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Disconnected in a pandemic: COVID-19 outcomes and the digital divide in the United States

Fei Li

Georgia State University, feili@gsu.edu

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Fei Li, feili@gsu.edu

Urban Studies Institute, Georgia State University

55 Park Pl NE, 8th Floor, Atlanta, GA 30303, USA

HIGHLIGHTS

- Lack of access to the Internet and digital technologies could exacerbate the impacts of the COVID-19 pandemic through multiple pathways.
- Two years into the pandemic, U.S. counties with lower levels of home access to Internet and computers are seeing higher rates of COVID-19 infection and death.
- Limited access to Internet and broadband services was also associated with slower vaccination rollout in April 2021, when vaccines were first available to the general public in the U.S.

ABSTRACT

The COVID-19 pandemic has exacerbated inequalities related to the digital divide. With wide adoption of remote working and learning, telehealth, and virtual events and social activities, the technology have-nots and know-nots experienced substantial marginalization and elevated risks of COVID-19 exposure in daily lives. This study discusses the pathways through which digital exclusion could aggravate the impacts of the pandemic and explored the linkage between digital access and COVID-19 outcomes in U.S. counties. It finds that counties with higher percentages of digitally excluded populations have seen higher COVID-19 case and death rates throughout the pandemic and possibly had slower vaccine rollout in early 2021.

Keywords: Digital divide, Internet access, Digital exclusion, Health disparities, COVID-19

1. Introduction

The digital divide, or the gap between those who can and those who cannot use and benefit from modern information and communication technologies (ICTs), has been a long-standing social and policy issue since we entered the information age. As Internet services, computers, and mobile phones become more prevalent and affordable, focus on the digital divide has extended from physical access to digital literacy and skills (Bodie & Dutta, 2008; Thomas et al., 2018; Van Deursen & Mossberger, 2018; Yu, Ndumu, Mon, & Fan, 2018). Nevertheless, the first-level digital divide – the unequal access to Internet, especially broadband connections, and devices such as home computers and mobile phones – persists even in the most developed countries and regions (Thomas et al., 2018; Winslow, 2019). Moreover, as the society as a whole is more accustomed to and dependent on digital technologies in all aspects of daily life, the consequences of being on the wrong side of the gap can be more pronounced in these countries and regions.

The digital divide is often closely associated with socioeconomic status (Fang et al., 2019; Forenbacher, Husnjak, Cvitić, & Jovović, 2019) and hence easily overlooked when the latter is seen as a more universal indicator of social inequalities. Being disconnected in an increasingly interconnected network society and consequently excluded from employment, education, and other opportunities, however, could replicate perpetuate existing inequalities. Interventions that address the digital divide directly and extend access to and utilization of ICTs among marginalized communities, on the other hand, have the potential of alleviating poverty, closing the achievement gap, and reducing health disparities (Azzopardi-Muscat & Sørensen, 2019; Kim, 2018; Mitchell, Chebli, Ruggiero, & Muramatsu, 2019; Rotondi, Kashyap, Pesando, Spinelli, & Billari, 2020; Soriano, 2007). Studying the digital divide as an additional dimension of social exclusion and better understanding its impacts can therefore have important policy implications.

The COVID-19 pandemic has exacerbated the inequalities associated with digital exclusion and brought renewed attention to the digital divide (Lai & Widmar, 2021; Watts, 2020). With much of the world swiftly turning to working from home, remote learning, and virtual activities ranging from concerts and church services to weddings and funerals following the initial COVID-19 outbreaks in 2020, individuals and households without reliable, high-speed internet or any of the hardware, software, and subscriptions needed to stay connected increasingly find themselves left out of the plan forward. The significance of digital inclusion as a social determinant of health has also multiplied: more extensive adoption of telehealth widens the gap between technology haves and have-nots (Clare, 2021; Ramsetty & Adams, 2020); lockdowns and social isolation take a heavier toll on the mental health and well-being of those unable to participate in online gatherings and social activities (Cho & Kim, 2022; Martins Van Jaarsveld, 2020); not to mention the indirect effects of the digital divide through magnifying inequalities in other social determinants of health (Alkureishi et al., 2021; Sostero, Milasi, Hurley, Fernandez-Macías, & Bisello, 2020).

There has been limited discussion and little evidence, however, on the impact of the digital divide on COVID-19 infections and deaths (Eruchalu et al., 2021), two of the most relevant health outcomes of the pandemic, despite the established linkages between race (Bhala, Curry, Martineau, Agyemang, & Bhopal, 2020; Gold et al., 2020; Hamidian Jahromi & Hamidianjahromi, 2020; Van Holm, Wyczalkowski, & Dantzler, 2021) or socioeconomics (Mena et al., 2021; Sy, Martinez, Rader, & White, 2021) and COVID-19 outcomes. Apart from the aforementioned influences of the digital divide on general health and telehealth access, there are multiple reasons to believe that digital exclusion may contribute to the spread of COVID-19 and more adverse outcomes:

