Blessings in Disguise: How Disasters Can Save Small-Town America by Facilitating Broadband Service Expansion

Citation
Gibson, Sherry Evans. 2024. Blessings in Disguise: How Disasters Can Save Small-Town America by Facilitating Broadband Service Expansion. Master's thesis, Harvard University Division of Continuing Education.

Blessings in Disguise: How Disasters Can Save Small-Town America by Facilitating Broadband Service Expansion

Sherry E. Gibson

A Thesis in the Field of Sustainability

for the Degree of Master of Liberal Arts in Extension Studies

Harvard University

March 2024

Abstract

Broadband is a critical part of modern infrastructure but is not available to all Americans and is lacking in rural communities. This is illustrated by the fact that in 2019, 42 million Americans (13% of the population) were without high-speed internet access – in contrast with universal access to indoor plumbing and electricity. This disparity contributes to a widening gap in educational and employment opportunities between rural and urban communities as well as a decline in rural populations. My research sought to examine the hypothesis that expanded broadband infrastructure deployed as part of federally funded disaster recovery efforts provides a mechanism for increasing rural population sustainability by increasing educational participation and increasing access to employment opportunities.

Household level data from the American Community Survey (ACS) and the US Census Bureau were combined with disaster relief information from the Federal Emergency Management Agency (FEMA) to evaluate the relationships between storms and broadband and between broadband and community sustainability variables. Linear regression analysis confirmed that broadband access: 1) is negatively impacted by natural disasters and that this effect is more pronounced in rural areas, 2) is a significant driver of population growth in rural areas, 3) increases school attendance in rural areas, and 4) drives entry into the labor market and obtaining employment – with a greater impact at lower education levels.

Taken together, the results of this research point to a clear, positive impact to rural community sustainability that can be gained by accelerating the expansion of broadband access following a natural disaster. The results could help government agencies evaluate the social benefits and cost effectiveness of including broadband deployment in parallel with the reconstruction of the electricity grid after a natural disaster. The results can also be used to inform the policy changes in the Stafford Act that will be necessary to allow for federal post-disaster recovery funds to be allocated to the construction of new broadband infrastructure.

Dedication

I dedicate this to my parents, Joseph and Patricia Evans, whose demonstration of the power of persistence, loyalty, and kindness are daily reminders of lives well lived.

.

Acknowledgments

This thesis and the preceding classwork would not have been possible without the support of my husband, David, and our daughters, Emily, and Ellen.

A special thanks to Dr. Joshua Schabla, whose guidance and insights as my thesis director were instrumental to its completion.

Table of Contents

List of Tables

List of Figures

Definition of Terms

AT&T	American Telephone and Telegraph and Associated Companies
ACS	American Community Survey
DSL	digital subscriber line
EUR	Euro
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
HUD	Housing and Urban Development
IPUMS-USA	Integrated Public Use Microdata Series-United States of America
ISP	internet service provider
M	million
Mbps	megabits per second
NOAA	National Oceanographic and Atmospheric Administration
SAT	Standard Aptitude Test
USD	United States Dollar

Chapter I

Introduction

Broadband is a significant part of modern infrastructure and is not available to all Americans, disproportionately lacking in rural communities (Karsten & West, 2016; Lee et. al., 2022; Tolbert & Snead, 2021; Vogels, 2021). This disparity contributes to the widening gap in the educational and employment opportunities between rural and urban areas in America, which in turn has contributed to trends in migration from rural to urban communities. Over the past century, out-migration and declining birth rates have decreased the population of rural small towns by 76% (Cromartie, 2017). Population loss represents a massive threat to the future of rural America. Declining population results in a smaller tax base for these towns, putting the significant investment required to develop broadband infrastructure out of reach. Not only are these rural communities not able to retain their existing populations, but they are also unable to attract new residents.

Small towns in the United States have experienced depopulation over the past several decades driven by an aging population and out-migration of younger residents (Slack & Jensen, 2020). From the early 1900s until 2010, the percentage of Americans living in rural communities declined from 95% to 19% (Cromartie, 2017). While the definition of rural varies, it is generally considered to be a community with fewer than 20,000 residents. By 2020, only 14% of the population of the United States remained in rural areas (Dobis et al., 2021). Two significant factors that contribute to a resident's decision to relocate from rural to urban areas are limited employment and educational opportunities (Carr & Kefalas, 2009).

One way to address the increasing economic gap between rural and urban residents over the last 15 years is to leverage remote work and educational opportunities (Kopparam, 2020). However, without broadband infrastructure, remote employment and education are harder to access, leaving small towns across the United States struggling to retain sustainable populations and remain economic centers (Alexander, 2017; Boustan et al., 2020; Strong Towns, 2020). Broadband is defined as systems that meets a minimum of 25 megabits per second (Mbps) download and three Mbps upload maximum possible network speed denoted as 25/3Mbps (Williams, 2022). Like other components of common infrastructure that were largely completed in the 20th century, including transportation, energy, water, and sewage, broadband internet service is a foundation for economic activity that has the potential to support and expand a broad range of economic activity in rural communities, thereby slowing the population decline that has occurred over the past several decades (de Sa, 2017). While the benefits of broadband expansion are clear, many small towns lack the resources necessary to make broadband infrastructure investments and service is not offered by commercial internet service providers because the cost to install fiber optic cables is too high relative to the profits generated in areas where homes and businesses are far apart (Kenny et al., 2022; Wright, 2021, First Citizen Bank, 2021). As an example, Conroy et al. (2023) reported that the addition of fiber optic lines to existing power distribution/telephone poles for broadband costs approximately $12,000 per mile (in 2014 USD) (Figure 1) (Porter, 2022). In Outagamie County, Wisconsin, a rural county with 277 people per square mile and higher installation costs, the cost to install broadband service was $54 person (Conroy et al., 2023). In Richland County, Wisconsin, a more rural county with 31 people per square mile, the cost to install the fiber optic lines was $387 per person, a more than 700% increase over their more urban neighbors (Conroy et al., 2023).

Figure 1. Fiber-optic installation.

Linemen installing fiber-optic cable for broadband internet to existing power distribution/telephone poles in Seneca, SC (Porter, 2022)

Climate change has increased the frequency and severity of natural disaster events. Rural communities are less able to recover from storm events without federal assistance due to limited resources and aging infrastructure (Hasse et al., 2020). Additionally, the destruction associated with severe storms continues to adversely impact economic conditions in rural areas after the event (Chorynski et al., 2022). The devastation caused when severe winds from hurricanes damage overhead electricity distribution lines seems an unlikely vehicle for stabilizing the depopulation of rural America.

However, these natural disaster events present an opportunity to incorporate broadband expansion into the federally funded reconstruction efforts if broadband fiber optic lines are installed concurrent with reconstruction of the electric power lines. Without federal assistance, the insurmountable cost to small towns of introducing broadband to the area means that residents that seek greater education and job prospects must relocate to benefit from the opportunities provided by cities (Marré, 2020). By incorporating broadband expansion into federally funded electric grid reconstruction efforts, the cost could be greatly reduced to small towns. Rural communities could pay the marginal cost of broadband by relying on crews and equipment provided by the federal government as part of storm recovery, reducing the cost of broadband by upwards of 60% (Kim, 2022). Such a strategy could simultaneously address the desire of millions of Americans to live in a rural setting and address the economic disparities that rural Americans face.

Research Significance and Objectives

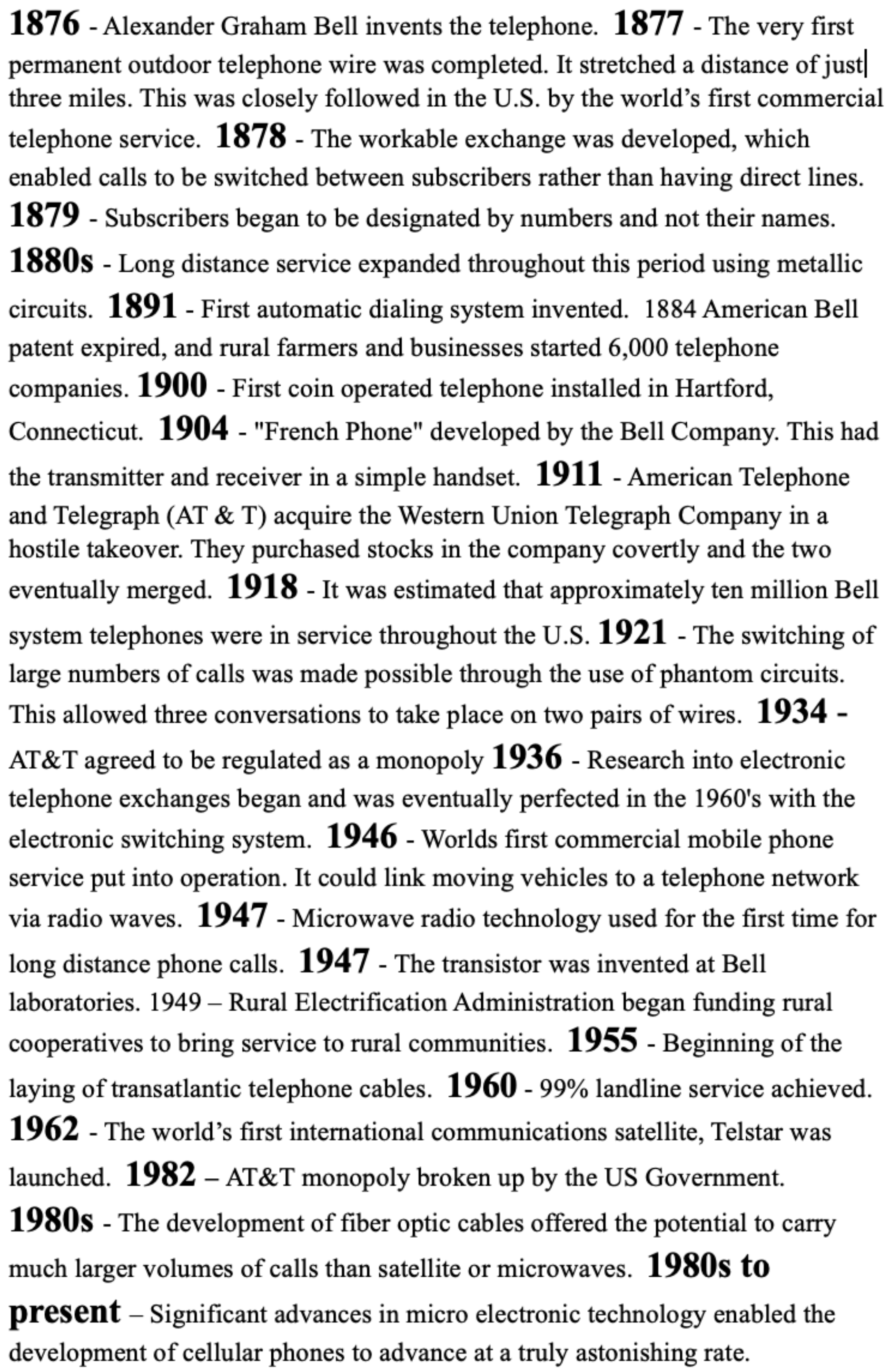
My results could help government agencies evaluate the benefit and effectiveness of including broadband deployment in parallel with the reconstruction of the electric grid after a natural disaster, which for the purpose of this research, was defined as a federally declared weather related disaster. Further, by establishing the relationships between education, employment opportunity and population loss, community leaders can prioritize where to focus their population retention efforts.

Therefore, the objectives of my research were to:

- Evaluate the impact that expanding broadband access has on educational and employment opportunity equalization between rural and urban areas and how these might impact population stabilization in rural American towns.
- Propose a paradigm shifting approach to broadband expansion following natural disaster events, that increases broadband adoption in rural communities through use of federal funding, reducing the cost burden borne by the community.

Background

The history of rural broadband deployment dates to the late 1870s with the installation of telephones in all major cities in the United States by the American Bell Company (Dawson, 2022) (Figure 2). American Bell held the patent for the telephone but did not offer telephone service to rural areas (Dawson, 2022). After the American Bell patent expired in 1894, rural farmers and businesses started more than 6,000 telephone companies by 1927 – serving 18 million consumers (7% of the United States population) (NTCA, 2023; Dawson, 2023). By 1934, American Bell, now called American Telephone and Telegraph and Associated Companies (AT&T), agreed to become a regulated monopoly (Dawson, 2022). AT&T was strongly rooted in American cities and small rural telephone companies also became regulated and did not thrive (Grabel, 2022). By 1949, the Rural Electrification Administration began funding rural telephone cooperatives to bring service to rural counties and achieved 99% landline



1876 - Alexander Graham Bell invents the telephone. **1877** - The very first permanent outdoor telephone wire was completed. It stretched a distance of just three miles. This was closely followed in the U.S. by the world's first commercial telephone service. **1878** - The workable exchange was developed, which enabled calls to be switched between subscribers rather than having direct lines. **1879** - Subscribers began to be designated by numbers and not their names. **1880s** - Long distance service expanded throughout this period using metallic circuits. **1891** - First automatic dialing system invented. 1884 American Bell patent expired, and rural farmers and businesses started 6,000 telephone companies. **1900** - First coin operated telephone installed in Hartford, Connecticut. **1904** - "French Phone" developed by the Bell Company. This had the transmitter and receiver in a simple handset. **1911** - American Telephone and Telegraph (AT & T) acquire the Western Union Telegraph Company in a hostile takeover. They purchased stocks in the company covertly and the two eventually merged. **1918** - It was estimated that approximately ten million Bell system telephones were in service throughout the U.S. **1921** - The switching of large numbers of calls was made possible through the use of phantom circuits. This allowed three conversations to take place on two pairs of wires. **1934 -** AT&T agreed to be regulated as a monopoly **1936** - Research into electronic telephone exchanges began and was eventually perfected in the 1960's with the electronic switching system. **1946** - Worlds first commercial mobile phone service put into operation. It could link moving vehicles to a telephone network via radio waves. **1947** - Microwave radio technology used for the first time for long distance phone calls. **1947** - The transistor was invented at Bell laboratories. 1949 – Rural Electrification Administration began funding rural cooperatives to bring service to rural communities. **1955** - Beginning of the laying of transatlantic telephone cables. **1960** - 99% landline service achieved. **1962** - The world's first international communications satellite, Telstar was launched. **1982** – AT&T monopoly broken up by the US Government. **1980s** - The development of fiber optic cables offered the potential to carry much larger volumes of calls than satellite or microwaves. **1980s to present** – Significant advances in micro electronic technology enabled the development of cellular phones to advance at a truly astonishing rate.

Figure 2. History of telephone service.

Telephone service from 1876 to present (Dawson, 2022; Schmidt, 2023; author's elaboration, 2023).

telephone service by 1960 (Dawson, 2022). AT&T generally held their monopoly until 1982 when it was broken up by the federal government (Grabel, 2022). New telephone companies then entered the market and focused on bringing competition to the cities, including the early internet access known as digital subscriber line (DSL) service (Dawson, 2022). While some of the remaining rural telephone companies installed DSL lines, they could not afford to keep pace with the upgrades that were being made in the cities (Dawson, 2022). Rural areas were again passed over starting in 1984 after the federal apportionment of AT&T into seven regional telecommunications holding companies that constructed cellular networks along interstate highways but not into the small towns that are scattered across the American countryside (Dawson, 2022; Schmidt, 2023). This experience with telephone service shows the importance of federal government assistance in expanding critical infrastructure and logically extends to broadband.

