THE ROLE OF A **ROBUST BROADBAND** INFRASTRUCTURE IN BUILDING **ECONOMIC RESILIENCY** DURING THE COVID-19 PANDEMIC

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EXECUTIVE SUMMARY

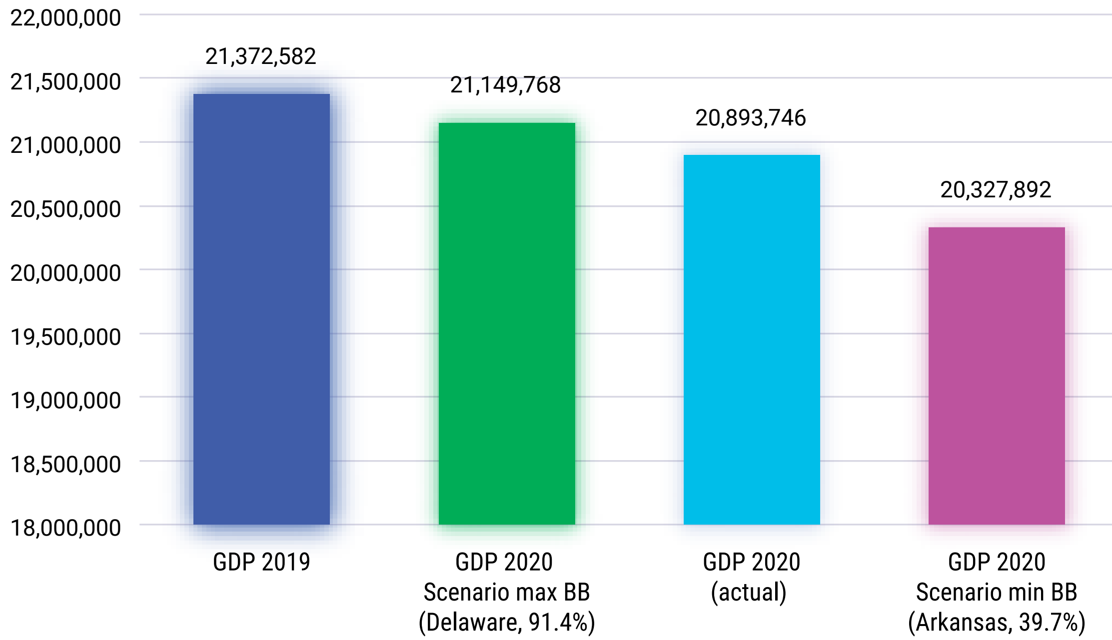
The COVID-19 pandemic has raised a fundamental challenge to the global socio-economic system, forcing us to reexamine social practices and production systems otherwise considered normal until the end of 2019. Governments around the world enacted massive social distancing measures, including severe lockdowns with implicit abrupt falls in travelling, tourism, and all physical work interactions. In the United States, the pandemic has seriously affected the performance of the daily routines of its population and businesses.

In this study we propose an economic growth econometric model that accounts for the role of fixed broadband in mitigating the economic losses resulting from COVID-19. First, to consider the impact of COVID-19 on economic output on the US economy, we rely on two main variables: an indicator of the quantity of deaths attributable to the disease for every 100,000 inhabitants; and the *Stringency Index*, a metric linked to the restrictions imposed in terms of home confinement, closure of offices, shops, and schools, among others. Following this, to account for the role of broadband in counteracting the economic effects generated by the pandemic, we add interaction variables between fixed broadband connectivity and the COVID-related indicators. Those variables are considered in a Cobb-Douglas production function, estimated within a structural multi-equation model to control for potential endogeneity.

Results show that had the national fixed broadband penetration been the same as that of the most-connected state (Delaware, 91.4%) rather than the actual level of 70.5%[1], the national GDP contraction in 2020 would have been 1% rather than the actual 2.2% (Figure A).

[1] All fixed broadband penetration data in this paper refers to connections of at least 25 Mbps download and 3 Mbps upload (the FCC broadband standard). The sources of national and state level broadband penetration are the FCC Internet Access Services reports (for data covering up to 2019) and the American Community Survey (to calculate the growth rate between 2019 and 2020).

Graphic A. National evolution of GDP by Broadband scenarios (in US$ million)

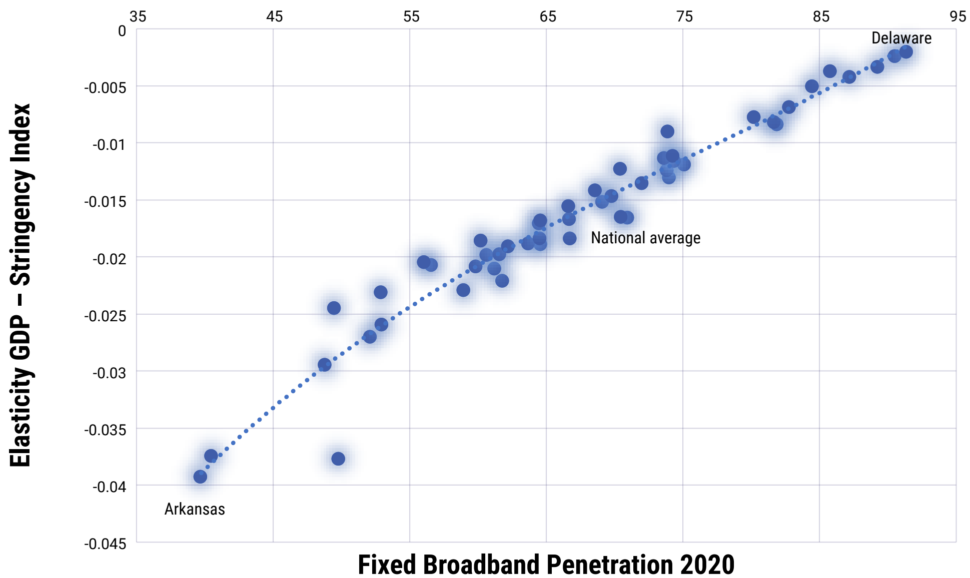


Source: Telecom Advisory Services analysis

The analysis also indicates that those states with higher adoption of fixed broadband infrastructure were able to mitigate a larger portion of their 2020 economic losses due to pandemic-related restrictions. That is the case of states with higher broadband penetration, such as Delaware (91.4%) or New Jersey (90.5%), where high connectivity levels allowed for an important part of the economy to continue to function during lockdowns. At the other end, the most affected states during 2020 were Arkansas, New Mexico, and Mississippi, partly because of their low fixed broadband penetration .

Graphic B presents the elasticity between GDP and the *Stringency Index*. This elasticity can be thought of as a measure of the percentage of GDP contraction after a 1% increase in the *Stringency Index*. The results are clear that the sensitivity of the economic contraction to restriction tightness increases when broadband penetration is lower.

Graphic B. Elasticity GDP – *Stringency Index* by level of BB penetration



Source: Telecom Advisory Services analysis

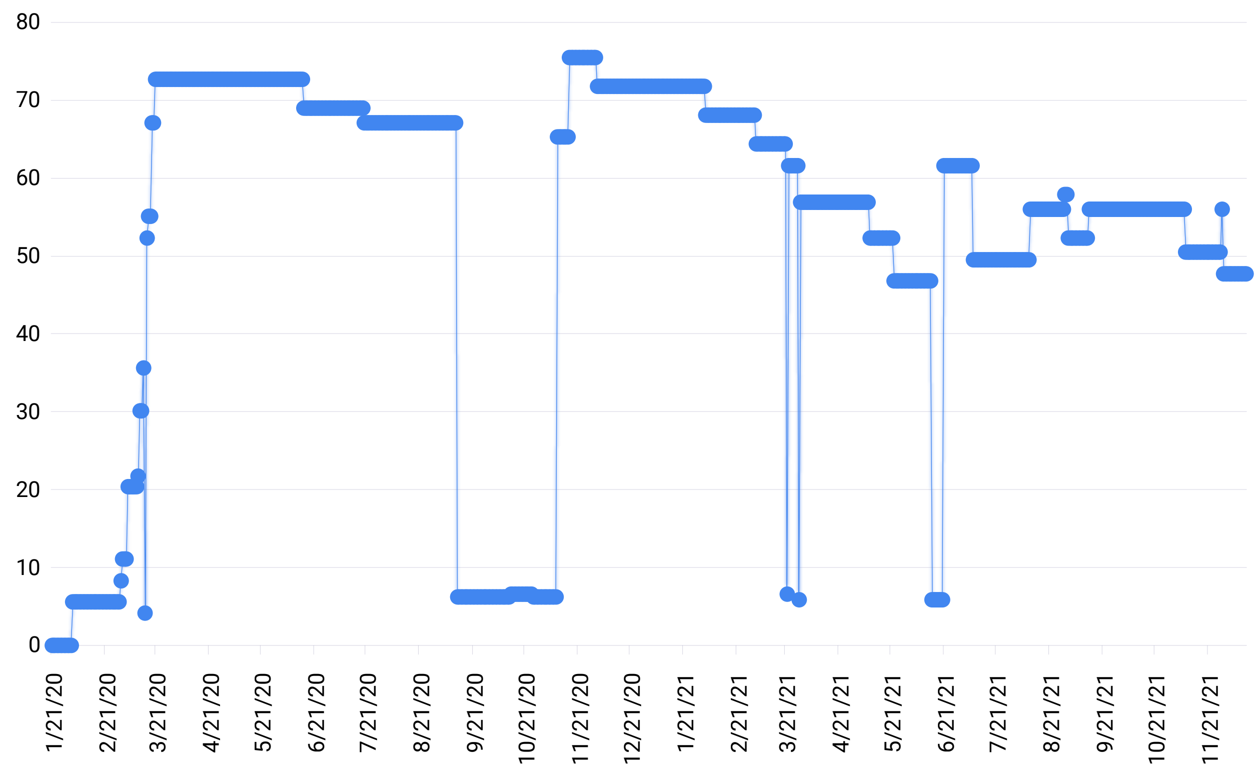
In conclusion, the pandemic highlighted the critical need to close the digital divide and to ensure universal access to high-quality broadband internet connection in all States. Public authorities should urgently focus on creating policy frameworks that allow operators to spur broadband infrastructure deployments in unserved areas and to find solutions to help all households connect to the Internet.