1. Digital exclusion limits individuals' ability to "shelter in place" and adhere to quarantine and isolation guidelines, especially in the early stages of the pandemic and during periods of high transmission in the subsequent waves. Having to work in person as opposed to remotely, for example, can substantially increase one's exposure to and risk of contracting COVID-19. While the ability to telecommute is largely determined by the nature of the occupation (Sostero et al., 2020), the technology have-nots and know-nots are essentially precluded from opportunities of telework or participating in the new digital economy and therefore restricted to occupations and industries that require in-person work. Likewise, inability to substitute other trips with digital technologies, such as virtual doctor visits, leads to more in-person contact and multiplies the risk of COVID-19 exposure and transmission.
2. Digital exclusion slows down the dissemination of information and knowledge, which can be crucial for timely responses and taking precautionary measures in a rapidly evolving pandemic. In digitally marginalized communities, the awareness and understanding of local pandemic situations, public health guidelines and policies could lag behind the most up-to-date information, leading to delays in social distancing, masking, sanitation and ventilation upgrades, testing and early treatment, etc.
3. Many of the pandemic response measures – from testing and contact tracing to treatment and vaccines, including the more recent distribution of home test kits and masks – depend on digital platforms and technologies. As a result, even when

digitally disadvantaged individuals are aware of COVID-19 outbreaks in their communities or seek to take precautions, they may face additional difficulties in locating and accessing the needed resources. The more effective N95 and KN95 respirators, for example, have been in short supply during much of the pandemic and often only found online. Apart from the cost factor, access to Internet and skills to identify and verify online stores are necessary to acquire such personal protective equipment (PPE) that offers the most protection. Similarly, in the first few months of the vaccine rollout, vaccination appointments could be extremely difficult to secure in some regions and require persistent searching, refreshing, and filling in scheduling forms online (Fowler, 2021; Santhanam, 2021). These technological barriers amplified the challenges facing the digitally marginalized in fighting COVID-19.

4. Digital exclusion could potentially distort perceptions of the pandemic and related issues, leading to more risky behavior and increased COVID-19 transmission. Although the COVID-19 pandemic is, first and foremost, a public health crisis, it has also become a crisis of public opinion and trust in the United States as well as many other parts of the world, complicating the public health efforts to contain the pandemic and its impacts (Algan, Cohen, Davoine, Foucault, & Stantcheva, 2021; Devine, Gaskell, Jennings, & Stoker, 2021; Gualano, Lo Moro, Voglino, Bert, & Siliquini, 2022). Mistrust in government, public health agencies, and scientists are associated with incompliance with public health measures, vaccine hesitancy, and mortality rates (Devine et al., 2021; Palamenghi, Barello, Boccia, & Graffigna, 2020). While the digital divide *per se* is not necessarily aligned with the ideological differences that often dictate COVID-19 perceptions, limited access to and

proficiency in digital technologies could restrict one's exposure to diverse information sources and ability to actively seek and verify information, making individuals more vulnerable to misinformation about COVID-19.

These theoretical considerations motivated this study to explore the linkage between the digital divide and COVID-19 outcomes in the United States. I formulate the following hypotheses:

H1: Access to digital technologies is negatively associated with COVID-19 infection and death rates.

H2: Access to digital technologies is positively associated with COVID-19 vaccination rates.

The following section describes the data and the analytical model. Section 3 presents the results, and Section 4 concludes the study with a discussion of the findings and policy implications.

2. Data and Methods

This study uses two primary data sources: 1) county-level digital access and socio-demographic data from the American Community Survey (ACS), 2015-2019; and 2) COVID-19 data from the CDC, compiled over time by the Opportunity Insights Economic Tracker (Chetty, Friedman, Hendren, & Stepner, 2020). The three key COVID-19 outcome variables are confirmed case, death, and vaccination rates. These metrics are available daily since January 2020, as seven day moving averages, in the Opportunity Insights Economic Tracker database. I converted the data to monthly series, using the last Sunday of each month, from 2/28/2020 to 1/30/2022. After verifying the data with the CDC Data Tracker[1], the COVID-19 dashboard by Johns Hopkins University[2], and state pandemic reports, I adjusted the dataset to remove obvious inconsistencies

[1] https://covid.cdc.gov/covid-data-tracker/#datatracker-home.
[2] https://coronavirus.jhu.edu/map.html.

and recalculated COVID-19 case and death rates based on confirmed case and death numbers and county population from 2015-2019 ACS. The states of Alaska and Hawaii, as well as 9 counties in California and Texas, are excluded from the study due to missing or inaccurate vaccination data. I also excluded 7 small counties with populations below 500 in the regression analysis, leaving 3,101 counties in the 48 contiguous states and the District of Columbia.

Figure 1 displays the case, death, and full vaccination rates in contiguous United States by 1/30/2022. While COVID-19 mortality is a direct result of COVID-19 infections, the geographic correlation between COVID-19 incidence and death rates is less straightforward. As Figure 1 shows, some of the areas with the highest death rates, such as Georgia, Montana, and parts of South Dakota and Texas, are not necessarily higher in case rates than neighboring regions. Similarly, while a negative correlation between vaccination and case/death rates can be seen along the east and west coasts, other regions with high vaccination rates, such as Arizona, New Mexico, southern Texas, and northern Michigan are also some of the hardest hit areas by COVID-19. A two-way relationship could be at play: while communities with higher vaccination rates may be better protected against future outbreaks, those that have seen higher levels of COVID-19 incidence and mortality may take a more aggressive approach to vaccination campaigns or have more people motivated to get the vaccine, leading to higher vaccination rates. The net relationship between vaccination rate and COVID-19 case/death rate, therefore, can be either negative or positive.

