THE EMPLOYMENT AND WAGE IMPACT OF BROADBAND DEPLOYMENT IN CANADA

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Abstract

Billions of dollars are spent to subsidize broadband deployment worldwide. This paper provides the first empirical assessment of the impact of broadband on employment and wage growth in Canada. The variation in elevation is used to estimate the causal effect. It affects the cost of deploying broadband and so explains the regional difference in broadband coverage. We find that the deployment of broadband in 1997-2011 promoted rural employment and wage growth in service industries. Goods industries are not impacted. The findings suggest that broadband helps service industry businesses overcome geographical barriers that have traditionally hampered rural growth.

Keywords: Broadband; Employment growth; Wage growth

JEL classification: L9, O3, R1

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1 Introduction

Government subsidies for the broadband deployment total in hundreds of millions of dollars in Canada and billions worldwide. Much of these funds have been allocated to rural and remote areas, where commercially motivated broadband deployment is not viable.[1] Investments in broadband deployment served to spur economic activity in these areas and promote economic growth and development. It is commonly understood that broadband helps overcome geographical distance by providing individuals and firms in remote areas with opportunities similar to those that exist in metropolitan centres.[2] The evidence suggesting that Internet connectivity lowers the cost of doing business in distant locations supports this conclusion.[3] And while it has been over 15 years since the first introduction of broadband, our understanding of the actual economic impact of broadband availability is limited.[4] The major unresolved question is: How has the deployment of broadband impacted economic activity and regional growth?

This paper evaluates the impact of broadband deployment on regional employment and wage growth. Our analysis uses the National Broadband Coverage data, which provide detailed records of broadband availability across Canada at various points in time. Our sample covers 4,344 communities over the 1997-2011 period. The sample allows for a comparison between rural and urban regions and spans a long enough period to allow for the impact of broadband investment to be realized and quantified. The data's high level of detail and long time series also allow us to account for several econometric and

[1]Extending broadband to rural and remote communities has been a goal of the Federal Government of Canada since 2000. The major early initiative is the Broadband for Rural and Northern Development program, which was launched in September 2002 as a three-year pilot program. Over $80 million was invested through this program funding 63 projects for the implementation of networks to build broadband infrastructure. The major recent initiative is Broadband Canada: Connecting rural Canadians Program, which ran from 2009 until 2012 and invested $225 million into funding of 84 projects.

[2]The source: `http://www.cio.gov.bc.ca/cio/networkbc/faq/index.page?`.
For example, e-learning has been touted as the ultimate barrier-free form of education with several highly reputable universities offering lectures for free over the internet. The broadband also enables businesses to access distant markets to sell their products and procure supplies.

[3]See, for example, **?**.

[4]Broadband first appeared in Canada in 1997 (Czernich et al., 2011).

data challenges, but the key empirical challenge is to credibly identify a causal effect from broadband deployment to economic activity. We argue that geography provides the necessary source of exogenous variation in broadband deployment. Specifically, we use the variation in elevation within each region as the instrument. The rationale for the instrument is simple: elevation variation affects the cost of deploying broadband and so explains the difference in broadband coverage across regions.

We find that the deployment of broadband in 1997-2011 promoted growth in aggregate employment and average wages in rural regions across Canada. This impact is limited to service industries. Goods industries are not impacted. Our industry-level results are largely in line with the industry intensity of information technology use documented in Jorgenson et al. (2012). We also find that while broadband promoted employment growth in services in rural regions, it limited such growth in urban regions. This suggests that broadband helps businesses in service industries overcome geographical barriers that have traditionally hampered rural employment growth, and in so doing, limits the urban/rural employment gap. At the same time, rural and urban regions do not differ in their impact on wage growth.

To put the estimates into prospective, we evaluate the impact under the scenario that all communities within a given economic region moved from having zero broadband coverage in 1997 to being covered by any one broadband technology in 2012. Our estimates predict that in such a scenario, employment growth in service industries will rise by 1.17 percentage points per year in rural regions and fall by 1.21 percentage points per year in urban regions, while average wage growth in service industries will rise by 1.01 and 0.99 percentage points per year in rural and urban regions respectively.

Perhaps the biggest challenge in evaluating the economic effects of broadband deployment is that coverage can be endogenous to economic conditions. Many of the factors influencing broadband deployment are intricately connected to economic activity. Regional population density and income levels, for example, can impact the profitability of broadband deployment and also relate to corresponding regional economic activity. Furthermore, economic conditions themselves can, directly or indirectly, influence broadband deployment rates. This reverse impact is likely given that the Federal Government of Canada has focused on extending broadband to rural and remote communities that are unlikely to be served by market forces alone since the year 2000. These communities generally lag behind the others in terms of economic activity. For these reasons, mere correlation of economic activity and broadband deployment does not imply causation. In order to identify the true, causal impact of broadband, it is necessary to isolate exogenous variation in broadband deployment. We argue that elevation variation within each region could be used for this purpose.

Elevation variation affects the cost of deploying broadband. It is significantly cheaper to deploy broadband in areas with little elevation change. For example, microwave wireless systems, such as Multichannel Multipoint Distribution Service (MMDS), can cover a range of 100 kilometers over flat terrain but the coverage range is significantly reduced in mountainous areas. The variation in elevation is also an important consideration for the infrastructure cost of wired technologies. Corning (2005), for example, notes that the cost of installing buried wired technologies, such as fiber cable networks, is prohibitively high in mountainous areas. In the UK, fiber to the cabinet (FTTC) has been dismissed as a viable option in many regions of Scotland due to challenging terrain.[5] Our own correspondence with representatives from the Eastern Ontario Regional Network (EORN), which serves to provide high speed internet to residents and businesses in Eastern Ontario, further confirmed that the cost of installing broadband infrastructure is increased in areas with varying elevation.

Even if our instrument accounts for significant variation in broadband deployment, the instrument may nonetheless be invalid if it fails the exogeneity requirement. An important concern in this respect is that elevation variation could be directly related to economic

[5] The source: `http://www.scotnet.co.uk/services/rural-broadband-solutions/bet/`

activity. This relationship could arise, for example, because topography impacts the level of industry agglomeration (Rosenthal and Strange, 2008). To mitigate this concern, we measure employment and wages in growth rates, rather than levels. Additionally, we control for factors that may be related to elevation variation and affect employment or wage growth (i.e., population, population density, the degree of urbanization, etc.).

