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170 Laurier Avenue, Suite 604

Ottawa, Ontario K1P 5V5

613-233-8891 info@csls.ca

CENTRE FOR THE STUDY OF LIVING STANDARDS

An Econometric Analysis of the Impact of Broadband Internet on Productivity

Timothy Sargent

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Abstract

In this paper we look at whether increases in broadband internet penetration have a significant impact on productivity. We use data on a panel of 116 countries over the period 2009–2019 to estimate the impact of increases in fixed broadband penetration rates and high-speed broadband penetration rates on labour productivity, measured as output per person. We find a significant impact on productivity from increases in fixed broadband penetration rates. Our estimates indicate that broadband internet increased labour productivity growth by an average of 0.20 percentage points annually in developed countries and 0.26 percentage points in developing countries: this meant that broadband internet accounted for around 16 per cent of productivity growth in developed countries and 20 per cent of productivity growth in developing countries. For Canada we find that broadband internet contributed an average of 0.15 percentage points annually to Canada's overall productivity growth of 0.91 per cent, about 17 per cent of total productivity growth. However, we did not find significant impacts for high-speed broadband over the period studies: it is possible that this is because applications that require higher speeds, such as videoconferencing, had not been widely deployed over our time period. This study emphasizes the crucial impact of broadband internet investment on boosting Canada's economy-wide productivity. This research indicates an important role for the government in facilitating the expansion of broadband access, optimizing regulatory frameworks, and stimulating private sector investment, especially in underserved regions, to enhance the social and economic benefits throughout Canada.

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Executive Summary

This report looks at the impact of broadband internet on labour productivity for a panel of 116 countries over the period 2009 to 2019. We estimate a standard economic growth model using a broad range of variables that potentially affect productivity, as well as measures of broadband internet penetration, in order to identify the specific contribution of broadband internet to productivity growth. We use both overall broadband penetration and a measure of high speed (or fast) internet penetration in our estimations.

We find that overall broadband internet penetration has had a significant impact on productivity in both developed and developing countries. For developed countries, broadband internet has added an average of 0.20 percentage points to productivity growth every year, whereas for developing countries the impact is 0.26 percentage points every year. These impacts explain around 15 to 20 per cent of overall productivity growth over the sample period.

Canada's experience is similar to the average: broadband internet penetration is estimated to contribute an average of 0.16 percentage points to productivity growth annually, responsible for 17 per cent of total productivity growth over the sample period.

In contrast to these results, we find little impact of high-speed broadband on productivity: we speculate that the applications specifically enabled by high-speed broadband did not have the same productivity impact as those enabled by regular broadband; however, this may be changing as bandwidth intensive applications such as videoconferencing have become more prevalent.

While there are some caveats to our empirical results, overall they indicate that broadband internet has had a very significant impact on productivity across both developed and developing countries over the decade of the 2010s: it remains to be seen whether high speed broadband will have the same impact.

This study emphasizes the crucial impact of broadband internet investment on boosting Canada's economy-wide productivity. This research indicates an important role for the government in

facilitating the expansion of broadband access, optimizing regulatory frameworks, and stimulating private sector investment, especially in underserved regions, to enhance the social and economic benefits throughout Canada.

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I. Introduction[1]

The widespread availability of broadband internet has allowed fast and reliable internet connection across the developed world, with individuals now able to engage in a multitude of activities—from telemedicine to e-learning, from videoconferencing to streaming movies—that would have been difficult if not impossible with the dial-up internet access technology that preceded broadband.

However, it is one thing for a technology to enrich people's lives, and another for it to have a pervasive impact on productivity across the economy. For this to happen the technology needs to significantly boost the ability of firms in every major sector to produce more goods and services than before from the same amount of labour. Certainly the potential for such a boost is there: business has adopted broadband internet as enthusiastically as individuals have, and broadband has allowed for productivity-improving enhancements such as real-time supply chain and inventory management that better matches production to demand, improved data sharing and communication that makes it easier for teams in different locations to collaborate on projects, and e-commerce platforms that allow companies to dispense with traditional physical retail channels and to deal directly with customers across the globe. The question though is whether these productivity improvements, important though they may have been in specific sectors, are large enough to have made a measurable impact on economy-wide productivity.

In this report we attempt to answer this question. We look at whether and to what extent investments in broadband internet have boosted economy-wide productivity over the period

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[1] This research report was prepared by Timothy Sargent, who is CSLS Deputy Executive Director and holds a Ph.D. in Economics from the University of British Columbia. Able research assistance was provided by two CSLS staff members: Sarah El Kaissi and Adriana Suuronen. We would like to thank TELUS for funding the project, and Joe Roswell and his team at TELUS for their insightful comments. We would also like to thank the technical advisory board for the insightful feedback. Their names and professional affiliations are to be found in Appendix 3. The opinions in this paper are solely the author's, and not those of the technical advisory board members. The database used to produce our results is available online at www.csls.ca. Comments are welcome and may be sent to Tim.Sargent@csls.ca.

2009–2019 for 116 developed and developing countries. We look at the impacts of all fixed broadband penetration, as well as high-speed broadband penetration, which in our data sets is defined as broadband with speeds over 10Mbps. This period saw significant investment in broadband internet across the world, and we use different countries' experiences to identify the overall impact of broadband internet on productivity.

We begin with a brief literature survey and indicate how our paper contributes to this literature. We then go on to outline our theoretical framework, which is based on the standard neoclassical economic growth model, and its empirical implementation in an econometric model. We then go on to present descriptive statistics for the data series that we use in the estimations. One novel feature of our work is that we use a dataset compiled by the United Nations Conference on Trade and Development's that has a broad variety of explanatory variables that reflect everything from a country's natural capital to its education levels to the quality of its institutions. This allows us to better model the cross-country and time series variation in productivity and thus to better distinguish the impact of broadband internet from other factors that affect productivity. We then report our estimation results and use these to calculate the impact of broadband internet on productivity in different countries, both developed and developing. We conclude with a summary of our results and their implications, as well as some caveats about the robustness of the results.

II. Related Literature

There is now a significant literature on the impacts of broadband infrastructure on the economy. This literature is surveyed at length in Bakiskan and El Kaissi (2023), and so we do not propose to provide a comprehensive account in this report. Rather, we shall provide a brief sketch, and highlight those papers that are closest to the approach we adopt here, which is to use time series data from a panel of countries to provide the broadest possible perspective on the issue.

This literature on broadband largely focuses on the impact on economic indicators of two key variables: penetration, often measured by the proportion of households with broadband internet access; and speed, which is sometimes measured directly, or is measured as the proportion of households with access to some measure of fast broadband. The main economic indicators that researchers focus on are output, labour productivity (output per hour or per worker), and total factor productivity (the contribution to output that comes from factors such as technology or how production is organized, rather than inputs of human or physical capital). Some studies use firm or industry level data, whereas other use data on a cross section of countries over time.

Most studies find economically and statistically significant impacts of increases in both speed and penetration on economic indicators of interest. However, there are some studies that find little impact; conversely some studies find impacts that seem implausibly large. One challenge in estimating the impacts of broadband internet, particularly on output, is endogeneity: while increases in speed and penetration can certainly increase output, higher output and thus income may increase consumers' willingness and ability to pay for broadband internet, so that causation between economic indicators such as output and measures of broadband internet may run in both directions. A number of studies try to deal with this issue using different econometric techniques.

The studies that come closest to ours use a panel of countries over time to examine the impact of broadband internet on productivity. Kongaut and Bohlin (2014) analyzed the effects of speed on GDP per capita in the 33 OECD countries between 2008 and 2012. They use a two-stage least squares (2SLS) approach to deal with potential endogeneity, where broadband speed is measured in the first stage as a function of fixed broadband penetration, the percentage of fibre subscriptions, GDP growth, population density and telecommunications revenue. In the second stage, they estimate GDP per capita as a function of gross fixed capital formation, labour force, broadband speed, the degree of economic freedom, urban population, and an income dummy to divide the analysis into high- and low-income countries. They find that a 10 per cent increase in broadband speed increases GDP per capita by 0.8 per cent. When they divide the sample into low- and high-income countries, they find that the impact of increasing broadband speed is greater in lower-income countries. Specifically, in low-income countries, they find that a 10 per cent increase in broadband speed increases GDP per capita by 1 per cent, while the increase in GDP per capita in high-income countries is 0.6 per cent.

Koutroumpis (2019) uses a panel of OECD countries to model the impact of broadband penetration and speed on output. He used an econometric approach similar to but more elaborate than that of Kongaut and Bohlin (2014), with four equations: an aggregate production function, demand and supply equations for broadband internet, and a broadband infrastructure production function. He found that broadband contributed 0.4 percentage points to annual OECD output growth over the period 2002–2016.

