The Need for Speed: Impacts of Internet Connectivity on Firm Productivity

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Abstract

Fast internet access is widely considered to be a productivity-enhancing factor. Internet access speeds vary regionally within countries and even within cities. Despite articulate pleas for network upgrades to accelerate internet access, there is little rigorous research quantifying benefits to individual firms that arise from upgraded internet connectivity. We use a large New Zealand micro-survey of firms linked to unit record firm financial data to determine the impact that differing types of internet access have on firm productivity. Propensity score matching is used to control for factors, including the firm's (lagged) productivity, that determine firms' internet access choices. Having matched firms, we examine the productivity impacts that arise when a firm adopts different types (speeds) of internet connectivity. Broadband adoption is found to boost productivity but we find no productivity differences across broadband type. The results provide the first firm-level estimates internationally of the degree of productivity gains sourced from upgraded internet access.

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Internet, broadband, productivity

Disclaimer

Contents

1 Introduction

Fast internet access is considered to be a productivity-enhancing factor (OECD, 2003a). As new technologies are introduced (e.g. copper-wire-based ADSL[1] in place of dial-up, fibre optic cable in place of ADSL), calls are made to upgrade telecommunications networks that service firms and households lest the local community is left on the wrong side of the 'digital divide'. Many of these calls originate from think tanks or lobby groups (for example, New Zealand Institute, 2007).

Despite well-articulated pleas for upgraded internet access, reference to rigorous research that quantifies benefits actually accruing from network upgrades is generally absent in supporting materials. A key reason for this conspicuous absence is that little rigorous research exists that measures the productivity impacts of a shift from one type of internet access to another. Most research in the field has been conducted at an aggregated (regional or national) level or has bundled together various types of information and communications technology (ICT) rather than separating out the internet access component. Neither type of aggregation enables reliable conclusions to be drawn about the extent of productivity improvements that might arise if, say, an ADSL network is upgraded to a fibre network.

Our study uses a large New Zealand micro-survey of firms to determine the impact that differing types of internet access have on firm productivity. Our data allow us to control for a wide range of factors (including the firm's own lagged productivity) that may determine a firm's access choice. The work utilises data from the 2006 Business Operations Survey (BOS), an official economy-wide sample survey of firms that includes a wide range of questions on firms' business practices, including questions relating to their access to, and use of, the internet. The BOS data is linked to a wealth of data from a variety of sources in the form of the prototype Longitudinal Business Database (LBD) (Fabling et al, 2008). We link the BOS data to data for each firm's productivity, derived from administrative tax and employment data. In addition, we are able to control for other firm characteristics recorded within the LBD.

[1] ADSL stands for Asymmetric Digital Subscriber Line.

We use propensity score matching (PSM) to control for factors that determine firms' internet access choices, and examine the impacts of various types of internet access 'treatment'. Specifically, we examine the productivity impact that arises (ceteris paribus) when a firm: (a) adopts broadband (of any type) relative to no broadband; (b) adopts 'fast' broadband (defined here as a cable connection) relative to 'slow' broadband (all other broadband types); and (c) adopts slow broadband relative to no broadband. We determine that the productivity benefits that arise from a switch from no broadband to broadband access are material; we do not find evidence for productivity differentiation based on the type of broadband connection (i.e. cable versus other).

Section 2 of the paper outlines prior studies that have linked internet access and related factors to productivity (or other economic outcomes). The review is brief simply because few studies have examined the issues in depth. We set the scene for subsequent analysis by reviewing the New Zealand ICT environment in relation to internet access, then formulate hypotheses from the review material that we subject to test in the paper.

Section 3 describes our data sources and presents descriptive statistics on firms' internet access. First, we report proportions of firms with particular characteristics (e.g. employment size) that have broadband access. Second, we report proportions of firms that use the internet for particular commercial purposes (e.g. making internet sales) according to whether they have broadband or not. Third, we report overall broadband and fast broadband access rates by region within the country, demonstrating considerable geographic diversity in broadband access. This diversity – reflecting different geographic availability of services - can be considered as a type of random assignment of firms across internet types within the economy. We use this diversity in our subsequent estimates. Fourth, we reverse the first and second comparisons; for each internet access type, we report characteristics and internet uses of firms. The descriptive statistics provide considerable information regarding firms' uses of the internet, information that has been largely lacking in prior studies.

Our PSM model results are presented in section 4. Probit and ordered probit models are used to predict firms' internet access choices; the results of these models are instructive in understanding why certain types of firms choose various internet access types. We match firms and calculate the treatment effects attributable to internet access type. Treatment effects are calculated using two differing matching technologies, across differing samples, and comparing differing access choices to test robustness of results. We pay particular attention to whether treatment effects differ according to urban or rural firm location given debates about whether to prioritise fibre upgrades to rural or urban regions (Forman et al, 2009).

Conclusions are presented in section 5 together with an outline of potential future work. We note that a follow-up survey, with a longitudinal element to the ICT questions, will be accessible in a forthcoming Statistics New Zealand survey, and suggest ways that the current analysis can be extended.

2 Prior Literature and Hypotheses

2.1 Prior research

Very little, if any, prior research specifically addresses the impacts of broadband and, in particular, fast broadband on firms. Some research has been conducted estimating aggregate economic impacts arising from Information and Communications Technology (ICT) in general (OECD, 2003a; Clayton, 2005; Hagen and Zeed, 2005) and broadband in particular (Greenstein and McDevitt, 2009). Other studies have conducted analysis of broadband deployment at the regional and/or industry level. For instance, Crandall et al (2007) estimate the benefits of U.S. broadband penetration on output and employment by sector at the state level over a three-year period. The study estimates that for every one percentage point increase in broadband penetration within a state, employment increases by 0.2-0.3 percent per year for the U.S. private, non-farm economy. The report identifies a positive relationship between employment and broadband penetration in the manufacturing and service industries (particularly finance, education, and health care). Based on these findings, the authors recommend that policies should stimulate broadband industry competition and encourage investment in broadband infrastructure.

A prior study (Lehr et al, 2006) analyzes broadband penetration at the industry, community (zipcode), and state level – but not at the firm level. The study includes employment growth, wages, rent, business growth, and industry structure as dependent variables. The results support the hypothesis that broadband penetration enhances economic activity. The most significant effects are seen on job growth (which diminishes as penetration rises) and business growth, particularly for larger businesses and for IT intensive sectors. The study found no significant impact of broadband penetration on wages, although did find an association with higher residential property values in broadband-enabled communities. More recent research (Forman et al, 2009) finds an association between firms' internet use and wage growth (at the county level in the United States) for richer counties, but finds little impact for poorer rural areas.

One reason for such contradictory findings is flagged by Lehr et al who note that state level data is at too high a level of aggregation to evaluate true measurable impacts. For example, the authors hypothesize two ways that job growth could be affected by internet access: (a) greater access could stimulate the economy, leading to job growth; and (b) job growth could decline as typically labour-intensive jobs are minimized because broadband facilitates capital-labour substitution. At the state level, the study finds that broadband penetration has a positive (but insignificant) impact on employment growth. However, when they add controls for urbanization and coefficients for growth in employment during the late 1990s, the direction of impact changes (albeit still insignificant). The aggregation dilemma is further emphasized when the authors contrast state level results with community level (zipcode) results; the community level data show a statistically significant positive impact of broadband availability on employment growth.

Australian research is summarized by Collins et al (2007) who cite two studies conducted by the Allen Consulting Group using firm level survey data. The survey, which focused on business perceptions as opposed to firm financial statistics, asked firms whether the internet has increased their knowledge of the market, increased sales, customers, or business revenue, and increased efficiencies in sale and distribution. Across all factors, broadband users were more likely to report higher impacts than their dial-up counterparts. However the differences were not large (67% to 61%, 49% to 40%, and 57% to 46%, respectively) and the results are difficult to interpret since the studies did not control for the two groups' other characteristics.

Finnish work (Marilanta and Rouvinen, 2006) has evaluated the use of "readily accessible technology" (laptops, data processing and storage devices networked with wireless capability) at the firm level. The models use a wide variety of technology-related input (independent) variables. The authors assign levels of technology, called 'ICT bundles' based on three primary areas: 1) processing and storage capabilities, 2) portability, and 3) connectivity. For example, a firm will be considered to be in ICT bundle group 'c' if they have desktop computers and a LAN connection, while another firm would be in ICT bundle 'f' if they have laptops and WLAN connectivity. The authors control for the firms' workforce composition (i.e., education, age, gender). Their results suggest that processing and storage capabilities will increase a worker's productivity by 9%, portability increases productivity by nearly 32%, and wireline and wireless connectivity boosts productivity by 14% and 6%, respectively.