The association between broadband deployment and economic growth has been studied in several papers (Crandall et al., 2007; Gillett et al., 2007; Shideler et al., 2007). More recently, the emphasis in the literature has been on estimating the causal effects. For example, Czernich et al. (2011) estimated the effect of broadband infrastructure on economic growth in OECD countries in 1996-2007 and found that broadband penetration raised annual per capita growth. Forman et al. (2012) examined the relationship between advanced Internet investment by business and wage and employment growth in US counties between 1995 and 2000. The study found that investment in the Internet contributed to 28 percent of wage growth, yet this growth was restricted to only 6 percent of US counties. These counties already had high income, high populations, and high skills prior to 1995, while the comparative economic performance of isolated and less densely populated counties did not improve. Kolko (2012) also did not find a strong economic benefit to broadband expansion. The study examined economic activity in the US in 1999-2006 and found that broadband expansion promoted population and employment growth, particularly in areas with lower population densities, but did not affect average wage and employment rate.

This paper combines and extends the approaches adopted in the literature. As such we owe much to previous work. First, we use the variation in elevation within each region as the instrument. This is similar to the approach in Kolko (2012), where the average slope of the local terrain is used as an instrument for broadband expansion. The author argues that the cost of extending broadband to areas with steeper terrain is high. We also follow Czernich et al. (2011), Forman et al. (2012), and Kolko (2012) by using data over several years to focus on growth rates and not the levels of economic activity. As Forman et al. (2012), we analyse data in long differences. We compare employment and wages in 1997, the year broadband first appeared in Canada, to those in 2011.

This paper differs from the earlier literature in three important respects. First, this is the only study to evaluate the impact of broadband deployment on economic activity in Canada. Second, since Canada was the first country to introduce broadband, our data allow analysis of economic growth over longer time periods. This is important since longer time periods are required to be able to cover the full adjustment of economy to broadband deployment. In comparison, the time periods considered in Forman et al. (2012) and Kolko (2012) are relatively short: 1995-2000 and 1999-2006. Also, Internet infrastructure capabilities in 1995-2000 were relatively weak compared to the broadband infrastructure deployed in later years. Third, our study distinguishes between goods and service industries. Such distinction is critical as the entire impact of broadband deployment is realized in service industries, while the aggregate impact is weaker.

The rest of the paper proceeds as follows. In Section 2, we outline our empirical strategy. Section 3 describes the data on broadband coverage, employment and demographic characteristics, and elevation variation. We examine the relationship between broadband deployment and elevation variation in Section 4. The results are presented and discussed in Section 5. Section 6 concludes.

2 Methodology

To estimate the impact of broadband deployment, we specify the following model:

$$\Delta Y_{jt} = \beta \Delta B_{jt} + \gamma X_j + \alpha + \alpha_t + e_{jt}, \tag{1}$$

The outcome variable ΔY_{jt} is the employment (or wage) growth in economic region j over period t. We consider two time periods: $t = 1, 2$. The first period is from 1997 (the year broadband first appeared in Canada) to 2005 (the first year of the National Broadband Coverage data). The second period is from 2005 to 2011 (the last year of the Labour Force Survey data). For each period, ΔY_{jt} is calculated as follows:

$$\Delta Y_{jt} \equiv \begin{cases} (\log Y_{j,2005} - \log Y_{j,1997})/(2005 - 1997) & \text{for} \quad t = 1, \\ (\log Y_{j,2011} - \log Y_{j,2005})/(2011 - 2005) & \text{for} \quad t = 2. \end{cases} \tag{2}$$

ΔY_{jt} measures the average annual log change in Y_{jt}, which approximates the average annual percentage change in employment (wage) in region j over period t.

The key independent variable is ΔB_{jt}. It measures the change in broadband coverage in region j over period t, and is defined in Section 4. The vector X_j includes regional controls for initial or permanent characteristics that may affect employment (or wage) growth. Initial controls (for the year 1997) are the log of population, population density per square kilometre, age distribution (the percentage of population aged below 15 and the percentage above 65), educational attainment (the percentage of university and high school graduates), and firm/establishment size (the percentage of employees employed in small firms, with less than 20 employees, and the percentage employed in large firms, with more than 500 employees). The vector X_j also includes two measures of the degree of urbanization: the percentage of population living in a census metropolitan area (CMA)[6] and an indicator variable for rural economic regions, which do not contain a CMA.

Our data set is a panel of two time periods. The time series variation allows us to account for a change in growth over time, which is expected given a shock to economic conditions brought by the 2008-2009 recession. To do that, we add the indicator variable for the second period, α_t, to (1). Last, α is a constant and e_{it} is an error term.

An important concern is that the change in broadband coverage could be endogenous to employment (or wage) growth. This is very likely for two reasons. First, broadband de-

[6] To create this variable, we first identified those economic regions that include a CMA and then for each economic region, we calculated the percentage of population living in a CMA.

ployment could be related to a wide range of economic factors affecting ΔY_{jt} but omitted from (1). Omitting such confounding variables can create a spurious association between ΔB_{jt} and ΔY_{jt}. Secondly, the economic conditions themselves can, directly or indirectly, influence broadband deployment rates, leading to a reverse causality from ΔY_{jt} to ΔB_{jt}. For these reasons, mere association between the economic activity and broadband coverage does not imply causation. To isolate exogenous variation in broadband, we use the variation in elevation within region j as the instrument. Elevation variation affects the cost of deploying broadband and so explains the difference in broadband coverage across regions. Our instrumental variable approach is valid under the key assumption that the variation in elevation within region j does not directly determine j's employment (or wage) growth. It only affects ΔY_{jt} indirectly by affecting broadband deployment ΔB_{jt}.

3 Data

3.1 Broadband Coverage Data

We use the National Broadband Coverage data, compiled by the Canadian Radio-Television and Telecommunications Commission (CRTC) and Industry Canada. These data were collected in two separate rounds that differed in scope and detail. In the first round, the data were gathered at the community level for November 2005. Broadband availability was recorded for 5,426 communities across Canada. In the second round, detailed coverage maps overlaid with a hexagonal grid were generated. Industry Canada assigned a unique ID to each hexagon containing one or more Dissemination Block Area (DBA) points.[7] Broadband availability was recorded for 49,999 such hexagons,[8] which correspond to

[7] DBA point (or centroid) marks the geographic center of a Dissemination Block Area, defined by Statistics Canada as "an area bounded on all sides by roads and/or boundaries of standard geographic areas. The dissemination block is the smallest geographic area for which population and dwelling counts are disseminated." Source: `http://www.statcan.gc.ca/pub/92-195-x/2011001/geo/db-id/def-eng.htm`.

