A Macroeconomic Analysis of Fibre Broadband Adoption in the OECD

Justin Desrosier

8204025

ECO 4186 Applied Econometrics

Professor Myra Mohnen

ECO 4186

University of Ottawa

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1 Introduction

The center of the technological revolution is the internet, containing vast quantities of information and a highly flexible technology for innovation, it is a comprehensive source of human opinion and a powerful tool for technologists to build systems within. The ability to search for and comprehend information has become exponentially more efficient and accessible thanks to the internet. All the while, telecommunications companies have seen extraordinary development in capacity and access to the internet during the 21st century as a provider of the public utility. However, change underway has varied from country to country and therefore requires debate over efficient public investment and the regulatory policy that is involved.

This research paper will be an analysis of macroeconomic impacta of fibre broadband infrastructure adoption which is closely associated with Gb/s capacity upgrades. It is well known that broadband adoption has a positive impact on GDP growth, however the effect on GDP when deploying broadband technology capable of ultra-fast speeds is less known. I will look at the relationship between fibre broadband adoption in the form of subscription uptake, on GDP in 33 OECD countries and examine the impact of fibre infrastructure broadband adoption.

Most governments in the high-income countries of the OECD have concrete plans for Gb/s infrastructure development. However, in countries with lower population densities, Gb/s infrastructure falls out of the infrastructure investment time agenda. It is an expensive technology to fund given tax payers with scarce any internet access at all. Thus, fibre infrastructure is mostly limited to metropolitan areas in which there is a business case for the private sector to invest in the high capacity Gb/s subscription speeds.

The Austrian Political Economist Joseph Schumpeter has correctly reviewed classical capitalist analysis saying "The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' good, the new methods of production or transportation, the new markets, the new form of industrial organization that the capitalist enterprise creates." (Schumpeter, 1942) says it is the process of Creative Destruction which revolutionizes the capitalist process from within, it is internet technology which manifests these traits in the 21st century, and therefore requires further examination to understand factor productivity.

2 Literature Review

Gb/s fibre infrastructure has become widely available to consumers only over the last decade, the research on macroeconomic effects of Gb/s infrastructure has been limited until even more recently. While early research has confirmed that broadband deployment and adoption of services and applications gives rise to growth in total factor productivity (Bresnahan & Trajtenberg, 1995). Further research that is more current is being carried out on the supply and demand side effects of fibre infrastructure technology. Researchers in telecommunications policy have conducted a survey of econometric analysis quantifying public welfare associated with increasing broadband investment and deployment using macroeconomic aggregates. They also investigate determinants and benefits of household broadband adoption and analyze existing literature on regulatory policy and competition when directing public funds to the deployment of broadband services (Abrardi & Cambini, 2019).

A study in Denmark analyzed the empirical evidence of diminishing marginal returns of broadband investment by showing that a GDP growth of 1.9% has a causal relationship with an increase in broadband speeds from 5 to 10 Mb/s, but only an increase of 0.5% in GDP when the speed increases from 25 to 30 Mb/s. Results suggest that broadband investment does have a significant positive causal effect on economic growth, though the impact is greatest for basic adoption. The study led to inconclusive evidence on an optimal investment strategy to maximize economic growth, it is difficult to determine what the equilibrium speed would be for maximum economic growth given cost of investment. It should also be noted that studies have shown significant correlation between Gb/s speeds and per capita GDP by region, though this could be interpreted in many ways (Rosston et al., 2010; Gruber et al., 2014).

At the household level it is clear that the price of service has an impact on broadband subscription uptake, the effect of the price variety might be more ambiguous, however. Research shows that the effect of intervention with supply side regulatory policy tends to decreases as the market matures, which stresses the importance of reaching the consumers with a progressively lower willingness to pay (Abrardi & Cambini, 2019). A study using a mixed logit model concludes that consumers find considerable value in switching from Digital Subscriber Line (DSL) to Fibre-to-the-home (FTTH) technologies, although the costs of switching are significantly high due to the price difference between the two technologies (Grzybowski et al, 2018).