Declining Rural Populations and Access to Broadband Internet Service

The population in non-urban areas has changed significantly from 2010 to 2016 (Figure 3). Seventy percent of the United States' land is outside of its metro areas, yet, over the past decade, the population of small towns decreased by 0.6% in contrast to an urban growth rate of 8.8% (Cromartie, 2017; Dobis et al., 2021). Furthermore, the area of rural population decline in the southeastern portion of the USA is in common with the coastal areas that are most frequently impacted by hurricanes (Cromartie, 2017).

Further analysis reveals that the population of persistently poor counties (defined as counties with 20% or more of its residents living below the federal poverty line for the past four U.S. Census national events) declined by 5.7% over the past decade while the

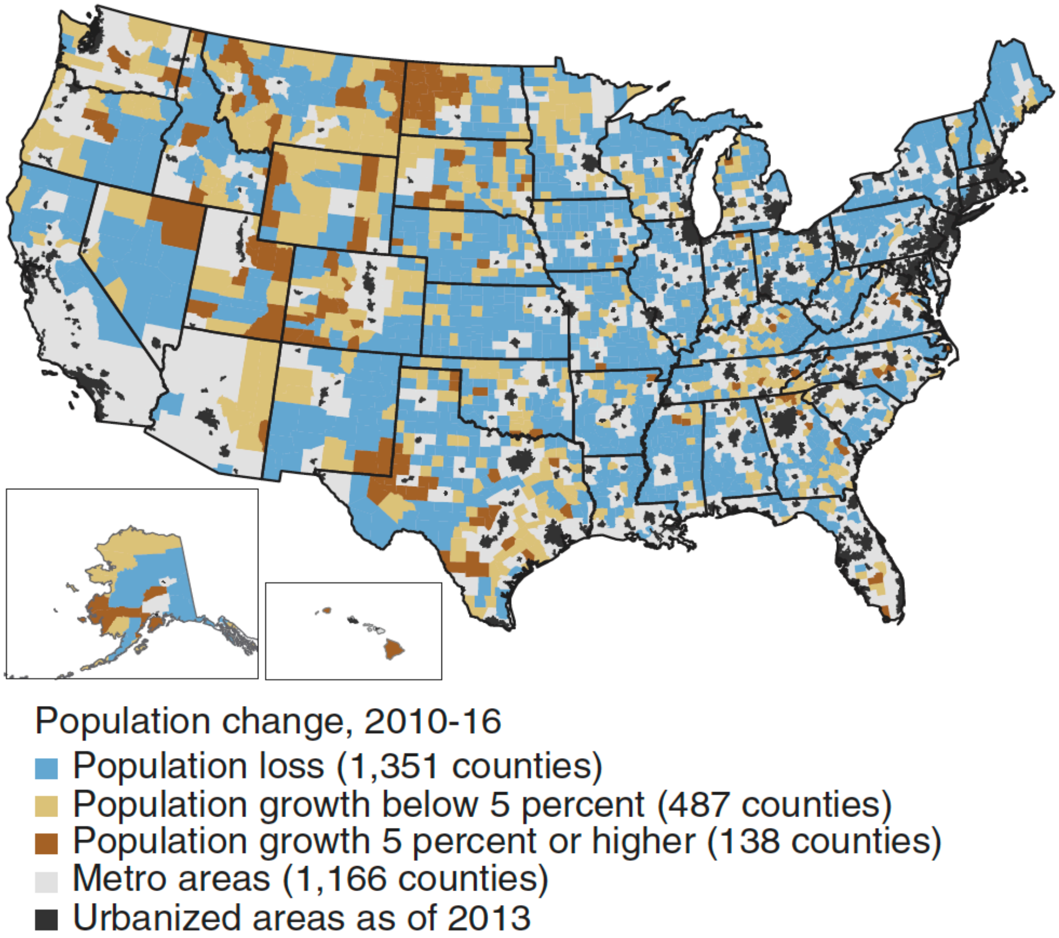
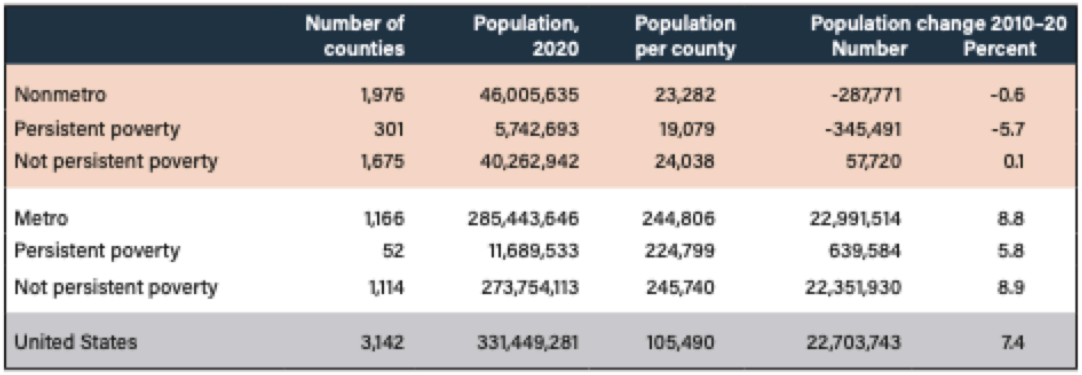


Figure 3. Rural population change 2010 – 2016.

Source: Cromartie, 2017

population of rural counties that are not persistently poor increased by 0.1% (Dobis et al., 2021). In urban counties, the population of persistently poor areas grew at 5.8% over the past decade while more affluent urban areas grew at 8.9% (Table 1). (Dobis et al., 2021).

Table 1. Population statistics.



	Number of counties	Population, 2020	Population per county	Population change 2010–20 Number	Percent
Nonmetro	1,976	46,005,635	23,282	-287,771	-0.6
Persistent poverty	301	5,742,693	19,079	-345,491	-5.7
Not persistent poverty	1,675	40,262,942	24,038	57,720	0.1
Metro	1,166	285,443,646	244,806	22,991,514	8.8
Persistent poverty	52	11,689,533	224,799	639,584	5.8
Not persistent poverty	1,114	273,754,113	245,740	22,351,930	8.9
United States	3,142	331,449,281	105,490	22,703,743	7.4

Population statistics for counties by poverty and metropolitan status 2010-2020 (Dobs et al., 2021).

Poor towns are declining while populations of wealthier cities increase (Dobis et al., 2021). The impact of the COVID-19 pandemic on small town populations is noteworthy. Despite extensive media attention focused on the exodus of people from cities to small towns during the pandemic, the United States Census Bureau reported that permanent migrations from cities to small towns dropped to historically low levels in

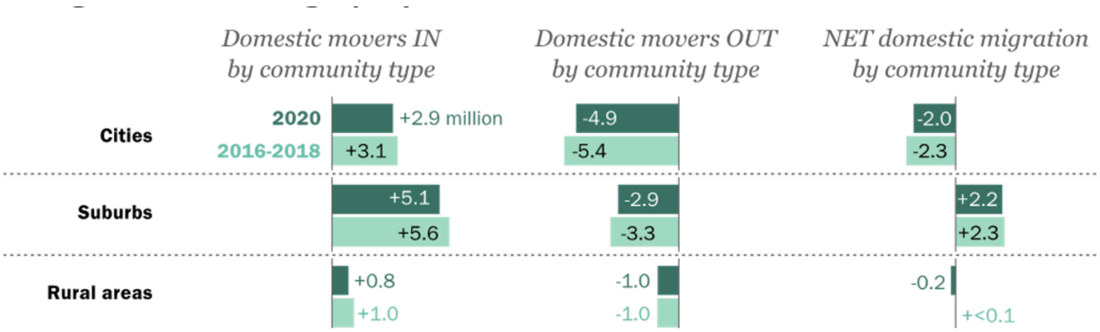


Figure 4. Residence changes.

Total and percentage of people ages 1 and older that changed residence in the US by year (Fry & Cohn, 2021).

2020 (Fry & Cohn, 2021; United States Census Bureau, 2021). Fewer people moved out of cities in 2020 than prior to the pandemic with the majority relocating to the suburbs (Figure 4) (Fry & Cohn, 2021).

An evaluation of the relationship between the availability and adoption of broadband and economic health of small towns in the United States has revealed a digital divide between small towns and urban centers (Figure 5). Census blocks in rural areas are categorized as having internet service if a single house in the census block can plausibly access broadband (Marré, 2020). In urban areas, census blocks are small and access for one household reasonably means access for all houses in the census block (Marré, 2020, Whitacre et al., 2014a). In rural areas, census blocks can cover hundreds of square miles and broadband service to one household does not practically mean that all households over the census block have access (Marré, 2020). Accounting for the difference in urban and rural census block sizes, Marré (2020) estimated that 42 million Americans (13% of the population) lacked access to high-speed internet in 2019. For comparison to other components of American infrastructure, 99.6% of households had complete plumbing and 100% of households had access to electricity in 1950 – reflecting universal access to these utilities (Tomer et al., 2020).

Expansion of broadband into rural areas impacts labor markets, homeowners, businesses, telemedicine, and education (Marré, 2020). A study of 887 remote rural counties in the United States with median home values of $101,831 and median household income of $44,070 found that broadband service had a positive impact on housing prices, with a 10% increase in coverage of at least 0.2 megabits per second resulting in a $661 increase in median home value (Deller & Whitacre, 2019). However,

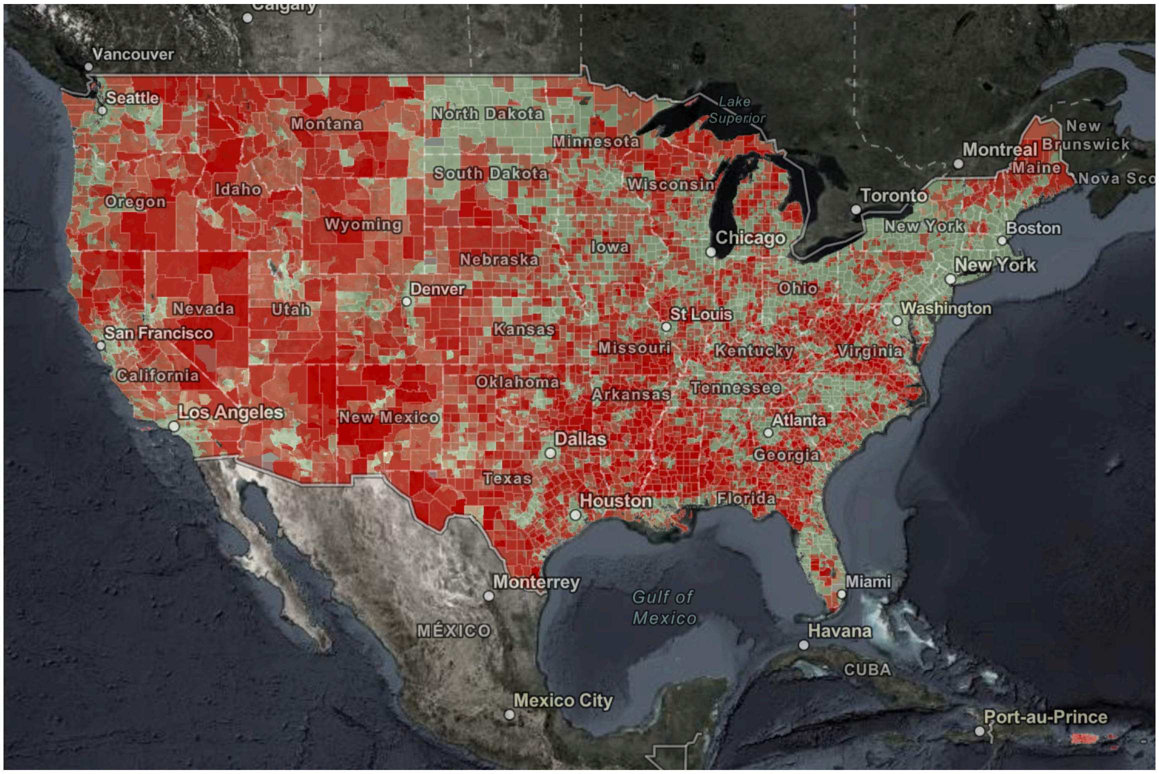


Figure 5. Map of broadband service in the United States.

American counties without access to broadband service at 25/3 Mbps are shown in red. (National Telecommunications and Information Administration, 2022).

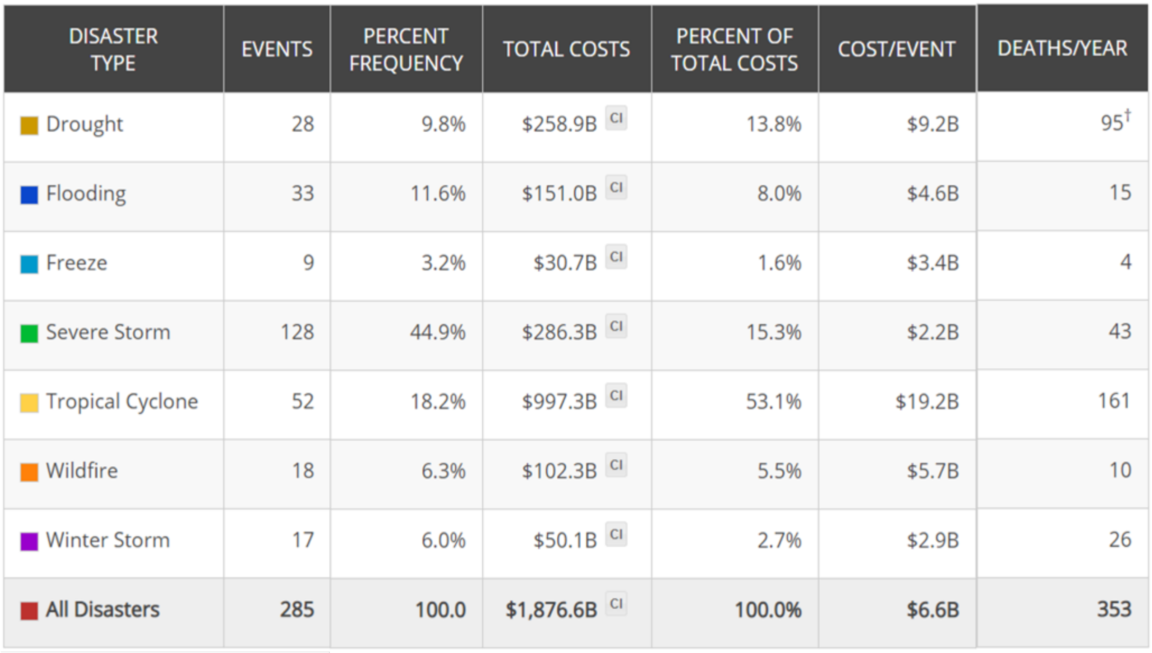
this extrapolation might be misleading. It was based on theoretical maximum internet speeds reported by the internet service providers in lieu of actual delivered speeds at the home. This assumption could yield different conclusions on the impact of broadband service on home values if delivered broadband service speeds are slower than reported. Additionally, similar to the FCC (2020) study, this study assumed that a single instance of broadband availability in a census block meant that service was available to the entire block which is often not true in rural areas.