[8] Each side of the hexagon is three kilometers long, making the area of each hexagon about 25km^2. The hexagon methodology is described at `http://www.ic.gc.ca/eic/site/719.nsf/eng/h_00035.html`

17,737 different communities across Canada. These data were gathered at several points in time from July 2009 to March 2012 and were used to evaluate proposals and track progress for the Broadband Canada Program, which ran over the same period.[9] Industry Canada solicited feedback from individuals and Internet service providers regarding the July 2009 data and based on this feedback, revised the data collection process in the following years. We choose March 2011 as the last data point in our empirical analysis (since 2011 is the last year of our Labour Force Survey data) and March 2012 as the last data point in our discussion of changes in broadband coverage over time.

In both rounds, each community/hexagon was polled for the three types of broadband access technology: Digital Subscriber Line (DSL), Cable Internet Connection (Cable), and Fixed Wireless Internet Service (Wireless). For each such technology, data were recorded as a binary variable—taking a value of one if the technology was available and zero otherwise. A specific type of broadband access technology is considered available if at least one service provider within the bounds of a given community/hexagon offers that type of service.

To compile the Broadband Coverage data, the CRTC and Industry Canada relied upon a number of sources. For wired broadband (i.e., DSL and Cable), the information on equipment locations, wire center boundaries, and local address ranges was gathered from the service providers. These data were then used to estimate coverage areas, either by cross-referencing address ranges and wire centre boundaries or by measuring coverage radii based on reported hardware capability. For wireless broadband, coverage areas were estimated using simulated coverage maps and circular coverage radii around wireless Internet towers.[10]

We examine broadband deployment rate over time and then relate this rate to changes in economic activity. To begin, we need to merge the two rounds of broadband data to-

[9] The data were collected for July 2009, March 2011, November 2011, January 2012, and March 2012.

[10] The authors would like to thank Daniel Winters of Industry Canada for providing a description of the broadband data and its sources.

gether. An important consideration in this respect is that the sample of communities differed across the two rounds. The second round was far more comprehensive, with a large number of new communities added to the original sample. These new communities were relatively underserved and also differed from the rest in terms of geography and economic characteristics. Such difference between the two samples could cause endogeneity bias and to prevent this, we limit our data to communities sampled in both rounds. We used the location information on each hexagon to extract community names from the 2011 data and then matched communities by name across the two rounds. The matched data set is a balanced panel of 4,541 communities sampled in both rounds.

Our analysis is at the level of economic region (ER).[11] The information on ERs is not provided in the Broadband Coverage data and so our next step is to incorporate this information. To do this, we utilized the Geographic Information System (GIS) software to divide Canada into its 76 ERs using the boundaries defined by Statistics Canada. We then used the hexagon centroid to assign each hexagon to a corresponding ER (where applicable). Hexagons not assigned to any ER were dropped (120 hexagons or 0.24%). Similarly, the communities in the 2005 data were assigned to their respective ERs. To accomplish this, we relied on the expanded hexagon-level data, where hexagons are linked to both communities and ERs. All but 197 communities in these data correspond to a single ER, and we focus our analysis on these communities with one-to-one correspondence. Our final broadband data set contains 4,344 communities, representing 76 ERs.

Figure 1 plots the average broadband coverage by technology over time. Broadband first appeared in Canada in 1997 (Czernich et al., 2011). Until 2005, the deployment of broadband was fastest for DSL, followed by Cable. Fixed Wireless broadband deployment was slow to start but eventually overtook wired broadband. In 2005, the average broadband coverage was 41% for DSL, 20% for Cable, and 11% for Wireless. By 2012,

[11] Statistics Canada defines an economic region as "a grouping of complete census divisions... created as a standard geographic unit for analysis of regional economic activity." Source: `http://www12.statcan.gc.ca/census-recensement/2011/ref/dict/geo022-eng.cfm`.

Wireless coverage reached 61%, exceeding both DSL and Cable coverage, which reached 54% and 34% respectively. What are the implications of this variation of broadband coverage across technologies? To answer this question, we must consider the technology itself.

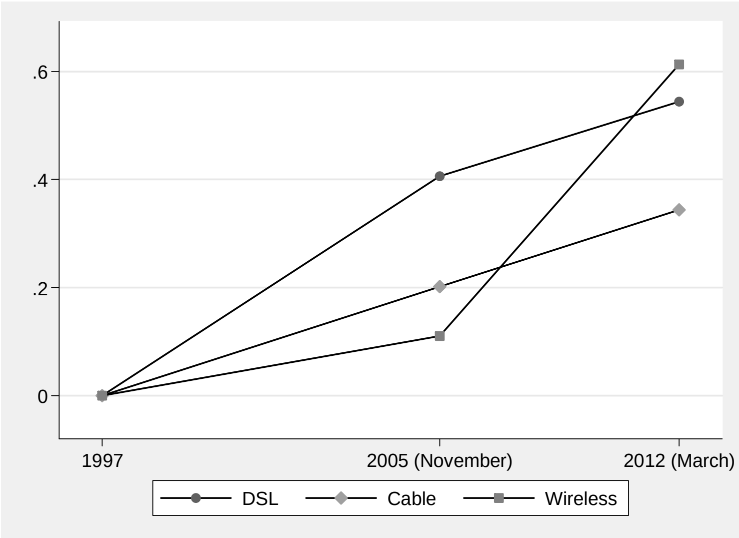

Figure 1: **Average broadband availability by technology**

The three technologies differ in network infrastructure. DSL uses copper wire-pairs of local telephone networks. Not to be mistaken with older dial-up technologies, DSL utilizes the higher frequency bands on these lines, allowing for a persistent Internet connection without engaging or interrupting standard telephone service. Cable utilizes existing coaxial cable lines of the local cable television network and, like DSL, provides persistent connectivity without affecting cable television service. Fixed wireless Internet service does not depend on wired connectivity to the end user, but rather provides fixed wireless Internet access through point-to-point links between networks across distant locations using microwaves or other radio waves.[12]

[12]Fixed Wireless service must be distinguished from two other types of wireless service. The first is mobile wireless service, which utilizes cell towers to allow end-users to connect their smartphones, tablet PCs and other mobile devices. The second is wireless local area networking, which is a short-range wireless distribution of an underlying wired network and a feature commonly available in consumer-grade routers.