One challenge with the approach adopted by Kongaut and Bohlin (2014) and Koutroumpis (2019) is that the instrumental variable techniques that underlie their econometric methodologies requires good instruments for broadband penetration: that is, variables that are strongly correlated with broadband, but not with output. Unfortunately, it is hard to come up with variables that are truly exogenous with respect to output: for example, Kongaut and Bohlin (2014) use fixed broadband penetration rates and mobile penetration rates as instrumental variables for broadband speed; however, if output affects speed (because people with higher incomes can afford faster internet coverage) then it presumably affects penetration rates as well.

In a recent study, Edquist (2022) examines the impact of mobile broadband internet speed over the period 2014–2019. He models labour productivity (measured as GDP per worker) as a function of the capital-labour ratio, human capital index, and mobile broadband speed. The author estimates the relationship using pooled OLS and fixed effects estimation to remove the effects of country-specific components. He finds a positive association between speed and labour productivity: a 10 per cent increase in the previous year's broadband speed is associated with a 0.2 per cent increase in labour productivity in the current period. He does not correct for simultaneity, arguing that is very difficult to find appropriate instruments with which to correct for simultaneity.

In our study we follow the approach of Edquist (2022) by modelling labour productivity rather than output per capita: as discussed below, we think broadband internet demand is likely to be somewhat less sensitive to productivity than to output per capita, which is also affected by changes in employment rates. However, we use a broader list of explanatory variables, and we focus on the impact of fixed broadband penetration and high speed fixed broadband penetration rather than median speed.

III. Methodology

A. Theoretical Framework

The economic model underlying the analysis is based on the standard neoclassical growth model made famous by Solow (1956). In this model, output (Y) is generated by capital (K) and labour (L) according to a constant returns to scale Cobb-Douglas production function[2]:

$$Y = AK^{\alpha}L^{1-\alpha} \qquad (1)$$

where α is capital's share of output. The parameter A is total factor productivity (TFP): it captures influences—such as the level of technology, the efficiency of markets, and the quality of the workforce—that are separate from the quantities of capital and labour employed, and which increase the contributions of these two factors to output.

By taking natural logarithms, the production function can be expressed as:

$$\ln\, Y = \ln A + \alpha \ln K + (1-\alpha) \ln L \qquad (2)$$

Subtracting the natural logarithm of labour gives:

$$\ln\left(\frac{Y}{L}\right) = \ln A + \alpha \ln\left(\frac{K}{L}\right) \qquad (3)$$

so that labour productivity (Y/L) is a function of an economy's capital-labour ratio (K/L) and its total factor productivity (A).

The equation provides for two channels for broadband internet to have an impact on labour productivity. The first is through an increase in the capital stock K, as telecommunications companies invest resources in constructing broadband networks. The second is through total factor productivity A, as broadband internet makes possible new kinds of products and business models, and increases the flow of information in ways that improves productivity across the economy. These latter gains do not accrue to the telecommunications companies: they "spillover" across the economy. In our empirical work below it is this latter impact of broadband internet on TFP that we shall seek to measure.

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[2] Constant returns to scale: increasing the inputs by a certain proportion will result in an increase in output of the same proportion.

B. Empirical Implementation

We implement empirically the equation determining labour productivity (3) using the following equation:

$$\ln(Y/L)_{it} = \beta_0 + \beta_1 ln(K/L)_{it} + \beta_2 ln(penetration)_{it} + \beta_3 X_{it} + \beta_4 t + \epsilon_{it} \quad (4)$$

where X_{it} is function of factors other than broadband internet (such as human capital or the quality of institutions) that affect total factor productivity, t is a time dummy and ϵ_{it} is a normally-distributed error with mean zero and constant variance. The time dummy is intended to pick up global macroeconomic shocks, such as the Great Financial Crisis, that have common impact across countries. This equation is estimated for a panel of 116 countries over between 2009 and 2019. We estimate two versions of the equation: one using overall broadband internet penetration; and one using high-speed broadband internet penetration.

We chose to estimate the equation separately for developed and developing countries, in order to see if there were significant differences in the impacts of broadband internet across the two categories of country.

One issue in using panel data of the kind we have here is whether to use a fixed effects estimator, which controls for constant differences in cross country productivity levels over time by giving each country its own dummy variable, and a random effects estimator, which assumes that all the variation is attributed to the explanatory variables or to the random error. Generally speaking the fixed effects estimator is usually preferred when using cross-country macroeconomic data, as it is likely that however complete the list of independent variables, they will not pick up all the idiosyncratic factors (such as access to the sea, climate, cultural influences) that determine productivity. If this is true, and these idiosyncratic factors are correlated with independent variables, then the random effects estimator may overestimate the impact of the independent variables. We use both estimators in our analysis, and use a Hausman test (see Torres-Reyna 2007) to decide which estimator is the most appropriate.

As discussed in the literature review, authors have approached in different ways the possibility that the dependent variable may affect penetration rates and therefore bias the estimates. This possibility arises in the present case because higher productivity increases incomes which can increase the demand for broadband internet. One approach is to use instrumental variables methods to correct for the bias: however, this approach relies on finding good instruments—variables that are strongly correlated with the potentially endogenous explanatory variable (penetration in this case), but not with the dependent variable. As noted by Edquist (2022), this is difficult to do, as variables that might affect broadband internet penetration are likely to be affected by income as well.

An alternative approach is to simply lag the potentially endogenous regressor one period. While this approach addresses endogeneity in the time series dimension, it does not address endogeneity in the cross-section dimension. Furthermore, it assumes uncorrelated errors: if the errors in the equation are correlated, then the lagged regressor will be correlated with contemporaneous regressor, and the endogeneity problem remains.

There does not therefore seem to be a good solution to the problem of endogeneity. We do think it will be less a problem in our case because we are using productivity, and not income per capita. While productivity does ultimately affect incomes, it is not the only factor: changes in employment rates or the terms of trade, for example, will also affect household incomes. We come back to this issue in the conclusion.

IV. Data and Descriptive Statistics

Our data set comprises information on 116 countries for the period 2009–2019. Of these 116 countries, 41 are developed countries and 75 are developing countries. (See Appendix 1 for the list of countries in each category). The number of countries and the time period is limited by telecommunications data that we use, which is taken from the International Telecommunications Union (ITU) database. Nonetheless, virtually all major developed and developing countries are covered: the countries missing are largely smaller developing countries. The time period covers significant changes in both overall broadband penetration and high speed penetration. The data set can be divided into three categories: telecommunications data on broadband internet; economic data on productivity and the capital–labour ratio; and the components of the productive capacities index. These are described in greater detail below, along with descriptive statistics.

A. Data on Broadband Internet

Data on fixed broadband subscriptions, which will be our proxy for broadband penetration, and fixed broadband subscriptions above 10Mbps, our proxy for broadband speed, are collected from the World Telecommunication/ICT Indicators database (International Telecommunication Union, 2023). Both variables are reported per 100 inhabitants.

Ideally, since our focus is on productivity, we would prefer to have a measure of broadband internet penetration that measures penetration amongst businesses. Unfortunately, those data are not available for most of the countries in our sample, and so we use broadband internet penetration per person as a proxy. This is an approach that has been adopted by other authors, and we think it is justifiable as both household and business adoption of broadband internet are likely to be closely related to the availability of broadband internet infrastructure in a given area.

In Table 1 below we show these data for both developed and developing G20 countries, for 2009 (the start of our estimation period), for 2019 (the end of our estimation period), and the percentage point change for the 2009–2019 period. We also show the unweighted averages for both G20 and all countries. (We do not show data for all countries for reasons of space).

Table 1: Descriptive Statistics on Broadband Infrastructure

	Overall Broadband Penetration			High-speed Penetration		
	Fixed Broadband Subscriptions (per 100 inhabitants)			Subscriptions Above 10Mbps (per 100 inhabitants)		
	2009	2019	2009-2019 (absolute change)	2009	2019	2009-2019 (absolute change)
Developed G20 Countries						
Australia	26.1	34.7	8.6	11.4	26.0	14.6
Canada	**30.6**	**40.4**	**9.7**	**5.8**	**36.1**	**30.3**
France	32.0	46.2	14.2	33.0	43.9	10.9
Germany	31.4	42.3	10.9	9.5	38.8	29.3
Italy	20.3	29.3	9.0	1.6	23.3	21.7
Japan	25.7	33.8	8.1	24.0	31.0	7.0
Republic of Korea	33.6	42.0	8.4	31.3	42.0	10.7
Russia	9.0	22.5	13.5	2.6	17.8	15.2
United Kingdom	28.7	40.3	11.6	9.6	39.0	29.4
United States	25.9	34.2	8.3	5.4	31.5	26.0
Unweighted Average: Developed G20	26.3	36.6	10.2	13.4	32.9	19.5
Unweighted Average: All Developed	23.6	34.1	10.5	5.2	30.7	25.5
Developing G20 Countries						
Argentina	8.6	19.7	11.0	1.2	12.7	11.5
Brazil	6.0	15.5	9.5	1.2	9.9	8.7
China	7.8	31.6	23.8	1.1	31.2	30.2
India	0.6	1.4	0.8	0.1	0.9	0.8
Indonesia	0.8	3.8	3.0	1.0	3.1	2.1
Mexico	8.7	15.5	6.8	1.0	14.3	13.3
Saudi Arabia	5.0	19.0	13.9	0.3	16.6	16.3
South Africa	0.9	2.2	1.2	0.3	1.0	0.7
Turkey	8.9	17.0	8.1	0.0	12.7	12.7
Unweighted Average: Developing G20	5.3	14.0	8.7	0.7	11.4	10.7
Unweighted Average: All Developing	4.2	9.1	4.9	0.3	5.6	5.3
Unweighted Average: All G20	16.4	25.9	9.5	7.4	22.7	15.3
Unweighted Average: All Countries	11.2	17.9	6.7	2.0	14.3	12.3

Source: World Telecommunication Indicators Database by the International Telecommunication Union (ITU), https://www.itu.int/en/ITU-D/Statistics/Pages/publications/wtid.aspx

Notes: Asterix (*) indicates that the first year of data is from later than 2009. First year of data is: 2011 for Japan and Russia; 2012 for France; 2013 for Brazil and Mexico; 2014 for Argentina and South Africa; 2015 for India; 2017 for Indonesia.