1. INTRODUCTION

The COVID-19 pandemic has raised a fundamental challenge to the global socio-economic system, forcing populations to reexamine social practices and production systems otherwise considered normal up to the end of 2019. Especially before the launch of vaccination campaigns, governments enacted massive social distancing measures, including severe lockdowns with implicit abrupt falls in travelling, tourism, and all physical work interactions. In consequence, the pandemic in the United States seriously affected the performance of the daily routines of its population and the functioning of enterprises. The *Stringency Index* published by *Our World in Data*,[2] which measures the level of closure of social and economic activity in response to the pandemic, including school and office closures, travel bans, among other measures, shows that the severity of lockdowns during 2020 was concentrated in the period from March to September of that year, while another period of strong restrictions was imposed between November 2020 and January 2021. Graphic 1 shows the daily evolution of the *Stringency Index*.

[2] The COVID-19 Stringency Index is a composite index based on six measures adopted by nations facing the pandemic, including school holidays, workplace closures, travel bans, among others. Each indicator is measured between 0-100. The data source comes from the Oxford COVID-19 Government Response Tracker. Blavatnik School of Government, University of Oxford.

Graphic 1. United States: Stringency Index

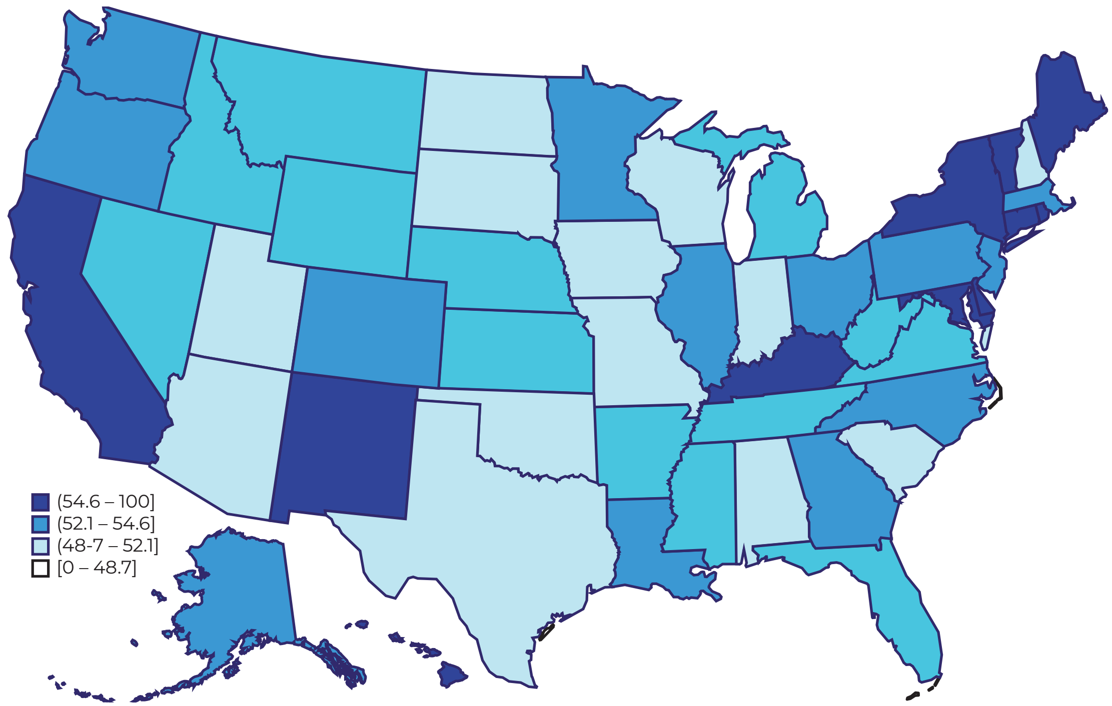


Source: Our World in Data

This degree of restrictions affected considerably the economic performance of the country. For example, as of June 2020, 66% of US respondents to Nielsen had started to work from home since the Coronavirus outbreak.[3] That said, the average national *Stringency Index* masks important regional differences. Figure 1 displays the index by state, indicating that the more severe lockdowns were imposed by the north-eastern states, as well as Maryland, Delaware, Kentucky, New Mexico, and California.

[3] Nielsen (2020). *The Nielsen Total Audience Report*, August.

Figure 1. United States: Stringency Index by state (2020 average)



Source: Our World in Data

Following the strict lockdowns carried out in 2020, strong anecdotal evidence has emerged suggesting that a robust ICT infrastructure has contributed to counteract some of the isolation measures, allowing economic systems to continue operating, at least partially. In this context, this study investigates the extent to which ICT adoption (more specifically, fixed broadband networks) mitigated the negative economic impact generated by the COVID-19 crisis in the United States. The study's hypothesis is that, beyond its economic contribution under normal conditions (addressed in our prior study[4]), broadband adoption can also be essential in building resiliency to face the economic disruption generated by the pandemic.

[4] Katz, R. and Jung, J. (2022). *The contribution of fixed broadband to the economic growth of the United States between 2010 and 2020.*

This situation raises a new research imperative. Our prior study focused on the contribution of fixed broadband to economic growth between 2010 and 2020: it concluded that, if broadband adoption and speed had remained unchanged since 2010, the 2020 US GDP would have been 6.27% below its current level. Another research question needs to be explored: if societies are transitioning to environments combining a mix of physical and virtual interactions, it is pertinent to assess whether, given its broadband penetration, the United States was also better prepared to deal with the pandemic than it would otherwise have been. A related question is whether this could also be tested in the case of those states that are better "connected" than others. If that were to be the case, the experience of the COVID-19 disruption would be useful in providing some evidence to that effect. The implication from a policy standpoint is self-evident: there is a critical need to accelerate the development of ICT infrastructure to be ready to deal with the "new normal" expected in the post-COVID world.

The next section of this study reviews the research literature on the issue of the impact of broadband on economic resilience in light of health and other emergencies. Section 3 presents anecdotal evidence on the usage of ICT infrastructure at the outset of COVID-19, prior to the advent of vaccines. Section 4 details the theoretical model and the dataset developed to test the study hypothesis. Section 5 presents and discusses the results of the econometric analysis focused on estimating the value of broadband adoption in mitigating the economic disruption driven by COVID-19. Based on the evidence presented in section 5, we raise some policy implications.

2. RESEARCH LITERATURE REVIEW

Studies on the economic impact of digital technologies produced for the past two decades confirm, to a large extent, that telecommunications and broadband in particular have an impact on economic growth and, in some cases, on employment and productivity (Hardy, 1980; Karner and Onyeji, 2007; Jensen, 2007; Katz et al, 2008; Fornefeld et al, 2008; Katz and Suter, 2009; Koutroumpis, 2009; Katz, 2011; Katz et al, 2012; Rohman and Bohlin, 2012; Mack and Faggian, 2013; Arvin and Pradhan, 2014; Katz et al, 2020a). Other authors have expanded their analysis to a broader definition, as that of digitization (Katz and Koutroumpis, 2013). Under normal conditions, digitization usually translates into productivity improvements by facilitating the adoption of more efficient business processes (e.g., marketing, inventory optimization, and streamlining of supply chains); in accelerated innovation by introducing new consumer applications and services (e.g., new forms of commerce and financial intermediation); and in more efficient functional deployment of enterprises by maximizing their reach to labor pools, access to raw materials, and consumers (e.g., outsourcing of services, virtual call centers). All these advantages provided by better connectivity can be crucial in a context of crisis in which physical interactions have to be avoided.

Beyond the positive economic impact in terms of GDP, employment, and productivity, broadband can also be critical in providing economic resiliency under emergency situations such as forced lockdowns. At the household level, broadband allows citizens to carry out many daily tasks that previously required physical contact. Examples of this are the ability to access telehealth apps shop online study by virtual tools and work remotely. In addition to providing workers the possibility to telecommute, digitized supply chains and electronic distribution channels can substantially contribute to keep economic activity operating in the situations in which face-to-face interactions with customers and suppliers must be avoided. Finally, ICT infrastructure can increase resiliency at the government level, by allowing public institutions to continue operating and delivering public services.[5]

In addition to typical ICT infrastructure such as broadband, specific technologies such as Wi-Fi, can also contribute to mitigate pandemic-induced social and economic disruption. For example, during 2020 free public hotspots have been deployed in such places as outdoor COVID-19 wards, other makeshift healthcare facilities, and in parking lots where in-vehicle wireless access is required. In addition, schools and libraries deployed hotspots outside buildings to facilitate access to distance learning for students and teachers that lack fixed broadband service at

[5] Beyond the services that are less impacted by the level of digitization (e.g., public health and safety), it is straightforward to see that a highly-digitized government has more capabilities to continue providing public services without interruption.

home. In some cases, school buses have been also equipped to provide "Wi-Fi on wheels," and families in need have been issued personal Wi-Fi hotspots for students to use for online learning. With access to these newly available hotspots, consumers that do not have broadband service because of an affordability barrier can rely on free Wi-Fi to gain Internet access.