Extreme Weather Events and FEMA Mitigation Funding in Rural Communities

Concurrent with depopulation trends, extreme storm events are increasing in frequency and intensity, which is adversely impacting small towns and urban areas (Vecci et al., 2021). The National Oceanographic and Atmospheric Administration (NOAA) identified 22 weather and climate disasters in the United States in 2020 that exceeded one billion dollars ($1B) in damages, including seven tropical cyclones, thirteen severe storms, one drought, and one wildfire (Smith, 2021). These 22 events combined for $95 billion in damage to US taxpayers (Smith, 2021). From 1980 through 2000, the US has experienced 285 weather and climate disasters that each cost the nation at least $1B, totaling $1.876 trillion (Smith, 2021; Tomer et al., 2020) (Table 2). Severe storms and tropical cyclones predominate the event frequency (63.1%) and percentage of total cost (68.4%) and correspond to the greatest likelihood of power outages.

To mitigate the impact of extreme weather events, the federal government has sought to increase the resilience of communities, recognizing that the components of small-town resilience are different from urban resilience (Office of the President of the United States, 2017; Haase et al., 2020). In additional to disaster relief, the Federal Emergency Management Agency provides funding to communities via planning grants to enhance 1) disaster preparedness knowledge, 2) infrastructure to mitigate the risks associated with disasters (e.g., communication systems, emergency healthcare services), 3) disaster mitigation planning and enforcement of building codes, and 4) natural resource management including floodplain and wetlands management (Haase et al., 2020). The aftermath of Hurricane Harvey in 2017 revealed that Texas communities lacked the resilience to recover from extreme weather events (Hasse et al., 2020).

Table 2. Summary statistics on billion-dollar disasters in the US, 1980 – 2000.



DISASTER TYPE	EVENTS	PERCENT FREQUENCY	TOTAL COSTS	PERCENT OF TOTAL COSTS	COST/EVENT	DEATHS/YEAR
🟨 Drought	28	9.8%	$258.9B CI	13.8%	$9.2B	95†
🟦 Flooding	33	11.6%	$151.0B CI	8.0%	$4.6B	15
🟦 Freeze	9	3.2%	$30.7B CI	1.6%	$3.4B	4
🟩 Severe Storm	128	44.9%	$286.3B CI	15.3%	$2.2B	43
🟨 Tropical Cyclone	52	18.2%	$997.3B CI	53.1%	$19.2B	161
🟧 Wildfire	18	6.3%	$102.3B CI	5.5%	$5.7B	10
🟪 Winter Storm	17	6.0%	$50.1B CI	2.7%	$2.9B	26
🟥 **All Disasters**	**285**	**100.0**	**$1,876.6B** CI	**100.0%**	**$6.6B**	**353**

Source: Smith, 2021.

Small town resilience is driven by the social, economic, physical, human, institutional, and environmental capacities of the community (Haase et al., 2020). Community resilience was found to decrease with decreasing population and decreasing population density with a particular vulnerability associated with small towns lacking the resources to staff emergency management personnel and maintain the associated policies and procedures (Hasse et al., 2020). Additionally, small towns were found to frequently lack the political sophistication to acquire recovery funds from the federal government (Hasse et al., 2020).

Economics of Broadband Accessibility and Adoption

Beyond studies of the immediate response to storm events, academic research on the economic impact of infrastructure investment after hurricanes and extreme weather events has been limited (Fussell et al., 2017). However, the impact of non-storm related investment in small town broadband infrastructure has been studied extensively. Improving broadband accessibility contributes to increasing population, higher rates of business formation, and lower unemployment rates (Marré, 2020).

In Finland, broadband connectivity increased for 33,717 people from 2012-2019 at a cost of EUR 43 million (45.1 million USD) from government funding, 65% of whom lived in sparsely populated rural areas and another 25% in rural areas (Lehtonen, 2020). Broadband construction made a measurable difference for rural population trends, with areas gaining broadband service losing 5.7% of their population while areas without broadband service losing 7.9% of the population (Lehtonen, 2020). This study also concluded that had broadband expansion been completed in 2010 rather than experiencing construction delays, the depopulation trend would have stabilized by 2018 with annual regional growth rates of 0.1%. Specific foci of improved broadband access have been employment and education impacts.

Employment Impact

One of the earliest and most influential papers demonstrated positive effects of broadband on the job market (Lehr et al., 2006). This work and the research that immediately followed focused primarily on urban areas, showing positive relationships between broadband and a variety of job market outcomes, such as firm location decisions, salaries, and economic growth (Gillett et al., 2006; Kolko, 2010; Kolko, 2012; Kuttner, 2012; Mack et al., 2011; Stenberg et al., 2009).

Two of the earliest investigations of the impact of broadband on rural areas were from Whitacre et al. (2014a; 2014b). Through an analysis of both broadband availability and adoption with county-level demographic and socioeconomic data, rural areas with higher levels of broadband availability and adoption were found to have more businesses and jobs than those areas where broadband was either not available or not used (Whitacre et al., 2014a). Analysis also included as variables the portion of non-farm workforce, the median household income, the number of companies with paid employees, and the total number of employed people. Whitacre et al. (2014a) found that counties with broadband adoption rates less than 40% had employment growth rates 3% lower than their counterparts with higher broadband usage and counties with residential broadband usage exceeding 60% had more businesses and total employed residents (Whitacre et al., 2014a). The Whitacre studies were limited in that they did not include broadband expansion areas that were financed by the 2009 American Reinvestment and Recovery Act and may underestimate the impacts of broadband on employment. The association of increased broadband usage with more non-farm businesses (entrepreneurs) and higher median household income led to a recommendation of broadband expansion to less economically developed areas (Whitacre et al., 2014a).

Adoption of broadband was also found to influence the selection of business locations in US rural areas. Zip codes with broadband availability were 60%-101% more likely to be selected by businesses and entrepreneurs than areas without broadband service (Kim & Orazem, 2016). They examined 63,241 commercial companies in Iowa and North Carolina, finding that improved broadband connection increased the number of local firms. Rather than using the approach of Whitacre et al. (2014a), which relates the rate of change between an input variable and an output variable, Kim and Orazem (2017), used a difference-in-differences approach. This approach compared the respective rates of change between two difference groups over time rather than looking at the overall rates of change within the United States. They found that the availability of broadband services increased a firm's first entry into a rural area by 83% if the rural area is close to an urban area with a population of at least 2,500 people (Kim & Orazem, 2017). Rural areas that are close to urban areas are shown as urban clusters below (Figure 6) (Cromartie, 2019). However, the study did not find that nationwide broadband availability would close the gap between urban and rural economic growth, but that broadband availability would result in economic growth favoring communities with broadband (Kim & Orazem, 2017).

The challenges of rural broadband availability are not unique to the United States. An evaluation of the impact of the availability of broadband internet service on labor markets revealed that Swedish small towns benefited from the addition of broadband (DeVos et al., 2020). First, broadband availability improved the business environment in small towns within 30 km of an urban area by attracting more businesses to the small town, increasing employment by an average of 0.8% with attainment of full connectivity resulting in a 1.4% increase in the employment rate (DeVos et al., 2020). DeVos et al. (2020) also noted that commuting distance was reduced in small towns within 30 km of an urban core as more small-town residents were able to find employment locally.

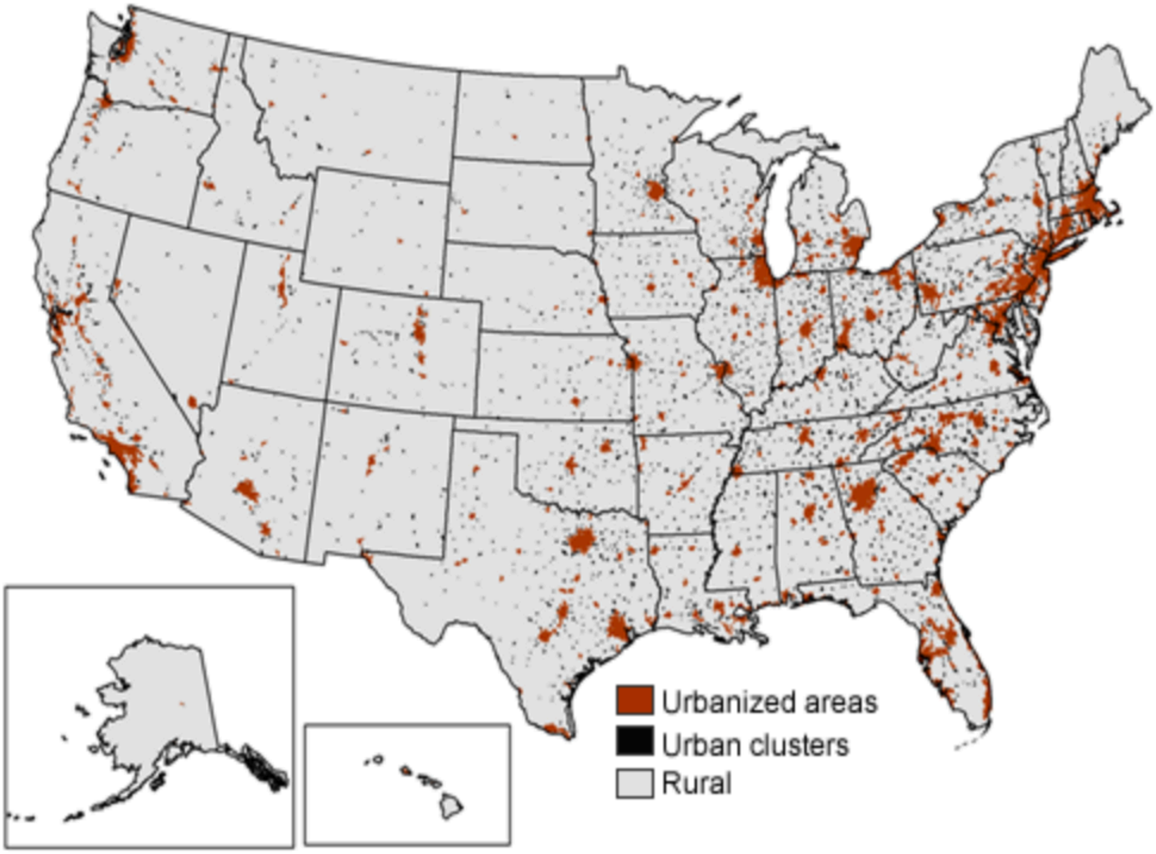


Figure 6. Map of urban areas.

Urban areas with more than 50,000 people are shown in red, urban clusters with 2,500 to 49,999 people are shown in black, and rural areas fewer than 500 people per square mile are shown in gray (Cromartie, 2019).

Commuting distances (distance of the worker from their employer) for towns farthest (> 30 km) from urban areas were found to increase the most with the introduction of broadband, which was loosely explained by the "work-from-home" phenomenon, wherein workers could remain in small towns and work for employers in a distant urban area (DeVos et al., 2020). These studies demonstrate the value of broadband connectivity to firm location decisions with commensurate impacts on rural employment rates.

Education Impact

Investigation of the relationship between broadband access and educational opportunities is surprisingly sparse. While access to broadband is commonly touted as a way to increase educational opportunities, and some startups have been created to provide remote opportunities, it was only with the COVID-19 pandemic that remote learning really took off as a subject of academic interest as well as a common tool for learning (Mayfield & Ali, 1996; Oliveira et al., 2021).

Only two studies have examined specific measures of educational performance based on broadband availability. However, the findings were what one would expect a priori: lack of broadband access hinders educational opportunities. Dettling et al. (2018) found a relationship between broadband access and standard aptitude test (SAT) scores. Specifically, having broadband access increased the overall score by 0.3% of a standard deviation. More striking is the finding that the presence of broadband in the home during both the junior and senior year of high school corresponded to a three percent increase in the number or students applying to top liberal arts colleges (from 536,566 students to 552,663 students) between 2001 and 2008 (Dettling et al., 2018). Sanchis-Guarner et al. (2021) found a one megabit per second (Mbps) increase in internet speed was correlated with a rise in test scores of 1.37 percentile ranks among 14-year-olds in the United Kingdom.

Though these effects of broadband access are relatively small, there are other benefits to remote educational opportunities that do not show up in test scores. These include benefits such as improved familiarity with online resources, remote communication skills, and improved access to educational opportunities (Lee et al., 2015;

Mason & Rennie 2004; Minichiello et al., 2013). Although quantifying these benefits remains to be accomplished, it is reasonable to assume that they will all be positively impacted by broadband connectivity. For example, the Education Commission of the States found that 17% of teenagers are often unable to complete homework assignments because they do not have access to a computer or internet connection (Kelley & Sisneros, 2020). Students without internet access had lower grade point averages, lower standardized testing results, and less interest in pursuing higher education (Kelley & Sisneros, 2020). In areas where broadband is available, remote learning has become an accessible option for students of all ages. In 2017, nearly 300,000 students attended full-time virtual public schools across 35 states (Kelley & Sisneros, 2020). In 2018, almost seven million students attended higher-education distance learning courses (Kelley & Sisneros, 2020). With increased rural connectivity, the educational impacts of broadband can be better addressed so that an individual is not required to leave their home to obtain a secondary education.

Synthesizing the findings in Slack & Jensen (2020) with those of Marré (2020), the two most significant causes of outmigration in small town America are due to job market prospects and educational opportunities. Broadband has a measurable impact on job creation, both locally and remotely, as well as on education. Therefore, it seems logical that broadband directly addresses significant contributors of outmigration in small-town regions. Improving broadband access addresses the most significant community sustainability issue facing rural America: how to improve small towns so that people want to live there.

Broadband Funding

Although research on the impact of investment in broadband infrastructure on small town sustainability after extreme weather events is nearly non-existent, after Hurricanes Irma and Maria struck Puerto Rico in 2017, the Puerto Rican and United States governments allocated $633.9 million (M) to support the construction of a new telecommunications system for the island via public-private partnerships (Cordova & Stanley, 2021). It will take many years to design, construct, and evaluate the impact of new broadband service for Puerto Rico, but the isolation of the island is likely to make it an interesting subject for future study.

Consumers in most regions of the United States purchase broadband internet service from internet service providers such as AT&T, Verizon, Charter, Comcast, Cox, and Lumen (Goovaerts, 2021). Broadband service is not available in many rural areas because the return on investment from rural accounts is not enough to cover the cost for these private companies to build an expansive network with few subscribers, a challenge known as the last mile problem (Campbell et al., 2021). The issue of limited revenues from areas with low population density is exacerbated by the additional costs to extend broadband to rural areas that are exceedingly remote or inaccessible via very rough terrain (Campbell et al., 2021). To fill this gap in the commercial marketplace, the federal government has been funding broadband construction since the passage of the Telecommunications Act in 1996 (Campbell et al., 2021). While progress has been made with these investments, some of the programs have low consumer adoption rates due to service restrictions and slow speeds (Campbell et al., 2021). The installation of broadband infrastructure is currently funded by a wide variety of federal and state investments and grants that are implemented by state, local, and tribal governments as well as corporations and public-private partnerships (Table 3) (Connected Nation, 2022).