Beginning with data on fixed broadband subscriptions, we see that developed countries (with the exception of Russia), had much higher penetration rates than developing countries in 2009, with a range of 20–34 subscriptions per 100 inhabitants, compared to 1–9 for developing countries. By 2019, the penetration rate in developed countries had risen by 8–14 subscriptions per hundred, so that penetration rates (except for Russia), were in the range of 29 per cent to 46 per cent. Some developing countries, particularly China, saw penetration rates rise as fast if not faster than in developed countries (in China the rate rose by 23.8 to a level higher than Italy's). However, poorer developing countries such as India and Indonesia saw only a small rise in absolute terms, although in percentage terms the increase was significant. India for example saw penetration rates more than double, but because penetration rates in 2009 were very low at 0.6, the penetration rate in 2019 was only 1.4 subscriptions per inhabitant.

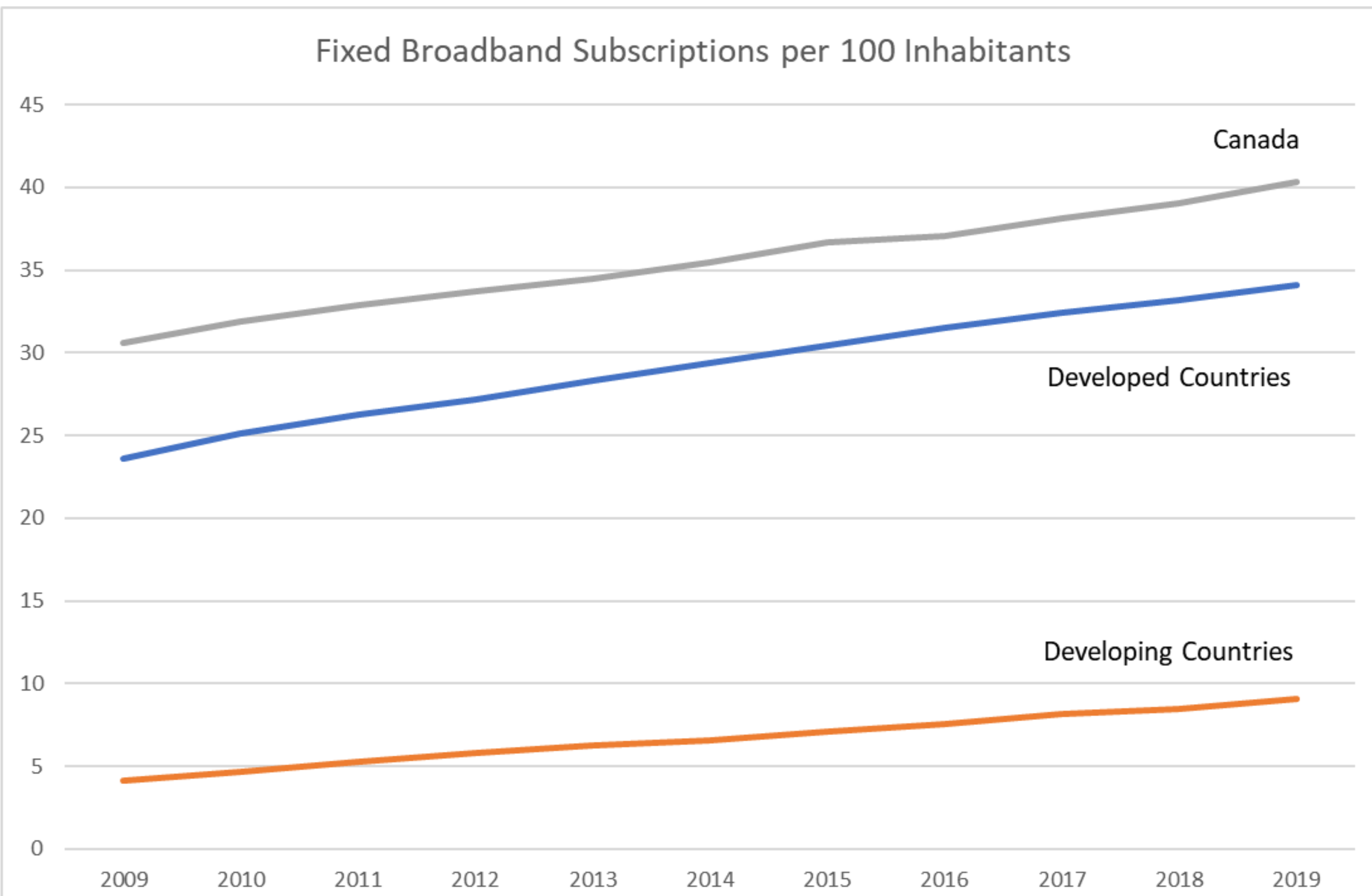
The picture for high-speed penetration is somewhat different, as few subscribers, even in developed countries, had subscriptions above 10Mbps in 2009. This changed substantially over the period: by 2019 90 per cent of subscriptions (30.7 percentage points out of 34.1 percentage points) were high-speed on average in developed countries. Among G20 countries, Australia (only 75 per cent high speed) and Russia (only 79 per cent) were outliers on the negative side, whereas Korea (100 per cent) and the UK (97 per cent) were outliers on the positive side. Canada was around average, with 89 per cent of subscriptions being high speed in 2019. Interestingly, Canada had the largest increase in high-speed subscriptions between 2009 and 2019 among the seven G20 countries for which we have complete data.

For developing countries the picture for high speed penetration is mixed. China was in a class of its own, going from very little high-speed penetration in 2009 to a level comparable to Japan or the U.S. by 2019. Middle income countries such as Argentina, Brazil, Mexico, Saudi Arabia and Turkey had achieved penetration rates of 9–17 per cent, roughly a third to a half of developed country levels. Low income developing G20 countries—India, Indonesia and South Africa—still had very low high-speed penetration rates in 2019.

Canada's relative position in the G20 remained high during the period. Canada was fourth in the G20 for all broadband subscriptions in 2009 and retained that position in 2019. Canada was fifth in the G20 for high-speed penetration in 2019 and above the G20 developed country average and the total developed country average in that year. Interestingly, Canada had higher penetration rates—both overall, and high speed, than other geographically large countries such as Australia and the United States.