2.2 New Zealand Context

According to OECD (2008), New Zealand falls around the middle of OECD countries for a range of broadband-related statistics. The country ranks 20th (of 30 countries) for broadband subscribers per capita, 14th for household broadband access, 13th for DSL coverage (at 93%), 5th for average advertised download speeds, and 15th least expensive for average broadband access costs (in PPP terms). Ford et al (2008) find that New Zealand's per capita broadband subscription rate is poor relative to other OECD countries once other factors (e.g. incomes and education) are accounted for. The low population density of the country is one reason they cite for New Zealand's low subscription rate.

Against this factual background,[2] there are several studies that discuss potential benefits of broadband for aggregate GDP in New Zealand, but no studies have been conducted at a micro-level. IDC Market Research (2006)[3] forecast additional nominal GDP that could be produced by additional broadband penetration. The forecasting model is based on the Gompertz curve (where growth is slow at the start and end of a period), and projects that New Zealand will reach broadband penetration of 50 subscribers per 100 of population by 2023 (compared with 16.5 per 100 in 2007; OECD, 2008). If this rate were accelerated and the level of 50 subscribers per 100 was reached within 10 years, the study predicts nominal

[2] Castalia (2008) provides further factual information on New Zealand broadband provision as at 2008.

[3] The broadband diffusion analysis for this report was conducted by the Economist Intelligence Unit (EIU).

annual GDP would increase by NZ$314 million by 2010, NZ$2,740 million by 2020, and NZ$7,215 million by 2030; these projected increases compare with nominal GDP of $131,500 million in 2007. However these figures must be treated as speculative; they are not based on New Zealand-specific research or on firm-level research linking broadband penetration to productivity gains.

One think-tank estimated that national economic benefits of moving from existing broadband to high-speed broadband would be in the range of $2.7 - 4.4 billion per year (New Zealand Institute, 2007). These estimates were based on international sources plus forecast global growth rates for industries and for the New Zealand economy. Examples of input variables included: growth in the digital media sector, 'telepresence' (the cost-benefit of domestic and international telecommuting), increase in speed efficiency, growth in the data storage and manipulation sector, increased internet access, growth in the online education sector, and potential for innovation and business retention in the "weightless" economy. There were no citations to firm-level analyses of productivity benefits arising from a move to fibre. A follow-up report (New Zealand Institute, 2008) argued that recent fibre developments were well behind its aspirations, and recommended regulatory and investment intervention to hasten fibre provision and uptake. Castalia (2008), by contrast, questioned the extent of demand by New Zealand subscribers for high-speed broadband, and provided evidence that existing services, coupled with planned broadband roll-outs and improved compression techniques, will cater for most uses that New Zealand subscribers are willing to pay for over the foreseeable future.

The review of prior research indicates there is little research that directly addresses the impact of broadband (fast or otherwise) on firm productivity. Some studies raise the issue of what is an appropriate definition of 'broadband'. Because of the changing nature of broadband, it is difficult to pinpoint a definitive definition; today's broadband will be regarded as tomorrow's narrowband. While acknowledging that broadband is a moving target, the majority of studies adopt the OECD's (2002) definition that broadband has the capacity to provide transmission speeds of at least 256 Kbps. "High-speed' or 'fast' broadband is generally regarded as internet access facilitated through fibre-optic cable or through other mechanisms that allow much faster speeds; e.g. 10Mbps (Castalia, 2008).

2.3 Hypotheses

We treat internet access as a "productivity shifter" within the firm production function. Specifically, we assume that firm i in industry j has production function:

$$Y_{ij} = A_{ij}F_j[L_{ij}, K_{ij}] \qquad (1)$$

where Y_{ij} is the firm's value added; L_{ij} (K_{ij}) is labour (capital) employed by firm i, F_j is a linearly homogeneous production function specific to industry j, and A_{ij} is a firm-specific productivity variable. Given the linear homogeneity of F_j, the logarithm of average labour productivity is given by:

$$\ln(Y_{ij}/L_{ij}) = \ln(A_{ij}) + \ln(F_j[1, K_{ij}/L_{ij}]) \qquad (2)$$

All firms in industry j face the same F_j and the same factor prices so, at the optimum, the last term in (2) can be replaced by an industry-specific constant, $\ln(C_j)$, thus:

$$\ln(P_{ij}) \equiv \ln(Y_{ij}/L_{ij}) - \ln(C_j) = \ln(A_{ij}) \qquad (3)$$

where $\ln(P_{ij})$ is (log of) firm i's labour productivity relative to the industry average; this is the dependent variable in our empirical applications.

We hypothesise that A_{ij} is potentially a function both of inherent characteristics of the firm (A^*_{ij}) and of the firm's speed of internet access. The type of internet access is split into broadband – which, in turn, may be split into fast broadband (cable) and slow broadband (i.e. all other broadband types) – and no broadband (including both dial-up and no internet access). We hypothesise that, ceteris paribus, firms with fast broadband will be more productive than firms with slow broadband which in turn will be more productive than firms without broadband access.

The ceteris paribus assumption is important since broadband access may be correlated with variables that influence A^*_{ij} and some of these variables may also influence choice of internet access. We address this issue by estimating an internet access discrete choice equation, then matching each 'treated' firm with a set of 'control' firms where the treated firm and control set have similar likelihoods of choosing the treatment. The treatment versus control options are variously modelled as: (i) having broadband (treatment) versus no broadband (control); (ii) having fast broadband (treatment) versus slow broadband (control); and (iii) having slow broadband (treatment) versus no broadband (control). In order to determine (i), we estimate a probit equation that splits firms into the two categories (broadband versus none). For categories (ii) and (iii), we estimate an ordered probit equation that divides firms into the three categories of fast, slow and no broadband. We use the same explanatory variables across the two equations.

Given prior studies, we hypothesise that a firm's internet access choice is determined by a range of factors (our alternative hypotheses, relative to the null of no effect, are outlined in parentheses): firm size (positive, reflecting resource availability within the firm, possibly with a non-linear effect); firm age (negative, reflecting older management); industry structure facing the firm (perfectly competitive firms may gain less from broadband adoption than other firms); the quality of ICT infrastructure in the firm's locality (positive); the knowledge of the firm's management regarding ICT issues (positive); application of 'modern' general management approaches within the firm (positive, reflecting openness to new ideas that may boost productivity); knowledge intensity of the firm's sector and whether the firm conducts R&D (both positive, reflecting greater need for information flows for high knowledge intensity sectors); being foreign-owned (positive, reflecting a need for communication with the parent and receipt of parental experience with improved connectivity); and the firm itself having a foreign subsidiary (positive, reflecting a need for communication with the subsidiary).

We examine data relating to each of these variables, together with labour productivity data, in the next section. Productivity data are used as the treatment outcome variable. It is possible that the firm's inherent productivity (A^*_{ij}) is one determinant of the firm's internet access choice. We cater for this possibility by also including the firm's five-year lagged productivity as an explanatory variable in the broadband prediction equations. Thus lagged productivity is one of the variables on which we match firms. This mitigates the potential problem that the observed productivity treatment effect may be due to inherently more productive firms adopting faster internet access.

In section 3, we provide descriptive data for uses of the internet by firms with differing internet connectivity. These latter variables are not used, however, when we estimate firms' probability of being treated since patterns of internet usage are likely to be endogenous to the firm's internet choice.

3 Data

Our data are obtained from two sources. First, we access unit record responses to Statistics New Zealand's Business Operations Survey 2006 (BOS06). This survey comprises three modules, A: Business Operations; B: Information and Communications Technology; C: Employment Practices. Each module includes detailed questions in relation to the individual respondent firm. The survey was posted to over 7,000 firms by Statistics New Zealand (Statistics NZ), the country's official statistical agency. Firms were selected from all firms within the country that had at least six employees[4] using random sampling within strata defined by sector and firm size. Each sampled firm is assigned a weight so that the weighted sample is representative of all firms with at least six employees in the economy. Unless otherwise specified, all descriptive statistics and estimation uses weighted data. Under the Statistics Act 1975, it is a compulsory requirement for respondents to complete the survey; in practice, this resulted in an 81.7% response rate (with 6,051 usable responses). The rigorous sampling from the universe of firms with at least six employees, coupled with the very high response rate, makes this an ideal source of information on firms' internet use and other characteristics.