While research on the contribution of ICT infrastructure to mitigate the economic impact of pandemics is limited, emerging evidence exists about its positive effects. So far, empirical evidence refers mainly to natural disasters, focusing on the capability of ICT to provide information for decision-making, or allow critical public services to continue operating under such circumstances. Teodorescu (2014) analyzes the role of information technologies (IT) for disaster mitigation, addressing the roles of the technology in improving resilience. He stresses that some IT tools, such as sensor networks or decision-supply systems, plus a reliable telecommunication infrastructure are crucial to create a comprehensive picture of an emergency to manage information and support decision-making. Similarly, O'Reilly et al (2006) argued that national infrastructures for power, emergency services, and finance rely heavily on information and telecommunications networks to keep providing services and conducting business in situations of natural disasters. In the specific case of pandemics, Chamola et al (2020) highlights the use of technologies such as the Internet of Things (IoT), Unmanned Aerial Vehicles (UAVs), blockchain, Artificial Intelligence (AI), and 5G, among others, to help mitigate the impact of these outbreaks. Other authors have studied the role of digital technologies during the COVID-19 pandemic. That is the case of Biancone et al (2021), who stated that telemedicine is providing new opportunities for interaction and complementarity of traditional care methodologies. The authors used a qualitative approach based on case study analysis, concluding the relevant role of telemedicine as a vehicle for social impact and sharing of medical knowledge. Similarly, Tortorella et al (2021) examined the contribution of digital applications during the COVID-19 outbreak, concluding that applications oriented to medical supply chain and patient diagnosis contribute to healthcare resilience, while Massaro (2021) highlighted the role of electronic data to track patients. In turn, Chi (2021) studied the role of electronic customer relationship management (e-CRM) applications on firms' innovation capabilities in the context of COVID-19, finding that knowledge management, customer orientation and technology-based CRM have a positive influence on long-term relationships and innovation capability; while Cao et al (2021) argued that the COVID-19 outbreak amplified the impact of information on human behavior, as internet has been a major channel to get information and to enhance social interactions while staying at home during the pandemic.

As for quantitative empirical evidence, Katz et al (2020b) provided econometric results showing the economic losses of the 2003 SARS outbreak were not equal for every country affected. Starting with a production function, the authors introduced two different variables to capture the effect of SARS: a dummy variable to identify the countries affected by the pandemic, taking value of 1 when at least one positive case had been reported, and a continuous variable based on the number of people infected for every 100,000 inhabitants. The results indicated that: (1) countries with more positive cases were economically affected more severely, and (2) countries with higher broadband adoption were able to counteract, to some degree, the effects of the pandemic. The results pointed out that countries with a 10% fixed broadband penetration underwent a decline in GDP of -0.045% for every increase of 1% in infections per population. Conversely, countries with a fixed broadband penetration of more than 20% incurred a negligible GDP contraction for every increase in 1% in infections per population.

Following up on their first analysis, Katz and Jung (2021) provided a subsequent analysis of broadband's contribution to mitigating the economic disruption of COVID-19. By applying a structural econometric model to a 121 countries panel, the authors concluded that economic damage was not uniform across countries: *ceteris paribus*, those economies endowed with better ICT infrastructure were able to achieve higher levels of mitigation. Countries reaching a threshold of 30% of fixed broadband penetration, or 50% for mobile broadband penetration, exhibited lower elasticity of economic impact from COVID-19, as the connectivity levels in these countries allowed for an important part of the economy and society to continue to function during lockdowns. In countries with less than 30% fixed broadband household penetration, a 1% increase in COVID induced deaths per 100 population (an indicator of pandemic damage) generated a contraction of GDP per capita of -0.024%. In countries with broadband penetration between 30% and 90%, a 1% increase in COVID deaths per 100 population generated a contraction of GDP per capita of -0.021%: consequently, 15 % of the economic damage faced by less-connected economies was mitigated. Likewise, countries with more than 90% broadband penetration had the least elasticity in economic impact, equal to -0.019%: they can mitigate the equivalent of 21% of the economic disruption caused to countries with the lowest connectivity.

Other studies have focused on the role of broadband in mitigating the pandemic disruption in the United States in specific economic variables. For example, Isley and Low (2022) explored the relationship between broadband and employment rates during April and May 2020 in rural US counties. Applying a two-stage least squares model, the authors found that rural fixed broadband availability and adoption appear to be associated with a higher employment rate. Research has also focused on assessing the impact of digital platforms (and consequently, broadband) in increasing the survival rate of small businesses. Using data from Uber Eats, an online food ordering and delivery digital service, Raj et al (2021) determined that the platform was critical in driving an increase in total restaurant activity, and orders following the closure of the dine-in channel.

Based on this research, one could assume that, in the medium term, economies with better connectivity infrastructure were able to more successfully mitigate some of the negative economic impact of COVID.

3. THE IMPACT OF COVID 19 ON ICT USE: DESCRIPTIVE EVIDENCE

The anecdotal evidence generated after the irruption of COVID-19 reveals both the seriousness of the outbreak and the importance of infrastructure development as a mitigating factor. During 2020, internet service providers saw significant growth in both downstream and upstream traffic, increasing at least 30% worldwide (BITAG, 2021[6]; Labovitz, 2020). The transition to telecommuting brought about a shift from enterprise to residential access. Telecommunications traffic was no longer primarily originated in central business districts, shifting instead to residential areas. Similarly, in response to the lockdown, a portion of data traffic shifted from mobile to fixed/Wi-Fi networks. Daily traffic patterns also changed. Contrary to the period prior to COVID-19, Internet traffic started to surge in the morning at levels close to the evening peak, partly because of telecommuting and videoconferencing, but also driven by sustained streaming usage.[7] Finally, mobile voice traffic grew strongly, driven by an increase in both the number of calls and their duration.

Simultaneously with the changes in traffic patterns, COVID-19 drove an acceleration of ICT service adoption trends. As expected, the use of e-commerce increased from a worldwide average of 9.5% of total retail trade in 2019 to 12.4% by the end of 2020.[8] In addition, a jump in Internet platform usage was also detected in terms of download of Apps by smartphone users: by the end of 2020 the time spent in apps per day was 4.2 hours, up 30% from two years prior in the United States, Turkey, Mexico, and India. In Brazil, South Korea and Indonesia it reached five hours.[9]

Usage of fixed broadband increased in all continents, albeit at different rates. Fostered by the need to accommodate teleworking, distance learning, remote entertainment, and telemedicine during 2020, fixed broadband jumped with respect to the previous year, reaching a faster growth rate during the pandemic in all regions excepting Asia (see Table 1). Excepting Asia-Pacific, in all regions fixed broadband penetration grew at a faster rate in 2020 that in the year before, which could be attributed to the connectivity needs during lockdowns.

6 Broadband Internet Technical Advisory Group
7 Reynolds (2020).
8 Source: Euromonitor
9 Kristianto (2021)

Table 1. Growth in Fixed Broadband connectivity (% of households)

Region	2018	2019	2020	Delta (2018-2019)	Delta (2019-2020)
World	51.57%	54.68%	58.31%	6.03%	6.63%
Africa	3.09%	3.46%	4.11%	12.00%	18.67%
Latin America and Caribbean	49.08%	51.35%	56.38%	4.62%	9.79%
Asia and Pacific	49.68%	53.76%	57.58%	8.22%	7.09%
Arab States	58.90%	61.71%	68.91%	4.77%	11.66%
CIS	60.76%	63.27%	66.12%	4.14%	4.49%
Europe	89.36%	91.37%	95.14%	2.25%	4.12%
North America	89.46%	92.00%	96.21%	2.83%	4.58%

Sources: International Telecommunication Union published in https://www.itu.int/en/ITU-D/Statistics/Documents/facts/Facts

Similarly, Wi-Fi traffic increased significantly. For example, in the United States the percent of time spent by a smartphone user on Wi-Fi jumped from 54.3% to 59.9% in less than one month. In Brazil, the increase amounted to an 11% (see Table 2).

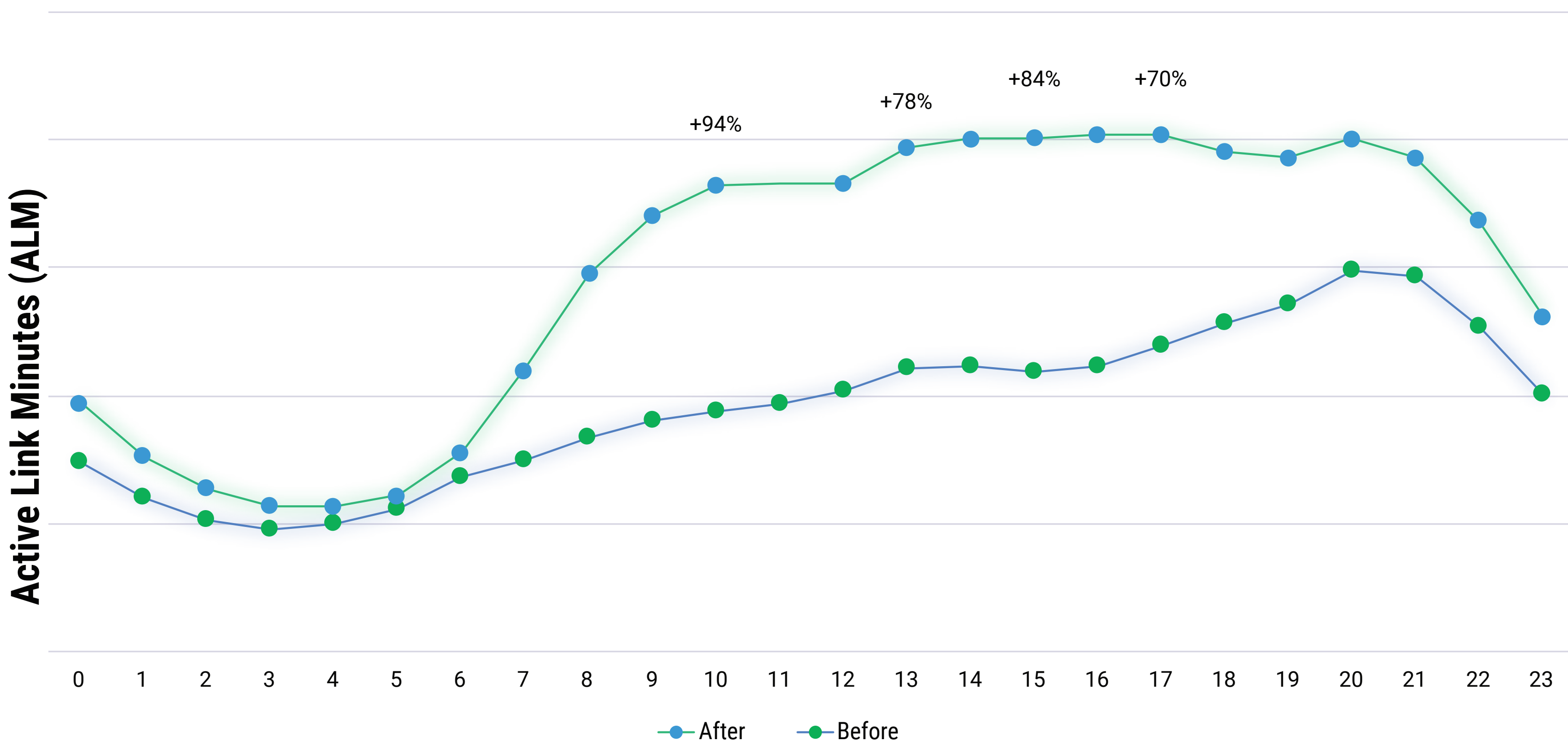
Table 2. Average weekly time spent on Wi-Fi by smartphone users (March 2020)

