The employment and wage impact of broadband deployment in Canada

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Abstract. Hundreds of millions of dollars are spent by the Canadian federal and provincial governments to subsidize broadband deployment. This paper provides the first empirical assessment of the impact of broadband on employment and wage growth in Canada. Variation in elevation explains the regional difference in broadband coverage and is used as an instrument to estimate the causal effect. We find that the deployment of broadband in 1997–2011 promoted rural employment and wage growth in service industries. Goods industries were not impacted. The findings suggest that broadband helps service industry businesses overcome geographical barriers that have traditionally hampered rural growth.

Résumé. *L'impact du déploiement de la transmission à haut débit sur l'emploi et les salaires.* Les gouvernements provinciaux et fédéral ont dépensé des centaines de millions de dollars pour subventionner le déploiement de la transmission à haut débit. Ce texte donne une première évaluation empirique de l'impact de cet investissement sur la croissance de l'emploi et des salaires au Canada. La variation dans l'élévation explique les différences régionales dans la couverture des communications à haut débit, et est utilisée comme instrument pour estimer l'effet causal. On découvre que le déploiement de la transmission à haut débit entre 1997 et 2011 a engendré une croissance de l'emploi rural et des salaires ruraux dans les industries de service. Les industries de biens n'ont pas été affectées. Ces résultats montrent que la communication à haut débit aide les entreprises dans le secteur des services à surmonter les barrières géographiques qui traditionnellement ont nui à la croissance rurale.

JEL classification: L9, O3, R1

1. Introduction

Governments worldwide are spending billions of dollars subsidizing broadband deployment, and Canada is no exception. Much of these funds are allocated to rural and remote areas, where commercial broadband deployment is not

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motivated.[1] The investments were intended to spur economic activity in these areas and promote regional growth and development. It is generally understood that broadband helps to overcome geographical distance by providing individuals and firms in remote areas with the same opportunities that exist in metropolitan centres. The evidence suggesting that Internet connectivity lowers the cost of doing business in distant locations supports this conclusion.[2] 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.[3] 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 representing 76 economic regions (ERs) over the 1997–2011 period. The sample allows for a comparison between rural and urban regions and spans a sufficiently long 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 address several econometric and data challenges. However, 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 examine broadband deployment rate at the level of economic region and use the variation in elevation within each region as the instrument. The rationale for the instrument is that 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. The impact is most pronounced in industries with high intensity of information technology (IT) use. Rural employment growth in IT-intensive industries declined when broadband was limited, but rose as broadband became more available. We also found that while broadband promoted employment growth in service sectors of rural regions, it curtailed such growth in urban regions. This finding suggests that broadband helps service industry businesses to overcome geographical barriers that have traditionally hampered rural employment growth, and in so doing,

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 more recent major initiative is Broadband Canada: Connecting Rural Canadians Program, which ran from 2009 until 2012 and directed $225 million into 84 projects.

2 See, for example, Forman et al. (2005a).

3 Broadband first appeared in Canada in 1997 (Czernich et al. 2011).

limits the urban/rural employment gap. Regarding wage growth, the impact of broadband deployment is the same across rural and urban regions.

To put these findings into perspective, we evaluate the impact under the scenario that all communities within a given economic region moved from having zero broadband coverage in 1997 to enjoying coverage 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 both the profitability of broadband deployment and regional economic activity more generally. Further, economic conditions themselves can, directly and indirectly influence broadband deployment rates. This reverse impact could result from the Government of Canada's focus on extending broadband to rural and remote communities least likely to be served by commercial forces alone. 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 can be used for this purpose.

Elevation variation affects the cost of deploying broadband. It is significantly cheaper to deploy broadband in areas with limited elevation change. For example, microwave wireless systems, such as Multichannel Multipoint Distribution Service (MMDS), can cover a range of 100 kilometres over flat terrain, but the coverage range of MMDS is significantly reduced in mountainous areas. 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, fibre to the cabinet has been dismissed as a viable option in many regions of Scotland due to challenging terrain.[4] Our own correspondence with representatives from the Eastern Ontario Regional Network, 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 activity. This relationship could arise, for

4 Source: www.scotnet.co.uk/services/rural-broadband-solutions/bet/

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 how investment in advanced Internet applications by business related to wage and employment growth in US counties between 1995 and 2000. The study found that investment in the Internet contributed to 28% of wage growth, yet this growth was restricted to only 6% of US counties. These counties already had relatively 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) examined economic activity in the U.S. in 1999–2006 and found that broadband expansion promoted population and employment growth in IT-intensive industries, 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, and as such we owe much to previous work. 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.[5] 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 did 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 cover the full adjustment of the 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.

5 In addition, Dinkelman (2011) used land gradient as an instrument for project placement when studying the employment effects of household electrification in rural South Africa.

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. Section 2 discusses theoretical foundations. Section 3 outlines our empirical strategy. Section 4 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 5. The results are presented and discussed in section 6. Section 7 explores the sensitivity of the results, and section 8 concludes.

2. Theoretical foundations

The theoretical literature provides valuable insights into the complex relationship between IT adoption and economic outcomes. The Internet is classified as a General Purpose Technology (Jovanovic and Rousseau 2005, Lipsey et al. 2005), the adoption and productivity benefits of which vary across regions or industries (Ristuccia and Solomou 2014).

