	0.455	0.605	***	0.441	0.676	0.829		***	***
b0711	Reduced costs of entering new markets	0.104	0.136	*	0.074	0.162	0.220		**	
b0712	Shifted activities to other businesses (eg, outsourcing)	0.091	0.184	***	0.088	0.162	0.366			***
b0713	Improved collaboration with other businesses	0.129	0.231	***	0.088	0.216	0.488	*	***	***

The table shows means of indicator variables where firms reported ICT use as important in achieving the outcome (see question 7 in appendix). Sample restricted to firms that did not have fibre in 2010 (ie, the probit adoption sample). The four complementary organisational investments are: "restructured the organisation" (b0804); "implemented new business strategies or management techniques" (b0805); "redesigned processes for producing or distributing products" (b0809); and "shifted production towards products that use ICT more intensively" (b0810). ***;**;* indicates mean self-reported outcomes significantly different from each other at the 1%;5%;10% level respectively. Mean self-reported outcomes are always significantly different from each other at the 1% level when comparing fibre adopters in the 0 and 2+ complementary investment groups, and when comparing fibre adopters in the 0 and 1+ (ie, 1 and 2+ pooled) complementary investment groups.

Appendix - BOS questions

7 **Mark all that apply. Has this business's use of ICT been important in achieving any of the following outcomes?**

- improved responsiveness to customer needs (eg customised goods or services) B0701
- greater understanding of markets (eg analysing customer purchasing patterns) B0702
- better sales or marketing methods B0703
- introduced goods or services not possible without ICT B0704
- reduced prices from suppliers (eg through ability to shop around) B0705
- improved efficiency of work flow, inventory management or ordering systems (eg just-in-time processes) B0706
- better coordination of staff and business activities B0707
- improved efficiency of production processes (eg due to reduced downtime or automation) B0708
- improved management of quality B0709
- improved management information systems (eg real-time performance monitoring) B0710
- reduced costs of entering new markets B0711
- shifted activities to other businesses (eg contracting out payroll functions) B0712
- improved collaboration with other businesses (eg on joint development or marketing) B0713
- or none of the above B0714

8 **Mark all that apply. In the last 2 financial years, has this business done any of the following activities to get more benefit from its ICT?**

- changed staff levels or skills mix B0801
- trained employees B0802
- introduced new work practices (eg teamworking) B0803
- restructured the organisation B0804
- implemented new business strategies or management techniques B0805
- physically relocated any business activities B0806
- invested in capital other than ICT B0807
- performed research and development B0808
- redesigned processes for producing or distributing goods or services B0809
- shifted production towards goods or services that use ICT more intensively B0810
- or no, none of the above were done to increase the benefits of ICT B0811

9 **Does this business use the Internet?** B0900

1 yes → go to **10**

2 no → go to **21**

11 **How does this business connect to the Internet?** B1100

1 ◯ both dial-up (ISDN and analog) and broadband connections → go to **12**

2 ◯ broadband connection only → go to **12**

3 ◯ dial-up connection only → go to **13**

or 4 ◯ don't know → go to **14**

12 **Mark all that apply. What types of broadband Internet connection does this business use?**

◯ DSL including ADSL (provided over your copper telephone line) B1201

◯ cable (eg cable plans available in Wellington and Christchurch) B1202

◯ fibre-to-the-premise B1203

◯ cellular technology (eg 3G Vodafone Mobile Connect, Telecom XT Network) B1204

◯ wireless (eg Woosh) B1205

◯ satellite (eg Farmside) B1206

or ◯ don't know B1207

13 **Mark all that apply. What were the considerations in choosing between types of Internet connection?**

◯ availability in business location B1301

◯ startup costs B1302

◯ ongoing connection and usage costs B1303

◯ connection speed B1304

◯ mobile access B1305

◯ compatibility with this business's existing technology B1306

◯ availability of technical support B1307

or ◯ none of the above B1308

Questions taken from the 2010 Business Operations Survey (question 10 is not used in the analysis and asks about the percentage of staff with access to the internet). Survey questions in 2012 are identical except that: the "fibre-to-the-premises" category in question 12 had this text "(fibre optic broadband network)" added; two preceding questions were added on the impact of security attacks resulting in question renumbering; two questions about future plans for fibre usage were added between questions 12 and 13; the category "connection speed" in question 13 was split into "download speed" and "upload speed"; and an additional category was added to question 13 "service level guarantees (eg guaranteed minimum speeds, guaranteed repair and response times)." For question 13 consistency we combine the speed categories and ignore the service level guarantees category.