Table 3. Broadband infrastructure funding.

Funding Source	Funding ($)	Recipients	Focus
The American Jobs Plan	$65,000,000,000	Individual states	Underserved areas Installation of fiber optic lines
Reconnect Loan and Grant Program	$1,300,000,000 (2021) $700,000,000 (annually after 2021)	Corporations, states, local, and tribal governments	Towns where 90% of household lack access to broadband. Towns with less than 20,000 residents
Coronavirus State and Local Fiscal Recovery Funds	$350,000,000,000 – may be used for broadband or other purposes	States, local, and tribal governments	Allocations set for every city and county in the United States
Coronavirus Capital Projects Fund	$10,000,000,000 – may be used for broadband or other purposes	States, local, and tribal governments	Investments in critical community hubs or other capital assets
Rural Digital Opportunity Fund Phase II	$20,400,000,000 over 10 years	Commercial entities via low bid to the FCC	Unserved rural homes and small businesses
Broadband Infrastructure Deployment Grants	$300,000,000	Public-private partnerships	Rural areas
State programs (except Mississippi)	Varies	Varies	49 states have programs to expand broadband service to rural areas

Major broadband infrastructure funding available in 2022 from federal and state programs (Connected Nation, 2022).

Post-disaster Funding

The Stafford Act, amended May 2021, governs how the United States government responds to natural disasters (FEMA, 2021). The Act is divided into seven titles that address how disaster declarations are made, preparedness activities, emergency assistance administration, the appropriate level of major disaster assistance, and how the costs are shared between federal, state, and local governments (FEMA, 2021). While the legislation includes a requirement that post-disaster recovery funds can only be used to rebuild infrastructure that was damaged and not for the construction of new projects, FEMA does have a grant program that provides funds to help communities increase resiliency by preparing for storm recovery (Housing and Urban Development [HUD], 2019). Communities desiring to rebuild outdated infrastructure to current standards must prove that building to the old standard would be inefficient or expensive (HUD, 2019).

The Stafford Act identifies critical infrastructure that can be rebuilt using federal funds as electricity, water supply, sewer, wastewater treatment, broadcasting and telecommunications, educational facilities, and emergency medical facilities, but broadband is not considered an essential service (FEMA, 2021). Though there are many federal programs to fund broadband installation, FEMA does not have the option to fund broadband construction concurrent with critical infrastructure reconstruction. However, when weather-related disasters damage and destroy large swathes of electrical infrastructure, the upfront cost of installing broadband can be reduced due to the opportunity to lay the broadband lines concurrently with the rebuilding of the electric power and other utility lines (Benesl et al., 2022).

Since it is improbable that a community would have a federal broadband grant available at the exact time they need to re-build their electrical system after a disaster, there is currently no way to integrate federally funded broadband expansion into disaster recovery projects. To correct this, it would be necessary for FEMA to recognize that broadband is of the same level of importance to rural communities of the 21st century as electricity was to rural communities of the 20th century.

Research Question, Hypotheses and Specific Aims

This thesis explored the following question: does installing broadband service concurrent with the reconstruction of damaged electric power grid in rural areas of the United States improve small town resilience?

This question was explored by testing the following hypotheses:

- Broadband adoption grows faster in regions that experience high-impact disasters (such as hurricane or flooding) rather than in regions that experience low-impact disasters or no disasters such as drought or tornados.
- Increased adoption of broadband reduces the rate of population decline.
- Increased adoption of broadband increases educational attendance
- Increased adoption of broadband increases labor market participation and employment rates

Specific Aims

The specific aims of this paper were to:

1. Select a timeframe, geography, and the associated storms that were federally declared disasters.
2. Combine relevant data from the FCC, FEMA, IPUMS-USA, US Census Bureau, and USA Spending data sources.

3. Integrate datasets using state and county federal information processing system codes to form a cohesive dataset allowing the evaluation of the relationship between storms and broadband and broadband and sustainability variables such as education and population growth.
4. Establish a linkage between broadband adoption/accessibility and major disasters, then evaluate the link between broadband usage and attending school (college), population growth rates, labor force participation, and employment rates. Use a linear regression model to measure broadband internet service and access (y_i) using controls for household income, population density, the cost of electricity, federal disaster spending per capita, and the year that the household was surveyed.
5. Use education attendance, population stability, and employment measures to proxy for small town viability.
6. Make policy recommendations from evaluating the linkage between storms and sustainability through broadband access.

Chapter II

Methods

This section provides a detailed description of the datasets used to evaluate the hypotheses, their strengths and limitations and how the samples used were constructed from these datasets. It also provides the summary statistics for the variables of interest. The primary regression model is presented, and then additional variables were incorporated. These models began by looking at the link between storms and broadband access. Once, the link was established between broadband and storms, the linkages between broadband access and community sustainability measures were explored. This was accomplished by studying the relationship between broadband and educational measures as well as how broadband impacts population growth.

Data Sources

There were four sources of data. The first dataset used was provided by IPUMS-USA (IPUMSUSA, 2022). The source of these data was the American Community Surveys (ACS) which are conducted annually, and which collect a variety of microdata. This dataset included information on what type of internet access a household had, household and individual income levels, whether anyone in the household attended school in the previous three months, population density where the individual lived at the time of the survey, household electricity costs, employment information, and location data. This last set of variables allowed for the matching of households to areas impacted by storms at the county and state level. In this model, the evaluated data span the years

2013 until 2020 inclusive, while *i* is a household unit. Therefore, this model measured what the impact was of living in a county that had a federally declared disaster (FEMA, 2022) on broadband access conditioned on income, population density, education, and the time trend.

Segregating Rural versus Urban Data

The location data of the individual respondent were known at the time of the ACS and information such as population density in the region they live in was encoded at that time. These data were stripped from the public use data to maintain the privacy of individual respondents. Creation of a dataset was thereby complicated by protections integrated into the public databases that minimize the chance of data being reported in a way that could personally identify a respondent. Therefore, geographic data on individuals depended on the ability of records to be reconstructed by the IPUMS from the publicly available data. The available geographic data were encoded at the lowest level the IPUMS team could confidently assign to the individual based upon available public data. Some respondents' locational data could be assigned at the county level or lower, others were only known at the state level. As a general rule this meant that those respondents living in a county that contained or was close to an urban area had county level information available on them. For those respondents who come from rural counties, the only level of geographic data that could be known about them was what state they lived in. Because of this, there were observations that were included in the county level estimates and observations that were excluded. The individual level summary statistics were broken down between included and excluded observations to evaluate the impact of this geographic classification (Table 4).

Table 4. Individual and state level broadband summary statistics.

	All Observations		Rural Only	
Variable	Included	Excluded	Included	Excluded
% Households with Broadband	56.90% (21.66%)	54.06% (21.16%)	55.58% (21.29%)	53.37% (20.95%)
% Households who lost power	0.35% (2.51%)	1.92% (1.74%)	0.30% (2.25%)	0.14% (1.35%)
Population Density (persons per square mile)	5822.69 (11431.33)	960.69 (2095.54)	548.89 (218.38)	216.74 (193.69)
Cost of Electricity (Dollars per year)	\$2090.20 (\$2079.15)	\$2116.91 (\$1916.92)	\$2089.04 (\$1820.53)	\$2127.26 (\$1856.67)
Natural Log of Income	10.83 (1.60)	10.63 (1.55)	10.81 (1.50)	10.58 (1.53)
# Observations	5,877,274	3,996,892	1,258,768	3,185,905

Included columns are those observations available at the county level, excluded at the state level only. All observations refer to the entire sample, rural refers to only those observations living in an area with a population density < 960.69. Standard errors in parenthesis.

Where the number of respondents in a rural county drop too low, the results were aggregated at the state level. Examining the state level summary statistics, population density was significantly different between those observations that were visible at the county level and those that were not. Population density was calculated as the geometric mean of population within the public use microdata area (PUMA). The rural areas measured at the county level could be “more urban” than the rural areas that are excluded as indicated by the higher population density measures. Additionally, as was discussed in the previous paragraph, the encoding of geographic data relied upon the presence of an urban area to “disguise” where an individual lives. That is, the reason more specific geographic information was hidden for some observations was because there were too few households living in an area and so a specific respondent could theoretically have their identity revealed as a respondent based upon the entirety of their responses.

To distinguish urban from rural residents, the dataset was partitioned into two parts: those that live in an area with a population density above 960 residents per square mile and those that live in an area below this threshold. The former were classified as urban residents while the later were rural. Those in rural settings have a more difficult time being identified more granularly than at the state level. This is reflected in Table 4 above where the population densities are 5,823 persons per square mile for observations available at the county level and 960 persons per square mile at the state only level.

The justification for partitioning the dataset at 960 persons per square mile was that the US Census Bureau (2022) defines a rural area as an area with fewer than 500 people per square mile. In this dataset, restricting observations to strictly under 500 people per square mile resulted in too few observations to draw an inference. The mean population density in the observations that were excluded from the county level measures due to a lack of a geographic identifier is 960 persons per square mile while those observations that county level identifiers were available for is 5,822 persons per square mile.

Columns 3 and 4 (Table 4) represent only the summary statistics of the rural observations, split between excluded and included observations. These columns demonstrate that the excluded observations were significantly more rural than the included observations. This was shown by comparing the mean population density measure for only those observations that live in an area with a population density below

960 persons per square mile, which were being defined as rural. The included rural population had a density of 549 persons per square mile and the excluded rural population had a density of 217 persons per square mile. Nearly all observations that were excluded from the county level models were rural, shown by comparing the number of observations in columns 2 and 4; nearly 3.1 million observations were classified as rural out of 3.9 million observations excluded from the county level models.

When looking at the population density of the sample comprised of individuals living in areas with population densities below 960 persons per square mile, the average population density was 327 persons per square mile. This demonstrated that the subsample of excluded observations was heavily comprised of individuals living in rural areas. Therefore, when defining an urban population and a rural population, using 960 persons per square mile as the delimiter was appropriate. The results at the county level were expected to be biased toward zero because the infrastructure is repaired in cities first to provide the maximum relief in the shortest amount of time possible after a disaster. This meant that the negative impacts of storms on broadband use should be relatively smaller than those in rural regions (Neal, 2005).

Table 4 provides further evidence that 960 persons per square mile was the appropriate demarcation line between urban and rural residents. From Lee et. al. (2022), rural households have less broadband access than urban ones. Therefore, there should be a significantly greater uptake rate of broadband by the urban population relative to the rural. To evaluate this, mean values were compared. The mean comparison test for the difference in broadband usage showed that people in urban settings are 2.84% more likely to use broadband than those in rural settings (Table 5). The expectation that rural households have less income relative to urban households was also supported (Table 6). Urban households had a mean income $9,157 higher than rural households.

Table 5. Mean comparison test for the difference in broadband usage between urban and rural households.

Difference.	2.840
Standard error	0.014
t-statistic	204.13
DF	9,874,164
Significance level	P < 0.0001

Table 6. Mean comparison test for the difference in income between urban and rural households.

Difference	$9,156.58
Standard error	$0.003
t-statistic	∞
DF	8,187,906
Significance level	P < 0.0001

Variables of Households

Household income provided the data for the variable "income", which was transformed into log-income to account for the heteroskedasticity and non-normal distribution of income. A consequence of this positively skewed distribution of income was that the median income was lower than the mean income.

The variable "school" was created from the question, "Have you attended school or college in the previous three months?" It took a value of 0 if they have not and a value of 1 if they had. From this variable, households were identified that had the respondent in school at the time of the survey. In this dataset, almost 80% of individuals that did attend school in the previous three months did not have children in the household.

The cost of electricity was used to create the variable "costelectric" as electricity prices and broadband usage may be related because they may be competing for household budgets. Including the cost of electricity allowed me to test whether this relationship held or not.

To measure broadband, the variable "pctbroadband" was created from a variable contained within the IPUMS dataset to measure what percent of the population in a county had broadband internet in their home. Specifically, IPUMS contains a variable that asks households whether they have internet access and if so what type of service they have. This variable measured whether a household actually had broadband internet access, not whether the household could have broadband internet access. Therefore, this measure underestimated the extent of broadband access because not all individuals with access to broadband will actually obtain it. However, this was a relatively good proxy for this analysis as the outcome of interest was broadband in the home after disasters. There was no reason to believe that, once controlling for income effects, broadband access should decrease after a storm for any reason except for lost broadband access.

Analysis of FEMA Power Outage Data

The second dataset came out of a government program designed to help uninsured and under-insured individuals meet basic needs and supplement disaster recovery efforts and is called the Individuals and Households Program – Valid Registrations Open FEMA Dataset (FEMA, 2022). This dataset contains information on the location of each registrant, whether they lost power, the disaster type they experienced, and the specific disaster name. There were nearly six million observations between 2014 and 2019 inclusive, of which almost 90% involved hurricanes, accounting for nearly 70% of observations that lost power. The observations were summarized by the number of households registering for FEMA aid by storm type as well as the fraction of individuals who lost power (Table 7).

Table 7. Summary statistics of storm data.

Incident Type	Raw Count	Percentage of Total	Fraction without Power
Earthquake	10,447	0.18%	1.38%
Fire	63,754	1.09%	80.31%
Flood	425,306	7.27%	21.58%
Hurricane	5,230,319	89.42%	69.84%
Severe Storm(s)	81,734	1.40%	18.95%
Tornado	15,567	0.27%	47.22%
Typhoon	18,946	0.32%	81.54%
Volcano	2,881	0.05%	35.42%

Source: FEMA, 2022.

The Individuals and Households Program dataset was used to create the variable “pctpwrout” which measured what fraction of individuals in a county lost power during a federally declared disaster. This dataset undercounted the total number of houses that lost electricity since the registrant’s electricity needed to still be out when they registered with FEMA to indicate they had no electricity. That is, their power had not yet been restored by the time they were in contact with FEMA. However, the dataset does capture the types of power outages that are more likely to have come from damaged infrastructure that requires days/weeks to repair rather than power outages that can be repaired within a day or two. These data were geographically identifiable at the county level and matched on those criteria with individual level data from the ACS.

Power outage was used as a measure for the destructiveness of disasters because they can be geographically large but have little infrastructure impact, geographically small with tremendous infrastructure impact, and so on. Storms that are highly destructive to infrastructure increase the likelihood that the electrical distribution system will need to be repaired or reconstructed (Federal Emergency Management Agency, 2022; Wilkinson et al., 2022). This creates an opportunity to reduce the costs of expanding broadband infrastructure by installing it during electric grid reconstruction. I used power outage as a proxy for the destruction of infrastructure due to the storm. The more homes which were out of power, the larger the negative impact on infrastructure the disaster was assumed to have on the region.

Broadband Model

Ideally, data on the percentage of households with access to broadband would be the independent variable and a measure on the amount of money spent on broadband in the aftermath of a storm the primary dependent variable. However, the data limitation described above prevented this approach. Additionally, the geographic level data necessary to allow a geographically detailed study of rural residents were lacking.