The three technologies also differ in connectivity. A connection's speed—as perceived by an end user visiting a website, downloading a file, streaming online video, etc.,—is dictated by latency and bandwidth.[13] DSL bandwidth capacity can range from 128 Kbps to 30 Mbps, depending on the distance between the end user and the DSL provider's switching station, and the gauge of the copper wire-pair connecting the points. Lower-end DSL offerings are excluded from Industry Canada's definition of broadband connectivity, according to which broadband service refers to download speeds of 1.5 Mbps or greater. The most popular variant of DSL is Asymmetric DSL, which dedicates a greater portion of available bandwidth to downloads (downstreaming or incoming data) than to uploads (upstreaming or outgoing data) to better suit the needs of the average home and business subscriber. Cable bandwidth capacity is usually greater than DSL. It is generally no less than 1.5 Mbps and can be as high as 55 Mbps or even greater. On the high end of this spectrum, transmission speed is heavily dependent on the quality of the cable modem with which the end user connects, the quality of the cable network overall, network load, and the degree of oversubscription in the user's locality. As with DSL providers, Cable Internet Service Providers typically offer asymmetrical packages where a greater portion of bandwidth is dedicated to downloads. Wireless speed is comparable to that of DSL and Cable, and is also frequently offered in asymmetric varieties to end users. Wireless speed may be affected by line-of-sight and non-line-of-sight propagation problems that are typical of all radio transmissions.

While the three technologies vary in bandwidth capacities and latency limitations, they all provide the minimum connectivity requirements for the majority of broadband

[13] A connection's *latency* concerns the amount of time it takes (i.e., delay) for a network packet to travel from a source device to a destination device, and depends heavily on the processing capability of the networking routers, switches, firewalls and other hardware along the network path between the two devices. A given connection's *bandwidth* is the maximum throughput on that network. Data transfer is typically measured in bits (b) transmitted per second, usually in metric units such as kilobits (i.e., 1,000 bits, abbreviated as Kbps) and megabits (i.e., 1,000,000 bits, abbreviated as Mbps). These measures are not to be confused with those typically used to describe storage, where capacity is measured in bytes (B) and usually in units that are an exponent of 2, such kilobytes (i.e., 2^{10} or 1,024 bytes, abbreviated as K or KB) and megabytes (2^{20} or 1,048,576 bytes, abbreviated as M or MB). For conversion purposes, 1 byte is comprised of 8 bits.

applications and services. As such, DSL, Cable, and Wireless exhibit a strong degree of substitution. In fact, when measuring broadband coverage to track the progress of the Broadband Canada Program, Industry Canada's approach was to focus on the availability of any broadband service, regardless of technology. Our analysis is consistent with this approach. We treat the three technologies as perfect substitutes and measure broadband coverage in a location l using the following index:

$$B_{lt} = \frac{D_{lt} + C_{lt} + W_{lt}}{3} \qquad \text{for} \quad l = h, k; \tag{3}$$

where D_{lt}, C_{lt}, and W_{lt} is the availability of DSL, Cable, and Wireless in community k (i.e., $l = k$) or hexagon h (i.e., $l = h$) at time t. The Broadband index B_{lt} is a simple average of DSL, Cable, and Wireless availability, with equal weights assigned to each technology.

Before we examine broadband deployment rate at the ER level, it is useful to provide a general description of the broadband data. Figure 2 shows the distribution of the Broadband index across communities in 2005 (on the left) and 2012 (on the right). The index for 2005 takes on one of four possible values: $B_{kt} = \{0, 1/3, 2/3, 1\}$, since the DSL, Cable, and Wireless coverage data are recorded as zero or one for each community. A particular value taken depends on how many types of access technologies are available in community k. For example, $B_{kt} = 0$ if a community is not covered by any technology and $B_{kt} = 1/3$ if a community is covered by only one technology, of any type. For 2012, B_{kt} is not limited to four values, because the original data are at the hexagon level. It is measured as the average index across all hexagons within community k: $B_{kt} = \sum_{h=1}^{H_k} B_{ht}/H_k$, where H_k is the total number of hexagons within community k.

It is apparent from Figure 2 that the distribution for 2005 is largely skewed to the left. Despite fast deployment of wired Internet in the late 1990s and early 2000s, as many as 47% of communities had zero broadband coverage in 2005. Across those with broadband,

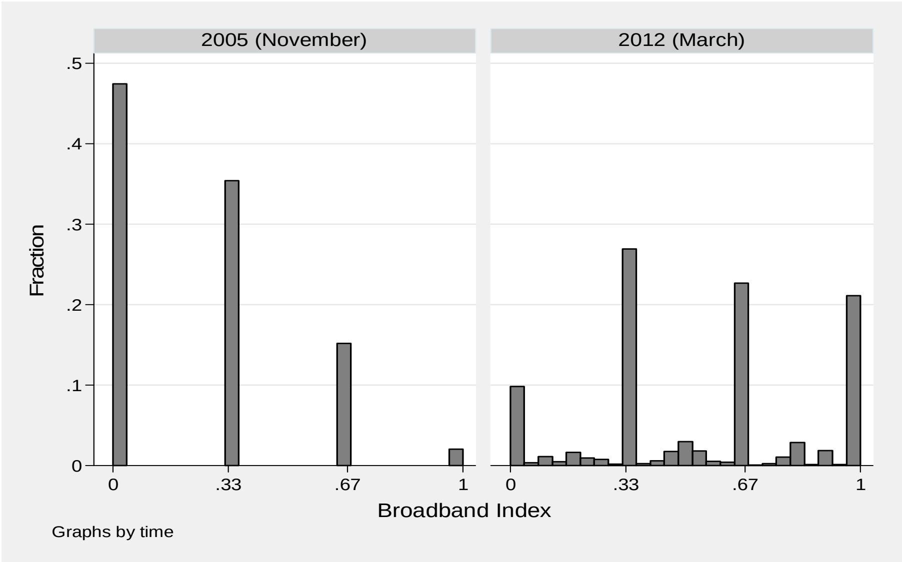

Figure 2: **The Broadband index across communities**

most communities (35%) had only one type of technology available. The distribution for 2012 is different. The fraction of communities with zero availability dropped to 10% and the fraction of communities with one type of technology available dropped to 27%. At the same time, the fraction of communities covered by more than one technology rose from 17% in 2005 to 58% in 2012.

3.2 Employment and Demographic Data

Additional data used in the analysis are from the Labour Force Survey (LFS), which collects information on different employment and demographic characteristics of the Canadian workforce. We use annual data for the years 1997, 2005, and 2011 on the following variables: total employment, average hourly wages, population, the percentage of population aged below 15 and above 65, the percentage of university and high school graduates, and the percentage of employees employed in firms with less than 20 and more than 500 employees. The estimates of employment and wages are detailed by industry and occupation, based on the 2007 North American Industry Classification System (NAICS) and the 2006 National Occupational Classification for Statistics (NOC-S). To calculate population density, we use land area data from the 2006 Census of Population.

The LFS contains information on 69 out of 76 ERs in Canada and so in the analysis that follows, we focus on these 69 ERs.[14] To account for the varying degree of urbanicity across regions, we distinguish ERs based on their urban/rural status. Regions containing a Census Metropolitan Area (CMA) are designated as urban, with the balance of regions designated as rural.[15] The two groups are roughly equal in size: 38 ERs are urban and 31 are rural.

