



Rural–nonrural divide in car access and unmet travel need in the United States

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Abstract

Car access is practically a necessity to get around in rural areas of the United States. Yet approximately 4% of rural residents or 4.3 million people do not have a car. Despite important rural–nonrural differences in the built environment and how people travel, research on rural mobility disparities by car access is limited. This paper addresses this gap by asking and answering the following questions: (1) What are the scope and scale of rural car access in the U.S. and what are the factors associated with not having a car? (2) How do rural carless residents get around relative to their nonrural peers? (3) What are the consequences of not having car access in rural areas? We used a dichotomous rural–nonrural classification to evaluate differences in car access and mobility outcomes between rural and nonrural areas using the U.S. Census Bureau Public Use Microdata Sample and the National Household Travel Survey. The results reveal new evidence on socioeconomic and mobility disparities by car access within and between rural and nonrural areas. Rural carless households earn 64% less and 40% less than their counterparts with full car access and their nonrural counterparts, respectively. Rural Native Americans, Black, and Asian populations have a 2.1 times, 1.3 times, and 1.3 times the odds of being carless, respectively, than their rural white peers, after controlling for other factors. Despite their lack of access to a car, a significantly smaller proportion of rural carless residents bike, walk, or take transit for work trips than their nonrural peers (38.9% vs. 74.6%), which may indicate infeasibility of sustainable modes in some rural areas. Consequently, rural carless residents are 2 times more likely to forsake trips than their nonrural peers due to a lack of transportation options. Our findings highlight rural mobility inequities that carless people face relative to their nonrural peers, which merit attention and tailored policy interventions to improve rural mobility, sustainability, accessibility, and equity.

Keywords Carless · Car-deficit · Rural · Mobility · Equity

Introduction

Travel behavior is associated with both place characteristics (transportation and land use systems) and individual characteristics (socioeconomic characteristics, abilities, resources, etc.). The confluence of place and individual factors, such as living in a dispersed rural area

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with limited access to a private vehicle, poses constraints to one's ability to travel how, when, and where they want to. Relative to their urban counterparts, the mobility challenges and barriers that rural households and residents face are notable because of the distances to destinations and limited transportation options. Rural mobility challenges are exacerbated when one lacks access to a household car, as public transit service is limited, on-demand mobility services can be expensive or unavailable, and infrastructure conditions often do not support pedestrian and bicycle travel.

Although the majority of U.S. households have private vehicles, more than 10 million households (about 9%) do not (FHWA 2018). Most households without cars are located in urban areas, yet 6.8% of rural households are carless (FHWA 2018). Although rural households are less likely to be carless than their urban counterparts, rural carlessness may pose greater mobility challenges, and socioeconomic disparities persist across the rural–urban divide. Relative to their urban counterparts, rural residents and households without a car are on average poorer and have far fewer mobility options. While previous research has evaluated barriers to transportation access in rural areas, much of this work focuses on access to healthcare or on broad conditions and policy approaches related to travel challenges. Little is known about rural carlessness, the associated characteristics, and differences between rural and nonrural areas due to the confluence of sociodemographic factors and infrastructure availability.

This study aims to address the research gaps identified in current literature by asking and answering three research questions: (1) What are the scope and scale of rural car access in the U.S. and what are the factors associated with not having a car? (2) How do rural carless residents get around relative to their nonrural peers? (3) What are the consequences of not having car access in rural areas? We evaluate these questions using nationwide data from the U.S. Census and from the National Household Travel Survey. We evaluate each question in rural and nonrural areas focusing on differences both within and between rural and nonrural areas at a nationwide scale. Throughout our analysis, we reflect on disparities observed and implications for barriers to mobility for populations that are underserved by current transportation systems.

The remainder of this paper is organized into five sections. We start with a review of current literature on car access and rural transportation inequities. We then introduce the data sources, measures, and methods used in the analysis. We then present and interpret the characteristics of residents and households that do not have a car in rural areas relative to nonrural areas. We also apply data visualization to highlight U.S. communities where residents and households without access to cars are concentrated. Lastly, we discuss policy implications and suggestions for improving rural car access, accessibility, and equity, describe the study limitations, and provide recommendations for future research.