Country	Mar 2-8	Mar 9-15	Mar 16-22	% Increase	Smartphone penetration
Australia	49.7%	50.5%	52.4%	5.43%	109.1%
Indonesia	33.4%	33.7%	34.7%	3.89%	131.7%
Malaysia	27.1%	27.8%	30.5%	12.55%	101.8%
Philippines	53.6%	55.8%	63.3%	18.10%	86.6%
Singapore	54.4%	54.9%	55.5%	2.02%	133.1%
Vietnam	68.7%	69.5%	69.9%	1.75%	75.4%
Egypt	54.8%	56.9%	61.2%	11.68%	76.1%
Germany	65.4%	65.9%	71.4%	9.17%	104.3%
Italy	52.3%	56.2%	59.2%	13.19%	92.0%
Saudi Arabia	48.7%	49.3%	51.9%	6.57%	130.0%
South Africa	50.4%	47.4%	51.2%	1.59%	104.8%
Spain	61.3%	62.6%	73.1%	19.25%	93.8%
Switzerland	53.2%	53.4%	58.9%	10.71%	103.0%
United Kingdom	64.5%	64.7%	68.9%	6.82%	87.8%
Argentina	64.3%	64.8%	72.5%	12.75%	97.7%
Brazil	65.1%	64.8%	72.5%	11.37%	86.3%
Mexico	59.9%	60.6%	64.0%	6.84%	61.2%
United States	54.3%	54.9%	59.9%	10.31%	92.9%

Source: Khatri and Fenwick (2020)

On a world-wide basis, the time smartphone users spend on Wi-Fi rather than on cellular networks since the outbreak of COVID-19 increased by 9.11%. Wi-Fi typically connects a user to a fixed broadband connection and therefore is a key technology enabling telecommuting, schooling from home, etc. Based on traffic measurement statistics, Wi-Fi has experienced peaks correlated with increased telecommuting (see Graphic 2).

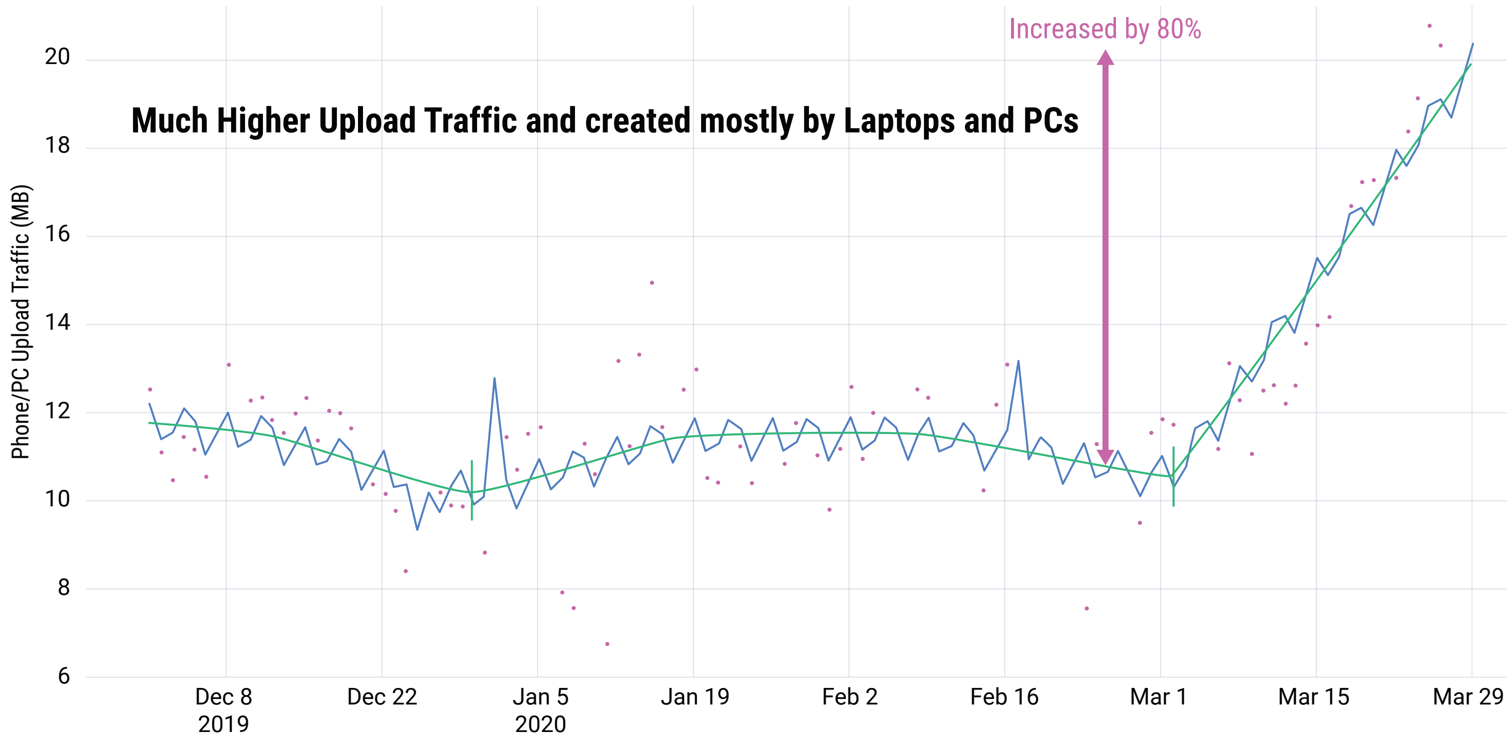
Graphic 2. Wi-Fi Link Activity Throughout the Day Before and After COVID-19 (Active Link Minutes)



Source: Vercammen and Delbar (2020)

As depicted in Graphic 3, data collected from 125 million Wi-Fi routers around the world show an 80% increase in PC uploads to cloud computing and document sharing through Dropbox, OneDrive, and SharePoint.

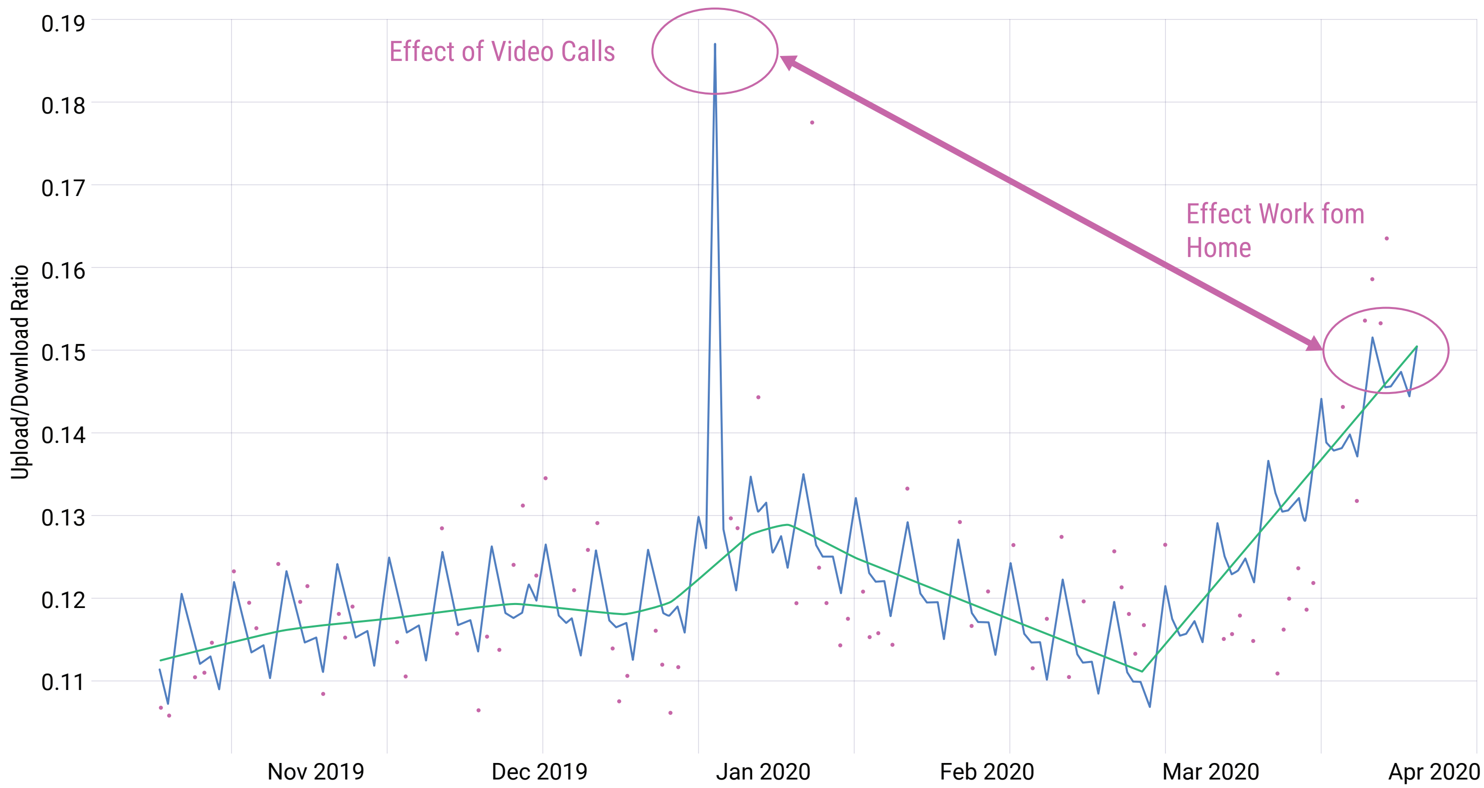
Graphic 3. Global Wi-Fi Traffic Growth (December 2019 – April 2020)