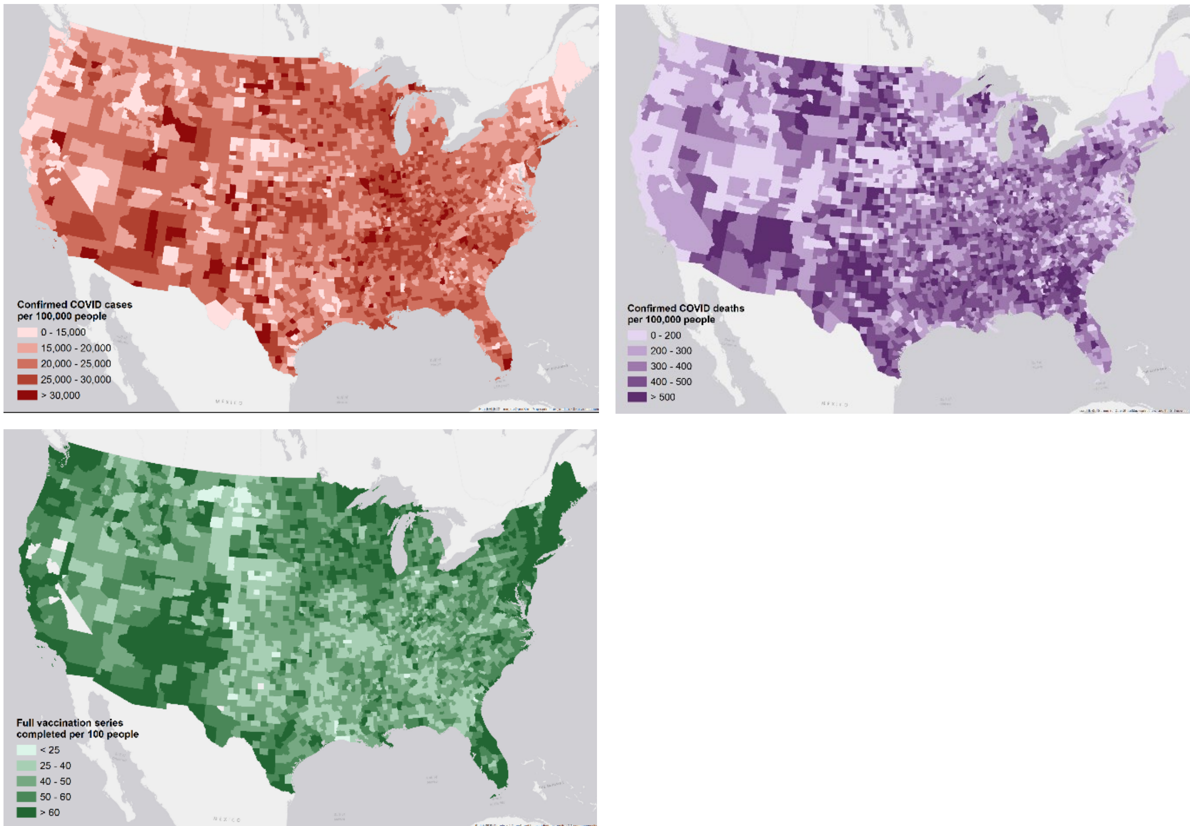

Figure 1. COVID-19 case, death, and full vaccination rates on 1/30/2022.

The independent variable, digital exclusion/access, also consists of three measures: the share of households with no Internet access, the share of individuals who have no computer at home, and the share of individuals who have broadband Internet subscription. The first two variables measure digital exclusion – without a computer or Internet plan, individuals and households are simply excluded from most resources or opportunities available online. The third variable measures digital access at a more advanced level, as a broadband connection is usually necessary for more intensive Internet use like streaming and video/audio meeting, essential for activities like telehealth, remote learning and working. I expect the first two measures of digital exclusion (% no Internet and % no computer) to be positively associated with COVID-19 case and death rates and negatively associated with vaccination rates, and the opposite relationships between the third variable (% broadband) and the outcome variables.

Figure 2 shows the distribution of digitally excluded and broadband connected populations across the lower 48 states. Compared with the three COVID-19 outcome variables, these measures are more closely related, especially the first two measures of digital exclusion, though the prevalence of home computers is much higher than that of the Internet. A substantial number of the U.S. counties have more than 20% of the households with no Internet access, with some as high as 40%. Some of these regions with the highest share of digitally excluded population, such as southern Texas along the U.S.-Mexico border and the Black Belt states, are also among the regions hardest hit by COVID-19 in Figure 1.