Literature review

Car access: definition, scale, and measures

Sprawling development patterns in the U.S. make private cars practically a necessity in many communities. U.S. residents travel by car for 78% of their daily miles traveled and more than 80% of their daily trips (FHWA 2018). Although the majority of U.S. households have at least one household vehicle, more than 10 million U.S. households, or about 9%, do not (FHWA 2018). And yet even in households that do not have a car, car access

remains an important feature of mobility as these households still make about one-fourth of their trips by car. This disconnect between car availability and car travel signals that car access is not a binary characteristic but is a matter of degrees (Lovejoy and Handy 2008).

To indicate the degrees of car access, scholars have classified households into three distinctive and mutually exclusive categories: carless¹ (or zero-car), car-deficit, and fully equipped households (Blumenberg et al. 2020). Carless households are defined as those with no car, car-deficit households are defined as those with car access but with less than one car per driver, and fully equipped households are defined as those with at least one car per driver (Blumenberg et al. 2020). Defining degrees of car access allows for a more nuanced understanding of who does not have a car, and how those without access to a car get around, relative to their counterparts with at least one household car.

Role of socioeconomic factors in car access

Many prior studies have collectively established the important role that income and financial status play on the degree of household car access. Compared to their counterparts with at least one household car, carless households earn much less. A study using the 2009 U.S. National Household Travel Survey (NHTS) found that about 40% of U.S. households earning \$5,000 or less do not own a car, while this number drops to less than 2% as incomes reach \$50,000 and above (Blumenberg and Pierce 2012). More recently, a study in California shows that three out of four carless households earn \$35,000 or less, compared to less than one-third of the general population (Blumenberg et al. 2020). Importantly, the economic divide between those with and without cars has grown over time. Between 1969 and 2013, the median household income of carless households decreased by 35% in real terms (\$26,492 vs. \$17,237), while households with at least one car earned 13% more (\$54,992 vs. \$62,187) over the same period (King et al. 2019).

Car access also tends to fluctuate as incomes rise and fall. Increases in incomes are associated with increases in car access (Blumenberg and Pierce 2012; Klein and Smart 2017). Conversely, financial difficulties is one primary reason that one transitions in carlessness in one's mobility history (Klein 2020). This instability of car access appears to be more severe among low-income groups than their peers. Research shows that about half of families in poverty transitioned into and out of carlessness across a one decade time horizon, while less than one-third of other families did so (Klein and Smart 2017). The high levels of volatility in car transitions among low-income groups may be partially explained by that they often tend to have volatile incomes, purchase less reliable cars that increases their average car maintenance and repair costs, and pay high costs of loan interest rates and insurance on cars due to discriminations in these programs (Fletcher et al. 2010; King et al. 2019; Klein and Smart 2017; Ong and Stoll 2007). As incomes increase, low-income households are more likely to purchase a car than their middle-income counterparts (Blumenberg and Pierce 2012; Klein and Smart 2017), indicating that having a household car may impact mobility and quality of life of low-income households and residents to a larger degree compared to that of their peers (Klein 2020).

After controlling for income, differences in car access by race and ethnicity remain notable (Blumenberg and Pierce 2012). Compared to the general population in California,

¹ We use the terms "carless" and "zero-car" interchangeably when we refer to prior studies. In our analysis, we use the term "carless" for consistency, which has the same definition as "zero-car."

households headed by Black or African American and Hispanic populations are 2.8 times and 1.7 times as likely to be carless, respectively; similarly, households headed by Asian populations are 1.3 times as likely to be car-deficit (Blumenberg et al. 2020). Notably, compared to their white peers, car access among people of color appears to be less stable, in which Black families are more than twice as likely as their white peers to transition into and out of carlessness (Klein and Smart 2017). Racial and ethnic disparities in car access can be partially explained by race-based discrimination in car loan programs and automobile insurance rates (Charles et al. 2008; Ong and Stoll 2007), signaling systemic disparities that disadvantaged groups face to obtain and maintain access to household cars.