Source: Gil (2020)

Beyond this change in daily traffic distribution, Wi-Fi use peaked due to the use of bandwidth intensive applications. Graphic 4 shows an upward trend and peaks in the ratio of upload/download driven by videocalls, since the end of March 2020.

Graphic 4. Global Wi-Fi Traffic Growth (December 2019 – April 2020)



Note: The December peak of video calls is driven by holiday traffic.
Source: Gil (2020)

The COVID-induced lockdown resulted in increased reliance on broadband and related ICT services. The NCTA (2020) reported that fixed downstream broadband use increased 20.1% in March 2020, while upstream use increased 27.7%. Verizon (2020) reported a ten-fold increase in its customers' reliance on collaboration tools, a doubling use of gaming platforms, 40% increase in virtual private networks, 33% growth in video usage, and 24% increase in web browsing, all these relative to pre-pandemic levels. In light of these dramatic changes, broadband networks were up to the challenge. BITAG (2021) analyzed the network performance in the United States during 2020, concluding that despite unparalleled and rapid changes in traffic demands, the internet has performed well, proving to be resilient and reliable. They argue that the open and interoperable standards, a competent technical and operational execution, the network capacity upgrades conducted during the pandemic, plus the significant long-term investments are some of the reasons explaining this resiliency.

Considering the descriptive evidence presented above, we should expect that more connected societies will exhibit higher economic resiliency in the case of a pandemic disruption. This will be explored through an econometric approach.

4. THEORETICAL MODEL AND DATASET

The empirical model to estimate the impact of broadband on regional output in the United States is based on an augmented Solow (1956) framework, where economies produce according to a Cobb-Douglas production function with various input factors:[10]

$$GDP_{it} = A_{it} K_{it}^{\alpha} L_{it}^{\beta} HK_{it}^{\gamma} \tag{1}$$

where represents Gross Domestic Product, K is the non-telecom physical capital stock, L is labor and HK denotes human capital, approximated as, $HK = e^{hk}$ where hk reflects the efficiency of a unit of labor, as in Hall and Jones (1999). Subscripts i and t denote respectively states and time periods (the model will be estimated for period 2016-2020). The term A represents Total Factor Productivity (TFP), which reflects differences in production efficiency across states over time. TFP is expressed as:

$$A_{it} = \Omega_i BB_{it}^{\Phi + \delta SPEED_{it}} \tag{2}$$

Therefore, TFP is assumed to depend on some state-specific characteristics, represented by the fixed effect Ω_i, a term reflecting time invariant idiosyncratic productivity effects, which may make some US states more productive *per se* because of unobserved characteristics. As it is supposed that internet connectivity contributes to increase productivity, A is assumed to depend positively on the level of broadband adoption, denoted by BB. Thus we expect a positive value for Φ, indicating the economic gains derived from broadband. Another important aspect that could shape the impact of broadband on state-level productivity is the existence of differentials in the quality of connections. To approximate quality, following Rohman and Bohlin (2013), the measure we use is the download speed of connections within each state. The moderating effect of the quality of connections in a state is hypothesized to be positive, i.e., $\delta > 0$. In other words, for two US states with the same relative number of broadband connections, we expect to observe a larger economic impact for the region with the higher speed.

Inserting equation [2] in [1], we obtain:

$$GDP_{it} = \Omega_i BB_{it}^{\Phi + \delta SPEED_{it}} K_{it}^{\alpha} L_{it}^{\beta} HK_{it}^{\gamma}$$

[10] This model was used by a previous study of Jung and López-Bazo (2020) to assess the impact of broadband on economic performance for a sample of Brazilian states.

Applying logarithms for linearization, and after some rearrangements, we get:

$$log\ (GDP_{it}) = \ \mu_i + \alpha\ log\ (K_{it})\ + \beta log\ (L_{it}) + \gamma hk_{it} + \Phi log\ (BB_{it}) + \delta SPEED_{it} log\ (BB_{it})$$

Where $\mu i{=}log\ (\Omega i)$ is a state-level fixed effect. Thus, we understand that the evolution of GDP depends on specific unobserved state-characteristics, on physical capital stock, on labor, on broadband adoption and on the speed of the connections. This model is appropriate to consider the effect of broadband on GDP under normal circumstances but is still incomplete to account for the role of this technology in mitigating the economic loses in a COVID-19 context. To consider the incidence of the COVID-19 on economic output, we add, on the right-hand side, indicators to account for the degree of propagation of the disease, with the assumption that the more the pandemic has propagated and the stricter the isolation measures to combat it, the larger is the expected economic damage. To account for the role of broadband in counteracting the economic effects generated by the pandemic, we add interaction variables between broadband connectivity and the COVID-related indicators.

As a result, by introducing the COVID-related indicators (denoted generically as COVID) and the interaction variables, the transformed equation is represented as:

$$log\ (GDP_{it}) = \ \mu_i + \alpha\ log\ (K_{it})\ + \beta log\ (L_{it}) + \gamma hk_{it} + \Phi log\ (BB_{it}) + \delta SPEED_{it} log\ (BB_{it}) + ɲ(COVID_{it}) + \zeta (COVID_{it})\ log\ (BB_{it}) \qquad [3]$$

In this equation, we expect the parameter associated with COVID to present a negative sign, given that the larger the incidence of the disease, the worse economic outcome, then $ɲ{<}0$. As for broadband, its economic effect under “normal circumstances” is absorbed by the parameters Φ and δ, while its effect in mitigating the pandemic crisis is captured by ζ.

In order to correctly interpret the signs of $ɲ$ and ζ, it is useful to differentiate equation [3] with respect to the COVID variable:

$$\frac{\partial log(GDP)}{\partial (COVID)} = ɲ + \zeta log\ (BB) \qquad [4]$$

As long as $ɲ{+}\zeta log\ (BB)\ {<}0$, an increase in the COVID propagation will generate a larger contraction of the GDP. However, we also expect that the more connected US states will be better prepared to mitigate part of the economic damage, and thus, result in a lower economic contraction. Because of this, the signs expected for both coefficients are the following: $ɲ{<}0$ and $\zeta{>}0$, being $ɲ{+}\zeta log\ (BB)\ {<}0$ as the mitigating role for broadband should be partial, not total. The econometric analysis to be conducted will aim to identify if the parameters behave as expected above. First, we need to determine the variable to be used to account for COVID propagation. For this, we rely on two main variables. We identified two channels through which the virus can lead to changes in production and consumption routines, and thus, to generate a negative economic effect. First, we consider an indicator of the number of deaths attributed to the disease for every 100,000 inhabitants, based on data provided by the Center for Disease Control and Prevention. These data indicate important differences by state, ranging from 22.5 (Vermont) to 205 (New Jersey) in 2020. This metric should be more reliable than, the infections ratio (more prone to reflect differences by state in terms of testing strategies), although there is still the risk of some misreporting of deaths if officially recorded as a result of other reasons. The second variable captures specifically the normative channel, linked to the restrictions imposed in terms of home confinement, closure of offices, shops, and schools, among others. This is measured through the average level of *Stringency Index* during 2020. Policy responses have varied significantly by state, from the strictest (New Mexico) to the lightest (South Dakota). Adding other policy-related variables, such as the share of vaccinated population, is not possible, as our data set extends only through the end of 2020, when vaccines were not yet available (the first vaccine in the US was administered in mid-December of that year).

Table 3 provides the description, sources and main statistics related to both variables[11]. Naturally, as the model will be estimated for a 2016-2020 panel, the COVID variables will take a value of zero for years before 2020, as there were no COVID deaths or lockdown restrictions imposed.

Table 3. Variables for COVID-19 analysis

Code	Description	Mean	Obs.	Source
COVID Deaths	Deaths by COVID every 100,000 inhabitants	20.935 [45.995]	245	Centers for Disease Control and Prevention
Stringency Index	Composite measure based on nine response indicators including school closures, workplace closures, and travel bans, rescaled to a value from 0 to 100 (100 = strictest).	10.265 [20.716]	245	Our World in Data

Source: Telecom Advisory Services analysis

Lastly, it is important to remember that a panel estimation allows for controlling for fixed effects. If the state characteristics related to potential measurement differences and exposure to the virus are time-invariant, these differences will be absorbed by the fixed-effects.

To control for potential endogeneity between GDP and broadband variables, equation [3] will be estimated in the context of a structural multi-equation model, as other authors have previously done (Roller and Waverman, 2001; Koutroumpis, 2009; Katz and Callorda, 2018).