Several theories highlight rural/urban geographical differences in the benefits of Internet deployment. Forman et al. (2005a), for example, provides an in-depth discussion of two contradictory theories, labelled urban leadership and global village. The urban leadership theory predicts that urban firms face relatively low costs of Internet adoption because urban regions provide greater access to complementary infrastructure and support resources. As a result, urban firms adopt the Internet more quickly and receive greater benefits from Internet technology. The global village theory, in turn, predicts that rural firms face relatively high marginal returns from Internet adoption, because Internet access reduces communication and coordination costs of doing business in remote areas and helps overcome barriers to business associated with a distant location and small economy size. Rural firms thus adopt the Internet more quickly, despite relatively high adoption costs, and benefit from Internet technology disproportionately more.

Forman et al. (2005b) also discusses the industry composition theory. This theory maintains that location decisions made by firms prior to the Internet result in industry clusters; this prior clustering of industries leads to regional differences in Internet adoption. High concentration of IT-intensive industries in urban areas, in particular, can explain high urban concentration in Internet technology adoption and account for a comparatively high benefit of Internet deployment in urban regions. In a similar vein, the industry composition of cities is key in determining the impact of improvements in IT in Glaeser and Ponzetto (2007).

Gaspar and Glaeser (1998) offers an alternative theory that emphasizes the interaction between electronic and face-to-face communications. Internet technology may cause some communication to shift from face-to-face to electronic. This substitution may reduce the benefit of low face-to-face communication costs offered by urban regions and cause some businesses to reallocate to rural areas.

At the same time, electronic and face-to-face communication can act as complements. Internet technology may increase the frequency of electronic communication, boosting face-to-face communication as well. This complementarity effect is particularly strong in urban regions, and so urban regions may benefit from Internet technology relatively more as a result.

The theoretical literature also emphasizes industry differences in the benefits of Internet deployment. Economic benefits of IT are concentrated in those industries with high IT investments, given that investment in IT is generally value producing (Brynjolfsson and Hitt 2000). Pre-Internet investment in IT impacts Internet investment decisions and determines use of the Internet (Forman 2005). Forman et al. (2003) further argues that IT innovation will concentrate by industry and compound over time as long as economic activities are reasonably stable within firms and across industries. Tambe and Hitt (2013) finds that intercorporate movement of IT labour results in productivity spillover across firms. Those industries in which IT investment is concentrated should see greater benefits from productivity spillover.

The model in Glaeser and Ponzetto (2007) emphasizes the difference between idea-producing and goods-producing industries when considering the impact of improvements in IT. Finance and professional services, for example, belong to idea-producing industries, while manufacturing is considered a goods-producing industry. The model predicts that advances in IT may hurt production-oriented cities but benefit idea-oriented cities.

While the theoretical literature has been useful in identifying a series of links between Internet deployment and economic outcomes, the direction of the impact of Internet deployment is not predetermined and becomes an empirical question. The empirical strategy employed in this paper builds on the above theoretical literature and examines regional and industry heterogeneity in the economic impact of broadband deployment.

3. 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 5. 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 the shock to economic conditions brought by the 2008 recession. To do that, we add the time effect α_t (i.e., the indicator variable for $t = 2$) 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 deployment 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}.

4. Data

4.1. Broadband coverage data

We use the National Broadband Coverage data, compiled by the Canadian Radio-Television and Telecommunications Commission (CRTC) and Industry Canada.

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.

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 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 during 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 centre 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.

We examine broadband deployment rate over time and relate it to changes in economic activity. To begin, we merged the two rounds of broadband data together. 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. These new communities

7 DBA point (or centroid) marks the geographic centre 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: www.statcan.gc.ca/pub/92-195-x/2011001/geo/db-id/def-eng.htm.

8 Each side of the hexagon is three kilometres long, making the area of each hexagon about 25km^2.

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

were relatively underserved and also differed from the rest in terms of geographic and economic characteristics. These differences between the two samples could cause endogeneity bias and to preclude 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).[10] 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, 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.

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 existing 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.[11]

10 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: www12.statcan.gc.ca/census-recensement/2011/ref/dict/geo022-eng.cfm.