Car access constraints also disproportionately arise among those who face other types of sociodemographic and physical disadvantages. Compared to their peers with at least one car, carless residents are more likely to be female, older, and have a disability, and they are less likely to be married or have children (Mitra and Saphores 2017).

Mobility characteristics of people without cars

Without a ready car, carless residents and households drive much less and tend to heavily rely on a wide range of alternative modes. Carless households in California make 20% of their total trips by car, while in contrast their peers with at least one car make 90% of their total trips by car (Mitra and Saphores 2020). Conversely, almost 80% of carless households in California use transit, walk, and bike, compared to about 10% of households with at least one car (Mitra and Saphores 2020). Consequently, carless households face numerous barriers to meeting their daily essential travel needs. Carless households in California make fewer than half as many trips and spend more time traveling than their counterparts with car access; about 50% of carless households still take public transit for trips longer than 15 miles, while only less than 4% of households owning a car may choose to do so (Mitra and Saphores 2020).

Despite not having a household car, car access remains an important component of the daily mobility of carless households. More than one-fifth of trips made among carless households are by car (Mitra and Saphores 2020). This notable proportion of car travel results from the use of taxicabs or ride-hailing services (such as Uber and Lyft), carpooling, borrowing cars, and getting rides from friends and family, and car-sharing services (such as Zipcar and Car2Go). In the U.S., 12% of carless residents use ride-hailing (FHWA 2018); in California, carless households make 90% of their trips by carpooling, and they are 4 times more likely to hold a car-sharing membership than the general population (Brown 2017). Notably, compared to their fully equipped counterparts, ride-hailing usage tends to be higher in car-deficit households (Sikder 2019). Car-deficit households in California generate 10% more person-miles than their fully equipped counterparts (63 vs. 57), which may suggest substantial car-sharing, carpooling, and coordinated car use among household members, with car-deficit households having limited car access (cars per driver—0.6 vs. 1.1) and larger size compared to their fully equipped counterparts (number of adults—3.2 vs. 2.3) (Blumenberg et al. 2020).

Characterizing rural contexts: what is rural?

The significance of car access to one's mobility varies across communities. Compared to urban and suburban areas, rural areas are structurally different in terms of the number of destinations, proximity between destinations, and infrastructure that connects them

(Cutsinger and Galster 2006; Hoggart 1990; Millward and Spinney 2011). The high density of urban communities yields the best access to jobs, services, and opportunities (Millward and Spinney 2011). To a lesser extent, suburban communities enjoy similar proximity to resources and multi-modal options that urban communities are privy to (Cutsinger and Galster 2006). In a factor and cluster analysis of neighborhood type, Voulgaris et al. (2016) further establish the relationship between the built environment characteristics of urban, suburban, rural communities, and travel behavior. They find that rural areas are dissimilar from other neighborhood types in that rural areas have the fewest destinations and largest distances between them (Voulgaris et al. 2016), which appear to be consistent with prior work (Cutsinger and Galster 2006; Hoggart 1990; Mattioli 2014; Millward and Spinney 2011; Voulgaris et al. 2016).

Rural–nonrural differences in the prevalence of alternative transport services present significant barriers and make it difficult or impossible for rural carless households to rely on public transit to meet their travel needs (Carlson et al. 2018; Glaeser et al. 2008). In rural areas, alternative transportation modes and services are limited: public transit is rare or non-existent (Pyrialakou et al. 2016); infrastructure supporting walking and biking is poor (McAndrews et al. 2018); long distances between destinations make using alternative modes challenging (Mattioli 2014). Consequently, despite their lack of access to a car, rural carless residents in California are 7 times less likely to use public transit for work trips than their nonrural peers (Barajas and Wang 2022). Collectively, the confluence of not having a car and lacking transportation options leaves rural carless households and residents even more vulnerable to failing to meet their essential travel needs.