3.3 Elevation variation

Variation in elevation within each region serves as an instrument for the rate of broadband deployment in that region. We calculate elevation variation as the standard deviation of the mean elevation across all hexagons within each ER. To generate mean elevation data at the hexagon level, the following procedure was employed. First, the latitude and longitude coordinates of each hexagon centroid (available in the National Broadband Coverage data) were plotted on a map using GIS software. Second, a buffer region at a radius of 10km was created around each centroid and for each such buffer region, the elevation data were collected using a digital elevation model (DEM).[16] Subsequently, the mean elevation around each hexagon centroid was computed.

4 Explaining Broadband Deployment

In this section, we examine changes in broadband coverage across 69 ERs for which the LFS data are available. First, we aggregate the broadband data to the level of ER. Depending on the level of detail in the original broadband data, we define the region-

[14]The following ERs are excluded from the data: 2490 (Nord-du-Qubec), 4680 (Northern, MB), 4760 (Northern, SK), 5970 (Nechako, BC), 6010 (Yukon), 6110 (Northwest Territories), and 6210 (Nunavut).

[15]Statistics Canada defines a Census Metropolitan Area (CMA) as area with an urban core of 50,000 or more and a total population of 100,000 or more.

[16]The average number of data points for each buffer region is greater than 400.

specific Broadband index as follows: $B_{jt} \equiv \sum_{h=1}^{H_j} B_{ht}/H_j$ for the hexagon-level data and $B_{jt} \equiv \sum_{k=1}^{K_j} B_{kt}/K_j$ for the community-level data, where H_j and K_j are the total number of hexagons and communities respectively within a region j. That is, B_{jt} measures the average broadband coverage across hexagons/communities within j. Next, we define the broadband deployment rate as the average annual log change in j's index over period t:

$$\Delta B_{jt} \equiv \begin{cases} (\ln(1 + B_{j,2005}) - \ln(1 + B_{j,1997}))/(2005 - 1997) & \text{for} \quad t = 1, \\ (\ln(1 + B_{j,2011}) - \ln(1 + B_{j,2005}))/(2011 - 2005) & \text{for} \quad t = 2. \end{cases} \tag{4}$$

We add one to B_{jt} before taking logs to avoid undefined values and set the initial level of broadband to zero: $B_{j,1997} = 0$.

The rate ΔB_{jt} approximates the average annual percentage change in broadband coverage in j over t. It is measured in percentage, rather than level, changes to allow for a non-linear (specifically, concave) relationship between employment (or wage) growth and the level of broadband coverage. This is important since the impact of broadband deployment is expected to be higher at lower levels of coverage.

Table 1 shows the results of the first stage regression. Column 1 reports the results of regressing ΔB_{jt} on the log of elevation variation and the time effect (i.e., the indicator variable for $t = 2$). It is apparent that the coefficient on the log of elevation variation is negative (-.006) and highly statistically significant. High elevation variation is associated with lower broadband deployment rate. The results also indicate that elevation variation is relevant for explaining variation in broadband deployment; the F statistic of 23.03 exceeds its critical value of 10 (Stock et al., 2002).

To ensure that our results are not driven by our definition of ΔB_{jt}, we check two alternative definitions. Columns 2 and 3 show the results. In column 2, the broadband deployment rate is measured in level changes as follows:

$$\Delta B'_{jt} \equiv \begin{cases} (B_{j,2005} - B_{j,1997})/(2005-1997) & \text{for} \quad t=1, \\ (B_{j,2011} - B_{j,2005})/(2011-2005) & \text{for} \quad t=2. \end{cases} \tag{5}$$

With this alternative definition, the relationship between employment (or wage) growth and broadband coverage is restricted to be: the impact of broadband deployment is assumed to be the same across all levels of coverage.

Table 1: **Broadband deployment and elevation variation**

	Column 1		Column 2		Column 3	
	Coeff.	St.er.	Coeff.	St.er.	Coeff.	St.er.
Log of elevation variation	-.006***	.001	-.010***	.002	-.008***	.002
Time effect	-.004	.002	.003	.003	-.038***	.006
Constant	.057***	.006	.078***	.009	.105***	.008
Observations	138		138		138	
Robust $F(1,68)$	23.03		24.47		19.79	
R^2	.15		.16		.33	

Note: *** denotes 1% significance level.
Standard errors are robust and clustered by ERs.

In column 3, we re-define the Broadband index B_{lt}. The definition (3) takes into account the number of technologies available in location l, which is most relevant when areas within locations vary in the type of technology available (i.e., each technology covers a distinct area within a location). In that case, the broadband coverage in a location l is greatest when all three technologies are available there. If, however, the coverage areas fully overlap (the same area is covered by multiple technologies) and technologies are perfect substitutes, then the definition (3) could lead to an overstatement of broadband coverage in location l. A more appropriate definition in this case is: $B'_{lt} = 0$ if a location l is not covered by any technology and $B'_{lt} = 1$ if location l is covered by any one or several technologies. The results reported on column 3 are based on this alternative definition, with the broadband deployment rate defined as in (5), where $B_{jt} \equiv \sum_{h=1}^{H_j} B'_{ht}/H_j$ for

$l = h$ and $B_{jt} \equiv \sum_{k=1}^{K_j} B'_{kt}/K_j$ for $l = k$.

It is apparent that the sign and the coefficient on the log of elevation variation and its significance are not driven by our definition of the broadband deployment rate. The coefficients on the log of elevation variation are also negative and highly statistically significant in columns 2 and 3. The F statistic exceeds its critical value of 10 in all three columns, suggesting that the elevation variation instrument is not weak.

5 Results

5.1 Employment Growth

In this section, we estimate the impact of broadband deployment on employment growth. We first examine aggregate employment and then consider employment by industry.

Table 2 reports the aggregate employment growth results.[17] Column 1 shows the results of our baseline regression (1), where the regressor of interest is the broadband deployment rate ΔB_{jt}, as defined in (4). We instrument ΔB_{jt} with the log of elevation variation variable. The coefficient on ΔB_{jt} measures the average impact of broadband deployment on employment growth across all ERs. Columns 2 and 3 distinguish ERs based on their rural/urban status. In column 2, we consider how the relative performance of rural regions is impacted by broadband. The regressor of interest is the interaction term between the broadband deployment rate and the indicator variable for rural ERs, $\Delta B_{jt} \cdot R_j$. The instrument here is the interaction between the log of elevation variation and R_j. In Column 3, we also control for the impact of broadband deployment in urban regions. We include both ΔB_{jt} and $\Delta B_{jt} \cdot R_j$ as regressors, respectively instrumented by the log of elevation variation and the interaction of that with R_j. In this specification, the coefficient on ΔB_{jt} measures the average impact on employment growth across all urban ERs, while the coefficient on $\Delta B_{jt} \cdot R_j$ measures the difference in the impact between

[17]The Appendix presents the summary statistics.

rural and urban ERs.