11 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,

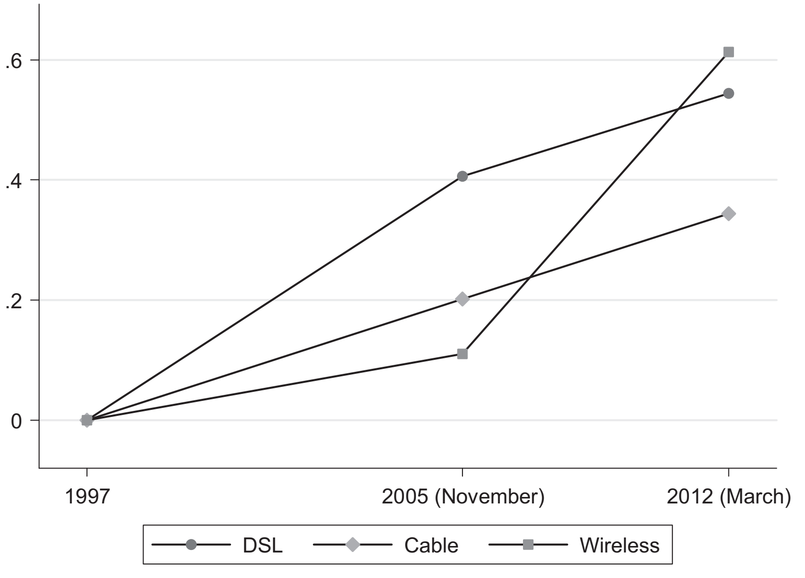

FIGURE 1 Average broadband availability by technology

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.[12] 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 disproportionate amount of the bandwidth available to downloads (downstreaming or incoming data), at the expense of 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

which is a short-range wireless distribution of an underlying wired network and a feature commonly available in consumer-grade routers.

12 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.

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, 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 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:

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

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 helps 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 communities which had broadband, most (35%) had only one type of technology available. The distribution for 2012 is markedly 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

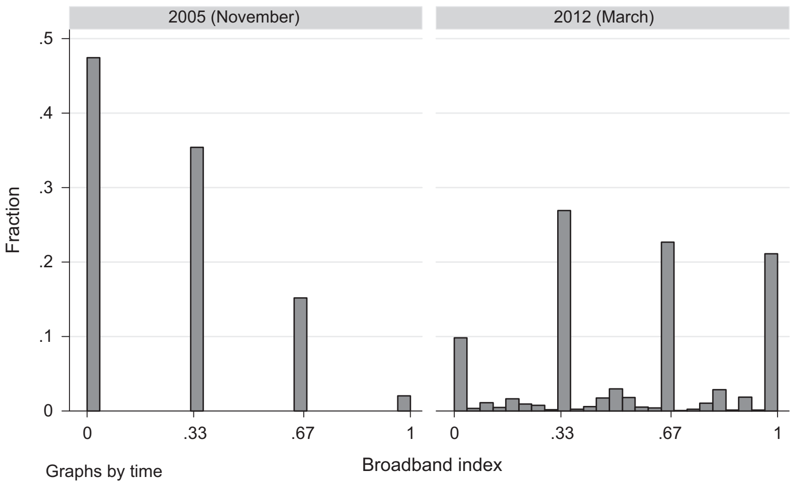

FIGURE 2 The Broadband index across communities

time, the fraction of communities covered by more than one technology rose from 17% in 2005 to 58% in 2012.

4.2. 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, based on the 2007 North American Industry Classification System (NAICS). 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.[13] To account for the varying degree of urbanicity across regions, we distinguish ERs based on their urban/rural status. Regions containing a CMA are designated as urban, with the balance of regions designated as rural.[14] The two groups are roughly equal in size: 38 ERs are urban and 31 are rural.

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

14 Statistics Canada defines a CMA as area with an urban core of 50,000 or more and a total population of 100,000 or more.

4.3. 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.[15] Subsequently, the mean elevation around each hexagon centroid was computed.

5. 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-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. In column (1), ΔB_{jt} is regressed on the log of elevation variation, the demographic covariates and the time effect. It is apparent that the coefficient on the log of elevation variation is negative (−.007) and highly statistically significant. The estimate implies that a one standard deviation (which equals .8681) increase in the log of elevation variation is associated with .0057 log points (or .57 percentage points) per year decline in the broadband deployment rate.[16] The standardized coefficient on the

15 The average number of data points for each buffer region is greater than 400.
16 The appendix presents the summary statistics.

TABLE 1
Broadband deployment and elevation variation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log of elevation variation	−.007***		−.004***	−.005***	−.010***	−.005***	−.009***	−.006***	−.007***
	(.001)		(.001)	(.002)	(.002)	(.001)	(.002)	(.001)	(.001)
Elevation variation (in 1,000s)		−.141***							
		(.029)							
Elevation variation squared		.210***							
		(.056)							
Rural indicator	.004	.004	.002	.006	.006	.006	.003	.005	.004
	(.004)	(.004)	(.003)	(.004)	(.007)	(.003)	(.008)	(.003)	(.003)
% of population living in a CMA	−.000	−.000	.001	.000	−.001	.001***	−.002*	.000	.000
	(.000)	(.000)	(.000)	(.000)	(.001)	(.000)	(.001)	(.000)	(.000)
Log of population	.005***	.004***	.005***	.004***	.006**	.004***	.005*	.005***	.005***
	(.001)	(.001)	(.002)	(.001)	(.003)	(.001)	(.003)	(.001)	(.001)
Density per km^2	−.001	.001	−.001	.000	.000	.007***	−.008**	.001	.003
	(.002)	(.002)	(.002)	(.003)	(.003)	(.002)	(.004)	(.002)	(.002)
% of high school graduates	.041*	.051**	.008	.058**	.064	.041**	.041	.041**	.011
	(.021)	(.021)	(.023)	(.025)	(.043)	(.020)	(.041)	(.020)	(.018)
% of university graduates	.051	.042	.027	.017	.114	.003	.098	.044	.036
	(.040)	(.040)	(.044)	(.043)	(.069)	(.031)	(.084)	(.036)	(.036)
% of population aged below 15	−.028	−.040	−.179***	−.320***	.354***	−.136**	.079	−.044	−.030
	(.052)	(.054)	(.066)	(.061)	(.105)	(.055)	(.089)	(.051)	(.048)
% of population aged above 65	.019	.008	−.044	−.115***	.190***	.002	.037	.017	−.008
	(.038)	(.038)	(.043)	(.039)	(.064)	(.037)	(.076)	(.036)	(.025)
Time effect	−.004	−.004	−.041***	−.010***	.046***				
	(.002)	(.002)	(.003)	(.004)	(.006)				
Constant	.007	−.009	.073***	.073***	−.119***	.027	−.016	.008	.021
	(.016)	(.015)	(.018)	(.019)	(.028)	(.017)	(.035)	(.015)	(.013)
Observations	138	138	138	138	138	69	69	69	69
R^2	.321	.331	.666	.298	.464	.654	.319	.602	.716
Robust F (log of el. var.)	24.74		10.82	11.01	18.86	17.25	14.26	24.55	59.68
Robust F (el. var.)		22.96							
Robust F (el. var. sq.)		14.04							
Robust F (el. var., el. var. sq.)		13.55							