Studies have also shown that when private sectors are unwilling to invest in fibre infrastructure there can be a valid case for government intervention, although public funding might be an inefficient way to achieve higher rates of adoption given the informational disadvantage about capital costs, such as future demand uncertainty. Despite this, where extremely costly, fiber-based networks will not materialize and other forms of public interventions are needed to reach a full cover age of the new technology (Bourreau et al., 2018).

Also, the relationship between competitive pressure, be it regulation induced or market forces, and ultra-fast network deployment (typically fibre technologies) tend to have an inverse-u relationship.

A small amount of service-based competition will lead to an under performing market, and while moderate competition will be beneficial, too much competition will result in market failure and reduce deployment (Briglauer et al., 2013). As well, there is hardly any sound empirical evidence on whether positive externalities beyond those associated with basic broadband networks will emerge under the new fiber-based broadband infrastructure (Briglauer & Gugler, 2013).

When looking at the role alternative regulatory instruments play in ultra-fast network deployment, research suggests that co-investment between investing firms and access seekers, could reduce deployment costs for very high capacity networks, and further boost investment. “An inclusive framework ensuring fair risk and cost sharing between investing firms and access seekers may have indeed a positive impact on network investments, especially in areas with limited scope for infrastructure competition” (Abrardi and Cambini, 2019). Co-investment between investing firms and access seekers, could lower prices making investment more feasible, positively impacting per capita GDP.

3 Methodology and Data

My empirical research strategy is to determine the effect associated with an increase in the number of fibre infrastructure broadband subscriptions on per capita GDP within 33 OECD countries. Using panel data from 2009 to 2017, and investigation using Instrumental Variable and Fixed Effect techniques, observation of the increase in number of subscriptions to fixed broadband services capable of 1 Gb/s bandwidth. However, for any given subscription the consumer or firm may not receive connections of 1 Gb/s due to capped speeds as agreed upon with their internet service provider. It is only relevant to my research that the broadband infrastructure is capable of 1 Gb/s as is fibre infrastructure, if there were business incentive to use this speed then they would pay the premium subscription rate.

Due to the lack of standard classification of broadband speeds, I will be observing the coverage and subscription rates of the commonly accepted ultra-fast speed range 100Mb/s download and 50Mb/s upload, at the household and firm levels. These speeds are achieved through coaxial cable, fibre cable or fixed wireless connections. It should also be noted that 5G Mobile can achieve speeds up to 1Gb/s as well although this technology is under current deployment and not commonly used in 2019.

Crucial to my analysis however is availability, precisely what percentage of the OECD countries are covered by broadband speeds capable of 1 Gb/s. This is achieved most commonly through fibre or fixed wireless, although the latter can only sustain speeds up to 128Mbps, whereas the former is cable of speeds up to 1 Gb/s. It should also be noted that 5G Mobile can achieve speeds up to 1 Gb/s as well although this technology has not yet been widely deployed for consumers.

Table 1. Variable Descriptions

Variables	Description
$fibrelan100_{it}$	The number of people in country *i* at year *t* who subscribe to an internet service provider for access to the internet via fibre infrastructure, for every 100 people
$datavoice100_{it}$	The number of people in country *i* at year *t* who have a data or voice mobile cellular plan, for every 100 people
$lncapitagdp_{it}$	The natural logarithm function of GDP per head of population in USD current prices, current PPPs, for country *i* at year *t*
$lncapital_{it}$	The natural logarithm function of gross fixed capital formation per head of population in USD current prices, current PPPs for country *i* at year *t*
$labourratio_{it}$	The ratio of total labour force to total population for country *i* at year *t*
$ictpatents_{it}$	ICT patent applications filed under the PCT. Inventor patents filed at application date (*t*), in country of residence (*i*).
$capitagdpgrowth_{it}$	Per capita GDP growth rate in country *i* at year *t*
$density_{it}$	Population density (people per sq. km of land) in country *i* at year *t*

The primary endogeneity problem of concern in the models employed is a reverse causality. My model attempts to capture the effect of telecommunication services on economic outputs although the reverse causality problem that may arise is that the number of subscriptions to telecommunication services in a given country could depend on economic growth. That is a certain possibility that countries which achieve significant growth throughout my observation period may tend to invest more in telecommunication sectors due to the increase demand of their citizens for better internet services following an income effect due to the rise in wealth.