Given these constraints, to answer my core question, whether responses to natural disasters can be used to improve rural community population stability, I used a fixed effects estimation technique to quantify the effects of broadband adoption. A fixed effects technique uses a variable, such as time, as a covariate. This accounted for any variation in the model that was constant for all units and was an extremely powerful econometric technique. By addressing the constant sources of variation, only those intermittent sources that come and go through time and location were left for the other covariates to measure. This allowed for whatever remained to be a truer measure of the impact that that covariate had on the dependent variable. I estimated the following individual level model (Equation 1):

$$y_i = \beta_0 + \beta_1 percent\ power\ out_{it-1} + \beta_2 household\ income_i + \beta_3 population\ density_i + \beta_4 cost\ of\ electricity_i + \delta year_t,$$

with the variables having the above defined definitions and $\delta year_t$ represented the year indicator variable. Year indicators were necessary because there was a clear time trend in broadband access in the dataset as demonstrated below (Figure 7).

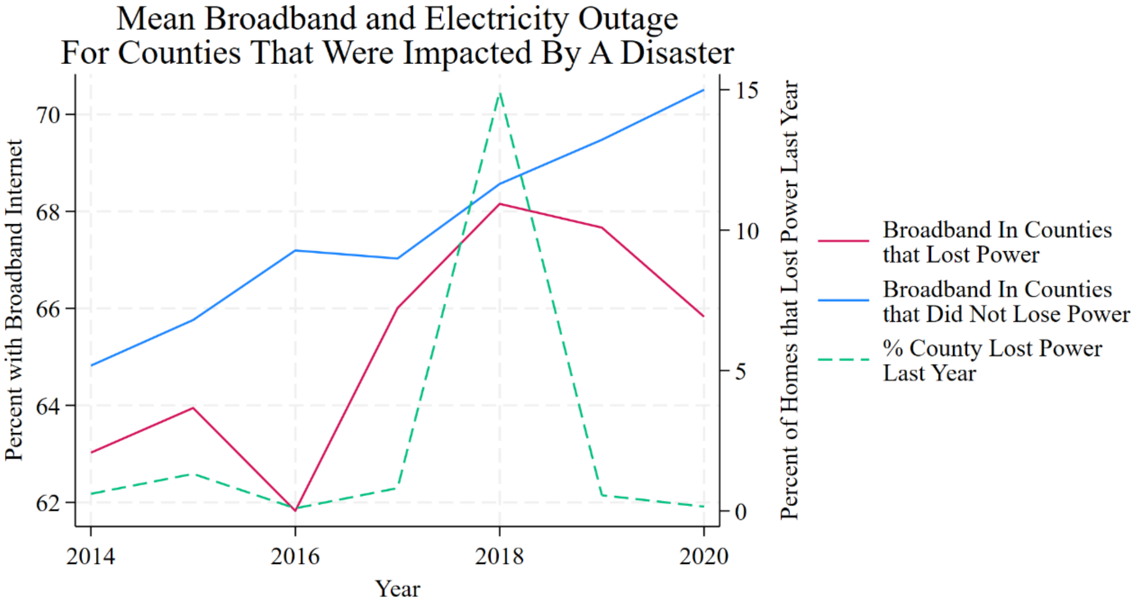


Figure 7. Percentage of homes that lost power in the previous period.

The percentage of homes that lost power in the previous period is shown in green, the percentage of households with broadband access that experienced a federally declared disaster is represented in blue, and the percentage of households with broadband access that did not experience a disaster is shown in red.

Community Sustainability Models

I investigated population growth rates, school attendance, and labor market participation for their impact on how broadband access shapes community sustainability.

Population Growth

For this model, a panel structure was used. That is, rather than estimating at the household level, the model evaluating population growth was at the county level and took advantage of the time component available in the measure of population growth. Specifically, this model (Equation 2) took the form:

$$
\begin{aligned}
&\mathit{population\ growth}_{\{i,t\}} \\
&\qquad = \beta_0 + \beta_1 \%\, \mathit{broadband}_{\{i,t-1\}} + \beta_2 \ln \mathit{hhincome}_{\{i,t-1\}} \\
&\qquad + \delta_t \mathit{year}_t
\end{aligned}
$$

Here, the previous period time was used in the right-hand side as this equation was modeling the covariates that determine population growth rate. That is, individuals were basing their decision on whether to move tomorrow based on information they had today. Specifically, each observation was now a county rather than a household, this was called the cross-sectional unit (counties), and the time period was by year. The dataset included approximately 3,000 counties measured over a period of seven years.

Identification was provided by having time fixed effects, which was captured by δ_t. These time fixed effects performed the same role as the time indicators in Equation 1. They measured time-invariant effects that impact migration rates. They also provided a way to demonstrate the validity of the model. If they had a different sign than expected, it was an indicator that the overall model was somehow mis-specified. After reviewing previous literature findings, it was expected that the estimated coefficients would be negative (Molloy et al., 2011). That is, there was a declining rate of migration into rural areas within the United States.

The income within a county may also impact the decision to migrate. Specifically, it was expected that individuals move to areas that have higher incomes. By including the control for household income, with the same natural log transformation as performed previously, this specification tested that hypothesis.

Finally, the variable of interest was the mean percentage of households with broadband in the county. There were two ways broadband could impact population growth rates within a county. The first was that that increasing broadband usage increases the population growth rate of a county. Conversely, a positive coefficient could also indicate that counties with more broadband see a smaller decrease in their population. In either situation, a positive coefficient on broadband indicated that household usage of broadband directly impacts population growth rates and can help prevent a rural region from losing population, with the commensurate increase in sustainability.

The sign and significance of income in the model could indicate that there was a specification error in the model. To address this, population density was included as a covariate because income effects could have been impacted by population density as the two variables are correlated as shown above. Areas with higher population densities also had higher incomes. Without controlling for population density, the true impact that income had would have been confounded by the impacts due to population density.

Including population density into the model could be accomplished in one of two ways. The first was to include it as a continuous variable, which is shown in the following (Equation 3):

$$
\begin{aligned}
&population\ growth_{\{i,t\}} \\
&\qquad = \beta_0 + \beta_1 \%\ broadband_{\{i,t-1\}} + \beta_2 \ln hhincome_{\{i,t-1\}} \\
&\qquad + \beta_3 population\ density_{\{t-1\}} + \delta_t year_t
\end{aligned}
$$

Equation 3 was based on Equation 2 with the addition of a continuous measure of population density. In this model, population density had the same interpretation as in Equation 1. An additional way to model population density in this model was as an indicator variable where it was partitioned into three parts to represent urban, suburban, and rural areas. For the purposes of this variable, the simple split described above at 960 individuals per square mile was insufficient as it didn't leave room for suburban residents. Therefore, following the census bureau, rural was be defined as a population density below 500 persons per square mile, suburban from 500 to 2,200 persons per square mile, and urban as those areas with a population density above 2,200 persons per square mile. Under this classification, 31.98% of households were urban, 51.74% were suburban, and 16.28% were rural. These values were reasonable when compared to the values obtained in the 2017 American Household Survey of 29%, 57% and 14% respectively, (IPUMSUSA, 2022). The model that results from this redefinition of population density modified Equation 3 so that rather than using a continuous measure of population density, population density was modeled discretely so that instead of a single marginal change applying to all levels of population density, three separate marginal effects were measured whose magnitude depended on the population density group it is applied to. Therefore (Equation 4) is:

$$
\begin{aligned}
&population\ growth_{\{i,t\}} \\
&\qquad = \beta_0 + \beta_1\%\ broadband_{\{i,t-1\}} + \beta_2 \ln hhincome_{\{i,t-1\}} \\
&\qquad + \gamma population\ density_{\{t-1\}} + \delta_t year_t
\end{aligned}
$$

Equation 4 was based on Equation 2 with the addition of a discrete measure of population density.

Broadband Accessibility and School Attendance

The next community sustainability measure evaluated investigated the relationship between broadband accessibility and school attendance. The hypothesis was that increasing availability of broadband access will have a positive impact on adult's school attendance through greater access to online schools that broadband internet speeds afford. To measure broadband access the variable "pctbroad" was used. As a reminder, this variable measures the percentage of the county that the household is located in that has broadband in their homes. For the reasons stated above, this variable captured both broadband access as well as broadband usage. Because of this, the variable contained variation created by the wealth levels of both the household and the county. This meant that the variable was expected to be biased in the negative direction because the motivation for school attendance implies a lower income. An individual with a high income has less reason to attend school while those with low income may desire to attend school but for reasons related to income, they may not be able to afford to do so. Thus, the proportion of the total variation of the measure of broadband access in this analysis that was caused by income effects drove the results in the negative direction, while the proportion of the variation due to accessibility drove the coefficient of interest in the positive direction. This can be thought of as being a regression of all the factors that impact the decision to have broadband.

Two of the factors were access to broadband and income. The more access someone has, the more likely they are to have broadband. The more income someone had, the more likely they were to have broadband. Broadband itself impacts the decision to go to school. If someone had broadband, they could more easily go to school. But, if someone had a higher income, they were less likely to pursue additional education. So, the portion of income that increases access to broadband diminished the likelihood of attending school. The portion of broadband caused by access increased someone's likelihood of going to school. So, when looking at the broadband measure, the portion that was attributable to access had a positive effect on school attendance while the portion of broadband that is attributable to income had a negative impact on school attendance. This point will be returned to shortly.

The model specification used to study the impacts of broadband access and the decision to attend school was (Equation 5):

$$y_i = \beta_0 + \beta_1 * pctbroad_i + \beta_3 \ln own\ income + \beta_4 \#\ children + \beta_5 age + \beta_6 marital\ status + \beta_7 gender$$

In this model, y_i was a measure of whether an individual attended school in the previous three months. It took a value of 1 if they had and 0 if they had not. Therefore, this ordinary least squares model was also interpreted as a linear probability model. The interpretation of the coefficients was the same as the standard ordinary least squares regression. That is, a percentage point increase in a covariate caused a percentage point change in the dependent variable. With this in mind, a 1% increase in population density was expected to cause a 0.38% increase in broadband usage in rural areas.

Another difference to highlight in this model was that personal income was used rather than household income. The justification for this was that an individual who was working was less likely to have the time to attend school. Measuring household income made it more difficult to unravel the impact of income as household income could mean the respondent was working but it also may have meant they are not. By measuring personal income, the impact of income on the individual's decision was clearer. Other measures that may impact the decision to attend school were also included. These included the number of children in the household, age, marital status, and gender.

Interpreting these covariates one by one, the greater the number of children present in the home should decrease the probability of attending school. Age was included as the older an individual is, the less likely it was they attend school. Marital status captured a similar, yet distinct, level of variation than the number of children. A married individual has a family, responsibilities, possibly a second income, and possibly children that will decrease the probability of attending school due to constraints or lack of need. Conversely, they also were likely to have financial and time support that could increase the probability of attending school. This variable's coefficient sign could be either positive or negative depending on the strength of the different components. Finally, gender was included as typically women are more likely to attend post-secondary school than men.

In the specification of the base model above, it was pointed out that the percentage of a county that has broadband captured both accessibility and income effects of broadband. Data existed to test a portion of this statement. While access cannot be directly measured, the income portion of broadband can be more directly measured using the variable that was used to generate the county level broadband measures. This was achieved using the IPUMS variable, "internettype" which asked respondents whether they had internet in their homes and if so what type of internet. This variable was transformed as nearly 98% of respondents replied as having either no internet connection or a broadband connection. While this measure had both the accessibility and the income effect tensions described for the county level measure, income effects were expected to be larger. That is, by transforming the variable to the county level, accessibility became a larger proportion of the variation in broadband usage.

The model specification for this individual level measure was identical to the county level; the only difference being in how broadband was captured.

Employment Rates and Labor Force Participation

The final measure of community sustainability that this paper investigated was the impact that broadband had on employment rates and labor force participation. To investigate this relationship the following model specification was used (Equation 6):

$$y_i = \beta_0 + \gamma internettype * education + \beta_1 age + \beta_2 age^2 + \beta_3 \# \; children \\ + \beta_4 gender$$

Equation 6 incorporated both labor force participation and employment rates. This model used multiple indicator variables and so a detailed description is necessary before presenting the model results.

First, there were three specifications that were investigated, each differing by the choice of the dependent variable. To measure employment status, IPUMS had a variable asking respondents about their employment status. This employment status variable was an indicator variable that took a value of 0 when the individual was not in the labor force, that is not employed or not looking for a job. It took a value of 1 when an individual was unemployed, and 2 when they were employed. Therefore, labor force participation referred to when an individual was in one of two categories: not looking for work or either employed/ unemployed. To measure employment status, only individuals who participated in the labor force were considered. These individuals were either employed or unemployed while those who do not participate in the labor force were excluded.

Education and Broadband Usage

The last variables explored were education and the variable of interest, broadband usage. These two variables interacted with one another, as they were both indicator variables, and every combination of the two outcomes was modelled. The variable "internettype" took the values of 0 for no internet, 1 for dial-up, 2 for broadband. Education was broken down as 1 for high school diploma, 2 for some college, 3 for a bachelor's degree, and 4 for graduate school. Therefore, there were $4 * 5 = 20$ combinations of outcomes. The base group to compare all others against was the most common combination as this provides the most statistical power: "no internet" and "high school diploma". Therefore, the constant term in this model was the impact that having "no internet" and a "high school diploma" had on labor force participation and the employment rate. For clarity the groups associated with dial-up and satellite were omitted as they were not the focus of this pattern, but it should be noted that they showed an increasing pattern between no internet and broadband that is explained below.

The various interactions, such as “broadband” and “graduate school” were interpreted relative to this base group. This meant that if there was a positive coefficient, this positive coefficient meant that broadband access in the home increased the probability of participating in the labor force or being employed relative to the base group. Conversely, when there was a negative coefficient, broadband access in the home decreased the probability of participating in the labor force or being employed. Because of these interactions, how broadband access impacts different education levels in participating in the labor force and obtaining a job was thereby explored.

Chapter III

Results

First, I used IPUMS-USA data to determine household internet type and then used FEMA data to explore whether storm events increased broadband adoption. I then evaluated whether broadband adoption improved economic indicators of sustainability, namely education, employment, and population rates. I found that storms do reduce broadband accessibility, that broadband is correlated with increasing rates of employment and education, and that population growth rates can be improved with increased broadband access.

Regression Results

The results of the primary regression equation are shown in column 1 (Table 8). Other model variables are explored and presented in the subsequent models. The first thing to notice is that the main model results located in column (1) explain a great deal of the variation in broadband ownership. The model worked well because of the inclusion of time trends as shown by the large drop in the R^2 value in column 2. Failing to control for the time trends produced a model that only explained about one percent of the variation of the model ($R^2 = 0.011$)versus 91% ($R^2 = 0.91$) when the time indicator was included.

Table 8. Relationship between power outage and broadband regression summary.