NOTES: ***, ** and * denote 1%, 5% and 10% significance levels, respectively. Standard errors in parentheses are robust and clustered by ERs.

log of elevation variation is −0.3782, while the standardized coefficient on the log of population, for example, is −0.0059. The estimate also implies that an increase in the log of elevation variation from its minimum of 1.2539 (Winnipeg, MB) to its maximum of 6.3222 (Lower Mainland–Southwest, BC) is associated with .0333 log points (or 3.39 percentage points) per year decline in the broadband deployment rate. For comparison, the average change in broadband coverage over the 1997–2005 period was .0270 log points (2.74%) per year. The results further indicate that elevation variation is relevant for explaining variation in broadband deployment; the F statistic of 24.74 exceeds its critical value of 10 (Stock et al. 2002).

In column (2), we control for the elevation variation measured in levels, rather than logs, and also include the square of the elevation variation to allow for a non-linear relationship between the rate of broadband deployment and elevation variation.[17] It is apparent that our results are not driven by our choice of functional form. The coefficient on elevation variation is negative and the coefficient on elevation variation squared is positive. Both coefficients are highly statistically significant. The joint hypotheses test (at the bottom of the table) also indicates that the two coefficients are jointly statistically significant. These results suggest that as elevation variation rises, the rate of broadband deployment declines at a decreasing rate.[18]

We next analyze the broadband deployment rate by technology. We focus on DSL in column (3), Cable in column (4) and Wireless in column (5). In column (3) for example, the rate is defined as in (4), where $B_{jt} \equiv \sum_{h=1}^{H_j} DSL_{ht}/H_j$ for $l = h$, $B_{jt} \equiv \sum_{k=1}^{K_j} DSL_{kt}/K_j$ for $l = k$ and DSL_{lt} equals one if location l is covered by DSL and zero otherwise. We find that the coefficient on the log of elevation variation is negative and statistically significant in all three columns. Thus, high elevation variation is associated with lower broadband deployment for all three technologies. According to the F statistic, elevation variation is most relevant for explaining variation in the deployment of Wireless. This makes sense considering that elevation variation limits the maximum range of wireless communication towers, requiring the installation of additional towers at extra cost in mountainous regions. No such additional costs are expected for wired deployments.[19]

In columns (6) to (8), we re-estimate the regression using cross-sectional, rather than two-period panel, data. We consider three individual time periods: 1997–2005 in column (6), 2005–2011 in column (7) and 1997–2011 in column (8). The coefficient on the log of elevation variation is negative and statistically significant in all three columns. The F statistic is the highest for 1997–2011 and lowest for 2005–2011. One potential reason for the difference in the result is that the period

17 The coefficients in column (2) are rescaled by dividing the level of elevation variation by 1,000.

18 The relationship between the broadband deployment rate and elevation variation is negative for 64 (out of 69) regions.

19 We also considered separately 31 rural and 39 urban regions and found that across regions, elevation variation explains most differences in broadband coverage in urban areas. Thus, geography influenced broadband deployment in urban regions more than in rural regions. We thank anonymous referee for suggesting the analysis.

of 2005–2011 is relatively short, another is that geography played a larger role in affecting broadband deployment in the earlier period.

Last in column (9), we consider a different sample of communities: 17,143 communities sampled in the second round, rather than 4,344 communities sampled in both rounds. The analysis utilizes cross-sectional data for the period of 1997–2011. As before, the coefficient on the log of elevation variation is negative and statistically significant. The F statistic rises only when all 17,143 communities are considered.[20]

6. Results

6.1. 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 group.

Table 2 reports the aggregate employment growth results. 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 ΔB_{jt} and the indicator variable for rural ERs 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 rural and urban ERs.

It is apparent from column 1 of 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 employ-

20 The broadband deployment rate is measured in log changes in table 1. We show in the online technical appendix (available in the online version of this article) that the sign of the coefficient on the log of elevation variation and its significance are not driven by our definition of the broadband deployment rate. The results remain qualitatively unchanged when the rate is measured in level or binary changes in tables S1 and S2.