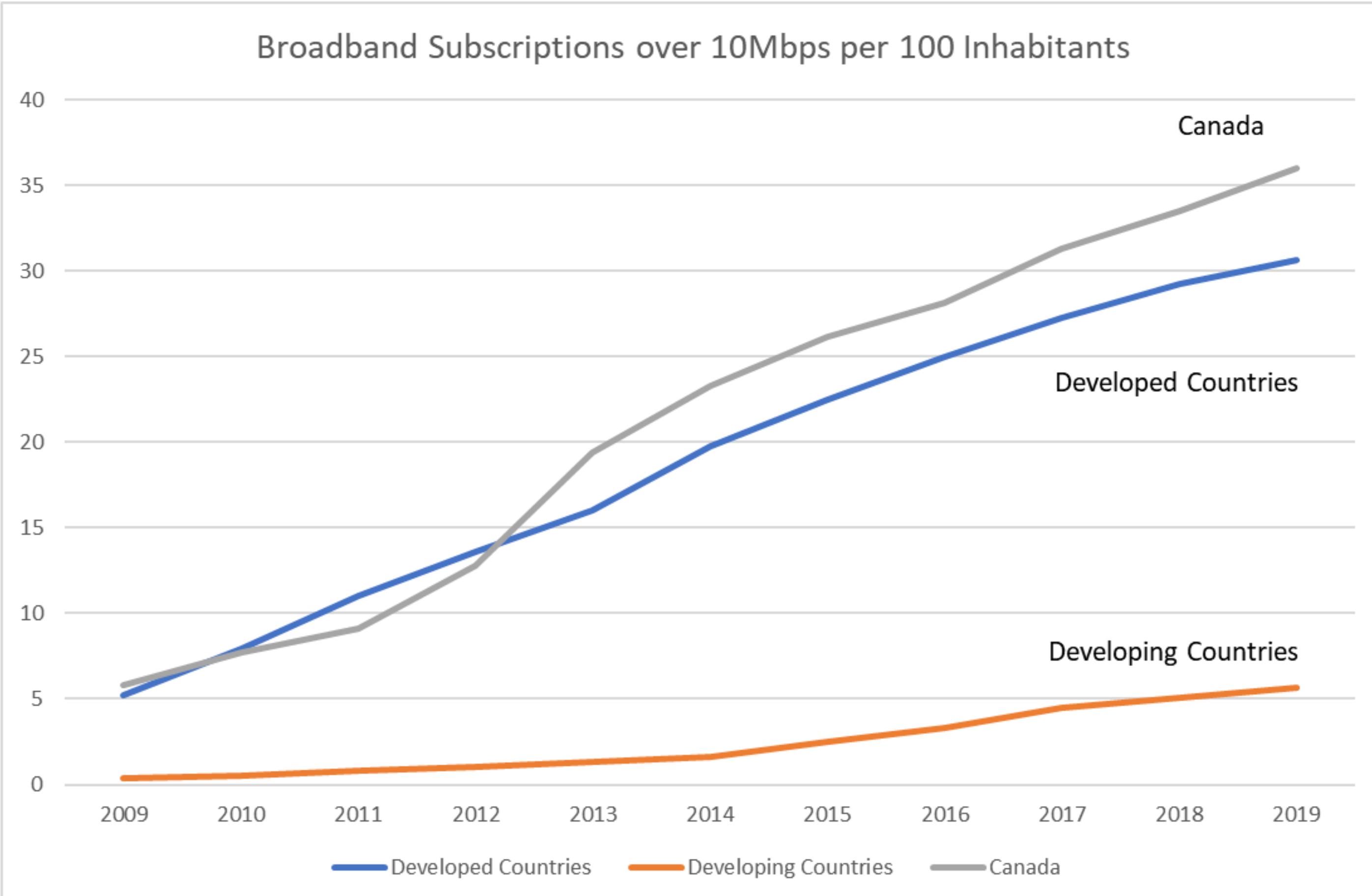
Below we show the time series behaviour for both overall fixed broadband (Chart 1) and high-speed broadband penetration (Chart 2), for developed and developing countries and for Canada.

Chart 1. Fixed Broadband Penetration 2009–2019



Source: World Telecommunication Indicators Database by the International Telecommunication Union (ITU), https://www.itu.int/en/ITU-D/Statistics/Pages/publications/wtid.aspx

Chart 2. High-Speed Broadband Penetration 2009–2019



Source: World Telecommunication Indicators Database by the International Telecommunication Union (ITU), https://www.itu.int/en/ITU-D/Statistics/Pages/publications/wtid.aspx

The time series behaviour for fixed broadband penetration is fairly smooth, with a gradual upwards trend, on average, for both the developed and developing country aggregates, as well as for Canada. The pattern for high-speed broadband is somewhat different: while there is a smooth upwards trend for developed countries, the pace of change for developing countries picked up after 2015. In Canada the pace of adoption of high-speed broadband picked up significantly between 2011 and 2013; since then, high-speed broadband adoption in Canada has remained significantly above the developed country aggregate. Overall it is notable that the pace of broadband adoption, both overall and for high speed, did not seem to be slowing, at least up to 2019.

B. Data on Labour Productivity and the Capital–Labour Ratio

Data on output, employment and the capital stock were collected from the Penn World Table 10.01 (Feenstra *et al.*, 2015). We calculate labour productivity as output per person employed, where output is measured in 2017 U.S. dollars, with national currency values converted using purchasing power parity (PPP) exchange rates. The capital–labour ratio is measured as capital per person employed, with capital also measured using 2017 U.S. dollars converted using PPP exchange rates.

Table 2: Descriptive Statistics on Labour Productivity and the Capital-Labour Ratio for G20 Countries, 2009 and 2019

	Labour Productivity (2017 US$ per person employed)			Capital-Labour Ratio (2017 US$ per person employed)		
	2009	2019	2009-2019 (average annual growth rate)	2009	2019	2009-2019 (average annual growth rate)
Developed G20 Countries						
Australia	96,063	102,287	0.63	420,039	457,293	0.85
Canada	**88,701**	**97,115**	**0.91**	**380,129**	**438,544**	**1.44**
France	96,387	103,928	0.76	538,940	586,230	0.84
Germany	88,195	96,306	0.88	427,809	439,007	0.26
Italy	96,513	96,413	-0.01	650,768	672,448	0.33
Japan	67,946	72,871	0.70	346,610	341,799	-0.14
Republic of Korea	66,832	81,838	2.05	311,669	398,248	2.48
Russia	48,206	56,539	1.61	234,366	248,364	0.58
United Kingdom	86,038	91,464	0.61	412,438	431,113	0.44
United States	115,999	129,903	1.14	428,314	436,258	0.18
Unweighted Average: Developed G20	85,088	92,866	0.88	415,108	444,930	0.70
Unweighted Average: All Developed	76,427	86,805	1.28	383,942	419,518	0.89
Developing G20 Countries						
Argentina	48,875	47,259	-0.34	141,888	155,265	0.91
Brazil	32,018	32,378	0.11	118,817	135,651	1.33
China	16,175	25,754	4.76	44,384	124,697	10.88
India	10,376	18,414	5.90	36,628	68,731	6.50
Indonesia	17,369	23,713	3.16	89,043	132,390	4.05
Mexico	40,721	43,758	0.72	181,150	188,333	0.39
Saudi Arabia	143,074	120,011	-1.74	418,521	482,593	1.43
South Africa	38,692	39,310	0.16	134,837	150,797	1.12
Turkey	59,906	79,853	2.92	232,338	344,243	4.01
Unweighted Average: Developing G20	45,245	47,828	0.56	155,289	198,078	2.46
Unweighted Average: All Developing	32,409	36,864	1.30	109,212	141,619	2.63
Unweighted Average: All G20	66,215	71,532	0.78	292,036	328,000	1.17
Unweighted Average: All Countries	47,967	54,515	1.29	206,315	239,842	1.52

Source: Penn World Tables 10.01, https://www.rug.nl/ggdc/productivity/pwt/?lang=en

In Table 2 above we show labour productivity and the capital–output ratio for G20 countries for 2009 and 2019, as well as the average annual growth rate. The U.S. has the highest labour productivity, at close to $130,000 in 2019, with most other developed G20 countries in the

$72,000 to $103,000 range (Russia is the exception). Interestingly, Japan and Korea lag the three EU countries, the UK, the US, Canada and Australia significantly in labour productivity, which likely reflects lower productivity in their services sectors. Average annual productivity growth was in the range of 0.60 to 1.1 per cent, with the exceptions of Russia and Korea, which grew faster, and Italy which saw no productivity growth at all. Capital–labour ratios were largely correlated with productivity; the main exception was the U.S., which had a capital–labour ratio that was in the middle of the ten developed G20 countries, even though its productivity was by far the highest.

There is much more disparity in productivity among developing countries. Saudi Arabia has by far the highest level of productivity, owing to its oil resources. Excluding Turkey, the other developing countries were in the range of $18,000 to $47,000. The countries with the lowest productivity in 2009—China, India and Indonesia—had the fastest growth in productivity, between 3 and 6 per cent per annum, whereas the better off countries of Brazil, Argentina, South Africa and Saudi Arabia had little or even negative productivity growth. Only Mexico had similar productivity growth to developed countries. As with developed countries, capital–labour ratios are correlated to productivity levels, and generally less than half of those of developed countries.

Canada ranked relatively highly in the ranking of productivity in the G7. In 2009 Canada's productivity was fourth highest in the G7; by 2019 that ranking had risen to third highest, behind the U.S. and France. Canada had the sixth highest capital–labour ratio in the G7 in 2009, rising to fifth highest in 2019. Canada's productivity growth rate was respectable, averaging 0.91 per cent: lower than the U.S. and Korea, but higher than most other developed countries.

C. Data on the other Drivers of Total Factor Productivity

For the determinants of total factor productivity other than broadband internet penetration, we largely rely on the components of the United Nations Conference on Trade and Development's Productive Capacity Index (PCI) (UNCTAD 2021). This index is made up of eight components that are equally weighted to construct the overall index. These components are:

1. *Human Capital*: education, skills and health and R&D
2. *Natural Capital*: availability of extractive and agricultural resources

3. *Energy*: availability, sustainability and efficiency of power sources
4. *Transport*: capacity of the roads and railways network, and air connectivity
5. *Information and Communication Technology*: extent of IT infrastructure
6. *Institutions*: political stability and efficiency
7. *Private Sector*: extent of regulatory and trade barriers
8. *Structural Change*: ability of resources to move from low-productivity to high-productivity economic activities.