[11] We also tested other variables to control for the links of a state with other countries, as that might make some states more exposed to the virus. First, we tested a dummy variable indicating if the state has a land border with another country (Canada or Mexico), interacted with a 2020 dummy; and also, considered a variable measuring the number of international passengers in each state's airports. Neither variable was found to be significant in the estimates conducted, being both discarded as a result.

Following Koutroumpis (2009), a 4-equation model, as depicted in Table 4.

Table 4. System of equations for the structural model

Aggregate production equation	$GDP_{it} = f(K_{it}, L_{it}, HK_{it}, BB_{it}, SPEED_{it}, COVID_{it})$
Demand equation	$BB_{it} = h(GDPpc_{it}, P_{it}, HK_{it}, URBAN_{it})$
Supply equation	$REVENUE_{it} = g(P_{it}, COMPETITION_{it})$
Broadband infrastructure production equation	$BB_{it} - BB_{it-1} = k(REVENUE_{it})$

Source: Telecom Advisory Services analysis

The aggregate production function is the same as that presented in equation [3]. The demand equation endogenizes broadband penetration, stating that it is a function of income (GDP per capita), the price of the service, education level (HK), and the percentage of the population that lives in densely populated areas (URBAN). The supply equation links the industry output with prices and a measure of the number of fixed providers in a market (number of operators for every 100,000 inhabitants). In our case, we will proxy sectoral output with revenue, rather than investment as done by Koutroumpis (2009). The reason is that there is not a reliable state-level broadband CAPEX series estimate for the US covering the considered period. Finally, the infrastructure production equation states that the annual change in broadband penetration is a function of the industry revenue[12].

In sum, as stated by Koutroumpis (2009), this system of equations effectively endogenizes broadband infrastructure[13] because they involve the supply and demand of broadband infrastructure. All equations include state-level fixed effects, and the empirical approach followed is three-stage least squares (3SLS) simultaneous equation estimate.

The description of the variables to be considered in the model is presented in the Appendix.

[12] Koutroumpis (2009) also adds R&D intensity and regulation (local loop unbundling) as determinants in the demand and supply equations, respectively. However, we understand that those regressors are suitable to explain demand and supply patterns in a cross-country context, but not for regional analysis as ours, as R&D is not necessarily a suitable indicator for regional disparities and regulation is much more uniform within the country.

[13] However, speed differentials remain exogenous, as the Koutroumpis (2009) framework does not account for it.

5. ESTIMATION RESULTS

In this section we present the econometric estimates for the model depicted in the previous section. We gradually consider the COVID-related variables presented in Table 3, and its interactions with broadband, in order to see how GDP is affected in each case. The results pointed below are consistent in suggesting the negative economic effects of an increase in both pandemic deaths and *Stringency Index*, while at the same time they highlight the role of broadband in counteracting that economic damage.

Table 5 summarizes the econometric results for the structural model. In column (i) we present a baseline model without including the COVID-related variables, with results showing the expected coefficients and signs. GDP depends positively on capital and labor. In addition, broadband has a positive effect on GDP, which is further increased with the availability of high-speed connections. In column (ii), the estimate introduces both pandemic deaths and *Stringency Index* as regressors, without interacting them with broadband. The coefficient estimate on pandemic deaths is interpreted as the percentage of GDP variation after an increase in one unit in the quantity of COVID deaths per 100,000 population. As expected, pandemic deaths have a negative and significant coefficient, highlighting the damage caused by the pandemic to the economy. This means that an increase in one death per 100,000 population is associated to a GDP contraction of -0.01%. In turn, the coefficient of the *Stringency Index* is interpreted as the percentage change in GDP after an increase in one unit in the tightenness of the restrictions. The *Stringency Index* also exhibits a negative and significant coefficient (at 10% level). This means that, as expected, the stricter the lockdowns, the worse the economic performance. In column (iii), we add the interaction between pandemic deaths and broadband. The interaction variable is positive and highly significant, thereby confirming our hypothesis that robust fixed broadband connectivity helped to mitigate economic damages during the first year of the pandemic in the United States. Note that in column (iii) the *Stringency* variable loses significance. This is because it is highly correlated with the pandemic deaths variable, since it is effectively capturing the economic effects from the pandemic. In short, results from column (iii) indicate that **an increase in pandemic deaths negatively affects economic performance, but that the economic contraction is mitigated through high connectivity levels**. This means that, for two states facing a similar death rate, we expect, *ceteris paribus*, that the better connected state will be less affected by lower economic damage, due its ability to keep the economy running as a result of higher broadband adoption. Next, in column (iv) we consider the *Stringency Index* as the only interaction with broadband. Again, the role of broadband is crucial in mitigating the economic damage, as the interaction variable presents a positive and significant coefficient. In this case, the deaths variable loses significance, as the *Stringency Index* captures most of the economic effects from the pandemic.

Table 5. Economic Impact of Broadband – Structural model (2016-2020)

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Dep. variable: *log(GDP)*						
log(K)	0.3989***	0.5029***	0.4575***	0.4520***	0.4327***	0.4275***
	[0.0323]	[0.0408]	[0.0416]	[0.0415]	[0.0410]	[0.0409]
log(L)	0.6063***	0.3153***	0.3723***	0.3803***	0.3748***	0.3823***
	[0.0381]	[0.0770]	[0.0773]	[0.0772]	[0.0753]	[0.0752]
HK	-0.0003	0.0009	-0.0003	-0.0005	0.0009	0.0007
	[0.0014]	[0.0014]	[0.0014]	[0.0015]	[0.0015]	[0.0015]
log(BB)	0.1387***	0.1281***	0.1505***	0.1524***	0.1570***	0.1587***
	[0.0146]	[0.0138]	[0.0146]	[0.0146]	[0.0144]	[0.0144]
*log(BB)*Speed>850*	0.0020***	0.0020***	0.0017***	0.0017***	0.0016**	0.0016**
	[0.0007]	[0.0007]	[0.0007]	[0.0006]	[0.0006]	[0.0006]
Pandemic deaths		-0.0001***	-0.0014***	-0.0001	-0.0014***	-0.0001*
		[0.0000]	[0.0003]	[0.0000]	[0.0003]	[0.0001]
Stringency Index		-0.0003*	-0.0002	-0.0042***	-0.0002	-0.0041***
		[0.000]	[0.0001]	[0.0009]	[0.0002]	[0.0009]
Pandemic deaths log(BB)*			0.0003***		0.0003***	
			[0.0001]		[0.0001]	
*Sringency Index*log(BB)*				0.0009***		0.0009***
				[0.0002]		[0.0002]
Dep. variable: *log(BB)*						
log(P)	-0.0696*	-0.0687*	-0.0494	-0.0446	-0.0362	-0.0314
	[0.0378]	[0.0378]	[0.0363]	[0.0363]	[0.0354]	[0.0354]
log(HK)	0.9870***	0.9687***	0.9571***	0.9639***	0.2485	0.2577
	[0.3231]	[0.3228]	[0.3198]	[0.3195]	[0.3726]	[0.3724]

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
log(GDP pc)	2.0219***	1.9330***	2.0215***	2.0181***	2.3143***	2.3082***
	[0.1852]	[0.1877]	[0.1847]	[0.1844]	[0.1939]	[0.1935]
log(URBAN)	3.7088***	4.5730***	4.0799***	4.1248***	3.1266**	3.1858**
	[1.3108]	[1.3288]	[1.2841]	[1.2786]	[1.2772]	[1.2711]
Pandemic deaths					0.0005	0.0005
					[0.0003]	[0.0003]
Stringency Index					0.0002	0.0002
					[0.0001]	[0.0007]
Dep. variable: *log(REVENUE)*						
log(P)	0.3723***	0.3679***	0.3706***	0.3672***	0.3714***	0.3682***
	[0.0678]	[0.0679]	[0.0678]	[0.0679]	[0.0678]	[0.0679]
Operators	0.0764	0.0787	0.0730	0.0727	0.0801	0.0798
	[0.0717]	[0.0715]	[0.0715]	[0.0714]	[0.0716]	[0.0715]
Dep. variable: $log\left[\frac{BB_t}{BB_{t-1}}\right]$						
log(REVENUE)	-0.2953***	-0.2882***	-0.2923***	-0.2986***	-0.2923***	-0.2996***
	[0.0598]	[0.0592]	[0.0593]	[0.0592]	[0.0593]	[0.0592]
Dep. variable						
Fixed effects by State $^{(x)}$	YES	YES	YES	YES	YES	YES
Observations	219	219	219	219	219	219
Estimation method	3SLS	3SLS	3SLS	3SLS	3SLS	3SLS

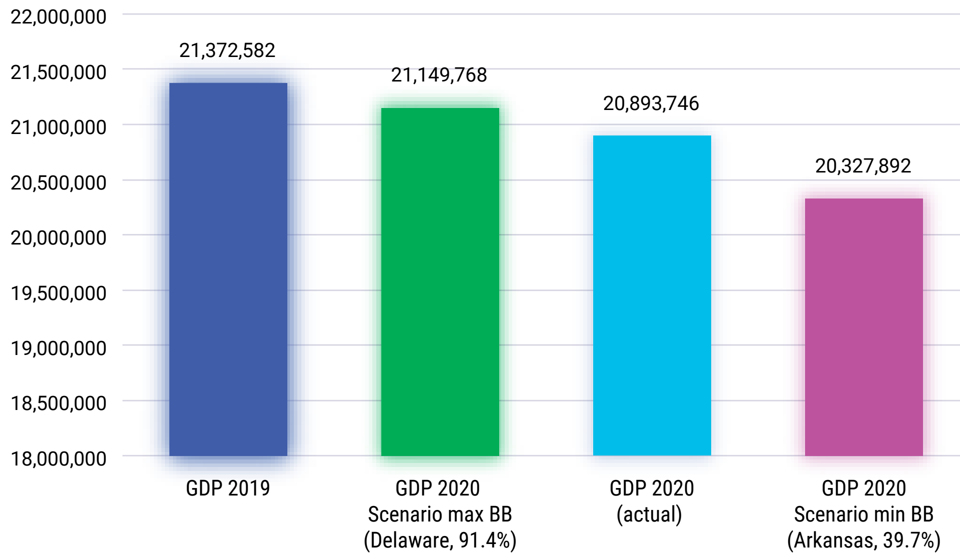
*Note: Standard errors in parenthesis. *p<10%, **p<5%, ***p<1%. $^{(x)}$ State-level fixed effects included in all model equations.*
Source: Telecom Advisory Services analysis

The previous estimates consider a baseline specification for the secondary equations, as represented in Table 4 above. However, the pandemic may have also impacted some of the terms of those equations. In particular, broadband demand may have also been influenced by the pandemic. Neglecting that possibility may have resulte in a biased estimate of broadband through the demand equation, affecting the results of the system. In order to check that concern, we replicate the previous estimates by incorporating the COVID-related variables as determinants of broadband demand. The results, presented in columns (v) and (vi), show a non significant effect from both COVID variables in the demand equation, with no substantial changes arising in the main equation.