TABLE 2
Aggregate employment growth

Variable	(1)		(2)		(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
First-stage robust F, ΔB_{jt}	22.88				16.48	
First-stage robust F, $\Delta B_{jt} \cdot R_j$			21.29		11.07	
Test of endogeneity						
robust F	0.66		4.74		2.97	
p-value	.418		.033		.058	
R^2	.228		.093		.028	

NOTES: 138 observations. ***, ** and * denote 1%, 5% and 10% significance levels, respectively. Standard errors are robust and clustered by ERs.

ment 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 of 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. In table 3, we consider two distinct industry groups: goods and services.[21] 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

21 Goods industries are: agriculture; resource-based, mining; construction; and manufacturing. Service industries are: trade; transportation & warehousing; information, culture, recreation; finance, insurance, real estate; professional, scientific, technical; business, building, other support; educational services; health care & social assistance; accommodation, food services; and public administration.

TABLE 3
Employment growth by industry group

Industry group		(1)		(2)		(3)	
		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

NOTES: 138 observations. *** and ** denote 1% and 5% significance levels, respectively. Standard errors are robust and clustered by ERs.

suggests that broadband deployment promotes service employment growth in rural regions at the expense of urban regions.[22]

To examine the industry variation more thoroughly, we re-estimate our model using the data on the industry intensity of IT use documented in Jorgenson et al. (2012).[23] Table 4 shows the results. The outcome variable varies by ERs, industries and time. In addition to controls in table 2, we include three interaction terms: between (i) the broadband deployment rate and the industry IT-intensity measure, $\Delta B_{jt} \cdot IT_i$; (ii) the broadband deployment rate, the rural indicator variable and the IT-intensity measure, $\Delta B_{jt} \cdot R_j \cdot IT_i$; and (iii) the rural indicator variable and the IT-intensity measure, $R_j \cdot IT_i$. The instrument for $\Delta B_{jt} \cdot IT_i$ is the interaction term between the log of elevation variation and IT_i, and the instrument for $\Delta B_{jt} \cdot R_j \cdot IT_i$ is the interaction term between the log of elevation variation and $R_j \cdot IT_i$. The specifications in the first two columns also include IT_i as a separate control, while the specifications in the last two columns include the set of industry fixed effects.

From columns 2 and 4 of table 4, the coefficient on $\Delta B_{jt} \cdot R_j \cdot IT_i$ is positive and statistically significant at 5% level, the coefficient on $\Delta B_{jt} \cdot IT_i$ is negative and marginally significant and the coefficient on $\Delta B_{jt} \cdot R_j$ is negative and statistically insignificant at 10% level. These results confirm that broadband deployment promotes aggregate employment growth in rural regions more than in urban ones and further indicate that this impact is most pronounced in industries with high IT intensity. It is also noteworthy that the coefficient on $R_j \cdot IT_i$ is negative while

22 The Hausman test of endogeneity rejects the null hypothesis that ΔB_{jt} and $\Delta B_{jt} \cdot R_j$ are exogenous at 1% level in columns 2 and 3 of table 3.

23 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. The industries with lowest IT intensity include: trade; transportation (for all but air transportation); warehousing and storage; construction; manufacturing; agriculture; resource-based industries; and mining.

Industries are at 2-digit NAICS level in our paper and 2-, 3- and 4-digit NAICS level in Jorgenson et al. (2012). To obtain 2-digit IT-intensity measure, we calculate a simple average across all industries within a given 2-digit industry.

TABLE 4
Employment growth and industry IT intensity

Variable	(1)	(2)	(3)	(4)
Broadband deployment rate, ΔB_{jt}	−.455*	.256	−.495*	.180
	(.272)	(.521)	(.260)	(.506)
The interaction $\Delta B_{jt} \cdot IT_i$		−2.632*		−2.507*
		(1.389)		(1.338)
The interaction $\Delta B_{jt} \cdot R_j$	1.033***	−.308	1.100***	−.046
	(.345)	(.748)	(.338)	(.719)
The interaction $\Delta B_{jt} \cdot R_j \cdot IT_i$		5.062**		4.320**
		(2.336)		(2.180)
Rural indicator, R_j	−.030***	.007	−.033***	−.000
	(.010)	(.021)	(.010)	(.020)
The interaction $R_j \cdot IT_i$	−.010	−.150**	−.005	−.127**
	(.011)	(.067)	(.010)	(.063)
Industry IT share, IT_i	.027***	.108**		
	(.004)	(.043)		
Industry fixed effects			included	included
First-stage robust F, ΔB_{jt}	26.49	15.38	26.55	15.14
First-stage robust F, $\Delta B_{jt} \cdot IT_i$		12.62		12.57
First-stage robust F, $\Delta B_{jt} \cdot R_j$	15.66	11.16	15.5	11.04
First-stage robust F, $\Delta B_{jt} \cdot R_j \cdot IT_i$		7.61		7.32
Test of endogeneity				
robust F	5.92	6.57	6.30	6.51
p-value	.004	.000	.003	.000
R^2	.043	.016	.134	.113