Each component is itself based on three to nine indicator time series (See Appendix 2 for a list of these indicator time series). Principal component analysis is used to weight these constituent indicator time series in order to construct a single time series each of the eight components. This is done for each country, and the resulting measures are bounded between 0 and 100.

In our analysis we do not use the ICT component, as it contains measures of broadband internet use that we model separately (the other components are highly correlated with the measures we use). We also do not use the Human Capital component: we prefer the index available from the Penn World Tables in order to be more comparable with other studies. This human capital index uses data on average years of schooling that are weighted by an assumed rate of return on education that declines with additional years of schooling to produce a measure of how much more productive an average worker is as result of his or her education[3]. To illustrate, if a country that has a human capital index twice that of another country, that means that an average worker is twice as productive, everything else being equal, as a result of more years of schooling.

Table 3 below provides descriptive statistics for the seven variables that we use to model TFP for the G20 countries. Developed countries score somewhat better on their energy infrastructure; however, they generally score lower on the measure of natural capital, as developing countries tend to be more reliant on natural resource extraction. Developed countries also score a little higher on transportation infrastructure, although some developing countries such as Turkey and South Africa are approaching developed country levels.

[3] See https://www.rug.nl/ggdc/docs/human_capital_in_pwt_90.pdf for further explanation.

Table 3: Descriptive Statistics for Productive Capacities Indices and for PWT IHC for G20 Countries, 2009-2019

	Average Index Level, 2009-2019						
	Energy Index (PCI)	Natural Capital Index (PCI)	Private Sector Index (PCI)	Structural Change Index (PCI)	Transport Index (PCI)	Institutions Index (PCI)	Index of Human Capital (per person)
Developed G20 Countries							
Australia	76.7	42.8	81.2	73.0	61.7	91.7	3.48
Canada	**74.8**	**27.9**	**83.0**	**77.8**	**61.8**	**92.8**	**3.68**
France	72.2	21.3	74.0	91.7	52.8	82.2	3.13
Germany	77.1	22.1	79.2	93.0	56.9	89.5	3.66
Italy	72.3	20.4	66.7	90.6	44.3	67.6	3.07
Japan	78.0	8.2	94.1	87.6	51.0	85.4	3.54
Republic of Korea	80.9	13.3	93.1	80.8	51.5	73.8	3.60
Russia	70.5	36.1	45.4	61.2	47.2	39.2	3.36
United Kingdom	74.4	31.2	75.7	88.2	57.6	88.0	3.25
United States	77.3	27.0	88.1	95.0	61.5	83.9	3.72
Unweighted Average: Developed G20	75.4	25.0	78.1	83.9	54.6	79.4	3.45
Unweighted Average: All Developed	71.4	27.5	68.3	73.2	53.2	78.5	3.34
Developing G20 Countries							
Argentina	62.0	39.2	43.3	56.9	41.4	50.8	2.95
Brazil	52.8	37.4	45.5	65.9	42.9	54.1	2.75
China	65.1	44.0	71.8	96.8	38.1	45.2	2.57
India	41.6	46.5	50.9	75.7	29.3	50.3	2.06
Indonesia	55.5	37.1	46.0	69.8	34.3	48.8	2.36
Mexico	61.6	37.9	55.3	70.4	40.0	49.5	2.68
Saudi Arabia	79.5	63.1	51.4	53.5	44.2	49.0	2.60
South Africa	59.0	52.4	59.5	70.3	45.2	59.0	2.68
Turkey	64.4	35.7	57.7	78.9	48.1	50.7	2.35
Unweighted Average: Developing G20	60.2	43.7	53.5	70.9	40.4	50.8	2.55
Unweighted Average: All Developing	49.0	43.6	47.6	53.0	36.9	48.9	2.38
Unweighted Average: All G20	68.2	33.9	66.4	77.8	47.9	65.9	3.03
Unweighted Average: All Countries	57.0	37.8	55.0	60.2	42.7	59.5	2.72

Source:
PCI - United Nations Conference on Trade and Development (UNCTAD), https://unctad.org/topic/least-developed-countries/productive-capacities-index
Index of Human Capital- Penn World Tables 10.01, https://www.rug.nl/ggdc/productivity/pwt/?lang=en

Bigger disparities between developed and developing countries are evident in the indices that reflect the strength of institutions, the freedom of the private sector, and the ease of moving resources (structural change). One outlier though is China, which has a level for the Structural Change index that is higher than any developed country, but which has the second lowest level in the G20 for the quality of institutions. This can be explained by the totalitarian nature of China's political and economic system, which allows the government to direct resources in ways that would be more difficult in more democratic economics that adhere more to the rule of law.

Finally, the level of the human capital index is uniformly higher in developed countries, with levels highest in the U.S., Canada and Germany, and lowest in India, Indonesia and Turkey. Although this is changing, China's education levels were lower than G20 developing countries in Latin America, as well as South Africa. Human capital levels take much longer to change than physical capital levels, because people have multi decade working lives and most human capital accumulation takes place before they begin working. Thus China is still feeling the impacts of very low human capital accumulation several decades ago.

Overall Canada does quite well across the seven potential measures of the drivers of total factor productivity. Canada has the highest levels of institutional quality, transportation infrastructure and human capital, and is above the average for all developed countries for all measures.

V. Results

In this section we will present estimates based on the empirical specification outlined in section III.B. We present estimates using both overall penetration rates and high-speed penetration rates, and for both random and fixed effects estimators.

A. Developed Countries

Table 4 below shows results using the 40 developed countries in our data set for the period 2009–2019, where Penetration denotes fixed broadband subscriptions per inhabitant and High-Speed Penetration denotes broadband subscriptions of over 10Mbps.

Table 4: Regression results for Developed Countries

	(1)	(2)	(3)	(4)
Dependent Variable:	ln Productivity	ln Productivity	ln Productivity	ln Productivity
Estimator	Random Effects	Fixed Effects	Random Effects	Fixed Effects
ln Human Capital Index	-0.165	-0.265**	0.0448	-0.054
	(0.123)	(0.132)	(0.148)	(0.165)
ln Capital–Labour Ratio	0.503***	0.524***	0.505***	0.522***
	(0.028)	(0.031)	(0.031)	(0.03)
ln Penetration	0.058***	0.054***		
	(0.016)	(0.016)		
ln High Speed Penetration			-0.007**	-0.006**
			(0.003)	(0.003)
Energy	0.006***	0.006***	0.006***	0.006***
	(0.001)	(0.001)	(0.001)	(0.001)
Natural Capital	0.001	0.001	-0.000	0.001**
	(0.001)	(0.001)	(0.001)	(0.001)
Private Sector	-0.001	-0.002**	-0.001	-0.002
	(0.001)	(0.001)	(0.001)	(0.006)
Structural Change	0.006***	0.006***	0.005***	0.006***
	(0.001)	(0.001)	(0.001)	(0.001)
Transport	-0.001*	-0.001*	-0.001*	-0.001**
	(0.001)	(0.001)	(0.000)	(0.000)
Institutions	0.003***	0.002***	0.004***	0.002*
	(0.00)	(0.001)	(0.001)	(0.001)
Constant	3.763***	3.737***	3.752***	3.744***
	(0.40)	(0.44)	(0.44)	(0.49)
Observations	451	451	395	395
R^2	0.6942	0.6358	0.6975	0.6300

Standard errors are in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

The Hausman test for which estimator should be preferred indicates that the fixed effects estimator is preferred for both overall penetration rates and high-speed penetration rates. We therefore focus on the fixed effects models in columns (2) and (4) as our preferred specifications.

We can see from column (2) that the overall broadband internet penetration rate is positive and significant at the one per cent level. The coefficient estimates indicate that a one per cent increase in the overall penetration rate leads to a 0.054 per cent increase in the level of productivity. These estimates are economically quite significant: as we shall see below, these estimates imply that increases in penetration rates increased annual productivity growth by 0.2 percentage points on average over the time period. However, the high-speed penetration rate is insignificant, and negative when year dummies are used.

Looking at the other explanatory variables, the capital–labour ratio is significant and the coefficient estimates of around a half are only a little higher than capital's share of output (what we would expect from the theoretical model). The estimates for human capital are generally insignificant. Of the other explanatory variables, Energy, Structural Change and Institutions are positive and significant across all specifications (except Institutions in the high-speed regression), whereas Natural Capital, Private Sector and Transport are either insignificant or incorrectly signed. The R-squared statistics for the preferred equations, which measure the proportion of total variation in the dependent variable "explained" by the regressors, are in the range of 0.63–0.64, which is reasonable for a panel with a lot of cross section variation.

B. Developing Countries

We next go on to estimate the same four specifications using our sample of 75 developing countries over the same time period. The results are shown in Table 5 below.