$$(1)\ lnCapitaGDP_{it} = \beta_0 + \beta_1 Fibrelan100_{it} + \beta_2 lnCapital_{it} + \beta_3 labourratio_{it} + \beta_4 UrbanPopulation_{it} + \beta_5 PopulationDensity_{it} + \beta_6 GDPGrowth_{it} + \varepsilon_{it}$$

Under classical assumptions of the Gauss-Markov conditions being satisfied, ordinary least squares is the best linear unbiased estimator, homoskedasticity is assumed meaning the variance about the errors of the explanatory variables is constant. However, given the presence of heteroskedasticity, the estimator remains unbiased but efficiency is lost, OLS will not provide the estimate with the smallest variance. To test for heteroskedasticity I ran a Breusch-Pagan chi-squared test following an OLS regression of my primary structural equation (1). The test statistic has a p-value below the appropriate threshold of $p < 0.05$, so the null hypothesis of constant variance (homoskedasticity) was accepted with a ($p = 0.01$), at the 99% confidence level. Due to homoskedasticity of the model, I did not have to concern myself with robust standard errors.

To begin my analysis, I must solve the heterogeneity problems which violate the assumptions required to have unbiased and consistent estimation using OLS. Due to correlation of the primary explanatory variable, $fibrelan100_{it}$ with the error term, as seen in table 2, IV analysis must be deployed. This is in order to uncover the causal effect of fibre subscriptions on the dependent variable, $lncapitagdp_{it}$. The correlation between $fibrelan100_{it}$ and $lncapitagdp_{it}$ is likely due to two sperate violations of the Gauss-Markov assumptions for multiple linear regression. First, the assumption of zero conditional mean, that the error term has an expected value of zero given any values of the independent variables is violated. However, as per table 2, this assumption is violated. Therefore, $fibrelan100_{it}$ is not an exogenous explanatory variable and the OLS estimator will be biased. This is likely due to factors mentioned above such an income effect when per capita wealth increase, that would increase demand for fibre infrastructure services. The second reason that there is an observable correlation between $fibrelan100_{it}$ and the error term is the reverse causation of increasing per capita GDP causing an increase in fibre subscriptions. As already noted, fibre infrastructure is costly as are internet subscriptions that require it when compared to the alternative, as such, an increase in the wealth of a country will likely increase the capacity of infrastructure investment and vice-versa.

The requirements for a legitimate instrument variable candidate are that of a variable which is correlated with the endogenous explanatory variable, $fibrelan100_{it}$, and not correlated with the error term. As such, a variable can be used to induce change in the endogenous $fibrelan100_{it}$, without any effect of its own on the dependent variable, per capita GDP. Upon testing several possible instrument candidates the following results garnered introduction of $DataVoice100_{it}$, and $ICTPatents_{it}$ as instrumental variables in my analysis. $DataVoice100_{it}$ is a variable measuring the number of people in each country in a given year with a mobile phone subscription which includes broadband connection at any speed as well as voice calls. This variable satisfies exogeneity to my model due to the commonality of this service, it has very weak correlation with unobserved effects in the error term, as observed in table 2, as well it has a significant correlation the endogenous regressor $fibrelan100_{it}$, as per table 2. As well, $ICTPatents_{it}$ has a weak correlation with the error term, as per table 2 and further, a weak but relevant correlation with the endogenous explanatory $Fibrelan100_{\mathrm{it}}$. The weak correlation is noted during further analysis of the postestimation results following 2SLS regression using these instruments.

The first candidate variable for IV analysis was competition, this is because it's plausible that the number of subscriptions on gigabit infrastructure is related to the error terms by means of unobservable factors such as a government highly valuing digitization of its services, or a high urban density population, however this assumptions failed to pass the tests of correlation with the endogenous explanatory variable $Fibrelan100_{\mathrm{it}}$.