Y = % Broadband VARIABLES	(1) Time Indicator	(2) No Time Indicator
Population Density	-2.12e-07***	-2.31e-07***
	(2.60e-09)	(8.63e-09)
Cost of Electricity	-3.98e-07***	1.34e-06***
	(1.39e-08)	(4.60e-08)
LN Household Income	0.00545***	0.0104***
	(1.80e-05)	(5.96e-05)
2014 Indicator	0.649***	
	(0.000117)	
2015 Indicator	0.658***	
	(0.000117)	
2016 Indicator	0.669***	
	(0.000116)	
2017 Indicator	0.670***	
	(0.000116)	
2018 Indicator	0.687***	
	(0.000118)	
2019 Indicator	0.693***	
	(0.000116)	
2020 Indicator	0.704***	
	(0.000115)	
Rural Indicator	-0.0382***	-0.0372***
	(7.28e-05)	(0.000241)
% Power Out Last Year	-0.0449***	0.369***
	(0.00133)	(0.00429)
Rural Indicator Interacted	-0.0361***	0.0498***
with % Power Out Last Year	(0.00350)	(0.0116)
Constant	-0.0481***	0.487***
	(0.000214)	(0.000667)
Observations	5,877,274	5,877,274
R-squared	0.910	0.011

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

Column 1 is the main regression studying the impacts of power outage on broadband. Column 2 is the same model without the time trend included. Standard errors are shown in brackets.

Turning to the main model results in column 1, verification checks made sure that the model produced reasonable results. First, the partial effects of income were positive, that is, the more income a household had the more likely that household was to have broadband. Next, the cost of electricity was negatively related to broadband access. This was also expected as a household that spends more on electricity should have less to spend on broadband. This contrasts with the model without the time effects where the price of electricity was positively related to broadband. That is, in this model the more a household spends on electricity the more likely it was to have broadband. This was the first sign that the model without time effects was misspecified.

Looking at the time effects, they were all significant and positive. This reflected the positive time trend evident in the broadband measure without power losses (Figure 7). If these were all negative it would indicate a misspecified model because the expectation was that as broadband access expanded through the years, more households would have broadband. If one or two were negative it would be a cause of concern that the model was mistaking a negative year effect for the effect of power outages.

Turning to the cost of electricity and population density measures, they were both negative and statistically significant in the main model. However, these effects were so small as to be effectively zero. To give a sense of scale, taken literally these coefficients meant that a standard deviation change in population density or the cost of electricity would only be expected to reduce broadband by six households per one million. Therefore, these variables' significance was considered spuriously significant and treated as if they were not different from zero. The model without the time indicators also found non-zero, statistically significant results, but they were also of similar magnitude and were ignored.

Turning to the rural indicator, both models found that rural residents were less likely to have broadband connections than urban residents. As a reminder, rural residents were defined as those individuals living in areas with a population density of less than 960 persons per square mile. This result matched data from the Census Bureau (United States Census Bureau, 2022).

The magnitudes of the coefficients indicates an ordering of importance (Table 8). That is, time had the largest effects on the change of broadband, consistent with the steadily expanding broadband network throughout the United States as well as the increasing use of internet for daily activities. Next in importance was being rural, which had an order of magnitude less impactful than time, but an order of magnitude more importance than income.

The impact that disasters have on broadband was captured by measuring the percentage of households that were without power at the time they register with FEMA after a federally declared disaster. There were two variables that captured this effect in the model, one covering urban residents represented by "% Power Out Last Year" and the other measuring rural residents represented by "Rural Indicator Interacted with % Power Out Last Year". For urban residents, the coefficient, -0.0449, was the impact that power outages had on broadband access. For rural residents, their coefficient, -0.0361, must be added to the urban residents to get the true magnitude of the effect, which was -0.081 ($-0.0449 - 0.0361 = -0.081$). Both of these coefficients were statistically significant, indicating that storms negatively impact urban residents, but impact rural residents even more negatively than urban residents.

Community Sustainability Models

Having established that disasters reduce the number of households with broadband, the next step was to understand how impact shapes community sustainability. There were three measures of sustainability I investigated: population growth rates, school attendance, and labor market participation.

The model results as well as two specification tests are shown in Table 9. The model results in Table 9 show collinearity between population density and income, increasing the variance of these covariates and so decreasing statistical significance. There were the two variables. What can be inferred was that individuals move towards regions with higher incomes, away from cities, and towards rural and suburban areas. In evaluating the signs of the coefficients, the first thing to take note of was that the time fixed effects have the expected sign and significance in both specifications, that is negative and statistically significant.

In the second column of Table 9, population density had been added and with its inclusion, income became insignificant though still positive. Looking more closely at population density, the negative coefficient (-2.53xe-5) was statistically significant at the 99% level, indicating that individuals were moving less frequently towards areas with higher population densities. This did not necessarily mean they are moving towards rural areas, however.

Table 9. The impact of broadband usage on population growth rates.

Y = % Pop Growth	(1)	(2)	(3)
VARIABLES	No Density	Continuous Pop. Density	Pop. Density Indicator
Lagged Percent Broadband	0.0206***	0.0233***	0.0284***
	(0.00400)	(0.00399)	(0.00406)
Urban Indicator			-0.381***
			(0.0535)
Rural Indicator			0.203***
			(0.0670)
LN Household Income	0.212*	0.178	0.195*
	(0.118)	(0.117)	(0.117)
2015 Indicator	-1.262***	-1.428***	-1.749***
	(0.262)	(0.261)	(0.266)
2016 Indicator	-1.344***	-1.511***	-1.838***
	(0.264)	(0.263)	(0.268)
2017 Indicator	-1.468***	-1.638***	-1.971***
	(0.266)	(0.265)	(0.270)
2018 Indicator	-1.550***	-1.719***	-2.053***
	(0.265)	(0.264)	(0.269)
2019 Indicator	-0.962***	-1.134***	-1.477***
	(0.269)	(0.268)	(0.272)
2020 Indicator	-1.798***	-1.970***	-2.317***
	(0.268)	(0.267)	(0.272)
Population Density		-2.53e-05***	
		(3.60e-06)	
Constant	-1.433	-1.001	-1.158
	(1.262)	(1.253)	(1.247)
Observations	3,003	3,003	3,003
R-squared	0.057	0.072	0.080

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

Column 1 of the regression model summary does not include population density controls. Column (2) includes a continuous value population density measure. Column (3) uses suburban residents as the base indicator and includes an urban and rural indicator.

When transforming the density variable into an indicator taking a value of 0 if density is above 2,200 persons per square mile, 2 if below 500 persons per square mile, and 1 otherwise, there was a statistically significant and positive effect of density when focusing on regions below 2,200 persons per square mile (Column 3, Table 9). Specifically, if 2,200 persons per square mile was urban, 500 to 2,200 persons suburban, and under 500 rural, then there was a negative impact for densities above 2,200 and positive effects under 2,200 as shown by the magnitude and signs of the urban indicator, rural indicator, and constant coefficients of column 3. Further, household income became statistically significant once again in column 3.

Impact of Broadband on School Attendance

A powerful demonstration that the results of the physical accessibility to broadband were understated by the measure used in this analysis is shown in Table 10. Specifically, in relation to this model, access to broadband increased school attendance. Since access had two drivers, cost and availability, it was clear that improving either condition would improve sustainability measures such as school attendance and population growth rates, as discussed above. Reviewing both columns below (Table 10), income, the number of children, age, and gender all had the correct signs and were statistically significant. These coefficients, along with the relatively high value of R^2 for human behavior indicates this model was correctly specified. Previously, it was discussed that marital status could be either positive or negative. Evaluating the model results, being married decreased the probability of attending school. Therefore, the potential benefits of being married were overwhelmed by the factors related to marriage that detract from school attendance.

Table 10. Regression models testing the impact of broadband on school attendance.

Y = school attendance VARIABLES	(1) County Broadband	(2) Individual Broadband
Percent of the	2.56e-05***	
County with Broadband	(4.12e-06)	
LN Own Income	-0.0382***	-0.0356***
	(8.00e-05)	(8.23e-05)
# of Children	-0.0294***	-0.0288***
	(0.000102)	(0.000102)
Age	-0.00545***	-0.00550***
	(5.47e-06)	(5.48e-06)
Married Indicator	-0.0280***	-0.0236***
	(0.000210)	(0.000213)
Female Indicator	0.000460**	0.00207***
	(0.000201)	(0.000201)
Personal Broadband		-0.0261***
Measure		(0.000208)
Constant	0.789***	0.778***
	(0.000891)	(0.000876)
Observations	6,091,548	6,091,548
R-squared	0.190	0.192

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

The first column (1) measures broadband access at the county level while the second column (2) represents broadband access at individual level. Standard errors shown in parenthesis.

As a reminder, the question of interest was: What impact does broadband have on school attendance? Beginning with the first column of Table 10, broadband access was measured with the variable measuring the percentage of a county that has broadband. In this specification, broadband has a positive and significant effect on school attendance (2.56xe-5). The magnitude of the coefficient was quite small however, being nearly an order of magnitude smaller than any other coefficient. Turning to the individual measure of broadband in column 2, which predominately reflects factors other than accessibility of broadband, the coefficient was now significant and negative in sign (-0.0261). Further, the magnitude of the coefficient was of the same order as income effects, children, and marital status.

That the coefficient was positive and significant in the first model when it was so negative in the second demonstrated just how large an impact income had on broadband use in the home. This also demonstrated that much of the variation in the percentage of a county that had broadband was driven by accessibility.

Labor Effects

The labor effects regression model specifications, in order of their appearance in Table 11, were labor force participation and employment status, which is to say the dependent variable took a value of 0, 1, and 2, defined above. In the second specification only employment status was considered, which is to say that the dependent variable took a value of 1 or 2. Finally, in the third model only labor force participation was considered, which meant the dependent variable represented only those that were employed or unemployed seeking work.

Table 11. Labor effects regression model.

VARIABLES	Both Outcomes (all people) (1)	Labor Force Participation (employed or unemployed seeking work) (2)	Employment Rate (employed) (3)
Broadband	0.411***	0.194***	0.0434***
	(0.00134)	(0.000672)	(0.000635)
No High School	-0.287***	-0.145***	-0.0181***
	(0.00183)	(0.000917)	(0.00120)
Some College	0.160***	0.0777***	0.0130***
	(0.00147)	(0.000737)	(0.000810)
Bachelor's Degree	0.443***	0.211***	0.0439***
	(0.00184)	(0.000922)	(0.000770)
Graduate Degree	0.526***	0.248***	0.0540***
	(0.00228)	(0.00114)	(0.000793)
Broadband	0.0858***	0.0481***	-0.000437
No High School	(0.00300)	(0.00151)	(0.00157)
Some College	-0.104***	-0.0510***	-0.00826***
	(0.00196)	(0.000984)	(0.000924)
Bachelor's Degree	-0.307***	-0.149***	-0.0281***
	(0.00223)	(0.00112)	(0.000865)
Graduate Degree	-0.345***	-0.165***	-0.0333***
	(0.00266)	(0.00134)	(0.000889)
Age	0.0895***	0.0449***	0.00231***
	(0.000202)	(0.000101)	(6.86e-05)
Age^2	-0.00111***	-0.000557***	-2.31e-05***
	(2.34e-06)	(1.17e-06)	(7.17e-07)
# Of Children	0.0216***	0.0114***	-0.000481***
	(0.000343)	(0.000172)	(0.000136)
Female	-0.119***	-0.0571***	-0.0110***
	(0.000706)	(0.000354)	(0.000267)
Constant	-0.403***	-0.176***	0.867***
	(0.00395)	(0.00198)	(0.00159)
Observations	4,861,918	4,861,918	4,008,919
R-squared	0.163	0.155	0.014

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The difference in the columns came from the dependent variable. Column (1) includes all people – employed, unemployed seeking work, and those not in the labor force. Column (2) includes only those that are employed or unemployed seeking work. Column (3) includes only people that are employed. Standard errors in parentheses.

Age had a non-linear effect on employment and labor force participation (Figure 8). To properly account for this non-linearity age was estimated as both age and age squared. This accounted for the rise, then fall, of labor force participation as an individual moved through the age distribution. Given the overall shape, the expectation was that the coefficient associated with age, β_2, was positive and with age squared, β_3, negative. Figure 9 illustrates the same dynamic as Figure 8 with only those that were employed shown demonstrating this relationship held for both labor force participation and employment rates.

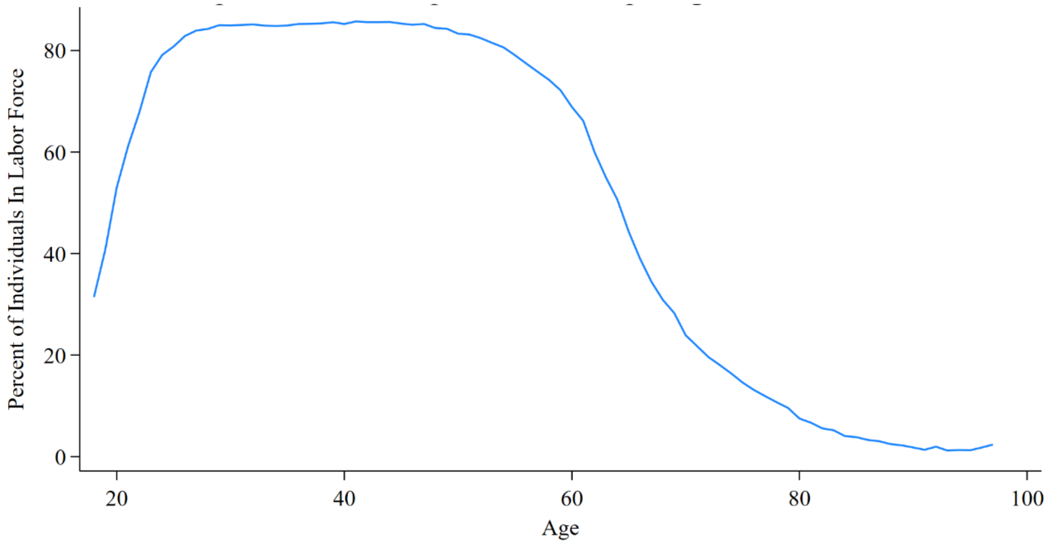


Figure 8. Proportion of individuals participating in the labor force by age.

This graph includes individuals participating in the labor force either by being employed and being unemployed and seeking work.

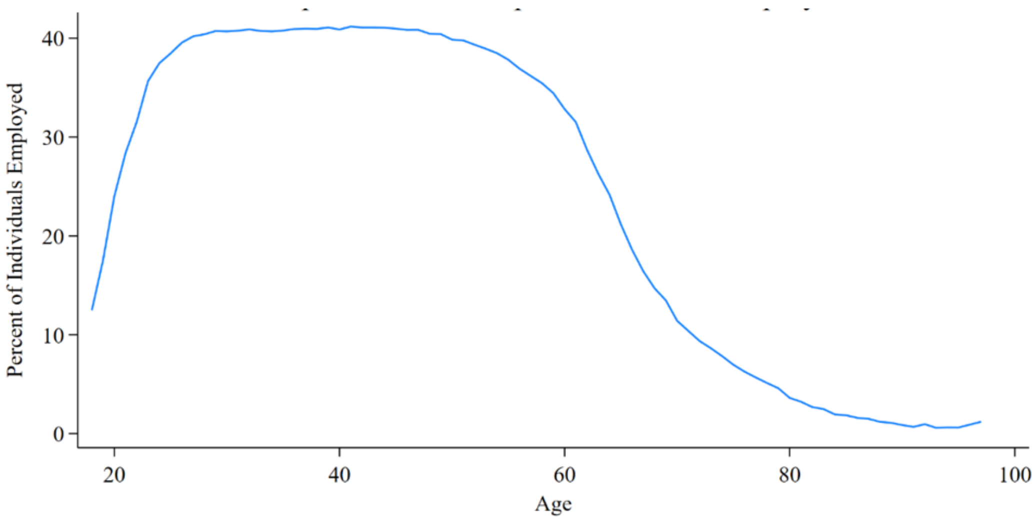


Figure 9. Proportion of employed individuals participating in the labor force.