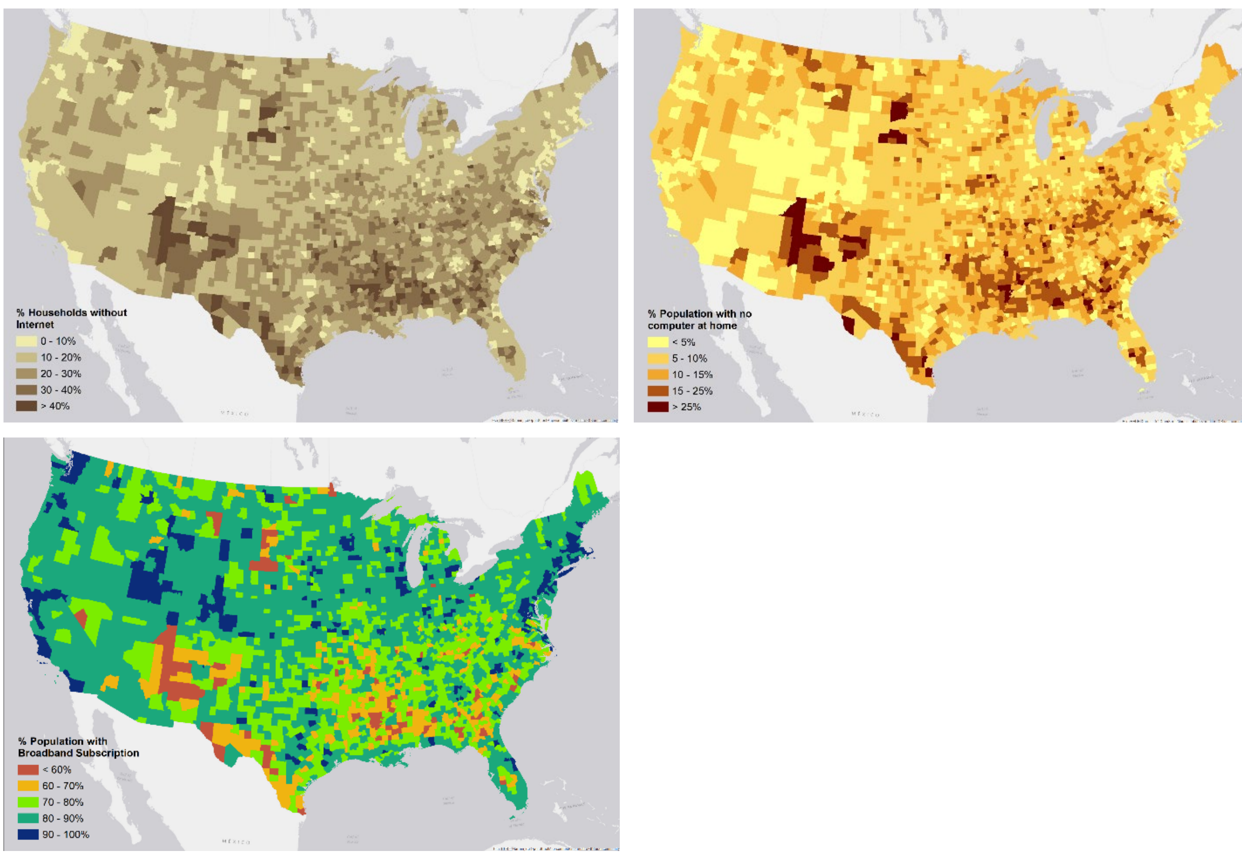

Figure 2. Percentages of households with no Internet, individuals with no home computer, and individuals with broadband subscriptions from ACS 2015-2019.

A simple comparison of the outcome variables among counties with different levels of Internet access, as shown in Table 1, supports the hypothesized relationship between the digital divide and COVID-19 outcomes: COVID-19 death rates in counties with the lowest level of digital access almost triple those in counties with the highest level of access. However, since digital access is highly correlated with urban/rural status, demographics and socioeconomic factors, many of which may also influence COVID-19 outcomes, the relationship in Table 1 may be a spurious one reflecting association with a common third factor. Therefore, the multivariate analysis controls for population density, age, race, housing tenure, poverty and income, as well as state fixed effects to account for different state-level responses to the pandemic. The regression models assume the following forms:

$$Case\ Rate = \beta DD + \vartheta Vaccine\ Rate_{t-1} + X\theta + u + \varepsilon \quad (1)$$

$$Death\ Rate = \beta DD + \lambda Case\ Rate_{t-1} + \vartheta Vaccine\ Rate_{t-1} + X\theta + u + \varepsilon \quad (2)$$

$$Vaccine\ Rate = \beta DD + \lambda Case\ Rate_{t-1} + X\theta + u + \varepsilon \quad (3)$$

where $Case\ Rate$, $Death\ Rate$, $Vaccine\ Rate$ are the three outcome variables described above; DD is one of the three measures of the digital divide; $Case\ Rate_{t-1}$ and $Vaccine\ Rate_{i(t-1)}$ are the COVID-19 case and full vaccination rates, lagged by one month, to account for the relationships between the three outcome variables; X_i is a vector of control variables; u represents the state fixed effects; and ε is the error term.

Table 1. COVID-19 outcomes in U.S. counties with different levels of Internet access.