Our second data source is Statistics New Zealand's prototype longitudinal business database (LBD) that links firm data derived from Statistics NZ's firm-based surveys and from various administrative sources to Statistics NZ's Longitudinal Business Frame, LBF (Seyb, 2003). The LBF contains descriptive information on each firm (e.g. sector, age, foreign-ownership status). The administrative data sources include firm tax data sourced from the Inland Revenue Department. The latter data enable us to formulate a measure of each firm's labour productivity defined as firm value added relative to the firm's employee count. We calculate labour productivity

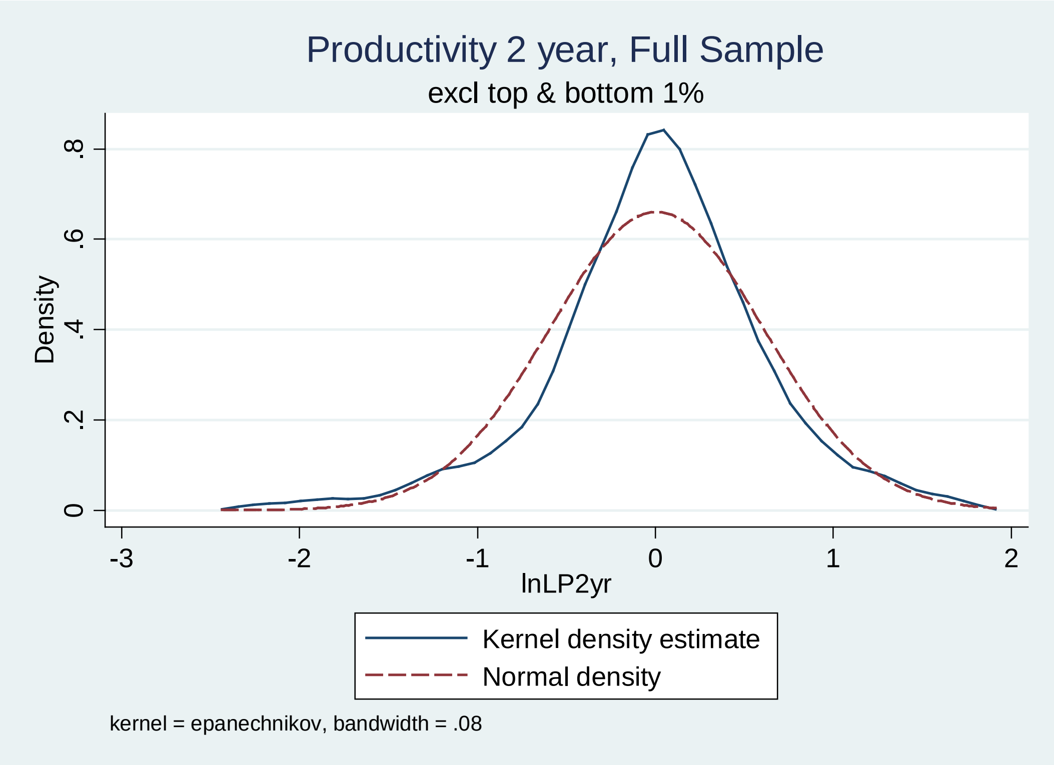
[4] Using a rolling mean employee (RME) count; see Statistics New Zealand (2006) for further details.

for a panel of years for each firm and for each four-digit sector.[5] In order to abstract from labour productivity differences attributable to differing sector capital intensities and other sector-specific characteristics, we express each firm's labour productivity as a ratio of the four-digit sector average. The sector average is calculated for all firms within the four-digit sector across the entire population of New Zealand firms. The resulting (log) labour productivity data therefore accord with $\ln(P_{ij})$ as defined in section 2.

The productivity variable used to measure the treatment effect, lnLP2yr, is the average of the firm's 2005 and 2006 (log) labour productivity (relative to the four-digit sector); we use the two year average to reduce noise in the data that may be due to timing effects in reporting value added components across years.[6] Figure 1 presents a kernel density graph of lnLP2yr for the firms in the BOS06 sample (excluding each of the top and bottom 1% of firms for confidentiality reasons), together with a normal density function. The productivity density is approximately normal albeit with greater density both at the mean and (fractionally) at each tail. Firm productivity (relative to the sector average) from 2001 is used as an explanatory variable in the prediction equations.

[5] In a very few cases we aggregate to the three-digit sector where numbers of firms for the four-digit sector calculation falls below 30 firms.
[6] We have also calculated the treatment effects using (unsmoothed) 2006 data and find similar results, albeit with slightly higher standard errors.

Figure 1: Log labour productivity (2 year)



We access a number of variables from BOS06. Our key variable relates to firms' internet access. Firms are asked a number of questions regarding their internet access, which we use to create a single index of internet access. Firms are asked whether they can access the internet or not; if so, they are asked whether they have broadband access[7], dial-up access only, or "don't know". If a firm has broadband access, it is asked the nature of that access from the following list: (i) DSL (including ADSL); (ii) cable; (iii) cellular; (iv) wireless; (v) satellite; (vi) don't know. Of these categories, we define cable as "fast broadband" and all others as "slow broadband". Within the cable category, fibre optic cable is included with other forms of cable (such as hybrid fibre coax). The match between 'cable' and 'fast' broadband is therefore imperfect, and this is one reason we compare 'broadband versus none' as well as 'fast broadband versus slow broadband versus none' in our empirical work.

Table 1 summarises the internet access modes recorded by all firms in the BOS06 sample. Data are presented for the numbers of sampled firms,[8] plus unweighted

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[7] Firms are asked if they have broadband access only, or have both broadband and dial-up access; we combine the two categories to a single broadband access category.

[8] All count data throughout the paper are randomly rounded to base 3 (a Statistics New Zealand confidentiality requirement); hence totals do not always add exactly.

and weighted percentages in each category. Using weighted data, 91% of firms have internet access, 76% have broadband access, while 7% have a cable connection.

Table 1: Internet access

Internet Access Mode		No. of Firms*	% of Firms	Weighted % of Firms
No Internet Access		282	4.66	9.16
Internet access:	- dial-up only	390	6.45	11.08
	- broadband (total)	5,145	85.03	76.40
	- don't know/DNA**	231	3.82	3.35
Broadband type:	- cable (fast)	786	12.99	7.46
	- other (slow)	4,359	72.04	68.94
Slow broadband:	- DSL	2,694	44.52	49.67
	- cellular	54	0.89	0.86
	- wireless	171	2.83	2.85
	- satellite	30	0.50	0.41
	- unknown	1,407	23.25	15.15
Total		6,051		

* All counts randomly rounded to base 3 for confidentiality reasons.
** DNA = did not answer.

Table 2 examines the propensity for firms with certain characteristics to have broadband (of any type) and to have fast broadband. In each case, we test whether the propensity for firms with that characteristic to have (fast) broadband is significantly different from the overall propensity to have (fast) broadband. These tests are all conducted without controls, so are simply descriptive. The prediction models in section 4 provide multivariate tests of significance.

Table 2: Who has broadband (BB)? (Full sample)

Firm characteristic		No. of firms*	Weighted % with BB*	Weighted % with fast BB*	% with BB cf Total (p-val)	% with fast BB cf Total (p-val)
Employees:	**- [6, 20]**	2,253	73.16	5.93	(0.0000)	(0.0000)
	- (20, 50]	1,605	84.61	9.53	(0.0000)	(0.0410)
	- (50, ∞)	2,193	92.02	18.23	(0.0000)	(0.0000)
Age (yrs):	**- [0, 5]**	1,281	72.89	7.35	(0.1488)	(0.9291)
	- (5, 10]	1,551	80.85	7.29	(0.0297)	(0.8754)
	- (10, ∞)	3,216	75.88	7.63	(0.7189)	(0.8151)
Foreign owned		912	93.36	19.55	(0.0000)	(0.0000)
Have foreign subsidiary		348	91.73	19.60	(0.0001)	(0.0011)
Competition:						
	- monopoly	258	76.15	7.89	(0.9534)	(0.8637)
	- oligopoly	1,002	77.33	6.01	(0.7633)	(0.1522)
	- Chamb. comp	3,216	80.52	7.90	(0.0023)	(0.5049)
	- perfect comp	1,173	73.76	9.34	(0.3260)	(0.2689)
Conduct R&D		609	87.47	15.33	(0.0057)	(0.0051)
Knowledge Intensity (KI):						
	- below median	2,931	72.29	6.37	(0.0109)	(0.1748)
	- above median	3,120	79.30	8.23	(0.0109)	(0.1748)
Management (MGMT):						
	- below median	2,874	71.02	5.80	(0.0000)	(0.0013)
	- above median	3,177	84.19	9.86	(0.0000)	(0.0013)
Quality of ICT in area:						
	- bad	621	64.48	3.32	(0.0019)	(0.0002)
	- mid	1,533	77.21	5.77	(0.7267)	(0.0427)
	- good	3,588	81.41	9.32	(0.0000)	(0.0005)
	- don't know	207	38.87	4.05	(0.0000)	(0.1480)
Firm has a webpage		4,140	90.20	11.48	(0.0000)	(0.0000)
Purchased G&S on internet		3,798	91.33	10.35	(0.0000)	(0.0000)
Entered new export market		384	91.80	14.13	(0.0000)	(0.0224)
% of sales made over internet:**						
	- 0	4,317	70.66	5.50	(0.0000)	(0.0004)
	- (0, 25]	1,524	93.15	11.68	(0.0000)	(0.0082)
	- (25, 100]	207	82.63	20.75	(0.5204)	(0.0850)
% internet sales international:						
	- 0	1,005	92.18	8.49	(0.4132)	(0.0180)
	- (0, 25]	549	91.51	22.15	(0.8411)	(0.0394)
	- (25, 100]	141	81.71	16.13	(0.3517)	(0.6910)
% sales from tourism:						
	- 0	5,316	76.36	6.95	(0.9505)	(0.3175)
	- (0, 25]	504	75.64	4.21	(0.8764)	(0.0043)
	- (25, 100]	231	78.34	19.62	(0.7781)	(0.0685)
Total		6,051	76.40	7.46		

* All counts randomly rounded to base 3 for confidentiality reasons.