Rural–nonrural disparities that carless and car-deficit households and residents face may be further exaggerated by other sociodemographic disadvantages in rural areas relative to their urban counterparts. Compared to their urban peers, rural populations experience higher rates of poverty, particularly in the South and among Black and Native American populations (USDA 2022). Rural populations are also more likely to be white than their urban peers, although the share of nonwhite rural populations is growing (Davis et al. 2022). Consequently, people of color in rural areas may be at higher risk of exclusion than their urban peers. In addition, rural residents tend to be aging, and the number of people who are of working-age is declining in rural areas, which may signal increased medical needs of these in rural areas relative to their urban peers (Davis et al. 2022). A recent study shows that in California, rural carless households earn 27% less than their nonrural counterparts; 8% of rural Black people are carless, which is about 2.5 times as many as their rural white peers; and rural residents who are unemployed and have disabilities are 1.7 times and 1.3 times more likely to be carless than their nonrural peers, respectively (Barajas and Wang 2022).

This relationship between socioeconomic status and car access operates in both directions, leading to undesirable reinforcement effects which are particularly notable among disadvantaged groups (Fletcher et al. 2010; Lichtenwaller et al. 2006; Raphael and Stoll 2001). Car access also appears to be positively and substantively associated with the likelihood of being employed and economic benefits (Bastiaanssen et al. 2020; Garasky et al. 2006; Gurley and Bruce 2005; Raphael and Rice 2002). After controlling for other factors, having car access is associated with a 16.8 percentage points increase in employment rates and a 11% increase in wages (Raphael and Rice 2002). The lack of alternative transportation and low access to employment opportunities that residents and households face in rural areas may be further exaggerated by not having a car (Bastiaanssen et al. 2020; Fletcher et al. 2010; Lichtenwaller et al. 2006), which may contribute to increasing socioeconomic

disparities between rural and nonrural carless individuals relative to their peers who have access to a car (Barajas and Wang 2022).

To evaluate rural–urban differences in mobility outcomes, most scholarship relies on the classification of rural and urban areas developed by the U.S. Census. Prior to 2020, the U.S. Census defined urban areas as those with 50,000 or more people, urban clusters as areas with at least 2,500 people but less than 50,000 people, and areas that were not located in an urban area or cluster were classified as rural. However, this widely adopted definition of rural–urban classification is limited in that it does not distinguish between rural areas that are near versus far from urban areas and urban clusters, or between rural areas with different development patterns. In reality, even within rural areas there is heterogeneity in the built environment (Isserman 2005; Mattioli 2014; Millward and Spinney 2011), in which the term “rural” can encompass small towns and highly dispersed communities, for instance.

Thus, with differences in mobility, sociodemographic characteristics, and car access between rural and nonrural areas, whether and to what degree mobility outcomes of carless households and residents in rural areas differ from that in the remaining areas of the nation merits scholarly attention. One primary step is to estimate the scope and scale of carlessness within and between rural and nonrural areas, measure rural–nonrural differences in socioeconomic and mobility characteristics for carless people, and understand how mobility barriers and burdens that rural carless people face differ from their nonrural peers.

Status and barriers to rural mobility justice

The confluence of rural–nonrural differences in socioeconomic factors and infrastructure availability can lead to consequences in access and life outcomes that disproportionately burden rural carless households and residents. Rural populations are known to take less frequent but longer trips than their urban and suburban counterparts, resulting in higher rates of vehicle miles traveled (Millward and Spinney 2011; Pucher and Renne 2005; Ralph et al. 2016, 2017; Voulgaris et al. 2016). However, this likely reflects greater mobility challenges rather than greater realized access, as evidenced by their greater travel costs (Bureau of Transportation Statistics, U.S. DOT 2022) and difficulty meeting essential needs (Delbosc and Currie 2011). Compared to their urban peers, rural residents travel two to three times farther to meet their medical specialists (Chan et al. 2006). The low levels of mobility, availability, and accessibility of transportation infrastructure that rural residents face are known to lead to decreased out-of-home activities, reduced job opportunities, and delayed or reduced medical care (Cristancho et al. 2008; Delbosc and Currie 2011; Goins et al. 2005; Mattson 2011; Morris et al. 2020).