% No Internet	# of counties	COVID-19 cases per 100,000 people	COVID-19 deaths per 100,000 people	Full vaccine series per 100 people
0 - 10%	236	20,192	161	62.7
11 - 20%	1,401	21,975	288	52.2
21 - 30%	1,096	22,412	381	44.9
31 - 40%	297	22,526	412	44.9
> 40%	78	22,881	458	49.7

Despite the use of lagged variables, Models 1 to 3 are not panel data or time series models. Instead, they are estimated as a series of cross-sectional models examining the cumulative rates of COVID-19 cases, deaths, and vaccinations at different time points. This is because 1) this study is more interested in exploring the inter-county relationship between digital access and COVID-19 outcomes, and 2) both the independent variables and the control variables were measured before the pandemic, and while the monthly COVID-19 metrics are available, there is not sufficient temporal variation in digital access or socio-demographics to explore during the two years of the pandemic. The lagged vaccination rate $Vaccine\ Rate_{t-1}$ is only included in time periods when vaccines were available, i.e., after December 2020.

As OLS regression can be biased by spatial autocorrelation, I also test a spatial lag model and a spatial error model, with the assumption that the outcome variable (COVID-19 case, death, or vaccination rates) is correlated across neighboring counties, or that the error term ε is correlated across neighboring counties, respectively. The R package 'spatialreg' is used to estimate the spatial autoregressive models.

Table 2 presents the descriptive statistics of the dependent, independent, and control variables. COVID-19 case, death, and vaccination rates in Table 2 represents latest updates from the last week of January 2022. Due to the Omicron surge in the U.S., there had been a sharp increase in COVID-19 cases in January 2022 compared to November and December 2021. Considering the delay between surges in cases and deaths, we may see a similar change in the death rate in February 2022 or subsequent periods. The maximum value of full vaccinate rates exceeds 100, representing a small number of counties that have administered more vaccine series than their residents, likely due to non-residents from adjacent jurisdictions taking vaccines in the county.

3. Results

Table 3 presents the modeling results for January 2022, the last time period in the dataset. Three models are estimated for each outcome variable, each using one of the three independent variables. Among the three outcome variables, COVID-19 death rate shows the strongest linkage with measures of the digital divide. As H1 states, counties with higher percentages of digitally excluded populations (with no Internet access or no home computer) see more COVID-19 deaths, while those with greater prevalence of broadband Internet services have lower COVID-19 death rates. The first measure of digital exclusion, % no Internet, is also positively associated with COVID-19 case rates, though the predicted relationships are not observed for the other two digital divide measures. In contrast, none of the digital divide measures have any significant relationship with vaccination rates in January 2022 (Table 3).

Many of the control variables behave as expected. Population density is positively associated with case, death, and vaccination rates, reflecting higher levels of COVID-19 transmission as well as stronger efforts of vaccination in more densely populated urban and suburban counties. Median income is negatively related to COVID-19 case and death rates and positively related to vaccination rates, corroborating the observation that lower-income communities tend to experience more severe COVID-19 outcomes (Mena et al., 2021). Some coefficients, however, run contrary to findings in earlier studies. Notably, the percentages of elderly, Black, and population under poverty, commonly considered as additional COVID-19 risk factors (Gold et al., 2020; Van Holm et al., 2021), are negatively associated with COVID-19 infections, although the former two have significant positive relationships with COVID-19 deaths. When looking at the series of cross-sectional models over time, the negative association between these socio-demographic factors and COVID-19 case rates seems to be a relatively recent phenomenon that occurred in the later stages of the pandemic, when the availability of vaccines and the emergence of more transmissible variants of the coronavirus changed the development path of the pandemic. For example, the coefficient between % Black and COVID-19 cases remained significantly positive through November 2020 and only became significantly negative after August 2021. Likewise, % 65 and over, % in poverty, and % renters are also positively associated with COVID-19 cases in the first months of the pandemic.

The relationship between socio-demographic factors and COVID-19 deaths has been more persistent over time. The percentages of population 65 and over and Black remain positively associated with the death rate throughout the pandemic, with magnitudes that grow bigger over time. The Opportunity Insights Economic Tracker dataset does not contain county-level COVID-19 test rates, though it seems probable that the results on case rates may be partly explained by different levels of testing across counties, which could well be correlated with the same socio-demographic factors. Moreover, the negative association between those risk factors and COVID-19 infections in later stages of the pandemic may be attributable to the higher vaccination rates in counties with higher percentages of elderly, Blacks, or renters. While vaccination rates seem to be positively related to case rates in Models 1, 2, and 3 in Table 3, as discussed earlier, this could reflect the effect of higher inflection rates on vaccination rollouts, as well as the potential confounding effects of more testing. Meanwhile, the protective effects of vaccines are clearly reflected in Models 4, 5, and 6, where vaccination rates are significantly negatively related to COVID-19 death rates (Table 3). The percentage of population under 18, including the age groups for which vaccines had not been available until much later or still are not available, is strongly associated with lower vaccination rates and higher COVID-19 case and death rates.

Table 2. Descriptive statistics of key variables.