** DK/DNA allocated to zero sales.

Small firms (those with 20 or fewer employees) are less likely than other firms to have general broadband (i.e. any kind of broadband) or fast broadband. Firm age has no significant association with fast broadband, and only mid-aged firms differ from the total in general broadband propensity (with slightly higher penetration). Foreign ownership (in both directions) is associated significantly both with greater general broadband and fast broadband penetration. By contrast, the firm's industrial market structure has no significant relationship with fast broadband adoption, and only one significant relationship with general broadband.[9] As expected, the nature of a firm's activities has a strong association with connectivity. Firms that conduct research and development (R&D) have much higher general and fast broadband penetration, and the degree of knowledge intensity of the firm's industry has a positive association with connectivity.

We calculate a direct measure of industry knowledge intensity. The question structure and stratified sampling of the BOS enables us to compile a knowledge intensity measure across sectors that is more graduated than a simple distinction between knowledge-intensive and other sectors used in other applications. BOS06 surveys the firm's total staff level and its composition according to four groupings: (i) managers and professionals; (ii) technicians and associate professionals; (iii) tradespersons and related workers (including apprentices); and (iv) all other occupations. We calculate the ratio of [(i)+(ii)]/total staff for firms within each three-digit industry (denoted KI).[10][11] Our prior is that connectivity is important for at least the first two categories of employee, so we use KI as our measure of knowledge intensity; each firm's KI is given by the value for its three-digit industry. Table 3 presents KI for each industry. This measure may have applicability for studies beyond the scope of this study.

[9] To assess market structure for each firm we use the firm's response to the question: "How would you describe this business's competition?" (BOS06 question A47). Choices, other than "don't know", and our shortened descriptor (in brackets) are: "captive market / no effective competition" (monopoly); "no more than one or two competitors" (oligopoly); "many competitors, several dominant" (Chamberlinian monopolistic competition [Chamb]); "many competitors, none dominant" (perfect competition).

[10] In a few cases, we split three-digit industries into finer distinctions where OECD information indicates a split between knowledge-intensive (KI) and other categories within the three-digit classification.

[11] We also produced another measure of knowledge intensity, calculated as the ratio of (i)/total staff for firms within each three-digit industry. The correlation between the two measures is very high as is their ranking of knowledge intensity across industries.

Table 3: Knowledge intensity by industry

Industry - 3 digit*	KI**
Business Services – "KI"	0.7478
Services to Finance and Insurance	0.4839
Health Services	0.4416
Electricity, Gas & Water Supply	0.4215
Finance & Insurance	0.4155
Education	0.4093
Business Services	0.3919
Rail Transport	0.3586
Machinery & Motor Vehicle Wholesaling	0.3308
Motion Picture, Radio and TV Services	0.3112
Property Services	0.3112
Manufacturing – "KI"	0.2697
Mining	0.2697
Communication Services	0.2615
Printing, Publishing and Recorded Media	0.2331
Personal & Household Good Wholesaling	0.2243
Air & Space Transport, water transport and storage	0.2238
Basic Material Wholesaling	0.2229
Agriculture	0.2096
Commercial Fishing	0.2054
Machinery and Equipment Manufacturing	0.2031
Service to Transport	0.1829
Sport and Recreation	0.1723
Personal & Household Good Retailing	0.1721
Petrol, Coal, Chemical & Assoc Prod Mfg	0.1706
Forestry and Logging	0.1698
Motor Vehicle Retailing and Services	0.1674
General Construction	0.1673
Metal Product Manufacturing	0.1658
Non-Metallic Mineral Product Manufacture	0.1577
Other Manufacturing	0.1570
Food, Beverage and Tobacco Manufacturing	0.1522
Community Services	0.1510
Construction Trade Services	0.1477
Textile, Clothing, Footwear, Leather Mfg	0.1461
Accommodation, Cafes & Restaurants	0.1291
Wood & Paper Product Manufacturing	0.1220
Services to Agric, Hunting and Trapping	0.1132
Food Retailing	0.0995
Road Transport	0.0915

* Where an industry has a "KI" suffix, the industry includes a finer gradation than the 3-digit level, corresponding to OECD (2003c) definitions of knowledge-intensive sub-sectors.
** KI = proportion of total staff who are "managers, professionals, technicians or associate professionals".

One of our hypotheses is that the firm's general management capability is related to its likelihood of adopting better ICT systems, including faster internet access. We use the rich question structure of BOS06 to formulate a proxy for each firm's general management capability. Module C contains ten questions on employment practices, each of which can be considered a component of a suite of 'high performance work systems' (Fabling and Grimes, forthcoming). Table 4 sets out the ten questions. We calculate the ten principal components for these questions and associated eigenvalues. The first eigenvalue (4.53) is more than four times the size of the second eigenvalue (1.09), summarising almost one half of the information in the responses to the ten questions. Given its dominance, we adopt the first principal component (MGMT) as our measure of each firm's general management capability.

Table 4: General management capability variable (MGMT)

Questions forming basis of MGMT principal component*

Does this business have any of the following practices in place on a formal basis for any non-managerial employees?

- employee feedback programmes (e.g. satisfaction surveys);
- flexible job design (e.g. job rotation);
- information sharing (e.g. joint management/staff meetings, information on performance or changes);
- problem-solving teams (e.g. teams limited to specific areas such as quality or work flow);
- employees engaged in regular decision making;
- employee participation in health and safety;
- performance reviews;
- childcare (allowances or facilities);
- being able to buy extra annual leave or take leave without pay;
- using personal sick leave, unpaid leave or compassionate care leave to care for other people who are sick.

Principal Component**	Eigenvalue
Component 1 (denoted MGMT)	4.53075
Component 2	1.09004
Component 3	0.89271
Component 4	0.86988
Component 5	0.66726
Component 6	0.56015
Component 7	0.42061
Component 8	0.37622
Component 9	0.33234
Component 10	0.26005

* Each question can either be answered Yes or No.
**Principal components are calculated using tetrachoric correlations.

Table 2 indicates that firms with above median values for MGMT have a significantly greater likelihood of having general and fast broadband than do below median firms. The questions on which the management variable is based have no direct relationship with ICT use in general (or internet connectivity in particular); hence any significant impact of MGMT on broadband choice is unlikely to be driven by reverse causality.

BOS06 questions firms on the quality of a range of infrastructure in their local area. One question specifically asks the firm to rate whether "information and communications technology (e.g. broadband availability, mobile phone coverage)" is "bad", "neither bad nor good" (which we denote "mid"), "good" or "don't know". Table 2 shows that the "bad/mid/good" responses to this question are related strongly to firms' adoption of both general and fast broadband with the expected relationships. One strength of the BOS design is that many questions give the option of a "don't know" response. Firms that indicate they don't know about the quality of ICT infrastructure in their area are far less likely to adopt general broadband even than those faced with bad ICT conditions. This response is indicative of a lack of ICT capability within the firm.

One reason that a firm may not have broadband, and especially fast broadband, is that the service may not be available in the firm's locality. A complication that arises in interpreting answers with respect to broadband adoption, and similarly for responses to the quality of local ICT infrastructure, occurs with multi-plant firms. In these cases, the nature of internet access could differ across plant locations for the same firm. In these situations, the BOS06 ICT infrastructure quality question directs the firm to respond in relation to the location where the largest share of the business's activities occur.

In our econometric work, we address the issue of multi-plant firms in two ways. For the full sample results, we adhere to the BOS06 guideline, and consider that the firm has answered relevant questions with respect to its largest operation. This approach may introduce noise in cases where internet access differs across plants. Our alternative approach reduces the sample size and considers just single plant firms. This results in a cut in the sample size for the probit equations determining broadband adoption from 5,598 (full sample) to 4,110 (single plant firms).

