THE CONTRIBUTION OF BROADBAND INTERNET TO HEALTHCARE BEFORE AND DURING THE PANDEMIC

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Contents

EXECUTIVE SUMMARY

The purpose of this study is to estimate the contribution of broadband internet to healthcare in the United States. The empirical research we have conducted covers two separate time periods: (i) the contribution of broadband internet to health outcomes for a period ending in 2019; and (ii) the impact of broadband internet during the pandemic. In the first part we attempt to link broadband internet adoption to a healthier state of the population, by reducing the impact of some of the most serious diseases. In the second part we study whether the technology has contributed to promoting vaccination and telemedicine use, therefore having a positive role during the pandemic.

Our analysis of the impact of the internet on health outcomes before COVID-19 relies on a first-differenced methodology to study the impact of broadband growth on health status between 2017 and 2019. This estimation procedure is usually used to address the problem of omitted variables in econometrics. After controlling for several socioeconomic variables (such as age, unemployment, poverty, and ethnic group), the US states where fixed broadband connectivity is higher exhibit lower rates of asthma, diabetes, obesity, and occasional smoking. The results suggest that **broadband adoption has been useful in helping to alleviate some of the critical health problems faced by the American population**.

Our study of broadband internet impact during the pandemic relies on data from a survey conducted between May and June 2021 by the Centers for Disease Control, which provides information regarding the likelihood of vaccination, and vaccine hesitancy. For this purpose, we developed a Structural Equation Model (SEM) linking the direct or indirect effect of Internet access on healthcare variables.[1] We tested whether internet access can increase the likelihood of vaccination directly and indirectly through the decrease of vaccine hesitancy. Beyond this, we also test the contribution of internet to the use of telemedicine tools. Most of these effects are found to be positive and statistically significant, highlighting **a key positive role of internet on healthcare in the pandemic**. To elaborate:

- High internet use results in lower vaccine hesitancy. In other words, more information as provided through the internet reduces the concerns about vaccination.
- More importantly, higher internet use increases the likelihood of vaccination either directly or indirectly (confirming the research literature reviewed, the internet can be a useful source for health information, something that may reduce concerns about vaccination).
- Similarly, internet access increases the reliance on telemedicine, which in turn should improve the health of the population.

In summary, the evidence we generate in this study suggests that **broadband internet is having a positive effect on the health of the US population, and that this effect has been enhanced during the COVID-19 pandemic**.

From a public-policy perspective, our results reinforce the critical need of closing the connectivity gap across American households. Some of the applications and uses through which these effects occur, such as telemedicine require high-speed internet access. Considering the wide broadband penetration differences existing between states (such as Delaware's rate of 91.4% compared to Arkansas's rate of 39.7%), public authorities should focus on implementing public policies that stimulate infrastructure deployment and to find the optimal technological

[1] Structural equation modeling (SEM) is a set of statistical techniques used to measure and analyze the relationships of observed and latent variables. Similar but more powerful than regression analysis, it examines linear causal relationships among variables, while simultaneously accounting for measurement error.

mix to deliver the highest performance. In addition, public policies should also be designed to stimulate adoption levels in covered areas, something that may require pricing flexibility in the development of commercial offers, the introduction of programs to enhance digital skills of the population, and the provision of economic incentives for disadvantaged families.

1. INTRODUCTION

Broadband internet connectivity has achieved a massive increase in adoption levels in the United States in the last decade. In 2010, fixed broadband service of more than 25 Mbps download speed and 3 Mbps upload (the broadband standard defined by the FCC in 2015) had been adopted only by 0.87% of households.[2] By mid-2019, household penetration levels for that speed tier reached approximately 65.69%.[3] Furthermore, according to the International Telecommunications Union, 91% of Americans were internet users in 2020.[4] These advances have contributed to improve several socioeconomic indicators of the American society.

According to the research literature from the past twenty years, broadband internet diffusion has been identified as a key driver of economic growth (as demonstrated by Koutroumpis (2009); Czernich et al (2011); Katz et al (2012); Bertschek et al (2013); Arvin and Pradhan (2014); and Katz and Callorda (2018), among many others). However, beyond economic growth, broadband internet has also been found to be a crucial tool for improving the people's quality of life.

Among the conditions required to increase welfare, healthcare is undoubtedly one of the most important levers. As we discuss below, the internet can contribute to improved health outcomes because it is a powerful source of health-related information (on balanced diet, healthy routines, exercise, meditation, etc.). It also is an enabler of telemedicine applications that facilitate remote medical consultation, fulfill some procedures, and enable remote health monitoring. That said, empirical research linking the role of broadband internet on health outcomes[5] is relatively scarce, although some authors (such as Whitacre and Brooks (2014) for the United States, or Dutta et al (2019) for a sample of Asian countries) have been able to provide initial evidence.[6]

Our purpose in conducting this study is to estimate the contribution of the internet to healthcare in the United States. Considering the COVID-19 pandemic disruption, we have structured our empirical research to cover two separate time periods: (i) the role of broadband on health outcomes covering a period up to 2019, to address pre-pandemic conditions, and (ii) the contribution of broadband to health care in the context of the pandemic. In the first period we attempt to link broadband internet adoption to a healthier state of the population. In the second period we study whether the technology has contributed to social behaviors that helped mitigate the impact of the pandemic (for example, vaccination).

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2 Federal Communications Commission. *Internet Access Services: Status of December 31, 2010*
3 Federal Communications Commission. *Internet Access Services: Status of June 30, 2019*.
4 Source: https://datahub.itu.int/data/?e=USA&c=701&i=11624
5 Health outcome is a metric that assesses the state of health of a given population, as measured by the prevalence of certain diseases (asthma, diabetes, and the like) or life expectancy.
6 In addition, beyond the impact on health outcomes, telemedicine tools can contribute to reduce costs associated to healthcare, both from the perspective of the medical centers and that of individuals.

The study is structured as follows. In Section 2, we provide a review of the research literature associated with internet connectivity and healthcare. Section 3 contains our exploratory analysis mainly derived from the data visualization platform *Mapping Broadband Health in America* from the FCC. In Section 4, we develop the empirical analysis to study, through a first-difference specification model, the role of broadband internet on the health of the population prior to the COVID-19 pandemic in the US. In Section 5, we present an alternative model where we use a specific dataset extracted from surveys conducted by the Centers for Disease Control and Prevention (CDC) during the COVID-19 pandemic, to find out the contribution that broadband internet might have had during this emergency. Finally, in Section 6 we conclude by outlining implications.

2. RESEARCH LITERATURE REVIEW

Broadband internet can contribute to health in two ways: (i) it can directly affect health outcomes, and (ii) the technology can improve the delivery of health care. As it is obvious, both areas are interrelated: better delivery could result in improved health outcomes. However, each area has specific dimensions to be considered. For example, broadband internet provides users access to health-related information which in turn can improve the health of the population. As an example, between January and September of 2019 one in three Americans downloaded at least one "health and wellness related" app to his cell phone.[7] More health-related information should have an impact on health metrics (for example, obesity reduction).

The impact of broadband internet on health care delivery includes solutions such as telemedicine, remote monitoring, telesurgery, and the like. The contribution of this second area ranges from reduced delivery costs, enhanced access, and higher frequency of health monitoring. Higher efficiency in delivery of health care should naturally lead to better health outcomes (for example, lower heart disease incidence).