NOTES: 1,885 observations. ***, ** and * denote 1%, 5%, and 10% significance levels, respectively. Other controls included. Standard errors in parenthesis are robust and clustered by ERs.

the coefficient on $\Delta B_{jt} \cdot R_j \cdot IT_i$ is positive, and both are statistically significant at 5% level. From column 4 specifically, the marginal effect of industry IT intensity in rural regions, given by $\partial \Delta Y_{jt} / \partial (R_j \cdot IT_i) = -.127 + 4.320 \Delta B_{jt}$, is negative at low values of the broadband deployment rate, but becomes positive at higher values.[24] This result indicates that rural employment growth in IT-intensive industries declines when broadband is non-existent or limited but rises as the availability of broadband rises.[25]

6.2. *Wage growth*

We now use the average hourly wage growth as the outcome variable.[26] As before, we first examine average growth across all industries and then consider growth by industry group. 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

24 The turnaround value of ΔB_{jt} is 0.0294. The actual value of ΔB_{jt} was above the turnaround value for 10 (out of 31) rural regions over the 2005–2011 period.
25 We thank anonymous referee for suggesting this comment.
26 When we use average weekly (rather than hourly) wage, the results are very similar.

TABLE 5
Average wage growth

Variable	(1)		(2)		(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
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	
Test of endogeneity						
robust F	3.77		1.39		1.91	
p-value	.056		.242		.155	
R^2	.282		.406		.265	

NOTES: 138 observations. ***, ** and * denote 1%, 5% and 10% significance levels, respectively. Standard errors are robust and clustered by ERs.

is .024 points higher in urban regions than rural ones. This difference in impact however is not statistically significant. From column 3, the coefficient on $\Delta B_{jt} \cdot R_j$ is not statistically different from zero.

Table 6 reports the results by industry group. In line with the employment growth results, 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.[27]

6.3. *Discussion*

In our discussion of results we focus on the service industry groups. 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 .0078 log points per year increase in rural

27 The data do not provide evidence that the impact of broadband deployment is more pronounced in industries with high IT intensity.

TABLE 6
Wage growth by industry group

Industry group		(1)		(2)		(3)	
		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

NOTES: 138 observations. *** and ** denote 1% and 5% significance levels, respectively. Standard errors are robust and clustered by ERs.

employment growth and .0079 log 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 log points per year increase in rural wage growth and .0066 log points per year increase in urban wage growth.

To put these estimates into perspective, 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.

Our finding of the positive impact on rural employment growth and a corresponding negative impact on urban employment growth is consistent with the global village theory discussed in Forman et al. (2005a). The theory predicts that rural regions benefit disproportionately from broadband deployment because broadband access reduces the costs of doing business in remote areas and helps overcome barriers to business associated with a distant location and small economy size. A similar finding would also arise if businesses relocate to rural regions following broadband deployment because broadband technology reduces the urban benefit of low in-person communication costs (Gaspar and Glaeser 1998). Our industry-level analysis further shows that the results are driven by service industries, while goods industries are not impacted. Relative to goods industries, service industries have relatively high reliance on IT and are also more IT-skill intensive. Likewise, Kolko (2012) found that positive impact of broadband deployment on rural employment growth is strongest in industries that rely on IT most. Service industries also rely on in-person communication more (in the absence of the Internet). Additionally, service industries are more footloose, meaning they are not tied to any particular location (e.g., because of proximity to raw materials) and can relocate with little delay in response to a changing economic environment.

Our results are qualitatively different from Forman et al. (2012), where Internet investment was found to promote wage and employment growth in advanced urban areas and have no impact elsewhere. One possible explanation for this difference is that the type of Internet technology studied is different: Forman et al. (2012) focused on advanced Internet applications while we focus on high-speed broadband Internet access, which provides improved access to both basic and advanced Internet services. Generally, benefit from advanced Internet applications requires highly skilled labour force, which is predominantly concentrated in urban areas. Another explanation is that Internet infrastructure capabilities in the 1995–2000 period studied in Forman et al. (2012), were less than those deployed in subsequent years. In Forman et al. (2012), at most 30% of firms were using advanced Internet applications in the year 2000. In our study, by contrast, broadband Internet services are more widespread; the fraction of communities with zero broadband coverage was 47% in 2005 and 10% in 2012. Furthermore, all of the firms sampled in Forman et al. (2012) are large (i.e., 100+ employees), since very few small firms deployed advanced Internet applications at that time. Our sample, on the other hand, includes firms of all sizes, the vast majority of which are small.

Our results are qualitatively similar to Kolko (2012), where the focus is on the expansion of broadband. The magnitudes of the impact are not directly comparable, as the measures of broadband availability used are different: Kolko (2012) uses the number of broadband providers with subscribers, while we use the number of access technologies available in a given community.

7. Sensitivity analysis

In this section, we provide further details about the analysis and explore the sensitivity of our employment growth results to our measure of the broadband deployment rate, the choice of communities in the sample and the choice of time period.[28] Tables 7 and 8 follow.