Differences in mobility and accessibility between rural and urban areas affect disadvantaged groups to a larger degree, including children, people without a household car, relative to their peers (Cristancho et al. 2008; Goins et al. 2005; Mattson 2011; Morris et al. 2020; Skinner and Slifkin 2007). Compared to their urban peers, rural children with special healthcare needs are less likely to make their medical appointments due to travel difficulties (Skinner and Slifkin 2007). Rural carless residents are less likely to participate in out-of-home activities, and they experience increased social isolation and reduced psychological and social well-being than the general rural population (Delbosc and Currie 2011; Morris et al. 2020). These rural–nonrural differences in mobility barriers and burdens among disadvantaged groups further highlight inequity concerns that rural residents and households face in meeting their daily essential travel needs and maintaining quality of life.

Despite the important role of mobility in getting around rural areas, 6.8% of rural households do not have car access. The barriers and burdens that rural households and residents disproportionately face relative to their nonrural counterparts, may be further exaggerated by having no or limited car access due to differences in access to destinations, transportation options, and socioeconomic characteristics between rural and nonrural areas. However, current literature has focused extensively on characterizing the built environment, travel behavior, and car ownership within urban and suburban communities. Little is known about the scope and scale of rural carlessness and who does not have a car in rural areas, and importantly, mobility outcomes of rural carless households and residents relative to their nonrural counterparts. This study addresses this research gap by quantifying the scope and scale of rural car access, how rural carless people travel, and what consequences rural carless people face as a result of not owning a car. Our analysis evaluates the differences between rural and nonrural areas, as well as the variation for populations living within rural areas. We reflect on disparities observed and the implications for groups that are currently underserved by transportation systems.

Data and methods

Data

We relied on three main data sources to identify disparities in socioeconomic and mobility characteristics by car access and rural–nonrural disparities among carless and car-deficit households and residents: the spatially aggregated 2010 Decennial data, the 2019 American Community Survey (ACS) 5-year Public Use Microdata Sample (PUMS) collected by the U.S. Census, and the 2017 U.S. National Household Travel Survey (NHTS) administered by the Federal Highway Administration (FHWA). Each of these data sources presents complementary merits. The aggregated Decennial data were used to define and distinguish rural and nonrural environments. The PUMS data provided indicators of car access and a series of socioeconomic and mobility characteristics at the individual and household levels. The ACS 5-year PUMS data is weighted sample and includes records of about 5% of the total population, which allowed for detailed cross-tabulations. However, the PUMS travel data is limited to work trips. To overcome this limitation, the NHTS data, which has more travel data but a smaller sample than the PUMS data, was used for indicators revealing mobility barriers and burdens.

The NHTS data includes a travel diary of all trips taken during a 24-h period by all household members aged 5 or older. Respondents report trip purpose, mode of transportation, time of day of travel, day of the week, and vehicle occupancy for each trip. The NHTS sample comprises 129,696 households. We use sample weights derived from sociodemographic characteristics (provided by the NHTS data) to make inferences about the U.S. population. The NHTS data has a relatively small sample of rural carless households, with our analysis including 1,571 rural car-deficit and 615 rural carless people in the survey sample. As discussed below, we compare the makeup of the population of rural carless households reflected in the NHTS data with the PUMS data to ensure that our estimates are robust. A combination of these three data sources together provides a comprehensive understanding of how rural carless and car-deficit residents and households meet (or fail to meet) their essential daily travel needs.

Methods

Descriptive statistics

We begin with the descriptive statistics and tests of significance to estimate the scope and scale of rural households and residents who have no or limited car access, quantify socio-economic and mobility differences by household car access, and identify whether disparities in household car access within rural areas differ from that in nonrural areas and to what degree. Building upon prior work, we grouped U.S. households by their degree of car access into three categories: carless, car-deficit, and fully equipped households (Basu and Ferreira 2020; Potoglou and Susilo 2008, Blumenberg et al. 2020). In producing the descriptive summary statistics, we conducted Chi-squared tests of independence for those factors that are categorical variables, such as gender, race and ethnicity, and educational attainment, and used the Kruskal–Wallis rank-sum test for those factors that have a continuous value, such as household income. All differences reported in the main text are statistically significant ($p < 0.05$) unless otherwise noted.