Table 2: **Aggregate employment growth**

Variable	Column 1		Column 2		Column 3	
	Coeff.	St.er.	Coeff.	St.er.	Coeff.	St.er.
Broadband deployment rate, ΔB_{jt}	.061	.201			-.514*	.310
The interaction $\Delta B_{jt} \cdot R_j$			.499*	.284	1.024**	.458
Rural indicator, R_j	-.005	.003	-.018**	.008	-.030**	.012
% of population living in a CMA	.000	.001	.000	.001	.000	.001
Log of population	.001	.001	.001	.001	.002	.001
Density per km^2	-.003	.002	-.002	.002	.002	.003
% of high school graduates	-.025	.025	-.023	.025	-.017	.027
% of university graduates	.101**	.042	.086**	.035	.104**	.043
% of population aged below 15	.193**	.076	.193**	.074	.201**	.081
% of population aged above 65	-.001	.041	-.020	.036	-.007	.042
% of employees in large firms	-.006	.057	.008	.056	.007	.058
% of employees in small firms	.018	.065	.032	.064	.022	.069
Time effect	-.008***	.002	-.007***	.003	-.008***	.003
Constant	-.027	.058	-.032	.055	-.028	.057
Observations	138		138		138	
First-stage regression robust F, ΔB_{jt}	22.88				16.48	
First-stage regression robust F, $\Delta B_{jt} \cdot R_j$			21.29		11.07	
R^2	.228		.093		.028	

Note: ***, **, and * denote 1%, 5%, and 10% significance level respectively.
Standard errors are robust and clustered by ERs.

It is apparent from column 1 in Table 2 that the coefficient on ΔB_{jt} is positive (.061) but not statistically significant. As such when all ERs are considered together, the average impact of broadband deployment on the aggregate employment growth is not statistically different from zero. We next explore if distinguishing the ERs based on their rural/urban status changes this finding. In column 2, we replace ΔB_{jt} with $\Delta B_{jt} \cdot R_j$ and find that the coefficient on $\Delta B_{jt} \cdot R_j$ is positive (.499) and statistically significant at 10% level, while the coefficient on R_j is negative (-.018) and statistically significant at 5% level. These results suggest that rural regions lag behind urban ones in terms of the aggregate employment growth, but the deployment of broadband works to limit the rural/urban employment gap. The results shown in column 3, where ΔB_{jt} is also controlled for, provide a stronger evidence in support this conclusion. The coefficient on $\Delta B_{jt} \cdot R_j$ is positive (1.024) and statistically significant at 5% level, while the coefficient on ΔB_{jt} is negative (-.514) and marginally significant. These results suggest that the differential impact of broadband deployment in rural regions is positive; broadband deployment promotes aggregate employment growth in rural regions more than in urban ones.

Next, we examine employment by industry. This analysis serves two purposes. First, it is used to confirm that the signs of coefficients on ΔB_{jt} and $\Delta B_{jt} \cdot R_j$ have not been unduly influenced by the aggregation of employment but hold at the industry-level as well. Second, it is used to explore the statistical significance of the results. Tables 3 and 4 show the results.

In Table 3, we consider two distinct industry groups: goods and services. It is apparent that this distinction is critical for our results. We observe no statistically significant impact on employment growth in the goods industry group. In the service industry group, by contrast, the signs of the coefficients on ΔB_{jt} and $\Delta B_{jt} \cdot R_j$ are consistent with those in Table 2, and the statistical significance of the coefficients is noticeably higher. The marginal effect of broadband deployment, given by $\partial \Delta Y_{jt} / \partial \Delta B_{jt} = -.549 + 1.082 R_j$, is positive (.533) for rural ERs ($R_j = 1$) and negative (-.549) for urban ERs ($R_j = 0$). This suggests that broadband deployment promotes service employment growth in rural regions at the expense of urban regions.

Table 3: **Employment growth by industry group**

		Column 1		Column 2		Column 3	
Industry group		Coeff.	St.er.	Coeff.	St.er.	Coeff.	St.er.
Goods	ΔB_{jt}	.116	.344			.344	.632
	$\Delta B_{jt} \cdot R_j$			-.059	.475	-.425	.898
Services	ΔB_{jt}	.008	.163			-.549**	.219
	$\Delta B_{jt} \cdot R_j$			.533***	.191	1.082***	.301

Note: *** and ** denote 1% and 5% significance level respectively.
Standard errors are robust and clustered by ERs.

Table 4 shows the results for individual industries. Again, we find no statistically significant impact in individual goods industries. We now explore service industries in more detail.

Table 4: **Employment growth by industry**

		Column 1		Column 2		Column 3	
Goods industries:		Coeff.	St.er.	Coeff.	St.er.	Coeff.	St.er.
Agriculture	ΔB_{jt}	-.794	.764			-.839	1.777
	$\Delta B_{jt} \cdot R_j$			-.749	1.040	.065	2.276
Resource-based, mining	ΔB_{jt}	2.529*	1.499			10.222	13.067
	$\Delta B_{jt} \cdot R_j$			.668	0.729	-8.783	12.334
Construction	ΔB_{jt}	-.912*	.493			-1.098	.870
	$\Delta B_{jt} \cdot R_j$			-.711	.488	.327	.975
Manufacturing	ΔB_{jt}	.270	.314			.409	.479
	$\Delta B_{jt} \cdot R_j$			.167	.425	-.258	.660
Service industries:							
Trade	ΔB_{jt}	.121	.315			-.179	.494
	$\Delta B_{jt} \cdot R_j$			.450	.382	.617	.552
Transportation & warehousing	ΔB_{jt}	-.362	.359			-.917	.641
	$\Delta B_{jt} \cdot R_j$			.022	.349	1.000	.754
Information, culture, recreation	ΔB_{jt}	.591*	.332			-.372	.573
	$\Delta B_{jt} \cdot R_j$			1.330***	.410	1.705**	.720
Finance, insurance, real estate	ΔB_{jt}	.434	.360			-.252	.495
	$\Delta B_{jt} \cdot R_j$			1.014**	.502	1.272*	.716
Professional, scientific, technical	ΔB_{jt}	-.996	.660			-2.316***	.752
	$\Delta B_{jt} \cdot R_j$			.743	.856	3.113**	1.223
Business, building, other support	ΔB_{jt}	-.537	.579			-1.748***	.648
	$\Delta B_{jt} \cdot R_j$			2.202**	1.035	4.055***	1.162
Educational services	ΔB_{jt}	.659**	.285			-.092	.379
	$\Delta B_{jt} \cdot R_j$			1.271***	.406	1.363**	.577
Health care & social assistance	ΔB_{jt}	.034	.168			.091	.289
	$\Delta B_{jt} \cdot R_j$			-.024	.170	-.118	.339
Accommodation, food services	ΔB_{jt}	-.135	.263			-.619	.413
	$\Delta B_{jt} \cdot R_j$			.265	.240	.870*	.451
Public administration	ΔB_{jt}	.952**	.448			.422	.630
	$\Delta B_{jt} \cdot R_j$			1.403***	.419	.983	.696

Note: ***, **, and * denote 1%, 5%, and 10% significance level respectively.
Standard errors are robust and clustered by ERs.