Upon discovery of adequate exogenous instrumental variables which pass the correlation tests, I can derive the estimator for my instrumented $Fibrelan100_{\mathrm{it}}$ variable as follows, where X_{it} is the structural explanatory variables outlined in (1) and $ICTPatents_{it}$ is the instrumental variable.

(2) $lnCapitaGDP_{it} = \beta_0 + \beta_1 X_{it} + \varepsilon_{\mathrm{it}}$

(3) $COV(ICTPatents_{it}, \varepsilon_{\mathrm{it}}) = 0$ AND $COV(ICTPatents_{it}, Fibrelan100_{\mathrm{it}}) \neq 0$

(4) $COV(ICTPatents_{it}, lnCapitaGDP_{it}) = \cancel{COV(ICTPatents_{it}, \beta_0)} + \beta COV(ICTPatents_{it}, X_{it}) + \cancel{COV(ICTPatents_{it}, \varepsilon_{\mathrm{it}})}$

(5) $\hat{\beta}_{IV} = \frac{COV(ICTPatents_{it}, lnCapitaGDP_{it})}{COV(ICTPatents_{it}, X_{it})}$

Once sure my instrumental variable satisfies the necessary correlation assumptions, as it does in table 2, I take the covariance of all variables on both sides of the equation with $ICTPatents_{it}$. Since the covariance of $ICTPatents_{it}$ and the error term is zero, and the β_0 estimator does not change with, time they cancel out of the equation. Rearranging for $\hat{\beta}_{IV}$ we have an unbiased estimator. In effect, I am controlling for the endogeneity problem of $Fibrelan100_{\mathrm{it}}$ being correlated to the unobserved values in the residual.

To continue my analysis I employ fixed effects techniques to solve unobserved heterogeneity problems in my intercept α_i, removing the endogeneity problem due to unobservable fixed characteristics of a country over time. I will primarily try to solve the issue of delay in output associated with increased broadband infrastructure, as well as an country fixed effects that do no vary with time, such as the effect of government sentiment toward digitization in countries like Estonia.

In order to remove the effect of unobserved heterogeneity in the model, I implement a fixed effects transformation removing the error derived from country dependent effects such as sentiment toward IoT (Internet of Things) technology. That is, due to a structural explanatory variables having serial correlation to some unobserved fixed characteristic inherent in countries across time, Gauss-Markov assumption of zero conditional mean E(u|x) = 0 and therefore violated. In order to solve this problem, I employ a fixed effects transformation to eliminate the fixed effect α_i in equation (6).

$$(6)\ lnCapitaGDP_{it} = \beta_0 + \beta_1 Fibrelan100_{it} + \beta_2 lnCapital_{it} + \beta_3 Employed_{it} + \beta_4 UrbanPopulation_{it} + \beta_5 PopulationDensity_{it} + \beta_6 GDPGrowth_{it} + \alpha_i + u_{it}$$

In order to implement fixed effects transformation, the mean of each variable for country *i* across all year observations, 2009-2017, must be calculated on each side of the equation and subtracted from the individual observations of country *i* at year *t*. The result is an effectively demeaned OLS model with estimators that no longer suffer from omitted variable bias, and are consistent given any fixed attributes across time. By taking the averages across time at the country level, the time constant variation in country can be eliminated. The time fixed α_i will be removed as the average across 2009-2017 not deviate from the initial α_i.

$$(7)\ \widetilde{lnCapitaGDP}_{it} = \beta_0 + \beta_1 \widetilde{Fibrelan100}_{it} + \beta_2 \widetilde{lnCapital}_{it} + \beta_3 \widetilde{Employed}_{it} + \beta_4 \widetilde{UrbanPopulation}_{it} + \beta_5 \widetilde{PopulationDensity}_{it} + \beta_6 \widetilde{GDPGrowth}_{it} + u_{it}$$

The drawback of using this model is an inability to test the effect of any time dependent variables on the dependent $lnCapitaGDP_{it}$, although this falls out of the scope of my analysis.