Our review of the research literature is split into two main sections. First, we review the research on the impact of internet on health of the population using connectivity tools to gain access to information and apps. Second, we expand the analysis to review studies that have analyzed the impact of using broadband in healthcare delivery.

2.1. BROADBAND INTERNET CONTRIBUTION TO HEALTH OUTCOMES THROUGH INFORMATION DELIVERY

There are two channels through which the internet can help people achieve better health outcomes: (i) provide general information contributing to overall health; (ii) facilitate access to specific data or apps related to health care.

First, the internet is a source of general information that potentially improves health and enhances healthy routines. Cline and Haynes (2001) were among the first researchers that analyzed the role of the internet for healthcare, highlighting at the time that over 50 million people sought health information online. Similarly, Kolko (2010) found that individuals with broadband access spent more time searching for health-related information, becoming better informed when compared to unconnected people. In a similar vein, Trotter and Morgan (2008) found that the number of internet users searching for health-related information increased from 36% in 2000 to 78% in 2008. Dutta et al (2019) highlighted that Information and Communication Technologies (ICT) can eliminate spatial or temporal barriers to access healthcare information with high efficiency and low cost. Specifically, the authors mention that ICT can

[7] Source: data.ai intelligence. Health and wellness apps include "Calm" (meditation), "AAPTIV" (cardio workout), "Studio: Tone it up" (yoga, kickboxing, etc.), "My Water balance" (daily drink tracker and reminder), and the like.

yield a “revolution” in terms of healthcare by improving the accessibility of information. They argue that ICT are also a tool for health promotion, which enables individuals to share the information and experiences among the population affected by a common health problem. Likewise, Whitacre and Brooks (2014) argue that searching for health information has become a common task for most internet users, as it helps them improve their understanding of health issues and allows them to take better care of themselves. The authors suggest that increased knowledge or information about health issues, the potential presence of a supportive online community or network, increased personal motivation and the increased ability to put knowledge into practice can be potential channels through which internet can positively impact health outcomes.

Second, broadband internet facilitates the delivery to the general population of specific healthcare solutions. Pandey et al (2003) found that most individuals searching for health-related information looked for material on a balanced diet, health status, and wellness including exercise and fitness. Siek et al (2021) argued that digital tools and applications are important instruments to support health information needs, highlighting solutions such as health trackers, remote monitoring devices, health apps and patient portals as drivers to improve health outcomes. In addition, information on medical centers or specialists, as well as that of health insurance plans, can be easily facilitated by the internet. Some studies analyzed the role of the internet for specific health outcomes or population segments. Among those, Fedha (2014) highlights that ICT have an important impact on the reduction of the chances of pregnant women missing clinical appointments, something that significantly reduces the infant mortality rate. Likewise, Musoke (2002) underlined the role of communication technology for providing health care to pregnant women in developing countries, as a successful tool to reduce maternal mortality rate.

As for the empirical analysis proving these effects, Whitacre and Brooks (2014) examined whether increasing levels of broadband adoption have impacted actual health outcomes in the United States. They relied on data from 92 metropolitan/micropolitan statistical areas in the US over the period 2002–2009 and incorporated a first-differenced econometric approach. Their results showed that higher rates of broadband adoption played a statistically significant role in explaining changes in 9 out of 24 health measures considered.

Dutta et al (2019) also conducted an empirical analysis, estimating the impact of ICT on the health outcomes for 30 Asian countries during the period 2000-2016. Their results suggested a positive and significant impact of ICT on health status of the population. The authors also suggested that innovative health applications can provide real-time feedback and mobilize the attendance of vaccination programs.

2.2. BROADBAND INTERNET CONTRIBUTION TO HEALTH CARE DELIVERY

Beyond being a source of information and apps, broadband internet enables health care delivery as a potential tool to increase health outcomes. The contribution has been studied in three areas: (i) impact on telemedicine, (ii) impact within the intensive care unit (ICU), and (iii) remote patient monitoring.

Within the first area, Bauerly et al (2019) established that broadband access is playing an increasingly important role in both healthcare and public health, highlighting that telemedicine is revolutionizing the delivery of health services. In turn, Snoswell et al (2020) argued that telemedicine represents an opportunity to redesign the way health care is delivered, highlighting several potential benefits, such as increased accessibility to care and the possibility of developing culturally appropriate services more suited to the needs of specific population segments.

Most authors analyzing the role of telemedicine have underlined its potential to overcome spatial barriers derived from remote location. This is the case of Dullet et al (2017), who argued that telemedicine is a model of care that can be especially useful for outpatient services when travel distance, time, and cost can be a barrier. Whitacre (2011), in turn, analyzed the role of telemedicine as a way of rural residents to take advantage of urbanized medical services. He studied a sample of 24 rural hospitals that implemented some modality of telemedicine across Arkansas, Kansas, Texas, and Oklahoma, and argued that telemedicine not only improves healthcare, but also offers significant economic contributions to local communities. Snoswell et al (2020) stated that telemedicine can provide productivity gains for health providers and patients through reduced travel and potential for cost savings.

With regards to the impact of broadband internet on the intensive care unit (ICU), Yoo et al (2016) conducted an analysis to estimate the incremental cost-effectiveness ratio of using telemedicine in the ICU, and its associated potential cost savings. Remote patient monitoring and telemedicine in the ICU is seen as an alternative to address some of the problems faced by health institutions, such as the difficulty to hire on-site internists, the limited availability of trained ones, plus the lack of financial resources. The authors conducted simulations using standard decision models and concluded that the use of telemedicine in the ICU ("tele-ICU") is cost-effective in most cases and cost saving in some cases. The base case analysis from the deterministic model projected that tele-ICU extended 0.011 quality-adjusted life years per patient with an incremental cost of $516 per patient compared with ICU without telemedicine. Consequently, tele-ICU had an estimated incremental cost-effectiveness ratio of $45,320 per quality-adjusted life year compared with ICU without telemedicine. Under this base case analysis, they consider tele-ICU to be cost-effective, as it is below their assumed threshold of $100,000 cost for an additional quality-adjusted life year. Likewise, analysis based on the use of telemedicine in the ICU, concluding that tele-ICU can extend the quality-adjusted life years per patient.

Chen et al (2017) conducted a systematic review of controlled trials or observational studies published between 2000 and 2016, intending to evaluate the impact of telemedicine programs on ICU, hospital mortality, and length of stay. They applied random-effects models to meta-analyses and sensitivity analyses. The review provided evidence that Tele-ICU programs may reduce ICU mortality, hospital mortality, and lengths of ICU stays, although they qualify the evidence as "limited".

Within the third area of impact, Bauerly et al (2019) argued that telemedicine can reduce health disparities, by bringing specialized healthcare to communities where medical services were not previously available. They focused primarily on the role of broadband to increase remote patient monitoring, as it can help patients manage chronic health conditions from home. Other potential uses of broadband are those of tele-dermatology, tele-dentistry, and tele-mentoring programs.