It is apparent from Column 1 that across all ERs, broadband deployment promotes employment growth in educational services and public administration. The results in Columns 2 and 3 further suggest that in these two industries, the positive impact is driven by rural ERs, while employment growth in urban regions is not impacted. A positive differential impact in rural regions is also observed in information, culture, and recreation industries; finance, insurance, and real estate; professional, scientific and technical services; and business, building and other support services. In two categories,— (1) professional, scientific and technical services and (2) business, building and other support services—an increase in employment growth in rural regions is accompanied by a reduction in employment growth in urban regions. No statistically significant impact on employment growth is observed in trade; transportation and warehousing; health care and social assistance; or accommodation and food services.

5.2 Wage Growth

We now use the average hourly wage growth as the outcome variable.[18] As before, we first examine average growth across all industries and then consider growth by industry. Tables 5–7 follow.

Table 5 reports the average wage growth results. It is apparent from the first three rows that broadband deployment promotes wage growth across all ERs, rural or urban. The coefficient on ΔB_{jt} is larger in column 1 (.368) than in column 2 (.344), suggesting that the contribution of broadband is .024 points higher in urban compared to rural regions. The difference in the impact is, however, not statistically significant. From column 3, the coefficient on the interaction term $\Delta B_{jt} \cdot R_j$ is not statistically different from zero.

Table 6 reports the results by industry group. In line with the results for employment growth, we find no statistically significant impact on wage growth in the goods industry group. The results for the service industry group are qualitatively the same as in Table 5, but the coefficients on ΔB_{jt} and $\Delta B_{jt} \cdot R_j$ are higher in magnitude and the estimates are more precise. Broadband deployment promotes wage growth in services in both rural and urban regions, with no statistically significant differential impact.

[18] When we use average weekly (rather than hourly) wage, the results are very similar.

Table 5: **Average wage growth**

Variable	Column 1		Column 2		Column 3	
	Coeff.	St.er.	Coeff.	St.er.	Coeff.	St.er.
Broadband deployment rate, ΔB_{jt}	.368***	.132			.409*	.239
The interaction $\Delta B_{jt} \cdot R_j$			.344**	.153	-.073	.286
Rural indicator, R_j	-.004*	.002	-.012***	.004	-.002	.007
% of population living in a CMA	-.000	.000	-.000	.000	-.000	.000
Log of population	-.002*	.001	-.001	.001	-.002*	.001
Density per km^2	-.002	.001	.000	.001	-.002	.002
% of high school graduates	-.013	.016	-.010	.016	-.014	.016
% of university graduates	.054**	.023	.068***	.020	.054**	.023
% of population aged below 15	.141***	.043	.147***	.040	.140***	.044
% of population aged above 65	.011	.029	.022	.026	.011	.028
% of employees in large firms	.016	.027	.015	.025	.015	.028
% of employees in small firms	.080**	.033	.071**	.030)	.079**	.033
Time effect	.009***	.002	.008***	.001	.009***	.002
Constant	-.038	.027	-.035	.025	-.038	.028
Observations	138		138		138	
First-stage regression robust F, ΔB_{jt}	22.88				16.48	
First-stage regression robust F, $\Delta B_{jt} \cdot R_j$			21.29		11.07	
R^2	.282		.406		.265	

Note: ***, **, and * denote 1%, 5%, and 10% significance level respectively.
Standard errors are robust and clustered by ERs.

Table 6: **Wage growth by industry group**

		Column 1		Column 2		Column 3	
Industry group		Coeff.	St.er.	Coeff.	St.er.	Coeff.	St.er.
Goods	ΔB_{jt}	-.024	.123			.044	.233
	$\Delta B_{jt} \cdot R_j$			-.080	.150	-.127	.300
Services	ΔB_{jt}	.459***	.128			.453**	.191
	$\Delta B_{jt} \cdot R_j$			.464***	.159	.011	.232

Note: *** and ** denote 1% and 5% significance level respectively.
Standard errors are robust and clustered by ERs.

Table 7 further shows that broadband deployment promotes wage growth in information, culture, and recreation industries; educational services; accommodation, food services; and public administration. In these four industries, broadband deployment is related to higher wage growth in rural and urban regions alike. In one category, namely health care & social assistance, broadband deployment promotes wage growth in urban regions only; in rural regions, the marginal effect is negative but relatively small: $\partial\Delta Y_{jt}/\partial\Delta B_{jt} = .774 - .807 = -.033$ (follows from column 3). No statistically significant impact on wage growth is observed in the other industries.

Table 7: **Wage growth by industry**

		Column 1		Column 2		Column 3	
Goods industries:		Coeff.	St.er.	Coeff.	St.er.	Coeff.	St.er.
Agriculture	ΔB_{jt}	-.034	.273			-.358	.678
	$\Delta B_{jt} \cdot R_j$			.125	.229	.491	.734
Resource-based, m ining	ΔB_{jt}	.707	.591			3.756	5.694
	$\Delta B_{jt} \cdot R_j$			-.055	.281	-3.244	5.076
Construction	ΔB_{jt}	.086	.142			.121	.235
	$\Delta B_{jt} \cdot R_j$			.054	.185	-.060	.298
Manufacturing	ΔB_{jt}	.062	.147			-.098	.264
	$\Delta B_{jt} \cdot R_j$			.194	.125	.295	.304
Service industries:							
Trade	ΔB_{jt}	.369*	.204			.291	.242
	$\Delta B_{jt} \times R$			.432*	.262	.160	.288
Transportation & warehousing	ΔB_{jt}	.137	.141			.149	.248
	$\Delta B_{jt} \times R$			.138	.197	-.020	.342
Information, culture, recreation	ΔB_{jt}	.331**	.151			-.009	.240
	$\Delta B_{jt} \times R$			.568***	.179	.576*	.305
Finance, insurance, real estate,	ΔB_{jt}	.155	.177			-.079	.273
	$\Delta B_{jt} \times R$			.386	.286	.466	.392
Professional, scientific, technical	ΔB_{jt}	-.032	.231			.030	.405
	$\Delta B_{jt} \times R$			-.116	.178	-.147	.470
Business, building, other support	ΔB_{jt}	.033	.275			-.291	.342
	$\Delta B_{jt} \times R$			.477	.373	.783	.489
Educational services	ΔB_{jt}	.267**	.115			.122	.183
	$\Delta B_{jt} \times R$			.387**	.168	.265	.260
Health care & social assistance	ΔB_{jt}	.383**	.168			.774***	.232
	$\Delta B_{jt} \times R$			-.016	.254	-.807**	.335
Accommodation, food services	ΔB_{jt}	.594***	.193			.417	.273
	$\Delta B_{jt} \times R$			.726***	.260	.318	.358
Public administration	ΔB_{jt}	.201	.212			-.035	.328
	$\Delta B_{jt} \times R$			.403**	.201	.438	.365