Table 2. Critical values of correlation matrix used in the discovery of instrumental variables

Variables	$\boldsymbol{Fibrelan100_{it}}$	$\boldsymbol{DataVoice100_{it}}$	$\boldsymbol{ICTPatents_{it}}$
$\boldsymbol{\varepsilon_{it}}$	-0.311	-0.073	0.024
$\boldsymbol{Fibrelan100_{it}}$	n/a	0.536	0.233

4 Results

Table 3. Descriptive statistics summary

Variable	Observations	Mean	Std. Dev.	Min	Max
$fibrelan100_{it}$	295	5.29	6.48	0.00	31.00
$datavoice100_{it}$	286	56.27	27.54	2.00	132.00
$capitagdp_{it}$	297	41515.45	15508.39	18796.53	105799.81
$capital_{it}$	297	8612.00	3595.15	3098.27	25211.62
$labourratio_{it}$	297	0.50	0.04	0.42	0.60
$ictpatents_{it}$	297	1233.53	3085.25	0.00	18078.42
$capitagdpgrowth_{it}$	297	0.88	3.45	-14.56	23.99
$density_{it}$	297	133.91	134.51	2.82	527.92

Tables 4 and 6 illustrate two primary models, 2SLS instrumental variable analysis, and fixed effects transformation, as well as a combination of the two. The two models return varying results that an increase in fibre infrastructure subscriptions per 100 people changes per capita GDP. However, the significance of the $fibrelan100_{it}$ estimator in model 6, pooled OLS fixed effects - IV regression, and the result of preceding model 5, pooled OLS fixed effects estimation, lead to optimistic conclusions.

Table 4. Preliminary OLS and instrumental variable analysis

Variables	Model 1	Model 2	Model 3	Model 4
Dependent variable: $lncapitagdp_{it}$ **Independent variables**				
$lncapital_{it}$	0.755*** (0.023)	0.764*** (0.025)	0.776*** (0.029)	0.765*** (0.024)
$fibrelan100_{it}$	-0.009*** (0.001)	-0.003 (0.003)	0.003 (0.007)	-0.003 (0.003)
$labourratio_{it}$	0.339 (0.265)	-0.025 (0.324)	-0.507 (0.578)	-0.033 (0.321)
$density_{it}$	0.000* (0.000)	0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)
$capitagdpgrowth_{it}$	-0.008*** (0.003)	-0.013*** (0.003)	-0.013*** (0.004)	-0.014*** (0.003)
Constant	3.662*** (0.193)	3.749*** (0.207)	3.861*** (0.245)	3.751*** (0.205)
Observations	295	285	295	285
R-squared	0.828	0.820	0.785	0.820

Model 1: OLS, model 2: IV (instrumented $fibrelan100_{it}$ by $datavoice100_{it}$), model 3: IV (instrumented $fibrelan100_{it}$ by $ictpatents_{it}$), model 4: IV-2SLS (instrumented $fibrelan100_{it}$ by $datavoice100_{it}$ and $ictpatents_{it}$)
*** indicates significance at 1%, ** indicates significance at 5% and * indicates significance at 10%.

Upon initial observation of the OLS analysis in model 1, the $fibrelan100_{it}$ estimator represents a decrease in per capita GDP by 0.9%, given a 1 subscription increase per 100 people in any country *i* for year *t*, although as mentioned earlier OLS estimation will not be unbiased and will be inconsistent due to a violation of necessary assumptions for OLS analysis detailed in section 3. The results from models 2 and 3 are that of single instruments and represent preliminary findings to the 2SLS analysis of model 4.

Model 4 employs a 2SLS - IV regression instrumenting $fibrelan100_{it}$ by $datavoice100_{it}$ and $ictpatents_{it}$. This model deals with the omitted variable bias and reverse causality inherent in the relationship between per capita GDP and the number of fibre internet subscriptions on fibre infrastructure per 100 people, as detailed in section 3. By inducing a causal effect of fibre internet subscriptions using alternative exogenous variables $datavoice100_{it}$ and $ictpatents_{it}$ as instruments, there we achieve unbiased, consistent estimators. The preceding analysis returned results of a 0.3% decrease in per capita GDP in country *i* at year *t* for 1 subscription increase of fibre infrastructure internet subscriptions. The following table containing postestimation results from the 2SLS - IV regression analysis confirms my findings that indeed, my instruments are valid, but contains notable information on the significance of that validity.