Table 5: Regression results for Developing Countries

	(1)	(2)	(3)	(4)
Dependent Variable:	ln Productivity	ln Productivity	ln Productivity	ln Productivity
Estimator:	Random Effects	Fixed Effects	Random Effects	Fixed Effects
ln Human Capital Index	0.0551	-0.154	-0.096	0.118
	(0.087)	(0.100)	(0.131)	(0.155)
ln Capital–Labour Ratio	0.468***	0.405***	0.335***	0.253***
	(0.030)	(0.035)	(0.042)	(0.053)
ln Penetration	0.011*	0.011*		
	(0.005)	(0.005)		
ln High Speed Penetration			-0.001	-0.001
			(0.002)	(0.003)
Energy	0.013***	0.013***	0.020***	0.021***
	(0.001)	(0.001)	(0.002)	(0.002)
Natural Capital	-0.002	-0.003*	-0.007**	-0.013***
	(0.001)	(0.002)	(0.002)	(0.003)
Private Sector	-0.001	-0.001	-0.001	0.000
	(0.001)	(0.001)	(0.002)	(0.002)
Structural Change	-0.003***	-0.003***	-0.001	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Transport	0.000	0.002	0.007***	0.008***
	(0.001)	(0.001)	(0.001)	(0.001)
Institutions	0.008***	0.008***	0.010***	0.011***
	(0.001)	(0.001)	(0.002)	(0.002)
Constant	3.983***	4.793***	5.028***	5.822***
	(0.33)	(0.40)	(0.48)	(0.63)
Observations	779	779	423	423
R^2	0.8522	0.8458	0.7335	0.6790

Standard errors are in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

We again performed a Hausman test to see whether the fixed effects or random effects estimator was preferred. For overall penetration, the null hypothesis of a random effects estimator was rejected at the ten per cent but not the five per cent level. However, the coefficient estimates were almost identical. For high-speed penetration the random effects estimator was rejected in favour of the fixed effects estimator at the one per cent level. We therefore focus, as we did for developing countries, on the fixed effects estimators.

The results for developing countries are quite different. The coefficient on penetration rate is about a fifth what it is for developed countries, and only statistically significant at the ten per cent level. High-speed penetration is not significant, consistent with developing country results. The estimate of the impact of the capital–labour ratio is positive and significant at the one per cent level, the coefficient is between 0.4 and 0.25, lower than for developed countries but reasonable from a theoretical standpoint. The human capital index is not significant. Looking at the other explanatory variables, Energy and Institutions are both significant and positive, as they largely were for the developed countries, as is Transport in the high-speed equation, unlike developed countries. Natural capital is negative and significant, unlike for developed countries where it was insignificant, perhaps indicative of the well-known “resource curse”, whereby countries with significant mineral rents often have slower growth partly as result of conflicts over these rents (See Auty 1993). Structural change is negative although not significant, whereas for developed countries it was positive.

Overall the equations for developing countries perform a little better than those for developed countries. The R-squared for the two specifications is in the range of 0.68 to 0.85, higher than the 0.63-0.64 range for developed countries.

C. Robustness checks

We performed some tests to test the robustness of the results. We tested to see if the year dummies are jointly significant: we found that they were, for both developed and developing countries. We also tested to see if lagged values of the overall penetration and high speed penetration were significant. We found that they were not in any of the four specifications, whether or not the contemporaneous values of these variables were included. We also used the human capital indicator from the Productive Capacities Index as an alternative to that from Penn World Tables; however, the results were very similar.

VI. Contributions of Broadband to Labour Productivity

In order to understand the economic significance of our results we calculate the implied contribution of broadband internet to productivity growth for G20 countries over the period 2009–2019. We then calculate what proportion of actual labour productivity growth is accounted for by the growth in broadband internet penetration. We use specification (2), which uses fixed effect. These results are shown in Table 6 below.

Table 6: Contribution of Broadband Internet Penetration to Productivity Growth: G20 Countries

	Average Productivity Growth 2009-2019 (%)	of which: Growth due to Broadband Internet Penetration (p.p.)	Proportion of Productivity Growth Accounted for by Broadband Internet
Developed G20 Countries			
Australia	0.63	0.16	0.25
Canada	**0.91**	**0.15**	**0.17**
France	0.75	0.20	0.27
Germany	0.88	0.18	0.20
Italy	-0.01	0.20	n.a.
Japan	0.70	0.15	0.22
Republic of Korea	2.03	0.12	0.06
Russia	1.59	0.50	0.32
United Kingdom	0.61	0.19	0.30
United States	1.13	0.15	0.13
Unweighted Average: Developed G20	0.92	0.20	0.22
Unweighted Average: All Developed	1.27	0.20	0.16
Developing G20 Countries			
Argentina	-0.34	0.09	n.a.
Brazil	0.11	0.10	0.93
China	4.65	0.15	0.03
India	5.74	0.09	0.02
Indonesia	3.11	0.18	0.06
Mexico	0.72	0.06	0.09
Saudi Arabia	-1.76	0.15	n.a.
South Africa	0.16	0.09	0.57
Turkey	2.87	0.07	0.02
Unweighted Average: Developing G20	1.70	0.11	0.06
Unweighted Average: All Developing	1.28	0.09	0.07
Unweighted Average: All G20	1.29	0.16	0.12
Unweighted Average: All Countries	1.28	0.13	0.10

Note: n.a. indicates that productivity growth was negative and so we do not show the contributions of broadband internet because they are negative.

The simulations show that growth in broadband internet penetration increased productivity growth by an average of 0.20 percentage points per year across the ten G20 developed countries over the period 2009 to 2019. Because total labour productivity growth was 0.92 per cent per year for these countries, on average, this means that broadband internet penetration accounts for 22 per cent of the average annual productivity growth observed in these ten countries. For the broader sample of 41 developed countries, broadband internet penetration can explain 16 per cent of total labour productivity growth over the 2009–2019 period.

The greatest contribution of broadband internet to productivity growth was in Russia, where broadband internet growth added 0.5 percentage points to productivity growth every year on average, reflecting the large percentage increase in broadband internet penetration in that country. Fully a third of Russia's productivity growth is estimated to have come from the increase in penetration over the 2009–2019 period. The lowest contribution, 0.15 percentage points per year was observed in Korea, which started the period with the highest broadband internet penetration, and so did not experience as big an increase in penetration as some other G20 developed countries. Because Korea's overall productivity growth was quite high over this period—averaging 2.05 per year, the highest among the developed G20 nations—only six per cent of Korea's productivity growth can be attributed to broadband internet penetration over the sample period.

Canada was in the middle of the pack: increases in broadband internet penetration added 0.15 percentage points to productivity growth over the period, 17 per cent of Canada's average annual productivity growth of 0.9 per cent. Canada was quite similar to the U.S. in the contribution of broadband internet to productivity growth. In Italy, productivity growth fell very slightly; the results indicate that productivity growth would have fallen by 0.21 per cent annually had it not been for increases in broadband penetration.

For developing countries, the contribution is somewhat smaller, given the lower estimates of the impacts of broadband internet in our regression results. Broadband internet penetration added between 0.18 (Indonesia) and 0.06 (Mexico) percentage points to annual average productivity growth between 2009 and 2019. Excluding countries with negative productivity growth, broadband internet accounted for between 2 per cent (India) and 93 per cent (Brazil) of total productivity growth. This greater dispersion than for developed countries is accounted for by the greater dispersion in productivity performance among G20 developing countries. Countries like China and India had much faster productivity growth, and so broadband internet is relatively less important. Overall the average contribution of broadband internet was 0.11 percentage points for