We first confirm that our decision to focus on all three technologies together does not drive our results. To show this, we limit the analysis to Wireless technology since from section 5, elevation variation is most relevant for explaining variation in the deployment of Wireless. The results remain qualitatively unchanged. From panel 1 of table 7, the coefficient on $\Delta B_{jt} \cdot R_j$ is positive and statistically significant at 5% level. This result confirms the positive differential impact of broadband deployment on aggregate employment growth in rural regions. When we consider two distinct industry groups in table 8, panel 1, we find no statistically

28 The results of the wage growth sensitivity analysis are reported in the online technical appendix, section S.2.2.

TABLE 7
Aggregate employment growth. Sensitivity

Variable	(1)		(2)		(3)	
	Coeff.	St.er.	Coeff.	St.er.	Coeff.	St.er.
Panel 1: Wireless						
Broadband deployment rate, ΔB_{jt}	.040	.130			−.193	.152
The interaction $\Delta B_{jt} \cdot R_j$			.308*	.159	.500**	.207
Rural indicator, R_j	−.006	.003	−.015**	.006	−.021*	.008
Panel 2: 1997–2005						
Broadband deployment rate, ΔB_{jt}	.524	.461			−.321	.565
The interaction $\Delta B_{jt} \cdot R_j$			1.095	.686	1.427	.926
Rural indicator, R_j	−.011**	.006	−.040*	.021	−.048*	.025
Panel 3: 1997–2011						
Broadband deployment rate, ΔB_{jt}	.106	.215			−.502	.314
The interaction $\Delta B_{jt} \cdot R_j$			.564*	.307	1.077**	.475
Rural indicator, R_j	−.006	.003	−.020**	.008	−.032***	.012
Panel 4: 17,143 communities						
Broadband deployment rate, ΔB_{jt}	.096	.195			−.374	.243
The interaction $\Delta B_{jt} \cdot R_j$			.590*	.308	.977**	.418
Rural indicator, R_j	−.006*	.003	−.017**	.007	−.023***	.008
Panel 5: Fraction control						
Broadband deployment rate, ΔB_{jt}	.091	.223			−.459	.355
The interaction $\Delta B_{jt} \cdot R_j$			.597**	.294	1.074**	.490
Rural indicator, R_j	−.005	.004	−.019**	.007	−.030**	.012
Fraction	.013	.016	.032*	.018	.035*	.019
Panel 6: Lagged						
Broadband deployment rate, ΔB_{jt}	−.335	.430			−1.267	1.089
The interaction $\Delta B_{jt} \cdot R_j$			.265	.464	1.575	1.248
Rural indicator, R_j	−.000	.006	−.009	.014	−.040	.031
Panel 7: Placebo test						
Broadband deployment rate, ΔB_{jt}	−.218	.464			−.064	.589
The interaction $\Delta B_{jt} \cdot R_j$			−.354	.547	−.294	.659
Rural indicator, R_j	−.005	.004	.005	.015	.003	.019

NOTES: ***, ** and * denote 1%, 5% and 10% significance levels, respectively. Other controls included. Standard errors are robust and clustered by ERs.

significant impact in the goods industry group. In the service industry group, the coefficients on ΔB_{jt} is negative and statistically significant at 5% level, and the coefficient on $\Delta B_{jt} \cdot R_j$ is positive and highly statistically significant. Thus, as before, we find that broadband deployment promotes service employment growth in rural regions at the expense of urban regions.

We next check if our estimates of the impact are qualitatively unchanged when we use the cross-sectional data for 1997–2005 and 1997–2011. In table 7, the coefficient on $\Delta B_{jt} \cdot R_j$ is statistically insignificant in panel 2 and positive and significant at 5% level in panel 3. Thus, the positive differential impact on aggregate employment growth in rural regions is confirmed for 1997–2011, but not for 1997–2005. The results by industry groups in table 8, panels 2 and 3, are

TABLE 8
Employment growth by industry group. Sensitivity

Industry group		(1)		(2)		(3)	
		Coeff.	St.er.	Coeff.	St.er.	Coeff.	St.er.
Panel 1: Wireless							
Goods	ΔB_{jt}	.072	.213			.170	.319
	$\Delta B_{jt} \cdot R_j$			−.037	.297	−.207	.456
Services	ΔB_{jt}	.005	.112			−.208**	.117
	$\Delta B_{jt} \cdot R_j$			.331***	.104	.529***	.136
Panel 2: 1997–2005							
Goods	ΔB_{jt}	.322	.546			.138	1.070
	$\Delta B_{jt} \cdot R_j$			.467	.853	.316	1.605
Services	ΔB_{jt}	.153	.391			−1.088**	.541
	$\Delta B_{jt} \cdot R_j$			1.094**	.552	2.208***	.803
Panel 3: 1997–2011							
Goods	ΔB_{jt}	.138	.340			.327	.614
	$\Delta B_{jt} \cdot R_j$			−.001	.494	−.349	.903
Services	ΔB_{jt}	.022	.176			−.595***	.223
	$\Delta B_{jt} \cdot R_j$			.591***	.209	1.187***	.317
Panel 4: 17,143 communities							
Goods	ΔB_{jt}	.118	.285			.228	.414
	$\Delta B_{jt} \cdot R_j$			−.001	.504	−.241	.739
Services	ΔB_{jt}	.020	.160			−.474***	.167
	$\Delta B_{jt} \cdot R_j$			.614***	.195	1.073***	.257
Panel 5: fraction control							
Goods	ΔB_{jt}	.272	.396			.432	.675
	$\Delta B_{jt} \cdot R_j$			.123	.525	−.357	.981
Services	ΔB_{jt}	.003	.176			−.505**	.219
	$\Delta B_{jt} \cdot R_j$			.583***	.204	1.091***	.299
Panel 6: lagged							
Goods	ΔB_{jt}	.004	.831			.995	1.756
	$\Delta B_{jt} \cdot R_j$			−.624	.896	−1.705	2.190
Services	ΔB_{jt}	−.128	.355			−.889	.733
	$\Delta B_{jt} \cdot R_j$			.444	.350	1.355*	.778
Business, building, support	ΔB_{jt}	−1.353	1.275			−6.351**	3.117
	$\Delta B_{jt} \cdot R_j$			4.196**	1.766	11.586***	4.452
Panel 7: placebo test							
Goods	ΔB_{jt}	−.259	1.077			−.128	1.421
	$\Delta B_{jt} \cdot R_j$			−.370	1.145	−.248	1.447
Services	ΔB_{jt}	−.243	.362			−.048	.641
	$\Delta B_{jt} \cdot R_j$			−.415	.322	−.369	.676