The proportion of employed individuals as a percentage of the total number participating in the labor force.

The number of children present in a home could have either increase or decrease the probability of participating in the labor market and being employed. The increase could come from the need for more money to support the household while the decrease could happen because more time was needed at home. Gender is a variable that has been shown in numerous studies to have an impact on labor force participation (Ganguli et al., 2014). The overall pattern expected was that being a woman lowered labor force participation rates and employment rates for a wide variety of reasons that are beyond the scope of this thesis.

The full labor effects regression results are shown in Table 11. The first task evaluated was whether the model returned results that are in-line with previous research. Age and age squared showed results that match what was expected. When considering employment status, age was positive, and age squared negative indicating a downward opening parabola fit to the curves presented above (Figures 8 and 9). This indicated that the model was reflecting the fact that the probability of participating in the labor force and being employed rises at a young age and falls at an old age. Turning to gender, there was a statistically significant and negative impact of being female on labor force participation and employment which matched research on gender differences in the workplace. The number of children was statistically significant and positive in columns 1 and 2 (Table 11) indicating that the more children in a household, the greater the probability that an individual will look for work. Unfortunately, column 3 (Table 11) indicates that they were less successful in obtaining work. The constraints imposed by children are detrimental to finding a job even if one desires a job.

Turning to the variable of interest, broadband showed stark patterns. Starting with the base case, no internet and a high school diploma which was shown by the constant term in column 1 (Table 11), showed that no internet had a negative overall impact. Recall that column 1 shows both labor force participation and employment rates. This can be decomposed into its constituents, labor force participation and employment rates, which are columns 2 and 3 (Table 11) respectively. These columns show that the base group being compared has coefficients of -0.403, -0.176, and 0.867 for columns 1, 2, and 3. When evaluating the rest of the coefficients, the comparison was made relative to this base group. That is, the coefficient was no longer compared to zero, it was compared to the value the constant takes.

The first set of categories, which were internet connection type combined with a high school diploma showed a clear pattern. As a reminder, for clarity dial-up and satellite categories were omitted from this analysis, but they showed the same pattern at a reduced magnitude and level of significance as what will be described for broadband.

Focusing on broadband, and again looking at only individuals with a high school diploma, there was a significant and positive impact of broadband in all three models, indicating that broadband both helps individuals enter the labor force and, once they have entered the labor force, obtain employment. That is, the true coefficient for broadband was $(-0.403 + 0.411 = 0.08)$, which, while small, was statistically different from zero. The true coefficient for labor force participation in column 2 (Table 11) was 0.18 $(-0.176 + 0.194)$ and that of employment was 0.9104 $(0.867 + 0.0434)$. Comparing the magnitude of these coefficients to other covariates, broadband access overcame the negative impact of being a woman on labor force participation, 0.18 compared to -0.0571, and overcame the negative impact of being a woman on employment status, 0.9104 to -0.0110. The same happened for the number of children, indicating that broadband access had a powerful effect of helping individuals who have only a high school diploma obtain work. The interpretation for these large and positive effects was that internet speed lowers the barriers that an individual experiences in looking for jobs as well as finding them. Furthermore, by easing the job search and opening remote opportunities, individuals with multiple children were able to work while still being able to take care of their families.

The next set of variables studied were the impacts that education had on labor force participation and employment status. These were reflected in the variables, No High School, Some College, Bachelor's Degree, and Graduate Degree. As a reminder, because of the interaction term these variables were all applied to those who have no internet access in this first analysis. These variables confirmed that education matters. Those without a high school diploma did worse than those with a high school diploma across both labor force participation and obtaining employment (Table 11). Going to college, completing college, and furthering one's education through graduate school, all increased the probability of entering the labor market and in finding employment. These results verified the validity of the models. If these coefficients were negative or decreased in magnitude as one became more educated, the model would be interpreted as flawed.

Turning to the interaction terms, how internettype interacted with educational attainment revealed interesting patterns. As a reminder, Table 11 omitted the results of internettypes dial-up and satellite. However, the same patterns held for broadband and so they were omitted from Table 11 for clarity but were included in the model. Looking at the coefficients associated with Broadband/No High School, Some College, Bachelor's Degree, and Graduate Degree, an immediate pattern was revealed. These interactions behaved in exactly the opposite direction as was indicated by education impacts alone. That is, the greater the education, the less important the internet became in entering the labor force and gaining employment. This seemingly counter-intuitive result has a logical interpretation.

The first element, entering the labor force, can be explained by the reasons that individuals pursue college degrees. The easiest way to see the logic is to start with a graduate degree. Most individuals pursuing a graduate degree have a specific field of study in mind. Further, they have qualifications and a network that can help them obtain work if they don't already have a specific position in mind. Finally, their advanced degrees make them highly employable and so they have the easiest time finding work out of the general population. These factors combined to mean that broadband just isn't as important to finding and obtaining employment for the portion of the population with more educational attainment. To obtain the true magnitude of this coefficient all the combined factors were collected. That is, for labor force participation, column 2, the effects of broadband on those with a graduate degree are ($-0.176 + 0.248 + 0.194 - 0.165 = 0.101$). This indicated that broadband still helps but comparing it to the impacts that simply having a graduate degree had, without considering the internet, is ($0.248 - 0.176 = 0.072$) was a small, though significant, effect.

These arguments extended to no high school diploma, some college, and a bachelor's degree. The final values with broadband and without are summarized in Table 12. Having broadband increased the probability of participating in the labor market regardless of educational level (Table 12) or employment (Table 13).

Table 12. True impacts of no internet and broadband given different educational levels on labor force participation.

	No Internet	Broadband	Change
No High School Diploma	-0.321	-0.0789	0.2421
High School Diploma	-0.176	0.018	0.194
Some College	0.601	0.744	0.143
Bachelor's Degree	0.035	0.08	0.045
Graduate Degree	0.072	0.101	0.029

The difference indicates the marginal change in labor force participation rate due to broadband. Change is the gain due to broadband.

Table 13. True impacts of no internet and broadband given different educational levels on employment.

	No Internet	Broadband	Change
No High School Diploma	0.686	0.729	0.043
High School Diploma	0.867	0.910	0.043
Some College	0.88	0.915	0.035
Bachelor’s Degree	0.9109	0.926	0.0151
Graduate Degree	0.921	0.931	0.01

The difference indicates the marginal change in the unemployment rate due to broadband.

Each table also includes a change column which shows that as education level increased, the importance of broadband decreased, though is still positive. That is, broadband positively impacted the labor force participation rate and employment rate, but this importance varied by educational status. The mechanism for effect is through networking, job opportunities, and skills obtained through education.

Chapter IV

Discussion

My research explored whether natural disasters can indirectly benefit rural communities. I investigated the impact of broadband access by asking the following questions: 1) Do localities that were affected by federally declared disasters experience an uptake in broadband usage? 2) To what degree does improved access to broadband address the educational and employment opportunity issues that exist in rural America? 3) With the improvement of educational and employment opportunities, does population decline in small towns stabilize? I hypothesized that expanded broadband infrastructure as part of federally funded natural disaster recovery efforts provides a mechanism for increasing rural population sustainability by increasing educational participation and increasing access to employment opportunities.

The finding that living in a rural setting had an order of magnitude larger impact on broadband access than income spoke to the importance of accessability to broadband. Specifically, even though my research did not capture the impacts of broadband access directly, the finding that being rural had such a large impact on broadband being in the home showed that it was capturing the effect of access. Outside of access and income/cost concerns, there were no reasons to expect homes in rural areas would have less broadband penetration than homes in urban ones to such a high degree. This was borne out in surveys which found that the significant drivers of broadband uptake in rural areas was access and income/cost effects (Humphreys, 2019). That is, while rural residents being older and less computer literate than urban residents was expected to have a lower demand for broadband when it was available, the contribution of these effects to the rural/urban gap has been shown to be much smaller than the three percentage point difference found (Table 4). Finally, the cost of electricity and population density were of such a low order of magnitude that they were effectively of no explanatory power.

Turning to the variable of interest for community sustainability, percent broadband, all three models agreed that broadband access was a driver of population growth (Table 9). Looking across all three models showed this result was consistent in both significance and sign. This was evidence that broadband's impacts on population growth were internally valid. It follows from this set of results that obtaining broadband access will have a positive effect on population growth in rural areas. This result agrees with previous research that investigated the relationship between broadband access and population growth (World Bank, 2022).

My results indicated that rural households broadband access was reduced by a larger amount than urban households for the same storm impacts. Causes for this included it being both more cost-effective and a higher priority to repair infrastructure for urban residents than rural. It is cheaper (e.g., for undergrond service lines, maintained rights-of-way, etc.) in urban areas, and the higher density of the population means proportionally fewer fixes required to restore power. For rural residents many miles of repairs may be required before an individual household experiences the repair. Looking at the magnitude of these impacts, I found that they were in line with the gap between urban and rural residents in the absence of disasters.

These impact of disasters on rural communities were sizeable. Figure 7 displays the power that disasters have. The blue line, which gives the proportion of households with broadband access, shows a steady and relatively constant rise over time. The red line, for households that experienced a federally declared natural disaster, initially rose in parallel with the blue line. However, when recovering from a storm there was a sharp decline in the level of access. This was most evident in 2018 where federally declared disasters in 2017 caused a fall in broadband use within households by 2019. It should be noted that the slight descrepancy in years was because of the various timing issues related to the survey. I interpreted this to mean that although a federally declared disaster in 2017 reduced broadband usage in 2018, these effects didn't appear until 2019 due to the timing of the surveys.

To make quantiative what has so far been qualitative, a 10% rise in the number of homes that lost power in a county resulted in a decrease in broadband usage in the home of 0.81% for rural residents. This was equivalent to a standard deviation increase in the impacts of a storm. When Hurricane Irma struck the State of Florida, more than 64% of Floridians were without power while the FEMA dataset only shows 55% of homes without power, (Hodge & Lee, 2017). Using these power outage values, a back of the envelope calculation of the impacts that Hurricane Irma had on broadband showed in the years following the hurricane that approximately 100,000 households did not have broadband than if the storm not struck. This impact represented about one percent of households.

Conclusions

Broadband is a critical part of modern infrastructure but is not available to all Americans and is lacking in rural communities (Karsten & West, 2016; Lee et al., 2022;

Tolbert & Snead, 2021; Vogels, 2021). This disparity contributes to a widening gap in educational and employment opportunities between rural and urban communities. It has also led to a decline in rural populations – which results in a smaller tax base to fund infrastructure improvements (Cromartie, 2017). To put this disparity in context, 2019 data indicated that 42 million people (13% of the population) lacked access to high-speed internet in contrast with universal access to indoor plumbing and electricity (Marre, 2020; Tomer et al., 2020).

My research explored the opportunity to reverse these negative trends by leveraging the reconstruction efforts that are necessary following a natural disaster to expand broadband access to rural communities. Severe storms and tropical cyclones (typically Atlantic hurricanes) are the most prevalent natural disasters in the United States and are a frequent cause of prolonged power outages resulting from damage to overhead distribution lines which make up the electricity grid. The frequency and severity of these storms continues to increase as a results of climate change (Vecci et al., 2021). Incorporating broadband construction into the post-disaster electricity grid repairs, using the same utility poles and geographical routing, offers the opportunity for significant cost savings and acceleration of broadband penetration into rural communities using federal funding. Cost savings using this approach could be as much as 60% (Kim, 2022). However, current FEMA policy dictated by the Stafford Act doesn't allow for this new construction and doesn't consider rural broadband as critical infrastructure – so policy changes will be necessary to take advantage of this opportunity (FEMA, 2021).

Linear regression analysis was used to evaluate the dataset to characterize the relation between storms and broadband as a first step, and to then understand how this affected the community sustainability measures of population growth rate, school attendance, and labor market participation. The analysis confirmed that broadband access is negatively impacted by natural disasters and that this effect is more pronounced in rural areas. The linear regression model also confirmed that broadband access 1) is a significant driver of population growth in rural areas, 2) increases school attendance, and 3) shows a strong correlation in terms of entry into the job market and obtaining employment. Beyond these basic relationships the analysis also showed some variation in school attendance based on the number of children in the household, age, marital status, and gender. Labor force participation and employment was also shown to vary with education status, age, household size, and gender – with more pronounced benefits for those at lower education levels.

The most immediate application of this research is in providing government emergency management officials at the federal and state level the justification to consider the construction of new broadband infrastructure in parallel with the electricity grid repairs that are often required following a storm – offering these vulnerable communities significant cost savings as well as the community sustainability benefits of a more stable population, increased access to remote education, and increased access to remote work. From a practical standpoint, a first step in this new approach might be a pilot project in a hurricane prone and persistently impoverished state such as Louisiana which could then be scaled up to the national level. Such a pilot project would be led by FEMA in partnership with the state emergency management agency, rural electric cooperatives, and local social justice organizations.

Since the scope of this research was limited to the 2014-2019 timeframe – there is also an opportunity to take a closer look at the impacts of the COVID-19 pandemic on the need for remote learning, the broader acceptance of remote work, and the resources that have been brought to bear to address those needs. There may be a delay in the resources needed to conduct this research as these data begin to emerge in the academic literature.

Finally, since the severity and frequency of extreme weather events is projected to continue to increase due to climate change, the challenges that this brings to broadband access and the opportunity to "build back better" will only expand going forward.

References

Alexander, B. (2017, October 19). What America is losing as its small towns struggle. *The Atlantic*, 543138. https://www.theatlantic.com/business/archive/2017/10/small-town-economies-culture/543138/

Benesl, Mlynek, P., Ptacek, M., Vycital, V., Misurec, J., Slacik, J., Rusz, M., & Musil, P. (2022). Cable monitoring using broadband power line communication. *Sensors, 22*(8), 3019-3039. https://doi.org/10.3390/s22083019

Boustan, Kahn, M. E., Rhode, P. W., & Yanguas, M. L. (2020). The effect of natural disasters on economic activity in US counties: A century of data. *Journal of Urban Economics, 118,* 103257-103264. https://doi.org/10.1016/j.jue.2020.103257

Campbell, J., Castro, J.R., & Wessel, D. (2021). *The benefits and costs of broadband expansion*. The Brookings Institution. https://www.brookings.edu/blog/up-front/2021/08/18/the-benefits-and-costs-of-broadband-expansion/

Carr, P., & Kefalas, M. (2009). *Hollowing out the middle: the rural brain drain and what it means for America*. Beacon Press.