From all the estimates reported in Table 5, it seems clear that both the pandemic-deaths and *Stringency Index* variables present overlapping information, as one loses significance every time we interact it with the other one. As a result, we will select only one of both COVID-variables to pursue the analysis. We believe that the more suited to explain the virus impact is the *Stringency Index,* because it measures aspects that directly affect the daily economic activity (in terms of imposed restrictions), rather than the deaths variable, which can be interpreted as to have an indirect role. In other words: it is not the deaths *per se* that drive the economic recession, it is the "lockdown" decision taken as a consequence. Therefore, we continue our analysis relying on the estimated coefficients from the specification presented in column (vi): $\eta = -0.0041$ and $\zeta = 0.0009$.

With the estimated coefficients, we can calculate the 2020 growth rate attributed exclusively to the restrictions imposed, which depends on the level of penetration, as seen above in equation [4]. With this information, we can simulate the GDP change according to two different scenarios of broadband penetration: that of the state with the highest broadband adoption (Delaware, 91.4%) and that with the lowest broadband adoption (Arkansas, 39.7%). Results are presented in Graphic 5 next to the actual values for 2019 and 2020 GDP. On a national level, if the United States broadband adoption was that of Delaware (rather than the current 70.5%), the GDP would have contracted only by 1% in 2020 a much lighter recession than the actual 2.2% contraction. Conversely, had broadband been below current levels, the GDP contraction would have been much more severe.

Graphic 5. National evolution of GDP by Broadband scenarios



Source: Telecom Advisory Services analysis

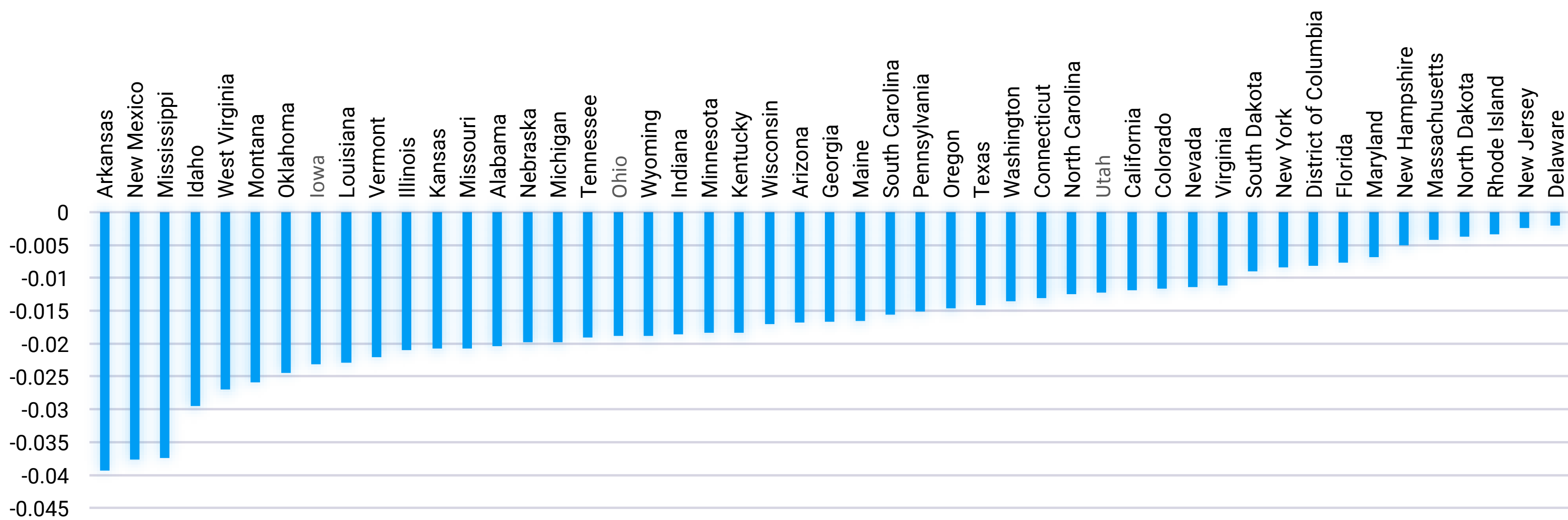
Next, we calculate the elasticity of GDP with respect to lockdown intensity, as a function of the *Stringency Index* and broadband penetration. Elasticity is an economic concept that measures the change in a variable resulting from a change in another indicator. In this case, we measure the sensitivity of GDP to a variation in the *Stringency Index*. Thus, the elasticity to be estimated has to be interpreted as how much the GDP will be contracted if governments decided to tighten up restrictions by 1%. By applying the estimated coefficients to equation [4], we are able to derive an estimate of the elasticity between lockdown intensity and GDP:

$$\varepsilon_{(GDP,\ STRINGENCY)} = (-0.0041 + 0.0009\ log\ (BB)\ ) * (Stringency\ Index)$$

The elasticity level in this equation depends both on broadband penetration and the *Stringency Index*. Using the average lockdown intensity and the national-level broadband penetration in 2020, we estimate a national elasticity of -0.014. This means that an increase in the strength of the restrictions by 1% above 2020 levels will result in a GDP contraction of 0.014%.

Graphic 6 presents the elasticity calculations by state, using in each case their respective *Stringency Index* and broadband penetration. This elasticity can be thought of as a measure of how much a state's GDP was negatively affected by an increase in the *Stringency Index*. The larger elasticity (in absolute terms) is that of Arkansas, where an increase in 1% in the *Stringency Index* reduces GDP by 0.039%. On the other end of the distribution, the states that are less sensitive to lockdown intensity are those of the Northeast (Delaware, New Jersey, Rhode Island), possibly because of being those with larger broadband adoption.

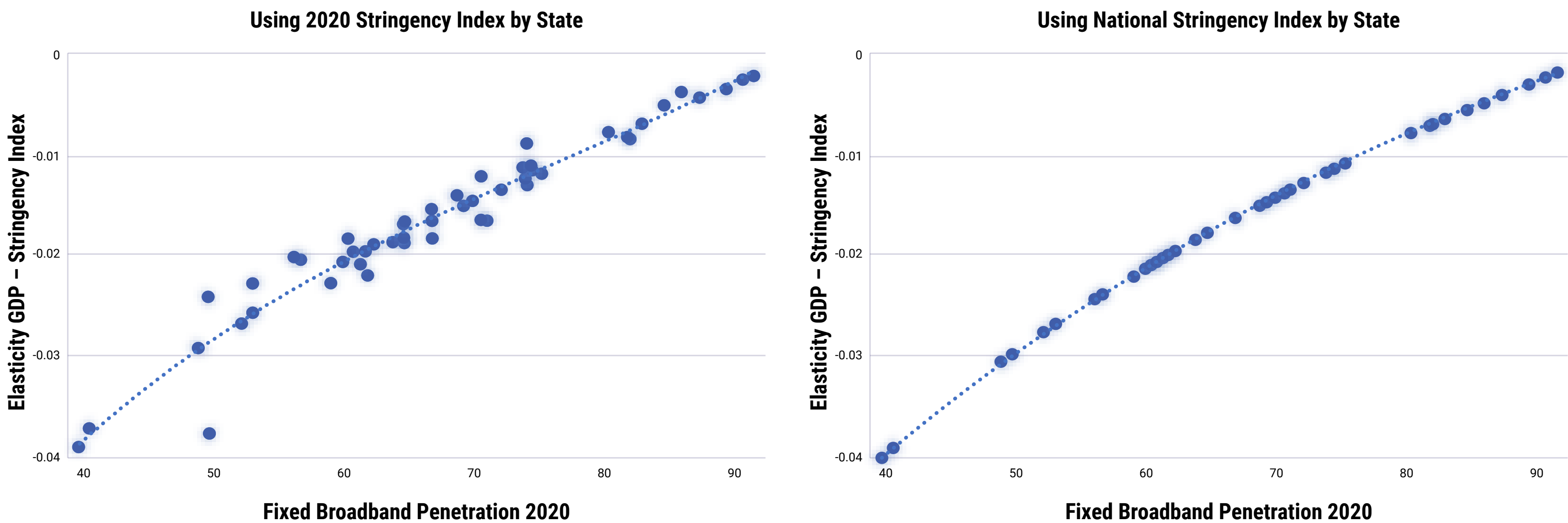
Graphic 6. Elasticity GDP – Stringency Index



Source: Telecom Advisory Services analysis

In Graphic 7 we plot the elasticities by state against fixed broadband penetration levels. In the graphic of the left, the elasticity calculation is plotted against the actual (real) 2020 *Stringency Index* by state. In the graphic on the right, we replicate the calculation but leaving constant the *Stringency Index* across states (using the national average) to isolate the specific differences in elasticity attributed to broadband penetration levels. What this shows is that in states with higher broadband penetration, the lower the economic damage as a result of increasing lockdown intensity above 2020 levels.