Table 5. 2SLS postestimation results (Table 4. Model 4)

Test	$\boldsymbol{p-value}$	$\boldsymbol{H_o}$
Test of endogeneity $\boldsymbol{H_0: variables\ are\ exogenous}$		
Durbin (score) chi2(1)	0.0091	Accepted
Wu-Hausmann	0.0096	Accepted
Test of overidentifying restrictions $\boldsymbol{H_0: instruments\ are\ uncorrelated\ with\ the\ error}$		
Sargan (score) chi2 (1)	0.3872	Rejected
Basmann chi2(1)	0.3924	Rejected
First-stage regression summary statistics $\boldsymbol{H_0: instruments\ are\ weak}$		
F(2,278) 50.75	**Adjusted R-Squared** 0.434	**Partial R-Squared** 0.267
2SLS Size of nominal 5% Wald test	10%: 19.93	15%: 11.59
LIML Size of nominal 5% Wald test	10%: 8.68	15%: 5.33

Table 5, regarding postestimation test results of the 2SLS IV regression instrumenting $fibrelan100_{it}$ by $datavoice100_{it}$ and $ictpatents_{it}$, it is confirmed that my instruments are valid, and the degree to which it is so. Particularly, the endogeneity test returned strong results leading to acceptance of the hypothesis that the $datavoice100_{it}$ and $ictpatents_{it}$ instruments can be approved as exogenous to the model, this hypothesis is accepted at the 99% confidence level. The following test of over identifying restrictions pertains to the validity of the specification of the regression equation, as well whether either of the excluded exogenous variables should be included in the structural equation. Since the p-values exceed the <0.05 threshold, the null hypothesis that the instruments are uncorrelated with the error term is rejected, the number of instruments does not exceed the number of endogenous regressors, $datavoice100_{it}$ and $ictpatents_{it}$ are indeed correlated with the error term.

Lastly, I tested the strength of my instruments with an observation of the first-stage regression summary statistics, which provides a deeper dive into the correlation between the $datavoice100_{it}$ and $ictpatents_{it}$ instruments and the endogenous variable, $fibrelan100_{it}$. The result is a relatively weak partial r-squared which describes the correlation between the variables aforementioned. This is likely due to the weak correlation between the endogenous $fibrelan100_{it}$ and $ictpatents_{it}$ as mentioned previously in section 3. As well, the first-stage regression summary statistics do indicate an F-statistic which is greater than the critical values determined by the Wald tests, allowing a rejection of the null hypothesis, although at the discretion of a low partial r-square. Given the pass of the 2SLS IV regression postestimation tests, the instrumental variables can be accepted as relevant to the model and a step toward the direction of OLS inference significance, as best linear unbiased estimator.

Table 6 contains estimation results from a pooled OLS with year dummies and a fixed effect transformation as well as combination of the same fixed transformation with the same 2SLS regression from model 4.

Table 6. Fixed effects transformation and further instrumental variable analysis

Variables	Model 5	Model 6
Dependent variable: $\widetilde{lncapitagdp\_it}$ **Independent variables**		
$\widetilde{lncapital\_it}$	0.283*** (0.013)	0.284*** (0.015)
$\widetilde{labourratio\_it}$	0.542*** (0.197)	0.573*** (0.210)
$\widetilde{fibrelan}100_{it}$	0.001 (0.001)	0.004*** (0.001)
$\widetilde{density}_{it}$	-0.002*** (0.000)	-0.002*** (0.000)
$\widetilde{capitagdpgrowth}_{it}$	0.001 (0.001)	0.001** (0.001)
Constant	-0.020*** (0.006)	-0.006 (0.032)
Observations	295	285
R-squared	0.840	0.781

Model 1: pooled OLS with year dummies and FE transformation, model 2: FE-2SLS-IV (IV-2SLS (instrumented $\widetilde{fibrelan}100_{it}$ by $\widetilde{datavoice}100_{it}$ and $\widetilde{ictpatents}_{it}$)
*** indicates significance at 1%, ** indicates significance at 5% and * indicates significance at 10%.