In turn, Dullet et al (2017) estimated travel-related and environmental savings resulting from the use of telemedicine for outpatient specialty consultations with a university telemedicine program. The analysis is based on data from the telemedicine program implemented by the University of California Davis Health System (UCDHS) between 1996 and 2013. The authors analyzed a total of 19,246 telemedicine consultations among 11,281 unique patients. They focused the analysis on the telemedicine outpatient services provided to 157 client sites located in 56 of California's 58 counties during the period. They analyzed travel savings from telemedicine in terms of both round-trip distance savings and transport cost savings (the difference between the distance traveled and costs expended from the patient's home address to the telemedicine client site and the distance traveled and the amount spent by the patient for an in-person consultation at the UCDHS). Finally, the reduction in pollution and greenhouse gas emissions was calculated from the reduction in travel distance, calculated by multiplying per-mile emissions by the travel distance savings. The authors were able to demonstrate the positive impact of a health system's outpatient telemedicine program on patient travel time, patient travel costs, and in reducing pollution. Table 1 summarizes the main study results.

Table 1. Savings due to Telemedicine estimated by Dullet et al (2017)

Item	Total savings	Savings per consultation	Savings per unique patient
Travel distance savings	5,345,602 miles	278 miles	474 miles
Travel time savings	4,708,891 minutes	245 minutes	417 minutes
Travel costs savings	$2,882,056	$156	$255
Emissions	1969 metric tons of CO2	102 kg	175 kg
	50 metric tons of CO	2.6 kg	4.4 kg
	3.7 metric tons of NOx	0.19 kg	0.33 kg
	5.5 metric tons of volatile organic compounds	0.29 kg	0.49 kg

Source: Dullet et al (2017), Telecom Advisory Services analysis

On average, travel distance savings can be quantified as 278 miles per consultation and 474 miles per patient (this is because some patients made more than one consultation). These saved miles represent time gained for patients (245 minutes per consultation, 417 minutes per patient) and cost savings ($156 and $255, respectively). Moreover, reduced transport use has been found to result in an important decrease in emissions, yielding significant environmental gains.

Xiao et al (2018) argued that home health care (facilitated by telemedicine) represents an opportunity to reduce preventable adverse events and costs following hospital discharge. The authors performed a retrospective cohort study between 2013 and 2015 at a tertiary care institution to assess healthcare utilization after discharge with home health care. Among 64,541 total patients, 11,266 controls were matched to 6,363 home health care patients across 11 disease-based Institutes. During the post-discharge year, home health care was associated with a mean unadjusted savings of $15,233 per patient. Home health care independently decreased the hazard of follow-up readmission and death.

To sum up, the research literature review suggests the following effects of broadband internet on health care:

Impact on health outcomes	Contribution to health care delivery
• Source of general information contributing to overall health • Access to specific data or apps related to health care.	• Impact on telemedicine • Impact within the intensive care unit (ICU) • Remote patient monitoring.

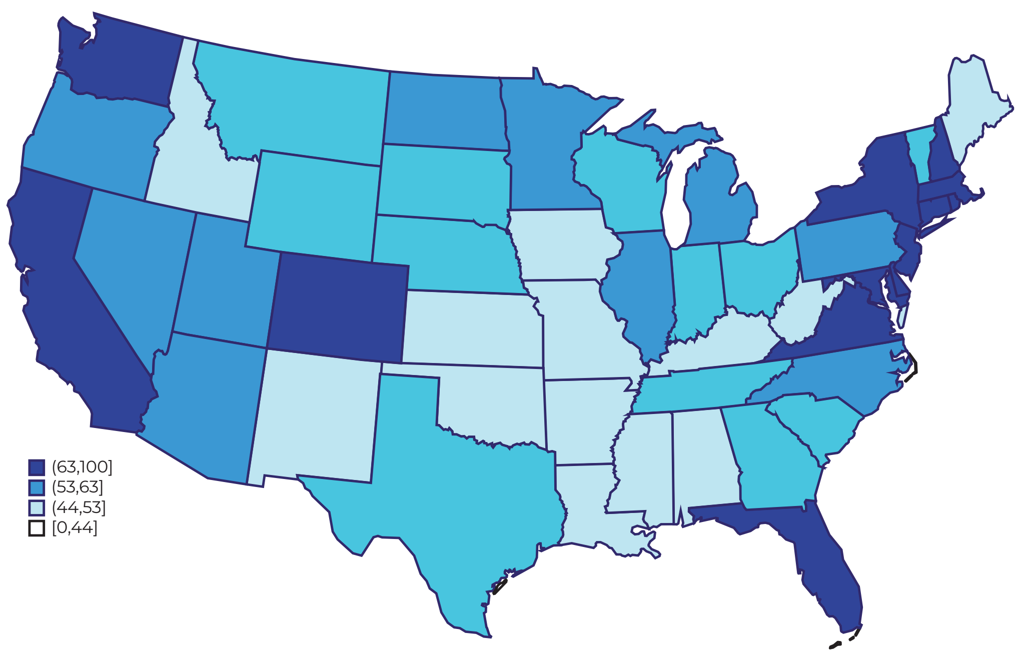
As expected, no research has been generated so far in terms of the impact of broadband under pandemic conditions.

3. EXPLORATORY DATA ANALYSIS

Our preliminary data analysis yields some initial insights regarding the correlational link between health outcomes and broadband connectivity in the United States. The data visualization platform *Mapping Broadband Health in America*,[8] developed by the FCC, allows us to compare for 2017 the spatial distribution of broadband connectivity with that of specific health measures, namely Diabetes, Obesity, Health status, Physician access, Preventable hospitalizations, and Sick days.

As a starting point, Figure 1 plots the spatial distribution of broadband connections.

Figure 1. Fixed Broadband penetration by US state (2017) (Percent households with fixed broadband connections over 25 Mbps)



Source: FCC Mapping Broadband Health in America

[8] https://www.fcc.gov/reports-research/maps/connect2health/index.html

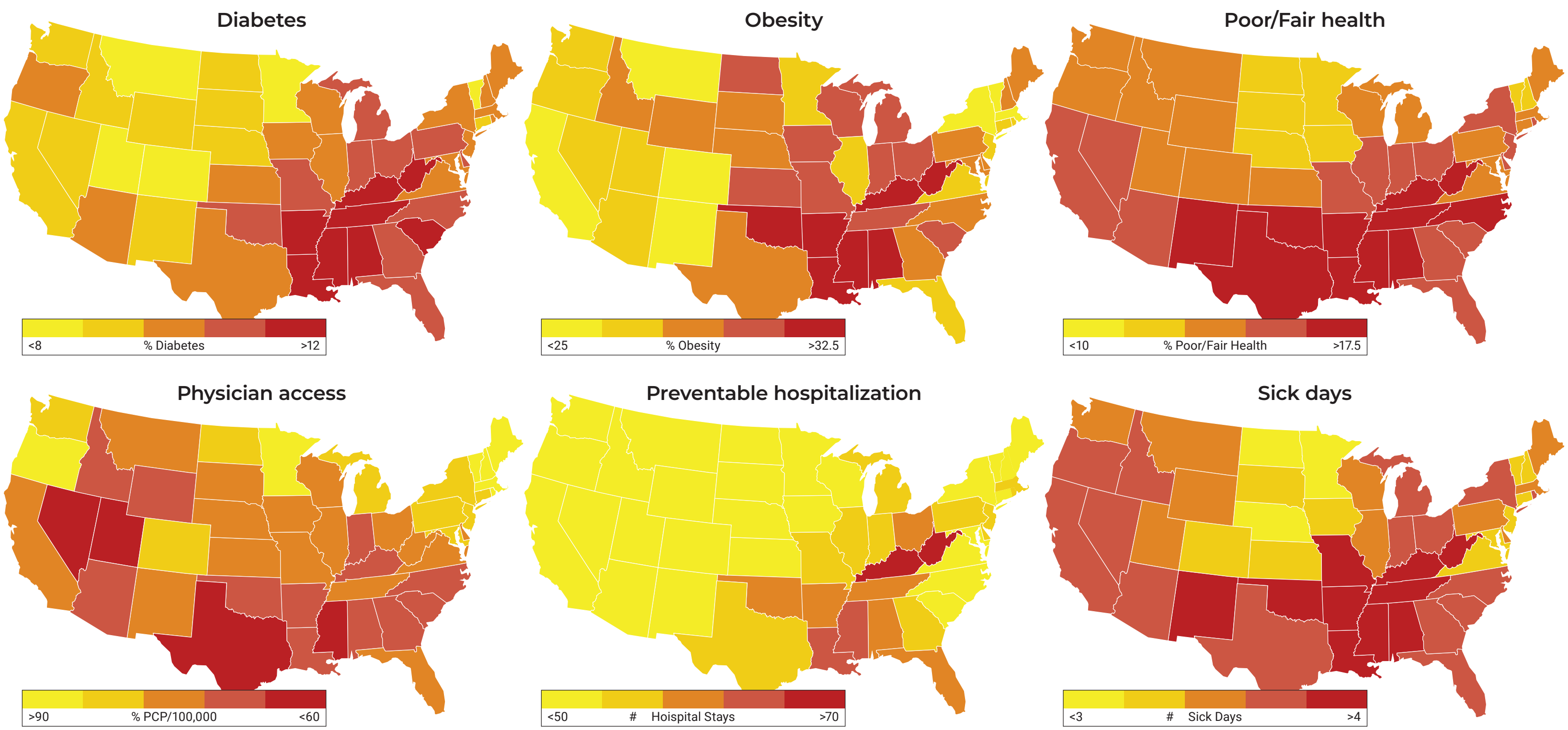
More connected states appear to be those situated in the east and west coasts of the country, with some exceptions such as Colorado or Utah.