Variable	*Mean*	*SD*	*Min*	*Max*	*Description*
Case rate	22,062	4,601	5,218	62,983	Confirmed COVID-19 cases per 100,000 people
Death rate	327	143	0	1089	Confirmed COVID-19 deaths per 100,000 people
Full vaccination rate	49.7	11.7	1.6	106	Full vaccination series completed per 100 people
% No Internet	20.6	8.2	2.5	59.6	% of households with no Internet access
% No computer	9.9	5.2	0.8	46.5	% of population with no computer at home
% Broadband	80.2	8.3	34.7	97.5	% of population with broadband Internet subscription
Population density	274	1,802	0	71,485	Population density (persons per square mile, log transformed in model)
% Under 18	22.2	3.5	7.3	41.8	% of population under 18
% 65 and over	18.8	4.6	3.2	56.7	% of population 65 and over
% Black	9.2	14.6	0.0	87.2	% of population Black
% Hispanic	9.4	13.9	0.0	99.2	% of population Hispanic
% Renter	28.3	8.2	6.9	80.3	% of housing units renter occupied
Poverty rate (%)	15.1	6.3	2.4	55.5	% of population living in poverty
Median income ($)	53,310	14,101	21,504	142,299	Median income, 2019 dollars (log transformed in model)
N	3,101				

Table 3. Digital access and COVID-19 outcomes, January 2022.

Dependent Variable	Cases per 100,000 people			Deaths per 100,000 people			Full vaccination series per 100 people		
	1	2	3	4	5	6	7	8	9
% No Internet	2505**			176.7***			1.571		
	(1224)			(42.59)			(3.629)		
% No computer		-444.6			122.1**			2.645	
		(1979)			(54.83)			(4.660)	
% Broadband			466.6			-78.72**			-0.391
			(1335)			(37.00)			(3.141)
Case rate (t – 1)				0.013***	0.013***	0.013***	0.000	0.000	0.000
				(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Full vaccination rate (t – 1)	39.42***	39.44***	39.41***	-1.189***	-1.193***	-1.186***			
	(7.937)	(7.944)	(7.944)	(0.220)	(0.220)	(0.220)			
Population density (logged)	290.6***	244.2***	241.7***	8.434***	7.076***	7.171***	1.619***	1.617***	1.605***
	(71.60)	(70.39)	(70.85)	(1.983)	(1.951)	(1.964)	(0.167)	(0.164)	(0.166)
% Under 18	5973**	6792**	6817**	725.6***	740.3***	744.3***	-40.96***	-41.11***	-40.71***
	(2819)	(2825)	(2819)	(78.11)	(78.37)	(78.22)	(6.629)	(6.637)	(6.623)
% 65 and over	-32477***	-32172***	-32160***	1050***	1053***	1057***	57.56***	57.42***	57.66***
	(2529)	(2537)	(2534)	(71.83)	(72.10)	(72.00)	(6.027)	(6.039)	(6.029)
% Black	-5433***	-5064***	-5049***	57.79***	69.28***	69.29***	13.37***	13.39***	13.50***
	(748.2)	(740.8)	(741.9)	(21.09)	(20.88)	(20.90)	(1.792)	(1.772)	(1.773)
% Hispanic	2848***	3073***	3089***	2.395	11.90	9.480	25.48***	25.55***	25.56***
	(791.7)	(786.9)	(789.0)	(21.96)	(21.85)	(21.92)	(1.812)	(1.800)	(1.805)
% Renter	-543	-1222	-1248	-43.50	-64.11*	-63.97*	20.32***	20.27***	20.09***
	(1255)	(1239)	(1240)	(34.76)	(34.34)	(34.38)	(2.933)	(2.890)	(2.896)
Poverty rate	-8421***	-7516***	-7447***	96.46	105.7	106.3	48.49***	48.17***	48.69***
	(2352)	(2383)	(2386)	(65.34)	(66.23)	(66.31)	(5.510)	(5.575)	(5.580)
Median income (logged)	-5717***	-6350***	-6372***	-115.3***	-135.1***	-134.9***	26.01***	25.95***	25.79***
	(738.3)	(708.2)	(709.8)	(20.80)	(20.06)	(20.12)	(1.730)	(1.657)	(1.664)
Intercept	88332***	95946***	95759***	1006***	1248***	1319***	-262.7***	-261.9***	-259.7***
	(8499)	(8102)	(7930)	(241.8)	(232.2)	(227.7)	(20.24)	(19.31)	(18.91)
N	3093	3093	3093	3093	3093	3093	3084	3084	3084
R Squared	0.41	0.41	0.41	0.53	0.53	0.53	0.50	0.50	0.50