Chorynski, P., Graczyk, D., & Krzyzaniak, M. (2022). The emergence of different local resilience arrangements regarding extreme weather events in small municipalities- a case study from the Wielkopolska Region, Poland. *Sustainability, 14*(4), 2052-2077. https://doi.org/10.3390/su14042052

Connected Nation. (2022). *Broadband related funding*. https://connectednation.org/current-broadband-funding/

Cordova, A. & Stanley, K. (2021). Public-private partnership for building a resilient broadband infrastructure in Puerto Rico. *Telecommunications Policy*, 45(4), 102106-102018. https://doi.org/10.1016/j.telpol.2021.102106

Cromartie, J. (2017). Rural America at a glance. *U.S. Department of Agriculture, Economic Research Service.* https://www.ers.usda.gov/webdocs/publications/85740/ eib-182.pdf?v=0.

Cromartie, J. (2019). *USDA ERS - What is rural?* Rural Classifications. https://www.ers.usda.gov/topics/rural-economy-population/rural-classifications/what-is-rural/

Dawson, D. (2022). *A brief history of rural broadband*. Broadband for All. https://potsandpansbyccg.com/2022/02/25/a-brief-history-of-rural-broadband/

Dawson, D. (2023). *Telephony in 1927*. Broadband for All. https://potsandpansbyccg.com/2023/01/06/telephony-in-1927/

Deller, S. & Whitacre, B. (2019). Broadband's relationship to rural housing values. *Papers in Regional Science*, *98*(5), 2135–2156. https://doi.org/10.1111/pirs.12450

Dettling, L., Goodman, S., & Smith, J. (2018). Every little bit counts: the impact of high-speed internet on the transition to college. *Review of Economics and Statistics*, *100*(2), 260-273.

de Sa, P. (2017). *Improving the nation's digital infrastructure*. Federal Communications Commission. https://www.fcc.gov/document/improving-nations-digital-infrastructure

De Vos, L, van Ham, M., & Meijers, E. (2020). Does broadband internet allow cities to 'borrow size'? evidence from the Swedish labour market. *Regional Studies*, 54(9), 1175–1186. https://doi.org/10.1080/00343404.2019.1699238

Dobis, Krumel, T., Cromartie, J., Conley, K., Sanders, A., & Ortiz, R. (2021). *Rural America at a glance: 2021 edition*. United States Department of Agriculture. https://ageconsearch.umn.edu/record/316344/

Federal Communications Commission [FCC]. (2020). *Broadband deployment report*. Federal Communications Commission. https://www.fcc.gov/reports-research/reports/broadband-progress-reports/2020-broadband-deployment-report

FCC. (2021). Fixed broadband deployment data from FCC form 477. https://www.fcc.gov/general/broadband-deployment-data-fcc-form-477

FCC. (2022). *Fixed broadband deployment*. http://broadbandmap.fcc.gov/#/

Federal Emergency Management Agency [FEMA]. (2021). *The Stafford act, as amended*. https://www.fema.gov/sites/default/files/documents/fema_stafford_act_2021_vol1.pdf

Federal Emergency Management Agency [FEMA]. (2022). *Hurricane and flood mitigation handbook for public facilities fact sheet 4.3. Electric Power Generation, Transmission and Distribution*. https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-4-3-electric-power.pdf

FEMA. (2022). OpenFEMA data sets. https://www.fema.gov/about/openfema/data-sets

Fry, R., & Cohn, D. (2021). *In 2020, fewer Americans moved, exodus from cities slowed*. Pew Research Center. https://www.pewresearch.org/short-reads/2021/12/16/in-2020-fewer-americans-moved-exodus-from-cities-slowed/

Fussell, C., Dunbar, M., Babb, M., Thompson, L., & Meijer-Irons, J. (2017). Weather-related hazards and population change: a study of hurricanes and tropical storms in the United States, 1980–2012. *The Annals of the American Academy of Political and Social Science, 669*(1), 146–167. https://doi.org/10.1177/0002716216682942

Ganguli, I., Hausmann, R., & Viarengo, M. (2014). Closing the gender gap in education. *International Labour Review, 153*(2), 173–207. https://doi.org/10.1111/j.1564-913X.2014.00007.x

Gillett, S., Lehr, W., Osorio, C., & Sirbu, M. (2006). *Measuring the economic impact of broadband deployment. final report, National Technical Assistance, Training, Research, and Evaluation Project*. US Department of Commerce, Economic Development Administration. http://cfp.mit.edu/publications/CFP_Papers/Measuring_bb_econ_impact-final.pdf

Goovaerts, D. (2021). *You'd be surprised who the top ISPs in the U.S. are, according to FCC data*. Broadband. https://www.fiercetelecom.com/operators/you-d-be-surprised-who-top-isps-u-s-are-according-to-fcc-data

Grabel, S. (2022). *This month in business history: the breakup of the Bell System.* History Factory. https://www.historyfactory.com/insights/this-month-in-business-history-bell-system/

Haase, T., Wang, W., & Ross, A. (2021). The six capacities of community resilience: evidence from three small Texas communities impacted by hurricane Harvey. *Natural Hazards (Dordrecht), 109(1),* 1097–1118. https://doi.org/10.1007/s11069-021-04870-y

NTCA. (2023). *History of rural telecommunications*. https://www.ntca.org/ruraliscool/history-rural-telecommunications

Hodge, T., & Lee, A. (2017, September). *Hurricane Irma cut power to nearly two-thirds of Florida's electricity customers*. Today in Energy. https://www.eia.gov/todayinenergy/detail.php?id=32992

Humphreys, B. (2019). Demand for broadband in rural areas: implications for universal access. Congressional Research Service. R46108. https://crsreports.congress.gov/product/pdf/R/R46108/#:~:text=According%20to%20the%20authors%20of%20a%202015%20study,infrastructure%2C%2052%25%20was%20attributable%20to%20lower%20adoption%20rates.

Integrated Public use microdata series USA. (2022). Data cart. https://usa.ipums.org/usa-action/variables/group

Karsten, J., & West, D. (2016). Rural and urban America divided by broadband access. In TechTank [BLOG]. The Brookings Institution. https://www.brookings.edu/articles/rural-and-urban-america-divided-by-broadband-access/

Kelley, B. & Sisneros, L. (2020). *Broadband access and the digital divides*. https://www.ecs.org/wp-content/uploads/Broadband_Access_and_the_Digital_Divides-1-1.pdf

Kenney, C., Jordan, A., Rapfogel, N., & Malus, H. (2022, March 29). *Stateside chat: small cities, big infrastructure challenges*. Center for American Progress. https://www.americanprogress.org/events/stateside-chat-small-cities-big-infrastructure-challenges/

Kim, J. (2022, July). *Fiber optic network construction: process and build costs*. Dgtl Infra. https://dgtlinfra.com/fiber-optic-network-construction-process-costs/

Kim, Y., & Orazem, P. (2017). Broadband internet and new firm location decisions in rural areas. *American Journal of Agricultural Economics*, *99*(1), 1-18. https://onlinelibrary-wiley-com.ezp-prod1.hul.harvard.edu/doi/full/10.1093/ajae/aaw082?sid=vendor%3Adatabase

Kolko, J. (2010). *Does broadband boost local economic development?* Public Policy Institute of California. https://www.ppic.org/wp-content/uploads/R_110JKR.pdf

Kolko, J. (2012). Broadband and local growth. *Journal of Urban Economics*, *71*(1), 100-113. https://www-sciencedirect-com.ezp-prod1.hul.harvard.edu/science/article/pii/S0094119011000490

Kopparam, R. (2020). *Gaps in US rural and urban economic growth widened in the post-great recession economy, with implications amid the coronavirus recession*. Washington Center for Equitable Growth. https://equitablegrowth.org/gaps-in-u-s-rural-and-urban-economic-growth-widened-in-the-post-great-recession-economy-with-implications-amid-the-coronavirus-recession/

Kuttner, H. (2012). *Broadband for rural America: economic impacts and economic opportunities*. Economic Policy/Briefing Paper. Hudson Institute.

Lee, H., Park, N., & Hwang, Y. (2015). A new dimension of the digital divide: Exploring the relationship between broadband connection, smartphone use and communication competence. *Telematics and Informatics*, *32*(1), 45-56.

Lee, N., Seddon, J., Tanner, B., & Lai, S. (2022). Why the federal government needs to step up efforts to close the rural broadband divide. In policy file. The Brookings Institution. https://www.brookings.edu/articles/why-the-federal-government-needs-to-step-up-their-efforts-to-close-the-rural-broadband-divide/

Lehr, W., Osorio, C., Gillett, S., & Sirbu, M. (2006). *Measuring broadband's economic impact. Presented at the 33rrd Research Conference on Communication, Information, and Internet Policy*. Arlington, VA. p. 1-36. https://www.researchgate.net/publication/266336485_Measuring_Broadband%27s_Economic_Impact

Lehtonen, O. (2020). Population grid-based assessment of the impact of broadband expansion on population development in rural areas. *Telecommunications Policy*, *44*(10), 102028–102063. https://doi.org/10.1016/j.telpol.2020.102028

Mack, E., Anselin, L., & Grubesic, T. (2011). The importance of broadband provision to knowledge intensive firm location. *Regional Science Policy & Practice*, *3*(1), 17-35

Mansury, Ye, X., & Yoon, D. (2021). Structural path analysis of extreme weather events: An application to Hurricane Katrina and Superstorm Sandy. *Applied Geography*, *136*, 102561-102575. https://doi.org/10.1016/j.apgeog.2021.102561

Marré, A. (2020). *Bringing broadband to rural America,* Volume 8, Issue 1. Federal Reserve Bank of Richmond. https://www.richmondfed.org/publications/community_development/community_scope/2020/comm_scope_vol8_no1

Mason, R., & Rennie, F. (2004). Broadband: A solution for rural e-learning? *International Review of Research in Open and Distributed Learning*, *5*(1), 1-19.

Mayfield, J., & Ali, K. (1996). The internet as an educational tool. *Computers & Industrial Engineering*, *31*(1), 21-24.

Minichiello, V., Rahman, S., Dune, T., Scott, J., & Dowsett, G. (2013). E-health: potential benefits and challenges in providing and accessing sexual health services. *BMC Public Health*, *13*(1), 790-797. doi:10.1186/1471-2458-13-790

Molloy, R., Smith, C. L., & Wozniak, A. (2011). Internal migration in the United States. Journal of Economic Perspectives, 25(3), 173–196. https://doi.org/10.1257/jep.25.3.173

Morris, J. (2019). History of the telephone. Nationalitpa.com. https://www.nationalitpa.com/history-of-telephone

National Telecommunications and Information Administration. (2022). Broadband USA map. https://broadbandusa.maps.arcgis.com/apps/webappviewer/index.html?id=e2b4907376b548f892672ef6afbc0da5

Neal, B. (2005). Disaster assistance in rural areas in the aftermath of Hurricane Katrina.http://www.mississippi.edu/urc/downloads/articles/DisasterAssistanceinRuralAreas-December2005.pdf

Office of the President of the United States. (2017). National security strategy 2017. https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf.

Oliveira, G., Torres, A., & Morais, C. (2021). An exploratory study on the emergency remote education experience of higher education students and teachers during the COVID-19 pandemic. British Journal of Educational Technology, 52(4), 1357–1376. https://doi.org/10.1111/bjet.13112

Porter, E. (2021, June 1). A rural-urban broadband divide, but not the one you think of. The New York Times. https://www.nytimes.com/2021/06/01/business/rural-urban-broadband-biden.html

Sanchis-Guarner, R., Montalbán, J., & Weinhardt, F. (2021). Home broadband and human capital formation. https://www.cesifo.org/en/publikationen/2021/working-paper/home-broadband-and-human-capital-formation

Schmidt, K. (2023). Steel in the air-wireless industry timeline. https://www.steelintheair.com/wireless-industry-timeline/

Slack, T. & Jensen, L. (2020). The changing demography of rural and small-town America. Population Research and Policy Review, 39(5), 775–783. https://doi.org/10.1007/s11113-020-09608-5

Smith, A. (2021). 2020 U.S. billion-dollar weather and climate disasters in historical context. https://www.climate.gov/disasters2020

Stenberg, P., Morehart, M., Vogel, S., Cromartie, J., Breneman, V., & Brown, D. (2009). Broadband internet's value for rural America (No. 1477-2016-121092). https://www.ers.usda.gov/webdocs/publications/46200/9335_err78_1_.pdf?v=7613.5

Strong Towns. (2020, June 24). *Small towns are dying. Can they be saved?* Strong Towns. https://www.strongtowns.org/journal/2020/6/24/small-towns-are-dying-can-they-be-saved

Tolbert, J. & Snead, R. (2021). Issue brief: closing the digital divide. *Environmental and Energy Study Institute*. Retrieved from https://www.eesi.org/papers/view/issue-brief-closing-the-digital-divide-2021

Tomer, F., Siefer, A., & Callahan, B. (2020). *Digital prosperity: how broadband can deliver health and equity to all communities*. The Brookings Institution. https://www.brookings.edu/research/digital-prosperity-how-broadband-can-deliver-health-and-equity-to-all-communities/

United States Census Bureau**.** (2021). CPS historical migration/geographic mobility tables**.** https://www.census.gov/data/tables/time-series/demo/geographic-mobility/historic.html

United States Census Bureau**.** (2022). *County population totals: 2010-2019*. https://www.census.gov/data/datasets/time-series/demo/popest/2010s-counties-total.html

Vecchi, L., Zhang, W., Villarini, G., & Knutson, T. (2021). Changes in Atlantic major hurricane frequency since the late-19th century. *Nature Communications*, *12*(1), 4054–4063. https://doi.org/10.1038/s41467-021-24268-5

Vogels, E. (2021, August 19). Some digital divides persist between rural, urban and suburban America. Pew Research Center. https://pewrsr.ch/3k5aU6J

Whitacre, G., & Strover, S. (2014). Does rural broadband impact jobs and income? Evidence from spatial and first-differenced regressions. *The Annals of Regional Science*, 53(3), 649–670. https://doi.org/10.1007/s00168-014-0637-x

Whitacre, G., & Strover, S. (2014). Broadband's contribution to economic growth in rural areas: moving towards a causal relationship. *Telecommunications Policy*, *38*(11), 1011–1023. https://doi.org/10.1016/j.telpol.2014.05.005

Williams, P. (2022). *What does mbps mean*? Bandwidth Place. https://www.bandwidthplace.com/what-does-mbps-mean-article/

Wilkinson, S., Dunn, S., Adams, R., Kirchner-Bossi, N., Fowler, H. J., González Otálora, S., Pritchard, D., Mendes, J., Palin, E., & Chan, S. (2022). Consequence forecasting: A rational framework for predicting the consequences of approaching storms. *Climate Risk Management*, *35*, 100412. https://doi.org/10.1016/j.crm.2022.100412

World Bank. (2022). *Making it possible for the world to log on*. https://www.worldbank.org/en/news/feature/2022/06/06/making-it-possible-for-the-world-to-log-on

Wright, A. (2021, November 22). *Rural leaders fear they'll miss out on infrastructure money.* The Pew Charitable Trusts. https://www.pewtrusts.org/en/research-and-analysis/blogs/stateline/2021/11/22/rural-leaders-fear-theyll-miss-out-on-infrastructure-money