Table 5: Geographic distribution of broadband

TLA Group	Full sample weighted % with broadband	Single plant weighted % with broadband
Far North District+Kaipara District	75.84	75.91
Whangarei District	82.54	81.10
Rodney District	73.09	71.00
North Shore City	79.91	78.89
Waitakere City	72.88	72.92
Auckland City	89.79	88.32
Manukau City	80.45	81.73
Papakura District+Franklin District	75.38	72.88
Thames-Coromandel District+Hauraki District+Waikato District +Matamata-Piako District+Waipa District+Otorohanga District +South Waikato+Waitomo District	60.67	56.44
Hamilton City	84.54	85.87
Taupo District+Western Bay of Plenty District+Whakatane District+Kawerau District+Opotiki District	65.72	61.16
Tauranga City	61.85	51.78
Rotorua District	71.88	73.09
Gisborne District+Wairoa District	58.39	54.93
Hastings District+Napier City	67.73	66.43
Central Hawke's Bay District+Tararua District+Masterton District+Carterton District+South Wairarapa District	71.65	67.39
New Plymouth District	67.95	76.04
Stratford District+South Taranaki District+Ruapehu District +Wanganui District+Rangitikei District+Manawatu District	61.51	69.21
Palmerston North City	71.01	66.55
Horowhenua District+Kapiti Coast District+Porirua City	69.70	62.75
Upper Hutt City+Lower Hutt City	76.68	69.99
Wellington City	89.61	91.69
Tasman District+Nelson City	71.27	70.74
Marlborough District	73.03	70.76
Kaikoura District+Buller District+Grey District+Westland District+Hurunui District+Waimakariri District	79.84	78.38
Christchurch City	83.67	84.83
Selwyn District+Ashburton District+Timaru District+Mackenzie District+Waimate District+Waitaki District	69.73	74.31
Central Otago District+Queenstown-Lakes District	83.96	81.46
Dunedin City	68.85	68.39
Clutha District+Southland District+Gore District	47.47	44.09
Invercargill City	86.99	88.44
Total	**76.40**	**75.35**

The association of location with internet access type can be seen from Table 5 that divides New Zealand into 31 groups of Territorial Local Authorities (TLAs); each geographical grouping includes at least 40 firms (as sampled in BOS06) and at least 9 firms with (and without broadband). In some cases, a group comprises a single TLA; in other cases, TLAs have been grouped together according to contiguity and similar rural/urban characteristics. For each geographical grouping, the table presents the (weighted) percentage of firms that had general broadband in 2006. The percentages are presented both for single plant firms and for the full sample. Across the two samples, proportions of general broadband adoption vary between 44% and 92% by area.

In 2006, fast broadband (cable) was primarily available in major cities, particularly Wellington/Hutt Valley, and Christchurch. Table 6 presents the same information as Table 5, but pertaining only to fast broadband for major city areas (plus all other areas grouped together).[12] The geographic location of a firm in relation to general and fast broadband provision can be considered a random element in deciding whether the firm receives (fast) broadband treatment or not.

Table 6: Geographic distribution of fast broadband

TLA Group	**Full sample weighted % with broadband**	**Single plant weighted % with broadband**
Auckland City	11.19	9.37
Upper Hutt City+Lower Hutt City	32.83	35.00
Wellington City	19.60	17.27
Christchurch City	16.50	13.86
All other areas	4.01	3.26
Total	**7.46**	**6.23**

Table 2 indicates a strong association between firms that use the internet for business purposes and the prevalence of general and fast broadband adoption. For example, 92% of firms that make internet sales have a broadband connection whereas only 71% of firms that make no internet sales have broadband. Over 90% of firms that have a webpage, purchase goods and services over the internet, and have recently entered a new export market have broadband. One surprising statistic is the only moderate adoption of general broadband by firms involved in tourism, possibly reflecting many tourist operators being located in rural areas that have relatively low broadband availability.

The differences in broadband adoption according to firm characteristics (Table 2) has the corollary that firms with differing internet access types, on average, have different characteristics from firms with other access types. Table 7 summarises characteristics of firms from the full sample according to internet access type in relation to key variables used in our predictive models of section 4. The variables correspond closely to the variables in the top portion of Table 2. One exception is market competition where the variables "monopoly", "oligopoly" and "Chamberlinian monopolistic competition" are reduced to a single variable, "imperfect competition", based on tests in which we could not reject the hypothesis of identical coefficients for the three competition variables. We also omit the "mid" category for ICT quality since this is the omitted category for that question in the prediction equations.

For each variable, the table presents the p-value for two F-tests: (a) a test of the difference between means for firms with fast broadband versus slow broadband; and (b) a test of the difference between means for firms with slow broadband versus firms with no broadband. We find a clear gradation between firms with fast, slow and no broadband respectively for firm size (firms with broadband tend to be larger), quality of local ICT infrastructure, having foreign ownership and/or a foreign subsidiary, having an R&D operation, sector knowledge intensity and general management quality. In addition, there is a clear distinction between having broadband (fast or slow) versus none for firms that don't know about the quality of local ICT infrastructure and for firms in imperfectly relative to perfectly competitive markets. Firm age appears unrelated to broadband adoption. Table 8, which summarises characteristics for firms in the single plant sample, shows very similar patterns.

[12] A majority of firms that report having fast broadband within 'all other areas' are situated in Kapiti Coast District which had a cable service in 2006.

Table 7: Characteristics of firms with fast, slow & no broadband (full sample)

Variable*	Mean			F-test of difference in means; fast v slow [p-value]	F-test of difference in means; slow v none [p-value]
	Fast	Slow	None		
SIZE (Employees)	78.6	29.0	11.5	0.0000	0.0000
AGE (Years)	14.6296	13.2355	13.7569	0.3134	0.6636
ICT-GOOD	0.7051	0.5906	0.4327	0.0032	0.0001
ICT-BAD	0.0495	0.0988	0.1860	0.0071	0.0018
ICT-DK	0.0248	0.0231	0.1065	0.9111	0.0004
IMP-COMP	0.7049	0.7381	0.6141	0.5108	0.0015
FOWN	0.1774	0.0725	0.0135	0.0000	0.0000
FSUB	0.0735	0.0293	0.0046	0.0028	0.0000
R&D	0.1331	0.0678	0.0341	0.0146	0.0300
KI	0.3997	0.2827	0.1896	0.0000	0.0000
MGMT	0.8702	0.7907	0.5586	0.0249	0.0000
lnLP2yr	**0.0035**	**-0.0365**	**-0.1666**	**0.5713**	**0.0013**

* Variables in Tables 7, 8 & 9 are defined in the Appendix (with sources)

Table 8: Characteristics of firms with fast, slow & no broadband (single plant)

Variable	Mean			F-test of difference in means; fast v slow [p-value]	F-test of difference in means; slow v none [p-value]
	Fast	Slow	None		
SIZE (Employees)	22.7	16.6	10.8	0.0029	0.0000
AGE (Years)	11.8615	12.62939	13.5962	0.5492	0.4621
ICT-GOOD	0.7059	0.5975	0.4328	0.0266	0.0002
ICT-BAD	0.0474	0.0918	0.1732	0.0596	0.0040
ICT-DK	0.0289	0.0247	0.0911	0.8493	0.0012
IMP-COMP	0.7168	0.7311	0.6175	0.8193	0.0061
FOWN	0.1307	0.0633	0.0147	0.0094	0.0000
FSUB	0.0610	0.0265	0.0037	0.0564	0.0001
R&D	0.1616	0.0653	0.0189	0.0095	0.0000
KI	0.4094	0.2822	0.1873	0.0003	0.0000
MGMT	0.8490	0.7823	0.5319	0.1653	0.0000
lnLP2yr	**-0.0055**	**-0.0530**	**-0.1807**	0.5968	0.0061

Also included in Tables 7 and 8 are data for the mean log labour productivity measure (lnLP2yr). Both tables indicate a significant "raw" productivity differential of approximately 13% for firms that have slow broadband relative to those that have none. There is a 4-5% productivity differential, on average, between firms with fast and slow broadband, but this difference is not significantly different from zero in either sample. In each case, these are raw productivity differences, i.e. prior to incorporation of any controls. We control for firm characteristics that may influence internet access type in the next section.

4 Matching Models and Treatment Effects

4.1 Methodology

We control for confounding influences on productivity by estimating probit and ordered probit models to predict each firm's connectivity type. In our basic approach, firms are separated into broadband (treatment) and no broadband (control) groups and their propensity to have broadband is estimated using a probit model. In this approach, firms with all types of broadband connection are included in the treatment group. In our extended approach, we estimate an ordered probit model with three types of firm: those with fast broadband (cable), those with slow broadband (all other broadband types) and those with no broadband. This approach technically enables us to differentiate between three broadband dichotomies: fast (treatment) versus slow (control); slow (treatment) versus none (control); and fast (treatment) versus none (control). In reporting our results, we exclude the last of these comparisons since these results reflect the combined effects of the first two dichotomies.