Next, we analyze the data for some specific health outcomes by state, defined as follows:

- Diabetes, defined as the percentage of adults reporting this condition
- Obesity, defined as the percentage of adults that report a body mass index of 30 or more
- Physician access, defined as primary care physicians per 100,000 people
- Poor / Fair health, defined as the percentage of adults self-reporting fair or poor health (age-adjusted)
- Preventable hospitalization, defined as the number of preventable hospitals stays per 1,000 people
- Sick days, defined as the average number of physically unhealthy days reported in the past 30 days (age-adjusted)

Averages by state for each metric are presented in Figure 2.

Figure 2. Selected health outcomes

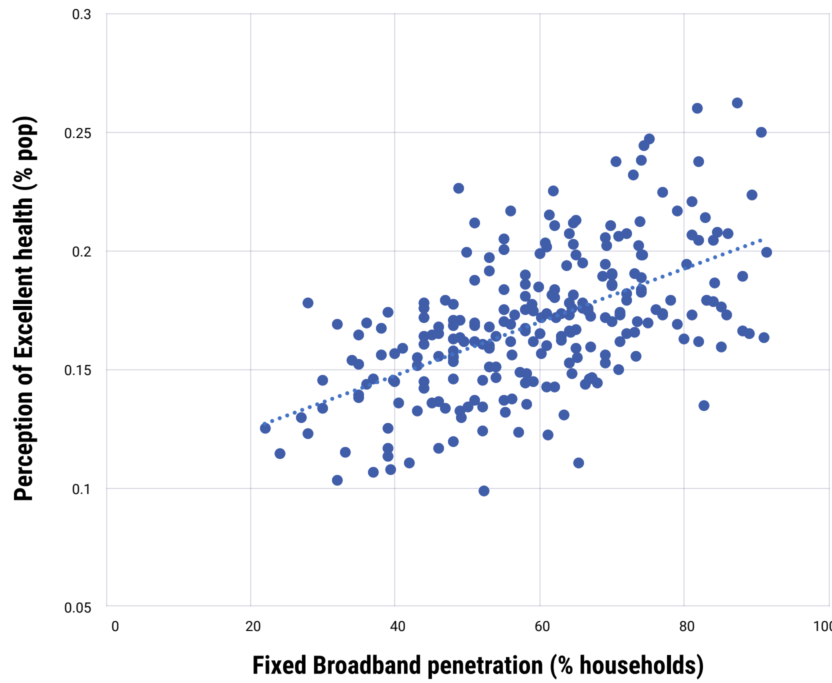


Source: FCC Mapping Broadband Health in America

States with poorest health indicators are typically those located in the south, such as Mississippi, Alabama, Louisiana, Arkansas, or Oklahoma. At the same time, these are usually the states with lower broadband penetration. All other factors being equal, higher broadband penetration is associated with better health indicators., and vice versa. That said, important exceptions exist. For example, while California or Nevada exhibit high broadband penetration, some of their health indicators (share of people with poor or fair health, the number of sick days, and for the case of Nevada only, the physician access) still lag. Similarly, some well-connected northeastern states as Maine or New-Hampshire exhibit poor indicators in diabetes and obesity.

However, if we use a different dataset that covers the period of 2016-2020 and develop a scatterplot linking broadband penetration (for connections above 25 Mbps) and self-reported perception of excellent health[9], a positive correlation emerges (Figure 3).

Figure 3. Fixed Broadband penetration and Health perception by state



Source: FCC, CDC surveys, Telecom Advisory Services analysis

To sum up, the descriptive evidence points to a positive correlation between broadband internet adoption and better health outcomes, something that seems to support the evidence provided by the literature reviewed above. However, in addition to the important exceptions highlighted in Figures 1 and 2, correlation does not necessarily mean causation: for example, low health outcomes and low broadband adoption could (and certainly are) linked to socio economic factors. Therefore, it seems important to conduct an analysis that controls for the factors that may have an impact on health, beyond broadband internet adoption.

[9] In the CDC surveys, one of the questions is: Would you say your health in general is excellent, very good, good, fair, or poor? For this indicator, we take those answering to perceive they have an excellent health.

4. THE IMPACT OF BROADBAND INTERNET ON HEALTHCARE BEFORE THE PANDEMIC

The following analysis examines the role of broadband internet on health outcomes covering a period between 2016 and 2019. In doing so, we attempt to link broadband internet adoption to a healthier state of the population.

4.1. THEORETICAL FRAMEWORK AND METHODOLOGY

Following the research by Whitacre and Brooks (2014), we propose a first-differenced model to assess the relationship between broadband adoption and health outcomes. The authors argued that contrary to a cross-sectional model, using first differences allowed them to rely on a model containing the *change* in health outcomes as the dependent variable and the *change* in broadband, and other socioeconomic characteristics, as explanatory variables. In addition, as these authors point out, we use this approach because it has the advantages of eliminating any potential bias in the results from unobserved factors that do not vary over time and lessening the effect of potential bias from reporting errors that persist over time.