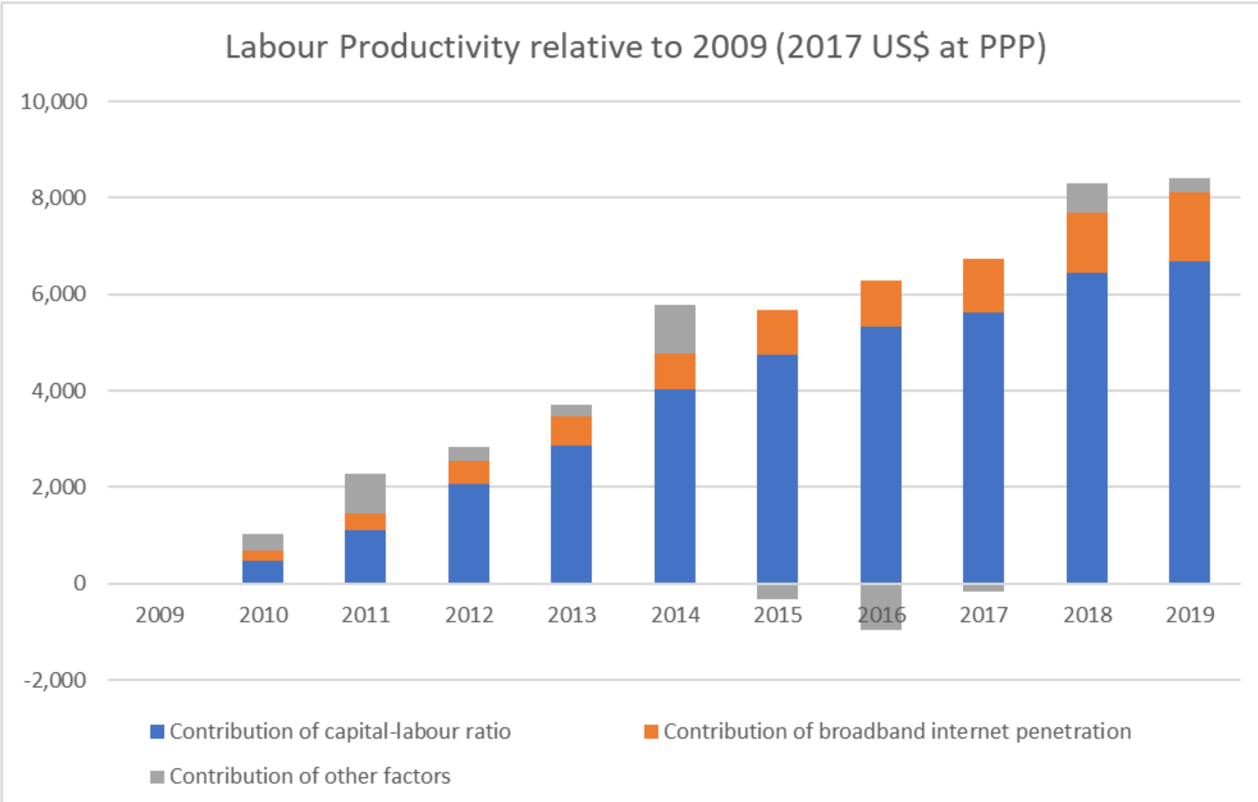
G20 developing countries and 0.09 for all developing countries, about half the developed country figure of 0.20 percentage points. This contribution of broadband internet accounted for 6 per cent of average G20 developing country productivity growth (this number is pulled down by fast-growing countries like India and China, as noted above), and 11 per cent of average productivity growth for all developing countries in our sample.

These estimated contributions of broadband internet to productivity, and thus to economic growth and income, are significant, given all the other factors that affect productivity, from human capital and physical capital intensity to factors such as infrastructure and institutions that we measure using the PCI.

That the average results for developed countries are about half of that of developing countries may come as a surprise, as recall from Table 5 that the estimated coefficient of the impact of broadband internet in developing countries is only a fifth of that for developed countries in Table 4. However, the percentage increase in penetration was much larger, on average, for developing countries, so the net effect on productivity is larger than estimated coefficient would suggest.

Chart 3 below shows the time path of the contribution of broadband internet penetration to overall increases in productivity growth for Canada. Between 2009 and 2019, labour productivity in Canada grew by $8,414 (in 2017 US dollars, adjusted for purchasing power parity). $1,426 of this increase, or 17 per cent, can be attributed to increases in broadband internet penetration.

Chart 3: Productivity Increases in Canada 2010–2019 and the Contribution of Broadband Internet



Interestingly, while overall productivity growth declined in Canada in 2015, partly as a result of a slowdown in the energy sector, broadband internet penetration continued to rise, and so the contribution of broadband internet to productivity also kept rising, ameliorating but not offsetting the overall decline of productivity in the economy in that year.

It is important to note that the estimated impacts on productivity from broadband internet penetration are in addition to the direct impact on productivity from capital investment in broadband internet. These effects are picked up separately through an increase in the capital–labour ratio.

VII. Policy Implications

Our finding that investment in broadband internet increases total factor productivity across the economy has important implications for public policy. This is because, as noted above, increases in TFP represent spillover benefits to the broader economy that are over and above those captured by the company making the investments. This makes broadband internet infrastructure similar to other public infrastructure, such as roads and highways, where the benefits are significant but diffused across the economy in ways that make it hard to ensure that the ultimate economic beneficiaries are paying a market price equal to the marginal benefit they receive from it. This is why governments have tended to provide these networks for free to users. (The exceptions include toll highways where access is easy to monitor; however, this represents a small fraction of the overall road network, and non-toll alternatives almost always exist). The existence of sizable spillovers implies that, like roads and highways, we should think of broadband internet as critical infrastructure for the modern economy, facilitating other sectors' growth and efficiency.

These spillovers mean that there is strong case for government to encourage broadband access, as these broader economic benefits will not be taken into account by the telecommunication companies when making investment decisions. This is because in a free market, companies invest only up to the point that their private return (from charging customers) exceeds the cost of making the investments. As a result, without any government intervention, the provision of broadband internet will be below the socially optimal level.

Policies to encourage broadband internet investment can take many forms. One approach would be for government could simply provide the service directly, as with the roads and highway example above. However, government provision is unlikely to be the best approach in the case of broadband internet. Building out a broadband network, especially with next-generation technologies, requires enormous capital investment that fiscally constrained governments will find difficult to afford. Even more importantly, given the rapidly evolving technology in this area, private companies are much better placed to respond to market incentives to innovate.

Alternative approaches to stimulate investment would include subsidies and tax incentives to telecommunications companies to encourage them to build out their network. This is the approach adopted by a number of countries, particularly for rural and remote areas. In the United

States, for example, the Federal Communications Commission's Connect America Fund (FCC 2012) is designed to ensure that consumers in non-urban areas have access to broadband at rates that are comparable to urban areas. In Canada the federal Government launched the Universal Broadband Fund in 2020, designed to connect 98 per cent of Canadians to high-speed internet by 2026 and 100 per cent by 2030 (see Canada (2023)).

Subsidies are not the only tool available to governments to incent investment in broadband internet. As noted above, broadband internet requires large amounts of capital investment; however, corporate income tax systems in most developed countries, including Canada, discourage capital investment, particularly when it is financed by equity rather than debt. Enabling more favourable tax treatment for broadband internet investment could therefore be another important tool for encouraging investment. This could take the form of accelerated depreciation allowances, a tool that has been used by a number of governments, including Canada, to promote capital investment in specific areas (see Canada 2018).

Government policy can also act on the demand side, by incenting adoption of broadband internet technology by users, particularly small businesses. Policies could include subsidies, such as the U.K.'s Gigabit Voucher scheme (UK 2021) that provides grants directly to business and individuals to adopt high speed broadband, or tax measures, such as eliminating sales taxes on internet services.

Finally, and as discussed further below, it is hard to separate the impacts of broadband internet from impacts of the software applications that it makes possible. To the extent that these applications also contribute to the significant TFP benefits that we have found, it will be important for governments to ensure that barriers and impediments to the adoption of new software applications are minimised.

VIII. Conclusion

In this report we have estimated the impact of broadband internet penetration on labour productivity using a panel of 116 countries over the time period 2009–2019. We looked at the impact of all fixed broadband internet, as well as high-speed broadband, defined as broadband internet with speeds above 10Mbps. Our conceptual model is the standard Solow model of growth accounting, which allows us to apportion increases in productivity growth between growth in inputs of physical capital, and growth in total factor productivity, or the efficiency with which factors of production are used. This allows us to separate out the gains which telecommunications companies receive directly from investment in broadband internet, which show up as gains to capital investment, and the broader benefits to the economy, which do not accrue to the companies making the investment, but which accrue to other businesses and their workers, through increases in total factor productivity.

Our results show statistically and economically significant impacts of fixed broadband internet on productivity growth for both developed and developing countries. We find that broadband internet increased labour productivity growth by an average of 0.20 percentage points annually in developed countries and 0.26 percentage points in developing countries from 2009 to 2019: this meant that broadband internet accounted for around 16 per cent of productivity growth in developed countries and 7 per cent of productivity growth in developing countries. The very low rates of broadband penetration in countries such as India, Indonesia and South Africa means that these countries have a very significant potential for a boost in productivity growth if they can boost broadband internet infrastructure, as China, for example, has done.

The results for Canada were fairly typical for developed countries, with broadband internet contributing 0.15 percentage points annually, on average, to Canada's overall productivity growth of 0.91 per cent. This contribution was similar to other large developed countries, reflecting similar trends in broadband adoption.

Overall, the results suggest significant spillovers to the rest of the economy from the adoption of broadband internet, attesting to the role of broadband internet as critical infrastructure for the economy, underpinning productivity across the economy. This suggests an important role for government in encouraging the building out of broadband internet: appropriate policies could include subsidies and tax incentives directed at both telecommunications companies and business users, especially small businesses. Indeed, many countries, including Canada, have adopted these kinds of policies.

While the results for overall broadband internet penetration showed very significant effects, the results for high-speed broadband internet penetration showed no additional impact. Taken at face value, this would suggest that while the applications associated with lower speed internet access, such as surfing the Web, have very positive impacts on productivity, more speed-intensive applications, such as gaming or videoconferencing do not, or at least did not over the sample period. Of course, the importance of videoconferencing did increase massively during and after the COVID 19 lockdowns: it is possible that with more recent data we would see much more significant differences between those countries that had the broadband internet infrastructure to support widespread videoconferencing and those that did not.

The result that increases in high-speed penetration do not seem to add to labour productivity is consistent with much of the recent literature, at least for developed countries. Edquist (2022), who looks at mobile and not fixed broadband internet, does not find robust effects for developed countries. Koutroumpis (2019) also finds that speed increases above 9.8 Mbps do not add to GDP for OECD countries.