Tables 5 and 6 showed considerable diversity of broadband uptake across regions, with a discernable urban/rural split (i.e. according to population density). We account for this factor by ranking all TLAs according to their population density (in 2001) and forming a variable (HIDEN) for those authorities that have a density of at least 200 people per km^2. Palmerston North is the least dense of this group with 214 people/km^2, over twice the density of the next densest TLA, Invercargill (102 people/km^2). One anomaly is that Dunedin City (New Zealand's sixth largest city, with a major university) is excluded from the high density group owing to inclusion of a large rural hinterland within its boundaries. Most Dunedin firms are located in the city proper, and so we include Dunedin in the HIDEN group.[13] We deal with the two groups in two separate ways. First, we include HIDEN as a separate variable in the prediction equations. This allows a level shift in probabilities between firms located in high and low density areas. Second, we estimate separate equations for firms in the high and low density authorities, and subsequently calculate separate treatment effects for urban and rural areas. Results from this latter approach are

[13] The HIDEN group includes the following TLAs: North Shore City, Hamilton City, Christchurch City, Wellington City, Tauranga District, Manukau City, Napier City, Waitakere City, Auckland City,

particularly relevant to policy debates about whether broadband (fibre) roll-outs should be focused primarily on urban or rural areas.

We are most confident about the connectivity data for single plant firms, for reasons already discussed. We therefore estimate the ordered probit models solely for the single plant sample. Furthermore, since cable is rarely available in low density areas, we do not estimate the ordered probit equation for the rural sub-set of firms. The probit models (broadband versus none) are presented for both the full sample and the single plant sample (all areas, and urban and rural sub-samples). We use each of the eight prediction equations to calculate propensity scores where the propensity score is the conditional probability of a firm within the relevant sample receiving the relevant treatment, given the covariates included in the prediction model (Rosenbaum and Rubin, 1983). The scores are used to match treated firms with suitable controls (using two different matching methods) thereby enabling us to determine the average treatment effect for the treated firms (ATT).

Extensive discussions of PSM models are provided in Caliendo and Kopeinig (2008), Dehejia and Wahba (2002), and Becker and Ichino (2002).[14] A key element required to implement the PSM approach is that firms with similar propensity scores must look the same statistically whether or not they have been treated. In order to test this 'balancing hypothesis', we split each sample into five or more strata according to their propensity score.[15] Within each stratum, we perform a t-test of the means of the covariates for treated and control firms. If all differences are insignificant, the balancing hypothesis is met. This property holds for each variable across all equations at the 0.1% significance level. For the four equations with the most homogeneous samples (single plant, high and low density; probit and ordered probit), the balancing hypothesis holds at (a minimum of) the 1% level, as is also the case for the full plant high density sample.

For our basic model (broadband versus none), the number of treated firms is over four times the number of control firms. We take account of this

Papakura District, Kawerau District, Porirua City, Lower Hutt City, Palmerston North City, Dunedin City. The variable HIDEN=1 for firms in these TLAs and 0 otherwise.

[14] Becker and Ichino (2002) outline the Stata programmes that form the basis of our application.

[15] The number of strata is determined by the requirement that we cannot reject the average propensity scores for treated and control firms being equal within each stratum; we begin with five strata in each case, and reduce the stratum width (i.e. increase the number of strata) until this requirement is met.

characteristic by choosing matching methods that use multiple control firms for each treated firm rather than using nearest neighbour matching. The latter would have to assign each control firm to at least three or four different treated firms which could create considerable noise in cases where a few control firms had large idiosyncratic productivity determinants. Instead, we choose strata matching and kernel matching approaches. Kernel matching utilises the full set of controls, with weights assigned according to the 'closeness' of control firms to the treated firm. Weights are inversely proportional to the distance between the propensity scores of the treated and control firms.[16] Compared with nearest neighbour matching,[17] the declining weight kernel specification (adopted here) trades off greater bias for lower variance. The greater bias arises because we do not choose the closest potential match for each treated firm, but the spreading of weights across numerous controls reduces the chance of a match to a large idiosyncratic outlier, so reducing variance. Strata matching adopts the strata used to test the balancing hypothesis for each model and computes the within stratum average treatment effect as the average of the outcome for the treated firms minus the average for the untreated firms in that stratum. The overall ATT is calculated as the weighted average treatment effect across the strata where the weights depend on the fraction of treated firms across the strata. Standard errors are calculated analogously.

4.2 Prediction Models

We begin by estimating the probit (and ordered probit) models for whether firms have broadband or not (respectively have fast, slow, no broadband). The probit models are estimated both for the full sample and single plant sample; the ordered probit models are estimated only for single plant firms.

SIZE (number of employees) is entered as a quadratic to account for potential non-linear effects. One complication is that SIZE may be endogenous with respect to broadband adoption, since if broadband affects firm performance, firm size may change as a result. In order to account for this possibility, we enter SIZE as the employment level of the firm lagged five-years (which is enabled by the

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[16] We use the default kernel and bandwidth from Becker and Ichino (2002). Both our kernel and strata matching methods are restricted to areas of common support.

[17] Nearest neighbour matching is a special case of kernel matching where a weight of one is placed on the control firm that is closest to the treated firm, with zero weights on all other firms.

longitudinal element of the LBD). Some firms surveyed in 2006 did not exist five years prior and therefore have no lagged employment level. We deal with this situation by recording these firms' (lagged) SIZE as zero and including a dummy term in the prediction equation (SIZEMISS) where SIZEMISS=1 if the firm had zero employment (i.e. did not exist in an economically significant form) in 2001 (and 0 otherwise).[18]

Other variables included in the prediction equations are a constant plus: firm age in years (AGE), good local ICT infrastructure (ICT-GOOD), bad local ICT infrastructure (ICT-BAD), don't know about local ICT infrastructure (ICT-DK), a dummy if the firm is in an imperfectly competitive sector (IMP-COMP), a dummy if the firm is foreign-owned (FOWN), a dummy if the firm has a foreign subsidiary (FSUB), a dummy if the firm conducts research and development (R&D), the management quality variable (MGMT), the relevant sector's knowledge intensity (KI), and a dummy if the firm is located in a high density area (HIDEN) where this latter variable is included only for the all-density samples. (High density and low density sub-samples are chosen on the basis of whether HIDEN =1 or =0 for the firm.)

[18] We also estimated the equations dropping all firms that had zero employment in 2001; results are robust to this change and so are not reported separately.

Table 9: Prediction Models[a]

	FULL PLANT SAMPLE			SINGLE PLANT SAMPLE				
	Probit			Probit			Ordered Probit	
Density	**All**	**High**	**Low**	**All**	**High**	**Low**	**All**	**High**
SIZE (Lagged)	0.0034*** [3.3959]	0.0032*** [3.2251]	0.0050* [1.9182]	0.0056** [2.5455]	0.0047* [1.8515]	0.0088 [1.6086]	0.0059*** [3.6009]	0.0056*** [2.9574]
$SIZE^2$ (Lagged)	-0.0000*** [3.2603]	-0.0000*** [3.0083]	-0.0000* [1.8913]	-0.0000** [2.2773]	-0.0000* [1.6542]	0 [1.0804]	-0.0000*** [2.7571]	-0.0000** [2.2956]
SIZEMISS	0.0516 [0.2975]	-0.1131 [0.5908]	0.2687 [0.9459]	0.0933 [0.5575]	-0.0516 [0.2477]	0.351 [1.3180]	0.0605 [0.3787]	-0.0799 [0.4260]
PROD (Lagged)	-0.1079 [1.5509]	-0.0951 [1.1012]	-0.068 [0.7353]	-0.0663 [0.9288]	-0.057 [0.5760]	-0.0596 [0.6467]	-0.0374 [0.6805]	-0.0231 [0.3132]
PRODMISS	-0.2176 [1.3587]	-0.1267 [0.7605]	-0.2845 [1.0236]	-0.2083 [1.3718]	-0.1454 [0.7824]	-0.3737 [1.4484]	-0.0583 [0.4228]	0.0177 [0.1118]
AGE	-0.0059** [1.9896]	-0.0088*** [2.6790]	-0.0023 [0.4531]	-0.0064* [1.7717]	-0.0108*** [2.5957]	-0.0027 [0.4567]	-0.0044 [1.3716]	-0.0068* [1.6995]
ICT-GOOD	0.0735 [0.6978]	0.1519 [1.1742]	0.0183 [0.1150]	0.1591 [1.4289]	0.2545* [1.7972]	0.011 [0.0666]	0.1714* [1.8697]	0.2116* [1.8708]
ICT-BAD	-0.3782*** [2.5829]	-0.2372 [0.9809]	-0.4145** [2.3029]	-0.3057** [2.0143]	-0.253 [0.9043]	-0.3904** [2.0991]	-0.2424* [1.7277]	-0.1383 [0.5089]
ICT-DK	-0.8069*** [4.0111]	-0.4464* [1.7433]	-1.5352*** [6.1061]	-0.6737*** [3.2520]	-0.3512 [1.2843]	-1.6455*** [5.6941]	-0.5878** [2.4990]	-0.2545 [0.8687]
IMP-COMP	0.2313** [2.4319]	0.0163 [0.1360]	0.4698*** [3.3120]	0.2298** [2.3232]	0.0532 [0.4026]	0.4815*** [3.3320]	0.1634 [1.6167]	0.0942 [0.7831]
FOWN	0.6348*** [4.5549]	0.5676*** [4.3780]	0.7108** [2.2805]	0.5600*** [3.5865]	0.6010*** [3.4844]	0.4958* [1.7118]	0.3717*** [3.9117]	0.3544*** [3.2715]
FSUB	0.5616** [2.1158]	0.4517 [1.5338]	0.6104* [1.8269]	0.3672 [1.3651]	0.37 [1.1276]	0.224 [0.4619]	0.227 [1.4176]	0.2166 [1.2029]
R&D	0.1772 [0.9242]	0.4365*** [2.8012]	-0.2009 [0.5787]	0.3888*** [2.6941]	0.4698*** [2.5936]	0.3484 [1.4175]	0.3810*** [3.2042]	0.4118*** [2.9118]
MGMT	0.5838*** [4.7983]	0.4573*** [2.9580]	0.7113*** [3.8677]	0.6704*** [5.3073]	0.5374*** [3.2264]	0.8132*** [4.3162]	0.5529*** [4.6959]	0.4353*** [2.8442]
KI	1.0562*** [5.2424]	0.9646*** [4.2089]	1.1832*** [3.3508]	1.0538*** [4.9720]	0.9433*** [3.7842]	1.2635*** [3.3655]	0.9258*** [5.6497]	0.9032*** [5.1003]
HIDEN	0.2045** [2.2355]			0.2086** [2.1330]			0.3029*** [3.2232]	
Obs.	5,598	4,284	1,632	4,110	2,823	1,287	4,110	2,820
Pseudo-R^2; (F-stat)	0.1288	0.0932	0.1841	0.1291	0.0977	0.1844	(9.5314***)	(5.3932***)
Blocks (FvS;SvN)[b]	19	11	30	11	6	7	7; 10	6; 5