Thus, the model to be estimated can be represented as follows:

$$\Delta\ HEALTH_{it} = \beta_0 + \beta_1\ \Delta\ X_{it} + \beta_2 \Delta\ BB_{it} + \varepsilon_{it}$$

Where *HEALTH* is the dependent variable, *X* is a vector of socioeconomic controls, and BB is broadband penetration; while on the other hand Δ indicates we are using the difference in these measures. The parameter of interest is β_2, which will show us whether broadband adoption growth results in better health. As for *HEALTH* outcomes, we selected a set of variables from the state-based Behavioral Risk Factor Surveillance System (BRFSS) survey conducted by the Centers for Disease Control and Prevention (CDC) since 1984[10]. The survey is used to collect prevalence data among adult U.S. residents regarding their risk behaviors and preventive health practices that can affect their health status. Respondent data are forwarded to CDC to be aggregated for each state, returned with standard tabulations, and published at year's end by each state. The CDC conducts these surveys annually, with the sample typically composed of approximately 400,000 individuals at the national level. While we would have liked to perform an empirical estimate at the individual level, we were unable to do so as the survey does not include individual indicators of broadband access and use. As a result, we transformed the dataset into state-level averages, for which broadband (and several other control variables) are available.

Table 2 summarizes the descriptive statistics for the health outcome variables selected, with averages and standard deviations corresponding to state-level data for the period 2016-2019. The data sample includes 48 states and the District of Columbia. This means that we have excluded from the analysis the states of Alaska and Hawaii for which there is no complete information on the broadband variable.

[10] https://www.cdc.gov/brfss/data_documentation/index.htm

Table 2. Descriptive statistics for selected health variables (2016-2019)

Variable	Description	Mean [Std. Dv]
Asthma	Respondents who have been told by a doctor, nurse or health professional that they had asthma and that they still have it.	9.582% [0.011]
Pneumonia	Respondents aged 65 or older who reported having a pneumonia shot.	74.941% [0.030]
Diabetes	Respondents ever told to have diabetes	14.581% [0.026]
Heavy drink	Adult men having more than 14 drinks per week and adult women having more than 7 drinks per week.	5.945% [0.012]
Everyday smoke	Respondents who reported having smoked at least 100 cigarettes in their lifetime and now smoke every day.	10.628% [0.023]
Someday smoke	Respondents who reported having smoked at least 100 cigarettes in their lifetime and now smoke some days.	4.333% [0.007]
Obesity	Respondents classified as overweight or obese based on body mass index.	31.702% [0.037]

Source: CDC Annual Survey Data

Finally, given that health outcomes are usually multicausal, a complete set of socioeconomic variables was included as controls. Following Whitacre and Brooks (2014), we included income (proxied by GDP per capita), unemployment, population, poverty, age structure, race, gender, and education. We also included as controls, indicators of health expenditure (per capita) and urbanization, as in Dutta et al (2019). We define the broadband variable as the number of fixed connections offering at least 25 Mbps download and 3 Mbps upload, per 100 households (data compiled from the Federal Communications Commission (FCC) Internet Access Services reports).

Table 3 summarizes the main descriptive statistics and sources for the complete set of explanatory variables.

Table 3. Descriptive statistics for explanatory variables (2016-2019)

Variable	Description	Mean [Std. Dv]	Source
GDP per capita	Gross Domestic Product per capita in current dollars	56,435.580 [21,863.530]	Bureau of Economic Analysis
Unemployment	Unemployment rate	4.027% [0.927]	US Bureau of Labor Statistics
Population	Total population	6,605,689 [7,311,591]	American Community Survey
Poverty	Share of population below poverty level	13.994% [0.030]	American Community Survey
Age 45-64	Share of population aged between 45 and 65 years old	15.950% [0.025]	American Community Survey
Age > 65	Share of population aged above 65 years old	4.937% [0.017]	American Community Survey
White	Share of population identified as white	77.390% [0.115]	American Community Survey
Native	Share of population identified as native American	1.371% [0.022]	American Community Survey
Black	Share of population identified as black	11.607% [0.107]	American Community Survey
Asian	Share of population identified as Asian	3.402% [0.026]	American Community Survey
Male	Share of males across overall population	51.592% [0.014]	American Community Survey
Urban	Percentage of population living in urban areas.	75.413% [0.146]	US Census Bureau
Human Capital	Share of the population aged 25-64 with tertiary education	43.264% [6.536]	OECD Regional Statistics
Health spending per capita	Per capita personal consumption expenditure in healthcare (in current dollars)	7,219.383 [1,166.965]	Bureau of Economic Analysis
Broadband	Fixed Broadband connections offering at least 25 Mbps down and 3 Mbps up, every 100 households	58.052% [15.293]	FCC Internet Access Services reports

Source: Telecom Advisory Services compilation

4.2. ESTIMATION RESULTS

The estimates were calculated through an OLS fixed effects models for the period 2017-2019, incorporating controls for both states and years. The inclusion of a state-level fixed effects parameter is especially important as it controls for every unobservable factor that may condition health outcomes, if they are time-invariant. Similarly, year fixed effects controls for time-related shocks affecting all states.

Results are presented in Table 4. All estimates incorporate robust standard errors, clustered at a state-level.

Table 4. Impact of Broadband on Health outcomes - OLS estimates (2017-2019)

Variable	Δ Asthma	Δ Pneumonia	Δ Diabetes	Δ Heavy drinking	Δ Everyday smoking	Δ Someday smoking	Δ Obesity
Δ log (GDP pc)	-0.0405	0.0335	0.1167	-0.0256	0.1194**	0.0297	-0.0386
	[0.0531]	[0.1263]	[0.0794]	[0.0463]	[0.0509]	[0.0403]	[0.0868]
Δ Unemployment	-0.0050*	-0.0015	0.0040	0.0008	0.0002	-0.0017	0.0087*
	[0.0028]	[0.0086]	[0.0046]	[0.0022]	[0.0036]	[0.0019]	[0.0046]
Δ Log (Population)	-0.4550	0.7711	-0.0622	-0.8621*	0.3539	-0.0434	-1.2143
	[0.3808]	[1.4723]	[0.6903]	[0.4737]	[0.5816]	[0.3719]	[0.8748]
Δ Poverty	0.7582	-1.2601	-0.1277	0.1196	1.0698	0.1968	0.4052
	[0.5999]	[1.7361]	[1.2231]	[0.6839]	[0.8387]	[0.4058]	[1.0278]
Δ Age 45-64	-0.0416**	-0.0607	-0.0501	-0.0235	0.0082	0.0178	0.0195
	[0.0175]	[0.0716]	[0.0500]	[0.0219]	[0.0323]	[0.0168]	[0.0378]
Δ Age > 65	0.2691***	-0.4720**	-0.0705	0.0325	-0.0285	0.0803	0.1151
	[0.0757]	[0.2092]	[0.1629]	[0.0864]	[0.1285]	[0.0611]	[0.1286]
Δ White	-0.0176	-1.7764	-1.2979	0.7852	0.5854	-0.2217	-0.8774
	[0.7848]	[2.2323]	[1.1906]	[0.6539]	[1.0135]	[0.4296]	[1.3335]
Δ Native	-3.2827	11.0979*	0.6856	-0.8048	0.6367	1.1214	3.7276
	[2.573]	[6.5471]	[4.5763]	[2.5648]	[3.6315]	[1.9246]	[5.6322]