None of this is to say that higher speeds might not be important for productivity in the future. Indeed, it is symptomatic of information technology that advances in hardware capacity that seemed well in advance of customers' need when introduced soon became essential for software applications that were developed to use the new capacity: hence the saying "What Intel giveth, Microsoft taketh away." (OSNews, 2007). Indeed, a recent OECD study (Calvino and Fontanelli 2023) finds that AI use is correlated with ultra-fast broadband: it may be that once firms start reaping the benefits of technologies like AI we will see a positive link between high speed broadband and productivity.

How robust are the results? Simultaneity is a potential problem that may bias the results upwards if higher productivity causes higher broadband internet penetration instead of the other way around. Another possibility that might bias the results upwards is omitted variables: while we included a broad array of variables that might affect labour productivity, it is possible that we have omitted a variable that matters for productivity and that is correlated with broadband internet penetration, exaggerating the role of the latter.

The other important caveat to make is that the productivity benefits from broadband infrastructure require accompanying software applications if these benefits are actually to be realised in practice. Disentangling the productivity impacts of these two factors would be quite challenging: we would need time series data on what software was being used by businesses across different countries, and we are not aware of the existence of such a dataset for a wide range of countries (although it is available for Canada—see below). That said, while not a sufficient condition, infrastructure investment is certainly a necessary condition for the productivity gains that we have estimated, without it they could not have occurred.

With these caveats in mind, we nonetheless believe that the data support the hypothesis that broadband internet penetration—although not high-speed penetration—had economically significant impacts on labour productivity during the estimation period by increasing the productivity of capital and labour across the economy. This conclusion reinforces the idea that investment in broadband infrastructure has very important network externalities across the economy and that the benefits to society go well beyond the returns captured by the telecommunications companies. Whether investment in higher speed broadband internet will have the same impact will depend on the evolution of applications such as cloud computing, data analytics and artificial intelligence, as ultimately the benefits of advances in hardware and in software are inextricably linked.

IX. Directions for Further Work

Our analysis has used country-level data to estimate the impact of broadband penetration on productivity. However, there is likely considerable regional and sectoral variation in broadband internet penetration that is not reflected in country-level aggregates. Furthermore, because business-level data was not available for many of the countries in our sample, we were forced to use broadband internet penetration for households as a proxy for the use of broadband internet by firms.

An obvious direction for further work would therefore be to use data on firms rather than households, broken down by region and sector. Not only might this give use more precise estimates of the overall impact of broadband, because we would be looking at firms not households, this disaggregated analysis would also be very relevant for policymakers who would be better able to target policies towards regions and sectors where the spillover impacts on productivity are the greatest.

Canada does have a dataset that could be used for this kind of study. This is the Survey of Digital Technology and Internet Use, which surveyed more than 10,000 firms across the Canadian economy, and covers 2013, 2014, 2019 and 2021, albeit with some changes in methodology. Data is available by firm size, industry and province, as well as on the activities that firms use internet access for, including e-commerce, cloud computing and the internet of things. Matching up changes in industry-level internet use over this period with changes in productivity would allow one to better understand how internet use, not simply availability, affects productivity at the industry level. Industry-level data may also be able to help us understand why we do not see more impact on productivity of high-speed broadband: it may be that high-speed broadband does boost productivity for those firms that use applications that require high speed, but that the number of firms using these applications may still be small. This would be very relevant to policymakers, as encouraging greater use of high-speed applications through greater availability of infrastructure might be an important avenue for raising productivity at the industry level, if indeed there is a connection by applications that require high-speed internet and productivity.

Another direction for further work would be to perform a more comprehensive cost benefit analysis of investments in broadband. This infrastructure is expensive, and governments would want to know the social rate of return on investment before committing funds. Key considerations would include the government's marginal cost of funds, and the extent to which investments might pay for themselves through increased tax revenues.

Finally, we have focussed in this paper on fixed broadband internet connections, and so have not considerable the very significant expansion of mobile broadband internet for many countries in our dataset. Indeed, one reason why we find weaker results for developing countries might be that in many of these countries consumers rely less on fixed connections, which are often expensive and not always reliable, and more on mobile connections. Another direction for further work could look at whether this expansion of mobile broadband has affected productivity in both developed and developing countries.

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Appendix 1: List of Developing and Developed Countries in the Dataset

Developed Countries:

Australia	France	Lithuania	Russia
Austria	Germany	Luxembourg	Serbia
Belgium	Greece	Malta	Slovakia
Bulgaria	Hungary	Netherlands	Slovenia
Canada	Iceland	New Zealand	Spain
Croatia	Ireland	Norway	Sweden
Cyprus	Israel	Poland	Switzerland
Czech Republic	Italy	Portugal	Ukraine
Denmark	Japan	Republic of Korea	United Kingdom
Estonia	Latvia	Romania	United States
Finland			

Developing Countries:

Angola	Dominican Republic	Laos	Qatar
Argentina	Ecuador	Lesotho	Rwanda
Armenia	Egypt	Macau	Saudi Arabia
Bahrain	Eswatini	Malaysia	Senegal
Barbados	Fiji	Mauritania	Sierra Leone
Benin	Gabon	Mauritius	Singapore
Bolivia	Guatemala	Mexico	South Africa
Bostwana	Honduras	Moldova	Sri Lanka
Brazil	Hong Kong	Mongolia	Sudan
Burkina Faso	India	Morocco	Taiwan
Burundi	Indonesia	Mozambique	Tanzania
Cameroon	Iran	Namibia	Thailand
Central African	Iraq	Nicaragua	Togo

Republic	Jamaica	Niger	Trinidad and Tobago
Chile	Jordan	Nigeria	Tunisia
China	Kazakhstan	Panama	Turkey
Colombia	Kenya	Paraguay	Uruguay
Costa Rica	Kuwait	Peru	Venezuela
Cote D'Ivoire	Kyrgyzstan	Philippines	Zimbabwe

Appendix 2: Indicator Variables and Sources of Data for Components of the PCI

Energy	
	Share of people with access to electricity
	Transmission and distribution losses as share of primary supply
	Renewable energy consumption as share of total final energy consumption
	GDP per kg of oil consumption
	Total primary energy supply per capita
	Total energy consumption per capita
Institutions	
	Control of corruption
	Government effectiveness
	Political stability and absence of violence/ terrorism
	Regulatory quality
	Rule of law
	Voice and accountability
Natural Capital	
	Agricultural land as share of land area
	Forest area as share of land area
	Share of all extraction flows in GDP
	Material intensity (total extraction flows over industrial value added)
	Total natural resources rent as share of GDP
Private sector	
	Domestic credit to private sector as share of GDP
	Cost to export a container
	Time to export (days)
	Cost to import a container
	Time to import (days)

	Enforcing of contracts (days)
	Starting a business (days)
	Trademark applications
	Patent applications
Structural change	
	Export concentration index
	Economic complexity index
	Gross fixed capital formation as share of GDP
	Industrial ratio (industry and services over total GDP)
Transport	
	Air transport, registered carrier departures worldwide per 100 people
	Air transport, freight (million ton-km)
	Air passengers per capita
	Logarithm of km of roads/100km2 land
	Logarithm of total km of rail lines per capita

Source: United Nations Conference on Trade and Development (UNCTAD), UNCTAD Productive Capacities Index

Appendix 3: Members of the Technical Advisory Committee

Catherine Beaudry
Professor of Engineering
Ecole Polytechnique
Université de Montréal
Montreal, Quebec

Jonathan Barr
Senior Director
Innovation, Science and Economic Development
Ottawa, Ontario

Margaret Dalziel
Associate Professor
Conrad School of Entrepreneurship and Business
Vice-President, Evidence Network
University of Waterloo
Waterloo, Ontario

Harald Edquist
Senior Researcher
Ericsson
Stockholm, Sweden

Dennis Fixler
Chief Economist
US Bureau of Economic Analysis
Washington, DC

Kevin Fox
Professor of Economics
University of New South Wales
Sydney, Australia

Arthur Grimes
Senior Fellow
Motu Institute
Wellington, New Zealand

Wulong Gu
Senior Advisor
Statistics Canada
Ottawa, Ontario

Thomas Niebel
Senior Researcher
Research Department Digital Economy
ZEW- Leibniz Centre for European Economic Research
Mannheim, Germany

Nelson Paterson
Director General
Economic Studies and Policy Analysis
Finance Canada
Ottawa, Ontario

Dirk Pilat
Former Deputy Director
Science and Technology
OECD
Paris, France

Bart van Ark
Managing Director
The Productivity Institute
University of Manchester
Manchester, United Kingdom

Leonard Waverman
Professor, Business Economics and Finance
Special Advisor to the Provost and VP Research
DeGroote School of Business. McMaster University
Hamilton, Ontario

Dany Brouillette
Innovation, Science and Economic Development
Ottawa, Ontario