Graphic 7. Elasticity GDP – Stringency Index by level of BB penetration



Source: Telecom Advisory Services analysis

6. CONCLUSIONS

The COVID-19 pandemic has raised a fundamental challenge to the global socio-economic system, forcing countries to reexamine social practices and production systems, and generating a severe global economic recession. This study has researched the extent to which fixed broadband networks mitigated the negative economic impact generated by the pandemic in the United States.

Results support the position that US states with higher broadband adoption were able to counteract a larger portion of the economic losses caused by the 2020 COVID-19 pandemic than states with lower broadband adoption. The states most affected by the pandemic were those exhibiting lower broadband penetration rates. Conversely, states with higher broadband penetration, such as Delaware or New Jersey, were able to mitigate a large portion of loses, as the connectivity levels allowed for important parts of the economy to continue functioning during lockdowns. At the national level, if the United States penetration figures were those of the more connected state, the GDP would have contracted only 1% in 2020 because of the virus -a much softer recession than the actual 2.2%.

In conclusion, the pandemic highlighted the critical need to close the digital divide and to ensure everyone can adopt a high-quality internet connection in the United States. Today, wide penetration rate disparities exist between states – such as Delaware's rate of 91.4% compared to Arkansas's rate of 39.7%. Because of this, public authorities should focus on creating policy frameworks that allow operators to spur infrastructure deployments and to find the optimal technological mixes to deliver the highest performance to the users.

BIBLIOGRAPHY

Arvin, M., and Pradhan, R. (2014). Broadband penetration and economic growth nexus: evidence from cross-country panel data. *Journal of Applied Economics*, 46 (35).

Biancone, P., Secinaro, S., Marseglia, R., & Calandra, D. (2021). E-health for the future. Managerial perspectives using a multiple case study approach. *Technovation*, 102406.

BITAG (2021). 2020 Pandemic Network Performance. Broadband Internet Technical Advisory Group.

Cao, J., Liu, F., Shang, M., & Zhou, X. (2021). Toward street vending in post COVID-19 China: Social networking services information overload and switching intention. *Technology in Society*, 66, 101669.

Chamola, V., Hassija, V., Gupta, V. & Guizani, M. (2020). "A Comprehensive Review of the COVID-19 Pandemic and the Role of IoT, Drones, AI, Blockchain, and 5G in Managing its Impact". *IEEE Access* (8): 90225-90265.

Chi, N. T. K. (2021). Innovation capability: The impact of e-CRM and COVID-19 risk perception. *Technology in Society*, 67, 101725.

Fornefeld, M., Delaunay, G., & Elixmann, D. (2008). The impact of broadband on growth and productivity. *European Commission (DG Information Society and Media), MICUS.*

Gil, T. (2020). Lockdown effect on home Wi-Fi: "New normal is Christmas Day level", *Wi-Fi Now* (March 30).

Hardy, A. (1980). The role of the telephone in economic development. *Telecommunications Policy*, 4 (4), 278-286.

Isley, C. and Low, S. (2022). "Broadband adoption and availability: impacts on rural employment during COVID-19", *Telecommunications Policy.* Available at: https://doi.org/10.1016/j.telpol.2022.102310.

Jensen, R. (2007). The Digital Provide: Information (Technology), Market Performance, and Welfare in the South Indian Fisheries Sector. *Quarterly Journal of Economics,* 122(3), pp. 879-924.

Jung, J., & López-Bazo, E. (2020). On the regional impact of broadband on productivity: The case of Brazil. *Telecommunications Policy*, 44(1), 101826.

Karner, J., and Onyeji, R. (2007). Telecom Private Investment and Economic Growth: the case of African and Central & East European Countries. Jonkoping International Business School.

Katz, R. L., Zenhäusern, P., and Suter, S. (2008). An evaluation of socio-economic impact of a fiber network in Switzerland. Polynomics and Telecom Advisory Services, LLC.

Katz, R., Vaterlaus, S., Zenhäusern, P., and Suter, S. (2012). "The Impact of Broadband on Jobs and the German Economy". *Intereconomics*, 45 (1), pp. 26-34.

Katz, R. and Callorda, F. (2018). The economic contribution of broadband, digitalization and ICT regulation. International Telecommunications Union.

Katz, R., Jung, J. & Callorda, F. (2020a). *The economic contribution of broadband, digitization and ICT regulation* *and Regional Econometric Modelling*. Retrieved in: https://www.itu.int/en/publications/ITU-D/pages/publications.aspx?lang=en&media=electronic&parent=D-PREF-EF.BDR-2020

Katz, R., Jung, J., & Callorda, F. (2020b). "Can digitization mitigate the economic damage of a pandemic? Evidence from SARS". *Telecommunications Policy*, *44*(10), 102044. Retrieved in: https://www.sciencedirect.com/science/article/abs/pii/S0308596120301361?via%3Dihub

Katz, R. and Jung, J. (2021). The economic impact of broadband and digitization through the COVID-19 pandemic: Econometric Modelling. Geneva: International Telecommunication Union. Available at: https://www.itu.int/dms_pub/itu-d/opb/pref/D-PREF-EF.COV_ECO_IMPACT_B-2021-PDF-E.pdf

Khatri, H. & Fenwick, S. (2020). *Analyzing mobile experience during the coronavirus pandemic: Time on Wi-Fi*. Opensignal (March 30).

Koutroumpis, P. (2009). The Economic Impact of Broadband on Growth: A Simultaneous Approach. *Telecommunications Policy*, 33, 471-485.

Kristianto, D. (2021). *Winning the attention war: consumers in nine major markets now spend more than four hours a day in Apps*. App Annie. Available at: https://www.appannie.com/en/insights/market-data/q1-2021-market-index/

Labovitz, C. (2020). Early effects of COVID-19 lockdowns on service provider networks: the networks soldier on! Available: https://www.nokia.com/blog/early-effects-covid-19-lockdowns-service-provider-networksnetworks-soldier/

Mack, E. and Faggian, A. (2013). Productivity and broadband: The human factor. *International Regional Science Review*, *36*(3), 392-423.

Massaro, M. (2021). Digital transformation in the healthcare sector through blockchain technology. Insights from academic research and business developments. *Technovation*, 102386.

NCTA. (2020). *COVID-19: How cable's internet networks are performing*. " April 1, 2020 available at: https://www.ncta.com/COVIDdashboard.

O'Reilly, G., Jrad, A., Nagarajan, R., Brown, T. and Conrad, S. (2006). Critical Infrastructure Analysis of Telecom for Natural Disasters, *Networks 2006. 12th International Telecommunications Network Strategy and Planning Symposium*, New Delhi, 1-6.

Raj, M. and Sundararajan, A. and You, C. (2021) *COVID-19 and Digital Resilience: Evidence from Uber Eats* (March 22, 2021). NYU Stern School of Business, Available at SSRN: https://ssrn.com/abstract=3625638 or http://dx.doi.org/10.2139/ssrn.3625638

Reynolds, M. (2020). *State of the Internet amid coronavirus pandemic*, S&P Global Ratings June 16

Roeller, L-E, and Waverman, L. (2001). Telecommunications Infrastructure and Economic Development: A Simultaneous Approach. *The American Economic Review*, 91 (4), 909-923.

Rohman, Bohlin, E. (2012) *Socio-economic effects of broadband speed*. Ericsson 3/221 01-FGB 101 00003.

Solow, R. (1956). A contribution to the theory of economic growth. *Quarterly Journal of Economics*, 70, 65-94.

Teodorescu HN.L. (2014) Survey of IC&T in Disaster Mitigation and Disaster Situation Management. In: Teodorescu HN., Kirschenbaum A., Cojocaru S., Bruderlein C. (eds) *Improving Disaster Resilience and Mitigation - IT Means and Tools*. NATO Science for Peace and Security Series C: Environmental Security. Springer, Dordrecht.

Tortorella, G.L., Fogliatto, F.S., Saurin, T.A., Tonetto, L.M., & McFarlane, D. (2021). Contributions of Healthcare 4.0 digital applications to the resilience of healthcare organizations during the COVID-19 outbreak. *Technovation*, 102379.

Verizon. (2020). 4/2 *Update: How Americans are spending time in the new normal*. April 2, available at: https://www.verizon.com/about/news/how-americans-are-spending-their-time-temporary-new-normal. (Accessed 2 April 2020).

APPENDIX

Table A.1. Variables and descriptive statistics

Code	Description	Mean	Obs.	Source
Main equation variables				
GDP	Gross Domestic Product in millions of current dollars	406,786.7 [507,853.3]	245	Bureau of Economic Analysis
K	Current-Cost Net Stock of Private Fixed Assets (excluding Broadcasting and Telecommunications) in billions of current dollars	931.766 [1,172.746]	245	Built with data from the Bureau of Economic Analysis
L	Total Full-Time and Part-Time Employment	3,982,840 [4,387,997]	245	Bureau of Economic Analysis
HK	Share of the population 25-64 with tertiary education	43.602 [6.574]	245	OECD Regional Statistics
BB	Fixed Broadband connections offering at least 25 Mbps down and 3 Mbps up, every 100 households	59.924 [15.232]	245	FCC Internet Access Services reports/ American Community Survey (ACS)
Speed	Average maximum available download speed (Mbps)	689.784 [231.204]	245	Technology Policy Institute
Variables for additional equations of the structural model				
Price	Average price for commercially-available residential plans offering at least 25 Mbps down	89.584 [17.010]	220	FCC
Operators	Number of fixed broadband operators every 100,000 inhabitants	2.609 [1.944]	245	FCC form 477
Revenue	Calculated as: average price*total broadband connections (in million USD)	168.460 [178.351]	227	Built from FCC and ACS data
Urban	Percentage of population living in urban areas.	0.755 [0.146]	245	U.S. Census Bureau

Source: Telecom Advisory Services analysis

NETWORK on