Variable	Δ Asthma	Δ Pneumonia	Δ Diabetes	Δ Heavy drinking	Δ Everyday smoking	Δ Someday smoking	Δ Obesity
Δ Black	-1.9891	-13.4221***	-1.0614	-3.1139*	1.3853	0.6770	-0.7682
	[1.3846]	[4.7886]	[2.7146]	[1.8474]	[2.3253]	[1.0976]	[4.5116]
Δ Asian	-3.3121	2.9079	-0.0059	1.0860	-3.8942	-0.1931	-6.0712
	[2.2333]	[4.7370]	[4.3975]	[1.7134]	[3.2940]	[1.3619]	[5.2066]
Δ Male	0.1500	0.2163	-0.3484	0.4265	0.1423	-0.2590	-0.1885
	[0.3087]	[0.6714]	[0.3225]	[0.2632]	[0.2861]	[0.1624]	[0.5040]
Δ Urban	-120.3327***	-111.0119	-158.1817*	71.7247	72.1429	47.1058	-0.8419
	[34.3697]	[148.8260]	[88.9657]	[71.9416]	[57.3753]	[34.6341]	[91.2709]
Δ Human Capital	0.0008	0.0014	-0.0022**	0.0004	-0.0001	-0.0004	-0.0019*
	[0.0006]	[0.0015]	[0.0009]	[0.0006]	[0.0007]	[0.0005]	[0.0010]
Δ Log (Health spending pc)	-0.1868**	-0.2175	-0.1512	-0.0244	0.1174	0.0201	0.1910
	[0.0710]	[0.2726]	[0.1215]	[0.0607]	[0.1111]	[0.0592]	[0.1977]
Δ Broadband	-0.0008**	0.0001	-0.0012***	0.0000	-0.0002	-0.0005*	-0.0013***
	[0.0003]	[0.0008]	[0.0004]	[0.0002]	[0.0003]	[0.0002]	[0.0004]
State fixed effects	YES	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES	YES
R-squared (within)	0.381	0.681	0.365	0.250	0.216	0.276	0.224
Observations	146	146	146	146	146	146	146

*Note: Robust standard errors in parenthesis. *p<10%, **p<5%, ***p<1%.*
Source: Telecom Advisory Services analysis

The results suggest that broadband adoption has been useful to overcome some of the health problems faced by the American people:

- Broadband exhibits a negative and significant coefficient as a driver of asthma affliction (at a 5% level). This means that, after controlling for several socioeconomic variables and unobservable factors, states where broadband connectivity growth is higher tends to face lower number of patients reporting asthma related issues. According to the coefficient estimated, an increase of broadband penetration of 10 percentage points (for instance, from 40% to 50% of households) is associated to a reduction in 0.8 percentage points of the share of population facing asthma (for instance, from 9.6% to 8.8% of inhabitants). This suggests that the internet is a tool of information sharing and telemedicine support that can effectively contribute to improve this health outcome.[11] In addition, a decrease in the asthma incidence can reduce the amount of funds currently spent in dealing with this disease. To illustrate this point, the American Academy of Allergy Asthma and Immunology reports that this disease costs approximately $ 3,000 per year per person for treatment, which, given the number of people affected, results in and expenditure of $ 60 billion for the country.
- A similar result was found when linking broadband penetration with diabetes: the more connected the population becomes through broadband, the lower the increase in the prevalence of this disease (in this case the result is highly significant, at a 1% level). According to the coefficient estimated, an increase of broadband penetration of 10 percentage points (for instance, from 40% to 50% of households) is associated with a reduction in 1.2 percentage points of the share of population facing diabetes (for instance, from 14.6% to 13.4% of inhabitants). Again, a decrease in diabetes can reduce the amount of funds currently spent in dealing with this disease. The average economic cost per person with diagnosed diabetes was projected to be $13,240. Connell and Manson (2019) estimate that the total health care cost of diabetes and prediabetes in the US amounts to $ 403.9 billion.
- Slightly weaker is the effect linking broadband penetration growth and smoking reduction: the effect is statistically significant (at a 10% level) only for the case of “someday smokers”, but not for “everyday smokers”. According to the coefficient estimated, an increase of broadband penetration of 10 percentage points (for instance, from 40% to 50% of households) is associated to a reduction in 0.5 percentage points of the share of population that “smoke somedays” (for instance, from 4.3% to 3.8% of population). This may prompt a reduction in the expenditure currently spent to deal with smoking. To contextualize, the proportion of health care expenditure attributable to smoking ranges between 6% and 18% across different states (Ekpu and Brown, 2015).

[11] As reported, many of the issues related to asthma are related to changing lifestyles, which is very much linked to information access and doctor counseling.

- Finally, there is a strong link between broadband adoption growth and obesity reduction (significant at 1%). This may be because the internet can be a successful tool to access information on balanced diets, exercise, and healthy routines, plus the telemedicine tools for regular checkups. According to the coefficient estimated, an increase of broadband penetration of 10 percentage points (for instance, from 40% to 50% of households) is associated to a reduction in 1.3 percentage points of the share of population facing obesity (for instance, from 31.7% to 30.4% of inhabitants). As in the previous cases, this health improvement can contribute to economic savings. The annual per capita care costs related to obesity in the US amount to $ 6,899 (including out of pocket expenses, inpatient and outpatient costs, office-base medical provider services, emergency room services, and medication) (Tremmel et al., 2017).

It is important to mention, that out of all the health afflictions tested in the above analysis, not all were statistically related to broadband, as the effects were found to be not statistically significant in the case of Pneumonia, Heavy drinking, and Everyday smokers. This can suggest that the nature of the impact enabled by broadband (access to information and telemedicine) may be more accurate for some diseases and less for others. This should depend on the nature of each disease, and on the specific factors influencing them in each case. However, considering the ones with statistically significant coefficients and their associated economic care costs, the positive contribution of broadband to a potential decrease of incidence can be economically meaningful.

5. THE IMPACT OF BROADBAND INTERNET ON HEALTHCARE DURING THE PANDEMIC

The evidence we found in the prior analysis is also expected to exist during the pandemic. However, given the challenge imposed by COVID-19, broadband internet could have acquired an even more significant role under these circumstances. While digitization has been key for keeping the economy functioning during the pandemic (Katz and Jung, 2021), and has helped keep people connected and entertained, it may also be the case that digital technologies have contributed to enhancing healthcare delivery.

The empirical methodology to estimate the model is structural equation modelling (SEM). SEM models are suitable for validating hypothesis with empirical data, involving multiple linkages and mediating relations, conforming a group of direct and indirect effects among two or more variables or constructs. The hypotheses can then be tested statistically in a simultaneous analysis of the entire system of variables to determine if it is consistent with the data (Pearl, 2012). Among the advantages of SEM, as these measurements are done simultaneously in one statistical procedure, the model errors are calculated using all information available from the model. Thus, the estimated errors are more accurate than those resulting from calculating each part of the model separately.

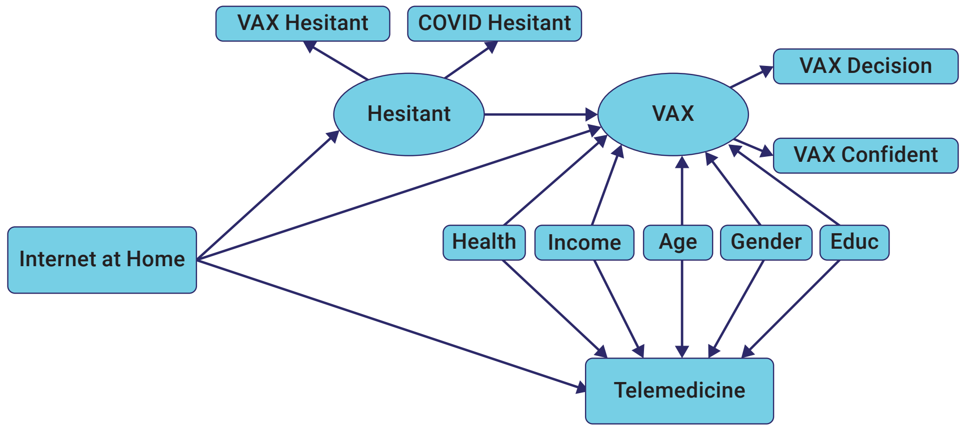
To estimate and test our conceptual model we will use the two-step method checking for the measurement and the structural model, additionally computing indirect and total effects. The SEM model will be estimated through the Maximum Likelihood approach, that offers asymptotically efficient results under the assumption of multivariate normality.