Note: ***, **, and * denote 1%, 5%, and 10% significance level respectively.
Standard errors are robust and clustered by ERs.

5.3 Discussion

In our discussion of results we focus on the service industries. From Table 3, the estimates of the impact on rural and urban employment growth are .533 and -.549 respectively. These estimates imply that a one standard deviation increase in the Broadband deployment rate ΔB_{jt}, which equals .0146 and .0145 in rural and urban regions respectively, leads to a .0078 percentage points per year increase in rural employment growth and a .0079 percentage points per year decline in urban employment growth. Next from Table 6, the estimates of the impact on rural and urban wage growth are .464 and .453 respectively. Thus, a one standard deviation increase in ΔB_{jt} leads to a .0068 percentage points per year increase in rural wage growth and .0066 percentage points per year increase in urban wage growth.

To put these estimates into prospective, assume for a moment that over the 1997-2012 period, broadband coverage rose from zero (not covered by any technology) to 1/3 (covered by any one technology) in all communities within a given economic region. Such change is equivalent to a 0.0204 log points per year increase in ΔB_{jt}. The estimates in Table 3 predict that in such a scenario, service employment growth would rise by 0.0109 log points (or 1.17 percentage points) per year in rural regions and fall by 0.0112 log points (or 1.21 percentage points) per year in urban regions. Further, the estimates in Table 6 predict that wage growth in services would rise by 0.0095 and 0.0092 log points (or 1.01 and 0.99 percentage points) per year in rural and urban regions respectively.

The results of our industry-level analysis in Tables 4 and 7 are largely in line with industry intensity of information technology (IT) use documented in Jorgenson et al. (2012). In Jorgenson et al. (2012), NAICS-based industries are classified by their intensity in the utilization of IT equipment and software. The industries with highest IT-intensity include: securities, commodity contracts and investments; professional, scientific and technical services; management of companies and enterprises; administrative and support services; educational services; broadcasting and telecommunications; and newspaper, periodical, book publishers. Correspondingly, we find a significant impact of broadband deployment in the matching industries in Tables 4 and 7. Comparatively, the intensity of IT use is relatively low in trade; transportation (for all but air transportation); warehousing and storage; construction; manufacturing; agriculture; resource-based industries; and mining. We find no impact of broadband deployment in these industries.

6 Conclusion

This paper studied the impact of broadband deployment on regional employment and wage growth. Despite the extensive government subsidies for broadband deployment, measured in hundreds of millions of dollars in Canada and billions worldwide, our understanding of the actual economic impact of broadband is limited. Perhaps the biggest challenge in evaluating the economic effects of broadband deployment is that coverage can be endogenous to economic conditions. The correlation of broadband deployment and economic growth has been studied in several papers, but without establishing causation. The emphasis of this paper was on estimating the true, causal effect. The analysis used detailed records of broadband availability across Canada at various points in time over the 1997-2011 period. The data's high level of detail and long time series allowed us to account for several econometric and data challenges. To credibly identify a causal effect from broadband deployment to economic activity, the variation in elevation within each region was used as the instrument.

The results show that the deployment of broadband in 1997-2011 promoted growth in aggregate employment and wages in rural regions across Canada. This impact is limited to service industries. Goods industries are not impacted. The industry-level results are largely in line with industry intensity of information technology use documented in Jorgenson et al. (2012). The results also show that while broadband promoted employment growth in services in rural regions, it limited such growth in urban regions. This suggests that broadband helps service industry businesses overcome geographical barriers that have traditionally hampered rural employment growth, and in so doing, limits the urban/rural employment gap. At the same time, rural and urban regions do not differ in their impact on wage growth.

To put the estimates into prospective, we evaluate the impact under the scenario that all communities within a given economic region moved from having zero broadband coverage in 1997 to being covered by any one broadband technology in 2012. Our estimates predict that in such a scenario, service employment growth would rise by 1.17 percentage points per year in rural regions and fall by 1.21 percentage points per year in urban regions, while average wage growth in service industries would rise by 1.01 and 0.99 percentage points per year in rural and urban regions respectively.

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Appendix

Summary statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
Aggregate employment growth	138	0.0143	0.0136	-0.0199	0.0557
Urban ERs	76	0.0170	0.0111	-0.0164	0.0403
Rural ERs	62	0.0110	0.0157	-0.0199	0.0557
Aggregate wage growth	138	0.0298	0.0090	0.0107	0.0521
Urban ERs	76	0.0284	0.0075	0.0126	0.0521
Rural ERs	62	0.0316	0.0103	0.011	0.0513
Broadband deployment rate	138	0.0270	0.0151	-0.0249	0.0639
Urban ERs	76	0.0306	0.0145	-.02491	0.0639
Rural ERs	62	0.0226	0.0146	-.01624	0.0545
Log of elevation variation	138	4.4578	0.8681	1.2539	6.3222
Rural indicator	138	0.4493	0.4992	0	1
% of population living in a CMA	138	1.1701	2.5911	0	15.2210
Log of population	138	5.2552	0.9716	3.5056	8.2303
Density per km^2	138	0.0952	0.3902	0.0002	2.9594
% of high school graduates	138	0.5404	0.0519	0.3842	0.6363
% of university graduates	138	0.1013	0.0384	0.0305	0.2100
% of population aged below 15	138	0.2058	0.0222	0.1622	0.2680
% of population aged above 65	138	0.1183	0.0301	0.0560	0.2094
% of employees in large firms	138	0.2791	0.0749	0.1138	0.4318
% of employees in small firms	138	0.4106	0.0742	0.2736	0.5960