[a] Constant included in all equations, but not reported. Robust z-statistics in parentheses; ***significant at 1%, **significant at 5%, *significant at 10%.
[b] All equations balance at the 1% level (or higher) other than columns 1, 3 and 4 (balance at 0.1%).

Table 9 presents the results for each of the eight probit and ordered probit prediction equations. Several consistent findings emerge. Larger firms have greater uptake of faster internet modes, although the marginal effect in almost all cases diminishes with size. Strong results are obtained for the importance of the quality of management (positive, always significant at 1%), knowledge intensity of the sector (positive, always significant at 1%), foreign ownership (positive, significant at 5% in all but one case), and, for the all-density samples, the urban/rural dummy variable (positive, always significant at 5%). Other generally consistent results across equations include impacts of firm age (negative), firm R&D (positive), competitive market structure (perfectly competitive firms have less uptake of broadband), lack of ICT knowledge within the firm (negative), good and bad local ICT infrastructure (positive and negative respectively), and having an overseas subsidiary (positive).

Lagged firm productivity is negative in each equation, but is never significant. This is important for our study since it indicates that any estimated positive treatment effects cannot be attributed to reverse causality, i.e. to inherently high productivity firms adopting (fast) broadband. (If the consistent negative coefficient were taken to indicate a true negative relationship between a firm's productivity and broadband adoption, the implication could be that formerly less productive firms subsequently adopt faster internet access in an effort to raise their productivity.)

The significance of HIDEN in the all-density equations indicates that there is at least a level shift in propensity to adopt broadband between urban and rural areas. A comparison of the high-density versus low-density equations suggests that some variables are more important in urban and rural areas respectively. For instance, bad local ICT infrastructure has a greater negative effect on broadband uptake in rural than urban areas, likely reflecting greater diversity of infrastructure standards in low-density authorities than in high-density (larger urban) areas. Lack of ICT knowledge also has much greater effect in rural than urban areas, consistent with greater knowledge spillovers between firms in urban areas. The conduct of R&D within the firm is significant in high-density areas, but not in low-density areas reflecting a general lack of R&D facilities outside major cities. Market structure is more important in rural than urban areas, possibly reflecting differing degrees of firm competition between the two types of area. These urban/rural differences make it important to interpret the ATT results for the separate area types as well as for the all-density samples.

Table 10 presents estimated average treatment effects (ATTs) for firm productivity based on the prediction equations in Table 9. We concentrate initially on the estimates of the treatment effects of moving from no broadband to broadband (of any type). All twelve estimates[19] are positive and significant (at the 5% level or less) with the ATT point estimates ranging from 0.073 (7.6% productivity improvement) to 0.122 (13.0% productivity improvement). The low-density samples indicate slightly higher productivity gains than do the high-density samples, but there is not a statistically significant difference between them.[20]

[19] I.e. six separate samples - all/single plants by all/high/low density - each with two matching techniques.

[20] To test robustness, we have calculated the ATTs excluding the top and bottom 1% of firms by productivity in case these data are spurious. The magnitude of results is similar for the all density and high-density samples, but the low-density ATT is now slightly lower than the high-density ATT, albeit again not statistically significantly different. Even if there were a difference in urban versus rural effects, this study is not a cost-benefit analysis since costs of infrastructure provision in different areas are not included here.

Table 10: ATT estimates, Relative Labour Productivity (lnLP2yr)
Based on prediction equations in Table 9

	N. Treated*	N. Control*	ATT	Std. Err.**	*t****
Full Sample; all-density; broadband versus none					
Stratified	4,632	795	0.087	0.032	2.698
Kernel	4,632	786	0.114	0.033	3.450
Full Sample; high-density; broadband versus none					
Stratified	3,474	426	0.073	0.043	1.713
Kernel	3,477	426	0.098	0.034	2.851
Full Sample; low-density; broadband versus none					
Stratified	1,203	378	0.113	0.045	2.543
Kernel	1,206	378	0.119	0.058	2.049
Single Plants; all-density; broadband versus none					
Stratified	3,069	675	0.100	0.041	2.442
Kernel	3,072	675	0.122	0.029	4.216
Single Plants; high-density; broadband versus none					
Stratified	2,061	273	0.089	0.048	1.837
Kernel	2,061	273	0.112	0.043	2.600
Single Plants; low-density; broadband versus none					
Stratified	852	324	0.114	0.055	2.076
Kernel	852	327	0.114	0.056	2.026
Single Plants; all-density; slow versus no broadband					
Stratified	2,688	681	0.091	0.033	2.802
Kernel	2,688	681	0.120	0.030	4.008
Single Plants; high-density; slow versus no broadband					
Stratified	1,863	351	0.099	0.046	2.165
Kernel	1,863	348	0.099	0.041	2.437
Single Plants; all-density; fast versus slow broadband					
Stratified	369	2,685	-0.024	0.051	-0.475
Kernel	369	2,688	0.002	0.045	0.041
Single Plants; high-density; fast versus slow broadband					
Stratified	342	1,863	-0.034	0.037	-0.921
Kernel	345	1,863	-0.018	0.056	-0.314

* All counts have been randomly rounded to base 3 for confidentiality reasons.
** Kernel standard errors are calculated using a bootstrap with 60 replications.
*** Critical values for the t-statistic (one-tailed test) at 1%, 5% and 10% are: 2.326, 1.645 and 1.282 respectively; a one-tailed test is appropriate since our alternative hypothesis is that the treatment raises productivity of the treated firm.

For the single plant (all-density and high-density) samples, the effects of shifting from no broadband to slow broadband are estimated to be of similar magnitudes (and similar significance) to the impact of moving to broadband in general. This is to be expected given that the majority of broadband connections in the sample are included in our definition of slow broadband. The average of the two all-density estimates indicates a productivity gain of 11.1% arising from adoption of slow broadband relative to no broadband. This compares with a raw productivity difference (before adding any controls) of 13.6% between single plants with slow broadband relative to none (from Table 8). Thus approximately a fifth of the differing productivity measures between the two sub-sets of firms is accountable by observable factors (including lagged firm productivity), with four-fifths attributable to the differing broadband status.

A quite different result emerges for the shift from slow to fast broadband. Our ATT estimates indicate no significant impacts arising from such a shift. In other words, our estimates imply no average firm productivity improvement as a result of a shift from say an ADSL connection to a cable connection. (We discuss why this may be the case in the Conclusions.) For this comparison, our controls play a major role in explaining productivity differences between the two sub-samples of firm. Table 8 indicates a raw average productivity difference between firms with fast relative to slow broadband of 4.9%. The approximately zero estimated ATT (after controlling for firm characteristics) suggests that this difference is attributable to inherently more productive firms adopting cable rather than a productivity-enhancing effect arising from cable adoption.

5 Conclusions

Much has been written in the popular press of the benefits of the internet revolution, and of the even greater benefits that could be brought about by linking firms (and households) to the internet through fibre optic cable. Yet, despite huge investment budgets associated with broadband (especially fibre) roll-outs, there has been little rigorous supporting evidence indicating that such connectivity brings material productivity benefits. Our study is the first, internationally, to estimate the productivity impacts of connectivity upgrades using firm level data after controlling for firms' connectivity choices based on their characteristics. The study utilises a representative, economy-wide sample survey, the Business Operations Survey 2006 (BOS06), of firms with at least six employees undertaken by Statistics New Zealand, commanding an over 80% response rate.