5.1. THEORETICAL FRAMEWORK AND HYPOTHESES

In this section, we focus on the impact of COVID related information delivered through broadband internet on the attitude of the population towards COVID prevention and vaccination. In other words, we are testing a hypothesis that the larger the amount of information that is delivered by broadband internet to the population, the more prone people will be to follow behavior preventing COVID infection and getting vaccinated. In addition, internet is expected to boost the possibilities to perform telemedicine medical consultations.

We assessed the impact of information on expected behavior through a multi-causal chain linking variables to test multiple hypotheses, as depicted in Figure 4.

Figure 4. Model to estimate the role of ICT during the pandemic



Source: Telecom Advisory Services

The components in Figure 4 are built around the following observed variables and constructs that we defined based on data from a survey conducted by the National Opinion Research Center at the University of Chicago during late spring to early summer of 2021[12]:

- INTERNET is an observed variable that refers to having internet at home.
- HESITANT is a construct that refers to the degree of hesitance felt toward vaccination: it is measured with survey answers to two questions: "Overall, how hesitant about vaccines in general would you consider yourself to be?" and "Thinking specifically about COVID-19 vaccines, how hesitant would you consider yourself to be?", in both cases the answer is represented by a scale taking values from 1 (Not at all hesitant) to 4 (Very hesitant).[13]
- VAX is a construct that refers to the attitude towards the COVID-19 vaccine: construct based on two items: (i) the decision to vaccinate (if the individual got the COVID-19 vaccine or not), and (ii) the degree of confidence the individual has on the vaccine outweighing its potential risks, taking values from 1 (Not at all confident) to 3 (Very confident).[14]
- TELEMEDICINE is an observed variable that refers to the use of Telemedicine tools: it is a dummy variable based on the affirmative answer to the question "In the last two months, have you had an appointment with a doctor, nurse, or other health professional by video or by phone?"

[12] See details on Survey data in Appendix A.
[13] Reliability was very good (Cronbach's alpha = 0.864).
[14] Reliability was good (Cronbach's alpha = 0.709).

As mentioned above, the underlying general hypothesis behind Figure 4 is that better access to INTERNET can help people to be better informed about health care, which in turn will lead COVID reluctant subjects to reduce their hesitancy to vaccination (HESITANT). If the degree of hesitancy is low, then the subjects would be more likely to vaccinate (VAX). Second, INTERNET is expected to stimulate the use of telemedicine services (TELEMEDICINE). Telemedicine facilitates the contact between doctors and patients, making them more informed and responsible for their healthcare. Finally, we establish a direct effect from INTERNET to VAX, as more informed people are more likely to vaccinate. Based on these causal flows, we can sketch multiple hypotheses:

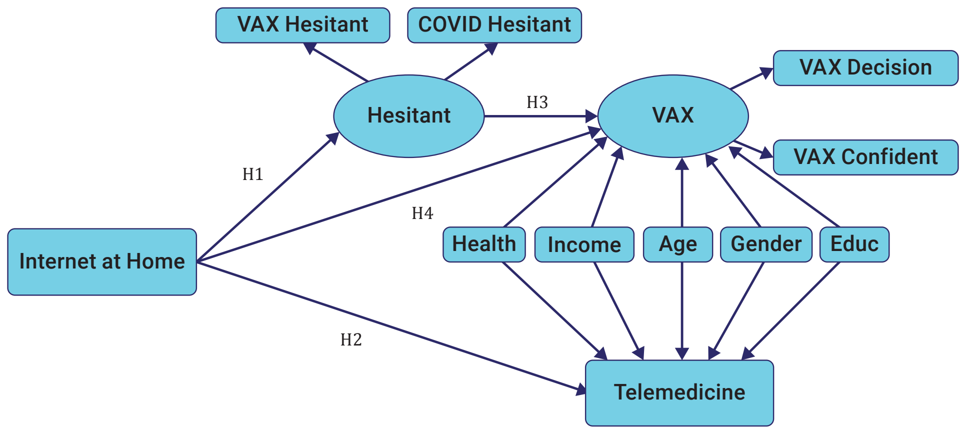
- H1: There is a direct and negative impact of **INTERNET** on **HESITANT** (vaccine hesitancy).
- H2: There is a direct and positive impact of **INTERNET** on **TELEMEDICINE** (telemedicine use).
- H3: There is a direct and negative effect of **HESITANT** (vaccine hesitancy) on **VAX** (vaccination)
- H4: There is a direct and positive effect of **INTERNET** on **VAX** (vaccination)

These hypotheses were tested empirically with a dataset from US individuals surveyed during the pandemic (4,301 observations). The assessment of the sample validity and descriptive statistics are included in appendix B.

5.2. ESTIMATION RESULTS

We ran the structural model adding control variables for income, education, perception of health status, age, and gender. Considering all the control variables and items belonging to each construct, the complete model we estimated is presented in Figure 5, including the hypotheses to be checked.

Figure 5. Complete model to estimate the role of broadband internet during the pandemic



Source: Telecom Advisory Services analysis

Estimates are shown in Table 6 (standardized direct estimates).

Table 6. Standardized Direct Effects

	Direct Effects	
	INTERNET	HESITANT
HESITANT	-0.036**	
TELEMEDICINE	0.029*	
VAX	0.020*	-0.976***

*Notes: Bootstrapped standard errors estimated for significance analysis. *p<10%, **p<5%, ***p<1%.*
Source: Telecom Advisory Services analysis

Regarding the relationships among outcomes we found, as expected, a significant and negative effect of INTERNET on HESITANT and a significant and positive effect of INTERNET on TELEMEDICINE and on VAX (although in these two cases the significance level is 10%). Thus, we can argue that better access to INTERNET helps people to be better informed and to reduce their hesitancy toward COVID-related treatment. In addition, better access to INTERNET stimulates the use of telemedicine tools. Accordingly, all this evidence allows us to confirm hypotheses *H1*, and *H2*.

Next, a reduction in HESITANT increases VAX. This validates hypotheses *H3* and clearly confirms that the less hesitant is a person towards the COVID-19 vaccine, the more likely he or she is to believe in the benefits of the vaccine and to vaccinate. Finally, we found a direct positive and significant effect of INTERNET→VAX, which validates hypothesis *H4*. This means that, after controlling for the indirect effects that materialize through hesitancy reduction, there is still a direct effect from INTERNET to VAX. This can be explained as internet access facilitates the vaccination process, enabling information gathering on vaccination points, on available slots, and the like.

Table 7 summarizes the status of each hypothesis. The four hypotheses were validated, providing important evidence of the role of INTERNET for health and COVID care.