***: p<0.01; **: p<0.05; *: p<0.1. All models include state fixed effects. Figures in parentheses are standard errors.

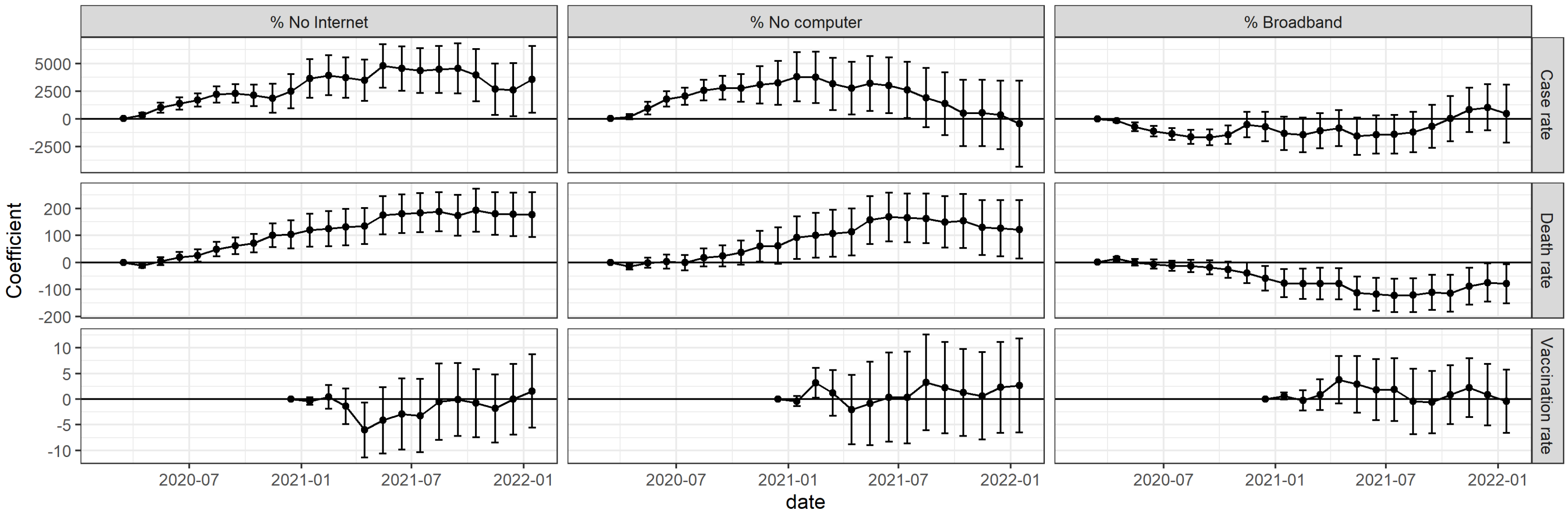

Figure 3. Estimates of the association between digital access and COVID-19 outcomes over time, March 2020 to January 2022.

Figure 3 illustrates the regression coefficients of the three digital divide indicators over time.[3] Interestingly, while the digital divide coefficients in Models 2 and 3 are not significant in January 2022 (Table 3), the percentages of population with no home computer or those with broadband connections actually demonstrated the expected relationships with COVID-19 case rates in earlier stages of the pandemic. As Figure 3 shows, % no computer had been positively associated with COVID-19 cases until summer 2021, and % broadband was negatively associated with COVID-19 cases until late 2020. The relationship between digital access and COVID-19 deaths, however, remained consistent throughout the pandemic and across all three digital divide measures. The results on vaccination rates are less clear. Table 3 indicates no associations between digital access and vaccination rates, though Figure 3 suggests there was a positive relationship between Internet access and full vaccination rates in April 2021 ($p = 0.028$ for % no Internet and 0.108 for % broadband), when all U.S. adults became eligible for COVID-19 vaccines per President Biden's deadline. This seems to be an indication that counties with more digitally excluded residents were somewhat slower in rolling out the vaccines, though the gap quickly diminished and disappeared within a few months. There was also a positive relationship between the percentage of individuals with no computer at home and full vaccination rates in February 2021, further complicating the relationship between digital access and COVID-19 vaccinations, though this could be a result of more residents in those counties qualified for early vaccines due to their age, occupation, or medical conditions.

In addition to the OLS regression models, spatial lag and spatial error models are fitted to account for spatial autocorrelation between adjacent counties. As spatial autoregressive models on a large dataset are computationally intensive, instead of estimating all nine models in Table 3

[3] Full results available upon request.

across all 23 periods, I estimated the models with COVID-19 case and death rates as the dependent variable for March 2020, August 2020, February 2021, August 2021, and January 2022, and the models with vaccination rates as the dependent variable for February 2021, April 2021, August 2021, and January 2022. Table 4 summarizes the coefficients of interest from these models. The results are consistent with those from the OLS models. Digital access, especially the access to Internet and broadband Internet, is positively associated with COVID-19 case and death rates throughout the pandemic, and temporarily related to higher vaccination rates in the first month of the vaccine rollout to the general public in the United States.

4. Conclusion

The digital divide is becoming a more prominent driver of social exclusion and inequalities in the age of the COVID-19 pandemic. As researchers reexamine the digital divide and digital exclusion as a social determinant of health (Clare, 2021; Ramsetty & Adams, 2020), this study argues that digital exclusion could have direct impacts on pandemic outcomes such as COVID-19 incidence and mortality. Digital exclusion could limit individuals' and communities' awareness and understanding of public health measures, obstruct preventative measures, and encourage or necessitate risky activities that lead to more coronavirus exposure. Using county-level data on digital access and COVID-19 case, death, and vaccination rates in the United States, I demonstrate that counties with a higher percentage of digitally excluded population have been consistently associated with higher COVID-19 death rates and experienced higher COVID-19 case rates, especially in the early stages of the pandemic.

Table 4. COVID-19 outcomes in U.S. counties with different levels of Internet access.