Amongst the sample of 6,051 firms, 13% have a fast (cable) broadband connection (7% when weighted), 72% (69%) have slow broadband; a majority of the remaining firms have a dial-up connection. Internet connection type is affected by the location of firms, with urban firms more likely to have broadband than rural firms; firms in the Wellington/Hutt and Christchurch areas are most likely to have a cable connection. Both our raw data comparisons between firms with and without (fast and general) broadband and our predictive probit models of connectivity type accordingly find that firms' urban/rural location and their assessment of local ICT quality helps to predict their internet access type.

Other strong predictors of connectivity choice are: firm size (larger firms choose faster connectivity), the firm's general management capability, being foreign owned, knowledge intensity within the firm's sector and (in urban areas only) R&D activity by the firm (all positively associated with connectivity). Sector market structure, firm age, ownership of a foreign subsidiary and firm-specific ICT knowledge also appear relevant.

Broadband-enabled firms are more likely to use the internet in their commercial transactions. In particular, they are more likely to have a webpage, to purchase goods and services over the internet, to enter new export markets and to make sales over the internet than firms without broadband. Perhaps curiously, tourism firms are no more likely to have broadband than other firms, possibly reflecting the geographic isolation of many firms in this industry.

In formulating variables to model connectivity choice, we derive two variables that may be of use in other studies. Our firm management capability variable (MGMT) is derived as the first principal component from ten questions relating to the firm's practices with regard to human resource matters. Despite its lack of direct ICT content, this variable proves to be a strong predictor of a firm's connectivity choices in keeping with our hypothesis that firms with high management capabilities will also tend to have high capability in other areas including ICT.

Our knowledge intensity variable (KI) is also a strong predictor of firms' connectivity choices. This variable is derived at the 3-digit (or finer) industry level from answers from all firms in the BOS06 survey. The industry stratification of the survey enables us to be confident that these figures are broadly representative for each 3-digit sector. We take the ratio of "managers, professionals, technicians and associate professionals" to total staff for firms across each sector and use this ratio to proxy the knowledge intensity of the sector. The resulting cardinal variable orders sectors in an intuitively appealing sequence that accords with other studies (e.g. OECD, 2007). A key benefit of our measure is that firms are not assigned to be in either a "knowledge-intensive" or "other" industry based on an arbitrary cut-off between the two groups; rather each sector has a value of between zero and one for its degree of knowledge intensity. It is likely that this variable could be used in other studies both in New Zealand and in similar economies internationally.

After estimating our prediction models for connectivity choices, we match each "treated" firm with a set of like "control" firms (both in terms of their estimated propensity to have broadband and on their observable characteristics). Two types of matching (kernel and stratified) are adopted to check robustness of results. We then estimate the average treatment effect for treated firms (ATT) across a range of samples. We focus on ATTs relating to shifts from: (i) broadband versus no broadband, (ii) slow versus no broadband, and (iii) fast versus slow broadband. We find a (levels) productivity effect of broadband relative to no broadband of approximately 10% across all firms. The estimates indicate a marginally stronger impact on firm productivity for firms in rural (low population density) relative to urban (high density) areas but the differences are not significantly different. Our estimates show that all of these productivity gains can be attributed to adoption of slow relative to no broadband, with no discernable additional effect arising from a shift from slow to fast broadband.

The finding that a move to fast broadband (cable) from any other form of broadband has no estimated effect should be interpreted with care. At least four explanations (other than an actual nil effect) could account for this result. First, our split between fast and slow broadband based on the distinction between cable and other broadband types may be a poor representation of differing internet speeds. In particular, 'cable' in New Zealand may include technologies with anything from average download speeds of 8Mbps to speeds of up to 1Gbps; by contrast, the average ADSL download speed is 5Mbps (Castalia, 2008). A distinction within the cable category, rather than between cable and other, may be more meaningful (but is unavailable within our dataset). Second, not all survey respondents may be aware of the technical nature of their firm's broadband connectivity type, introducing noise into the data. Third, the cable/other distinction may be meaningful but firms may have only recently adopted cable and are yet to achieve the full productivity benefits from doing so. Fourth, the productivity benefits of moving to fast broadband may currently only be relevant to a small proportion of firms, and so the full future benefits may not be apparent in the existing data. If this were the case, our average firm effect would not be appropriate as an estimate of future benefits of fibre upgrades across the full economy.

Future work could expand on our rural/urban distinction to test whether the benefits of a shift to (fast) broadband are greater for certain types of firm than others. This may include an examination of whether firms with greater propensity to adopt broadband (i.e. firms with a higher propensity score) also, on average, gain more from doing so. Alternatively, firms in certain sectors may gain more or less from broadband adoption reflecting factors that are separate from those captured by our knowledge intensity and other explanatory variables.[21] Current and future upgrades from ADSL to fibre across areas should produce a growing longitudinal sample of firms that gain faster internet access by virtue of an event exogenous to the firm (i.e. a spatially-specific upgrade to fibre). Until the data for such longitudinal analysis become available, we conclude that firms with faster connectivity make greater use of the internet in their commercial transactions. Furthermore, on the basis of our propensity score matching, we conclude that a shift to broadband connectivity (from dial-up) appears to raise firm productivity.

[21] Preliminary work found no evidence that the average treatment effect varies according to the likelihood of treatment (i.e. as the propensity score rises). However, we leave it to future work to test whether the ATT varies across other definitions of firm type (e.g. sector, R&D intensity, etc).

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Appendix Definitions of variables in Tables 7, 8, 9*

SIZE	Number of employees (Average of twelve monthly PAYE employee counts in the year. These monthly employee counts are taken as at 15th of the month.) plus working proprietors (Linked Employer Employee Database definition). Source: Statistics New Zealand (SNZ) prototype Longitudinal Business Database (LBD).
SIZEMISS	Dummy =1 if no 2001 employment data available (=0 otherwise). Source: LBD.
PROD	ln(labour productivity) = value added/employment (where employment given by SIZE), where value added is sales less purchases from the 'Business Activity Indicator' database (GST tax return, GST101). Source: LBD.
PRODMISS	Dummy =1 if no 2001 labour productivity data available (=0 otherwise). Source: LBD.
AGE	Number of years since establishment of the firm. Source: LBD.
ICT-GOOD	Dummy =1 if firm answers "good" to question: "When thinking about the city, town or district in which this business operates, how would you rate … information & communications technology infrastructure (eg broadband availability, mobile phone coverage)?" (=0 otherwise). Source: 2006 Business Operations Survey (BOS06/LBD).
ICT-BAD	Dummy =1 if firm answers "bad" to question: "When thinking about the city, town or district in which this business operates, how would you rate … information & communications technology infrastructure (eg broadband availability, mobile phone coverage)?" (=0 otherwise). Source: BOS06/LBD.
ICT-DK	Dummy =1 if firm answers "don't know" to question: "When thinking about the city, town or district in which this business operates, how would you rate … information & communications technology infrastructure (eg broadband availability, mobile phone coverage)?" (=0 otherwise). Source: BOS06/LBD.
IMP-COMP	Dummy =1 if firm answers either "captive market/no effective competition" or "no more than one or two competitors" or "many competitors, several dominant" to question: "How would you describe this business's competition?" (=0 otherwise). Source: BOS06/LBD.
FOWN	Dummy =1 if firm answers yes to the question "Did any individual or business located overseas hold any ownership interest or shareholding in this business?" (=0 otherwise). Source: BOS06/LBD.
FSUB	Dummy =1 if firm answers yes to the question "As at the end of the financial year, did this business hold any ownership interest or shareholding in an overseas-located business (including its own branch, subsidiary or sales office)?" (=0 otherwise). Source: BOS06/LBD.
R&D	Dummy =1 if firm answered "yes" to question "did this firm undertake or fund any research and development activities". Source: BOS06/LBD.
MGMT	Cardinal measure of firm's general management capability as derived in Table 4. Source: BOS06/LBD.
KI	Cardinal measure of knowledge intensity in the firm's 3-digit sector as derived in Table 3. Source: BOS06/LBD.
HIDEN	Dummy =1 if firm is located in a high-density area (i.e. within: North Shore City, Hamilton City, Christchurch City, Wellington City, Tauranga District, Manukau City, Napier City, Waitakere City, Auckland City, Papakura District, Kawerau District, Porirua City, Lower Hutt City, Palmerston North City, Dunedin City), (=0 otherwise). Source: LBD.
lnLP2yr	Average value of PROD over 2005 and 2006. Source: LBD.

*(Lagged) in Table 9 indicates that the 2001 value for this variable is included in place of the current value.

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