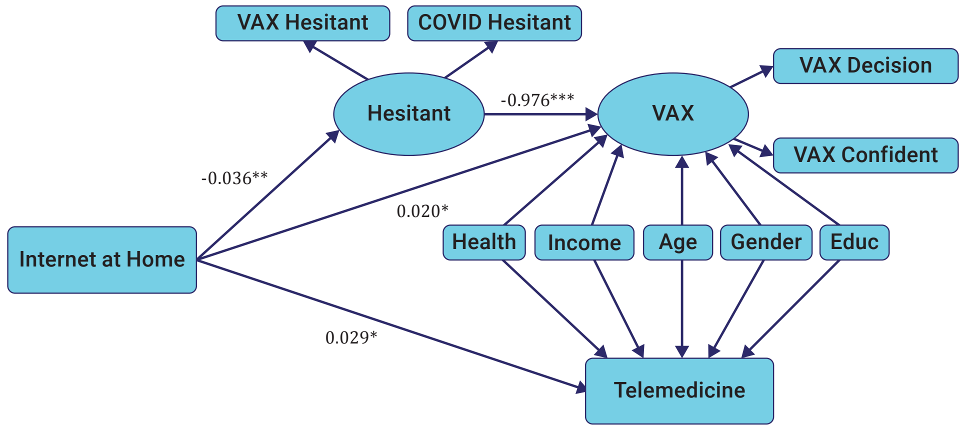
Table 7. Hypotheses validation of direct effects

Hypothesis	Path	Sign	Findings
H1	INTERNET→HESITANT	-	Validated
H2	INTERNET→TELEMEDICINE	+	Validated
H3	HESITANT→VAX	-	Validated
H4	INTERNET→VAX	+	Validated

Source: Telecom Advisory Services analysis

We now present again the diagram depicted above, incorporating the coefficient and significance level for each effect (Figure 6).

Figure 6. Complete model and estimated standardized direct effects



*Notes: Bootstrapped standard errors estimated for significance analysis. *p<10%, **p<5%, ***p<1%.*
Source: Telecom Advisory Services analysis

We then calculate the indirect effects from INTERNET to VAX, being positive and taking a value of 0.035 (significant at 5% level). The sum of direct and indirect effects provides the total effect from INTERNET to VAX 0.055, which is highly significant (1%). These results validate the important and positive role that INTERNET has on healthcare and COVID-19 vaccination.

6. CONCLUSIONS

Throughout this study, we were able to provide a theoretical model and empirical evidence regarding the links between the internet and health outcomes in the United States. First, we reviewed the research literature, which allowed us to theoretically argue in favor of the causal relationship.

Next, we performed an exploratory analysis, taking advantage of the *Mapping Broadband Health in America* inputs provided by the FCC. However, as this preliminary evidence does not allow us to infer causal effects, we developed two econometric models. The idea behind splitting this econometric analysis is to take advantage of two different datasets available, one suitable for estimating this issue under normal circumstances (before COVID-19), and another one to assess the expanded role that internet may have gained during the pandemic.

The first model is based on the first-differenced methodology proposed by Whitacre and Brooks (2014) to study the impact of broadband growth on health outcomes. The results suggest that broadband adoption has been useful to help reduce the incidence of some of the health problems faced by the American population, namely asthma, diabetes, smoke reduction and obesity reduction.

The second model is based on a survey conducted during COVID-19, that provides useful information regarding people's behavior with respect to vaccination hesitancy, and mask wearing. We developed an SEM model linking the effects from internet access to vaccination, that can be materialized either directly and through hesitance reduction, while we also hypothesize internet as a crucial tool to enhance telemedicine use. All these effects were found to be statistically significant, supporting a key positive role of internet in vaccination and in the use of telemedicine tools.

The evidence generated in this study suggests that broadband internet has had a positive effect on Americans health, and that effect has been enhanced during the COVID-19 pandemic. From a public-policy perspective, these results reinforce the critical need of closing the connectivity gap across the American households. Some of the applications and uses through which these effects occur, such as telemedicine which may involve a remote video consultation with a doctor, require high-speed internet access. Today, wide penetration rate disparities exist between states for 25 Mbps and above broadband service – 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 ensure that as many people as possible adopt broadband. This is especially relevant for lagging states in connectivity that, as seen above, are usually those with the worse health outcomes. In addition, public policies should also be designed to stimulate adoption levels in covered areas, something that may require flexibility to develop commercial offers, programs to enhance digital skills of the population, and economic incentives for disadvantaged families

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APPENDIX A. SURVEY DATA

The sample for the second part of our study comes from the Research and Development Survey (RANDS). The RANDS is an ongoing series of surveys conducted by the Division of Research and Methodology at the National Center for Health Statistics (NCHS) of the United States. The survey we used is denominated as the “RANDS during COVID-19 Round 3”.

The survey was conducted by NORC at the University of Chicago (an independent research institution) during late spring to early summer 2021. Data collection began on May 17 and ended on June 30 of 2021. NORC invited 7,852 of its panel members to complete the questionnaire via web and phone. Of the panel members contacted, 5,458 completed the survey, resulting in a 69.5% completion rate. From that quantity, we discarded those who didn’t answer the telemedicine and internet questions, keeping as a result 4,301 observations for our empirical research.

In the sample, 57% were women, while 43% were male. The average age was 53.2 years. The average self-perception health status of the surveyed is 2.7 in a scale from 1 to 5 (where 1 is excellent health and 5 is poor health). The geographical distribution is the following: Northeast (12.8%), Midwest (25.2%), South (37.4%), and West (24.6%).

APPENDIX B. DATA SAMPLE ANALYSIS

Our constructs are distinct both conceptually and in terms of their underlying factors, reducing any risk attributable to common method variance. Descriptive statistics, reliability estimates (Cronbach's alpha, in brackets) and correlations are presented in Table B.1.

Table B.1. Descriptive statistics

			Correlations			
	Mean	Std. Dv.	INTERNET	HESITANT	TELEMEDICINE	VAX
INTERNET	0.817	0.387				
HESITANT	0.000	1.000	-0.019	(0.864)		
TELEMEDICINE	0.250	0.433	0.010	-0.004		
VAX	0.000	1.000	0.067	-0.675	0.014	(0.709)

Notes: Kendall correlation coefficients presented.
Source: Telecom Advisory Services analysis

We also tested discriminant validity[15] by comparing the square root of the Average Variance Extracted (AVE) with respect to correlation indices of each construct with the other ones; AVE's higher than all the correlation measures indicate the constructs are valid. The VAX construct presents a square root of AVE equal to 0.78, above the maximum correlation (0.675, with HESITANT). HESITANT, in turn, presents a square root of AVE equal to 0.87, larger than the correlation coefficient with VAX.

To estimate and test our conceptual model we used the two-step method checking for the measurement and the structural model, computing additionally indirect and total effects.[16] To ensure their significance, we applied bootstrapping 95% confidence intervals using the percentile method. Considering that to perform bootstrapping we needed a complete dataset, we filled missing data with the sample averages, by relying on the Maximum Likelihood approach.

The measurement model yielded a good fit (NFI = 0.937; IFI = 0.939; CFI = 0.939; RMSEA =0.083). The standardized regression weights (SRW) for the items of each construct were all significant ($p<0.001$), all of them over 0.7. This evidence brings support to the convergent validity of the scales.

[15] Discriminant validity implies that each construct must be significantly different from the rest of the constructs with which it is not related according to the theory.
[16] The data were analyzed with structural equation modelling (SEM) using the software AMOS version 26.