DV		*IV*	March 2020	August 2020	February 2021	August 2021	January 2022
Case rate	Spatial lag	*% No Internet*	25.06***	1850.30***	3659.14***	4117.63***	3179.40**
			(8.06)	(351.30)	(864.49)	(1028.28)	(1470.53)
		% No computer	22.68**	2281.40***	3406.76***	1726.64	-750.52
			(10.33)	(451.20)	(1112.27)	(1293.58)	(1882.73)
		% Broadband	-19.18***	-1434.83***	-1498.85**	-1168.00	447.59**
			(6.97)	(304.57)	(751.39)	(884.55)	(221.31)
	Spatial error	*% No Internet*	30.71***	1957.30***	4331.08***	4557.87***	3391.27**
			(8.69)	(370.74)	(917.29)	(1094.98)	(1541.78)
		% No computer	27.81**	2307.41***	3409.49***	1708.96	-1370.50
			(11.09)	(474.16)	(1174.63)	(1365.88)	(1971.01)
		% Broadband	-23.54***	-1448.26***	-1754.39**	-1065.56	885.62
			(7.51)	(321.18)	(796.18)	(937.59)	(1333.22)
Death rate	Spatial lag	*% No Internet*	-0.81	34.10***	127.21***	181.43***	197.25***
			(0.61)	(12.82)	(32.06)	(36.01)	(40.69)
		% No computer	-0.48	9.05	95.38**	148.07***	132.08**
			(0.78)	(16.47)	(41.25)	(45.22)	(52.41)
		% Broadband	0.60	-5.30	-80.13***	-113.58***	-89.97**
			(0.53)	(11.11)	(27.79)	(30.89)	(35.31)
	Spatial error	*% No Internet*	-0.75	35.58***	126.05***	182.64***	197.91***
			(0.63)	(13.71)	(33.70)	(38.00)	(43.11)
		% No computer	-0.40	8.79	94.20**	148.00***	133.16**
			(0.80)	(17.57)	(43.19)	(47.45)	(55.25)
		% Broadband	0.50	-4.09	-77.04***	-108.59***	-88.59**
			(0.54)	(11.88)	(29.16)	(32.49)	(37.34)
			February 2021	April 2021	August 2021	January 2022	
Full vaccination rate	Spatial lag	*% No Internet*	0.51	-5.14**	-4.96	-3.50	
			(1.09)	(2.29)	(3.50)	(3.35)	
		% No computer	2.88**	-3.37	-1.81	-2.29	
			(1.39)	(2.95)	(4.39)	(4.30)	
		% Broadband	-0.09	3.82*	3.45	3.10	
			(0.94)	(1.98)	(3.00)	(2.90)	
	Spatial error	*% No Internet*	0.47	-5.36**	-2.78	-1.76	
			(1.16)	(2.46)	(3.80)	(3.62)	
		% No computer	3.25**	-3.02	-0.01	-1.10	
			(1.48)	(3.14)	(4.71)	(4.61)	
		% Broadband	0.25	4.93**	3.56	3.52	
			(1.00)	(2.13)	(3.23)	(3.12)	

***: p<0.01; **: p<0.05; *: p<0.1. All models include state fixed effects. Figures in parentheses are standard errors.

The relationship between digital access and COVID-19 vaccination rates is less straightforward. Significant associations are only found in the first months of the vaccine rollout, with an indication that higher percentages of residents with no Internet or broadband access are associated with lower vaccination rates in April 2021, when the vaccines were first made available to all U.S. adults. Another measure of digital exclusion, the percentage of residents with no computers at home, is positively associated with vaccinations in February 2021, when the vaccines were still limited to at risk populations. A number of other county-level factors, including the percentage of Black and elderly populations, are also shown to have changing relationships with COVID-19 case rates over time. Like other studies using COVID-19 metrics, findings regarding confirmed COVID-19 cases may be affected by testing rates (Omori, Mizumoto, & Chowell, 2020). Nevertheless, the temporal variation in these relationships reflect an evolving landscape of the pandemic, and understandings of the neighborhood determinants of COVID-19 incidence based on early data may need an update.

These findings highlight the importance of digital inclusion in bridging health disparities in the pandemic. In a country with one of the highest prevalence of digital access, there remain substantial gaps between counties that are well connected and those that are poorly connected, with the latter experiencing much higher COVID-19 incidence and mortality. Even as the current wave of Omicron surge recedes and governments relax containment measures, the impacts of the pandemic on vulnerable populations and communities are far from over. Further research is direly needed to better understand the implications of the digital divide on pandemic impacts and resilience, especially research on the individual level that can shed light on the four potential pathways through which digital exclusion may lead to worse COVID-19 outcomes. Such understanding can help government and public health agencies address the immediate challenges in digitally disconnected communities. For example, if the inability to telework and avoid exposure is a main driver of the higher case and death rates, policy measures should target better COVID-19 protection, including ventilation and sanitation standards and PPEs, in workplaces for essential workers and public transportation. If the delay in information dissemination is a key factor, offline channels of education and outreach should be expanded in communities with lower levels of digital access. However, to reduce health disparities related to digital exclusion in the long term requires addressing the digital divide itself. Policy makers must recognize broadband Internet as an essential service and critical infrastructure in the digital era and make the essential technologies accessible and affordable to all.

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