The results of the initial fixed effect transformation are in an increase of 1 fibre infrastructure subscriber per 100 people is associated with 0.1% increase in per capita GDP, however this result shows little significance, other than confirmation of an operational fixed effect estimator. The following fixed effect transformation combined with the 2SLS regression model 4, had highly significant results, which tend to be in line with the literature. From model 6 there is an observable 0.4% increase in per capita GDP following a 1 subscriber per 100 increase on fibre infrastructure in any given country, controlling for annual fixed effects and elimination of Gauss-Markov violations. This result is significant at the 99% confidence level.

5 Conclusion

Governments must do all they can to preserve and maintain growth on this frontier. Internet access to all has become high on Canadian government agenda in recent years, legislators must be careful not to hinder the growth of technologies that rely on the internet by imposing restrictive regulation in the telecommunications industry, while being sure to direct public funds toward technologies that will benefit public welfare the most. This paper concludes that Gb/s infrastructure development requires a cautious observation of the macroeconomic aggregates associated, due to the possibility of wasteful government spending. Although, the results are somewhat inconclusive, this is a confirmation that greater analysis is needed before investing public funds into very high speed infrastructure. It is clear the there are many positive externalities associated with broadband infrastructure adoption, although to what speed is government intervention necessary? It is estimated that it will cost Canada $12 billion public dollars to achieve 100% internet coverage at speeds of 50 Mb/s. Despite inconclusive evidence that Gb/s infrastructure adoption may have no net benefit on well-being the EU is going ahead with high capacity targets, should Canada follow suit?

Data Appendix

This appendix provides further description of the sources and data manipulations for reference.

Broadband Subscription data, $fibrelan100_{it}, datavoice100_{it}$: The subscription data was compiled and published by the OECD Broadband Portal. The OECD broadband portal provides access to a range of broadband-related statistics gathered by the OECD. The information is available for policy makers who must examine a range of indicators which reflect the status of individual broadband markets in the OECD.

Level of GDP Per Capita, Total Economy, $capitagdp_{it}$, $capital_{it}$*:* It presents the three approaches of the GDP: expenditure based, output based and income based. It has been prepared from statistics reported to the OECD by Member countries in their answers to annual national accounts questionnaire.. – USD Current Prices, Current PPPs – GDP Per head of population. Gross fixed capital formation per capital USD, current price, current PPP.

ALFS Summary tables, $labourratio_{it}$*:* The "ALFS Summary tables" dataset is a subset of the Annual Labour Force Statistics database which presents annual labour force statistics for 36 OECD member countries, plus Colombia, Costa Rica, Brazil and Russian Federation and 4 geographical areas (Major Seven, Euro zone, European Union and OECD-Total). The labour ratio is calculated as total labour force divided by total population.

Patents by Technology, $ictpatents_{it}$*:* Patents filed under the Patent Cooperation Treaty. Inventors country of residence and PCT patent counts are based on data received from the EPO (EPO Bibliographic database, publications up to May 2019). Patents filed under the Patent Co-operation Treaty (PCT), at international phase, that designate the EPO (from 1978 onwards); The OECD's Directorate for Science, Technology and Industry has developed patent data and indicators that are suitable for statistical analysis and that can help addressing Science & Technology policy issues.

Regional Demography, $density_{it}$*:* The Regional database of the OECD contains annual data from 1995 to the most recent available year (generally 2018 for demographic and labour market data, 2017 for regional accounts, innovation and social statistics). The data collection is undertaken by the Centre for Entrepreneurship, SMEs, Regions and Cities (CFE). Statistics are collected through an annual questionnaire sent to the delegates of the Working Party on Territorial Indicators (WPTI), and via downloads from the web-sites of National Statistical Offices and Eurostat.

Per Capita GDP Growth, $capitagdpgrowth_{it}$: The Open Data Catalog at the World Bank website lists all data adhering to the Open Data terms of use. The Data catalog provides a single point of access to all publicly available data through World Bank sites. Microdata Library lists all survey data and administrative records, Data Bank provides access to time series data.

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