NOTES: ***, ** and * denote 1%, 5% and 10% significance levels, respectively. Other controls included. Standard errors are robust and clustered by ERs.

qualitatively unchanged. Broadband deployment promotes service employment growth in rural regions at the expense of urban regions and has no impact on employment growth in the goods industry group. The coefficients in panel 2 are about twice the size of those in panel 3, suggesting that the impact of broadband deployment on service employment growth is larger over the shorter period.

Thus far, we analyzed 4,344 communities sampled in both rounds, which represents 80% and 25% of communities sampled in the first and second round respectively. If communities in the first round were non-randomly sampled, then our estimates of the impact might be biased. To ensure that the missing data is not a serious concern, we perform two checks. First, we re-estimate the impact using the data on 17,143 communities sampled in the second round. This analysis covers the period from 1997 to 2011. Second, we directly control for the fraction of communities sampled in both rounds within each ER.[29] The results, shown in panels 4 and 5, confirm our previous findings. Quantitatively, the estimates in table 8 are comparable to those in table 3. The statistical significance of the estimates rises only when 17,143 communities are considered. The coefficient on the fraction of communities is only marginally significant in columns 2 and 3, table 7.

In panel 6, we check if the deployment of broadband over the 1997–2005 period impacted employment growth over the 2005–2011 period. We do not find a statistically significant impact of lagged broadband deployment on employment growth in either the goods or the services industry group. One exception is Business, building and other support services, which includes three sectors: (i) Management of companies and enterprises, (ii) Administrative and support services and (iii) Waste management and remediation services. The results in the last two rows in panel 6, table 8 show that in this industry, the deployment of broadband in 1997–2005 promoted employment growth in rural regions at the expense of urban regions in 2005–2011.

Last, we conduct a placebo test. We check if the deployment of broadband over 1997–2005 impacted employment growth over 1990–1997.[30] If our identification strategy is correct, future broadband deployment should have no effect on past employment growth. The results in panel 7, tables 7 and 8, pass the placebo test: none of the key coefficients are statistically different from zero.[31]

8. 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

29 The fraction ranges from .11 to .64, with a mean value of .26.

30 Controls included (for 1990): log of population, density per km^2, % of high school graduates, % of university graduates, % of population aged below 15, and % of population aged above 65. Also included: fraction of communities and constant. The data on other controls at the ER and CMA level, as well as the data on average hourly wages by ERs and CMAs, are not available for 1990.

31 We also did not find evidence that the deployment of broadband over 1997–2011 impacted employment growth over 1990–1997.

The broadband deployment rate is measured in log changes in tables 7 and 8. The results for the rate measured in level or binary changes, shown in the online technical appendix (section S.2.1), are qualitatively similar.

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 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.

We found that the deployment of broadband in 1997–2011 promoted growth in aggregate employment and wages in rural regions across Canada. This impact was limited to service industries. Goods industries were not impacted. The impact was most pronounced in industries with high intensity of IT use. Rural employment growth in IT-intensive industries declined when broadband was limited, but rose as broadband became more available. We also found 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 did not differ in the impact on their wage growth.

Our results show that broadband deployment decreases regional disparities in employment opportunities and enhances the economic viability of rural regions. In this regard, policies promoting broadband deployment may be said to serve the objectives of bridging the urban-rural digital divide and reducing regional inequality. However, our findings also indicate that the observed improvements in rural employment options come at the expense of those in urban areas. This second finding leaves open the question of whether increased broadband deployment actually serves the goals of promoting national economic growth and competitiveness. Judging the true value of broadband deployment to the nation will require further analyses of the various impacts (e.g., on national productivity, innovation, business profitability), and these analyses call for future research.

Appendix

TABLE A1
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

(*continued*)

TABLE A1
(*Continued*)

Variable	Obs.	Mean	Std. dev.	Min	Max
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

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Supporting information

Additional supporting information can be found in the online version of this article.