Ordinal logistic regression model

We then carried out an ordinal logistic regression model to examine whether the effects of factors associated with car access vary by rural status, and to what degree. Building upon the literature (Anowar et al. 2014; Basu and Ferreira 2020; Potoglou and Susilo 2008), we selected an ordinal logistic regression model as the appropriate specification for the following reasons: (1) Our dependent variable, car access, is an ordered categorical variable with three levels of responses—carless, car-deficit, and fully equipped; (2) The probabilities by three levels of car access are strictly increasing as the number of categorical responses included increases, known as cumulative probabilities; and (3) The three levels of car access are mutually exclusive, in which the possibility of being in one given response level is dependent on the possibilities of being in other response levels. In an ordinal logistic regression model, the probability of one having a response level J for $J = 1, 2, 3, \dots, j$, can be written as:

$$Pr(Y_i \leq j) = \frac{\exp(\beta_j - \beta_1 * X_{1i} - \beta_2 * X_{2i} - \dots - \beta_k * X_{ki})}{1 + \exp(\beta_j - \beta_1 * X_{1i} - \beta_2 * X_{2i} - \dots - \beta_k * X_{ki})}$$

where $Pr(Y_i \leq j)$ represents changes in the probability as the ordered responses change from carless, car-deficit, to fully equipped. β_j indicates the intercept term of each category of car access where $1 \leq j \leq J - 1$, in which the level 1 indicates carless ($j = 1$), the level 2 indicates car-deficit ($j = 2$), and the level 3 indicates the reference group—fully equipped. X_{ki} is the k_{th} predictor with the i_{th} value, and k indicates the number of independent variables included. β_k indicates the coefficients of each independent variable.

Building upon the associated factors of car access we identified in the literature, we then applied the model performance measures of aGSIF—the adjusted generalized standard error inflation error—to test the multicollinearity using the threshold of 1.6 (Fox and Monette 1992), and RMSE—the root mean square error—to identify the best model (presented in the results section below).

Defining and quantifying car access

In defining and quantifying household car access, we first indicate whether or not a household has a car. We then measure the degree of each household's access to cars. Specifically, *car access* is an indicator estimated at the household level and is calculated as the number of household cars available per adult (person aged 18 or older). Households with a car access indicator value of zero are defined as carless households, households with a car access indicator greater than zero and less than one are defined as car-deficit households, and households with a car access indicator equal to or greater than one are defined as fully equipped households. Our approach of defining and quantifying household car access is conceptually consistent with prior work (Blumenberg et al. 2020).

Indicating rural and nonrural areas

Our analysis requires a definition of rural and nonrural areas. However, the data sources we use differ in the availability of a rural–nonrural indicator: the NHTS data includes rural classifications while the PUMS does not. The NHTS data are designated as rural and urban areas at relatively fine spatial scales. The NHTS binary rural–urban classification is based on home address location and the urban area type (urban, urban cluster, or rural) from the Census 2014 TIGER/Line Shapefiles. The NHTS definition classifies households as urban if they live in urban areas and urban clusters, and rural if they do not. Under the NHTS nonrural–rural definition, 82.5% of the households in the NHTS sample (out of the total 129,696 households) are classified as nonrural, while 17.5% are designated as rural.

The PUMS data provides the variables that are available at the Public Use Microdata Area (PUMA) scale—large areas of geography consisting of at least 100,000 people. PUMAs thus cover a broad range of land use types and require an indicator of rural–nonrural status which is not currently available in the PUMS data. To overcome this limitation, we calculated the degree of rurality for each PUMA from the spatially aggregated Decennial population estimates to derive a binary classification. We used the 2010 Decennial data at the census tract level to obtain the rural population, the urban population, and the total population. We then conducted a spatial join and merged the Decennial variables to the PUMS data by assigning a census tract to a PUMA if the centroid of the census tract fell within the boundaries of the PUMA. We then aggregated the rural population and the total population from the census tract level to the PUMA level. Lastly, we calculated the percentage of the total population in each PUMA that lives in a rural census tract as an indicator of rurality.

To obtain the appropriate definition of rural and nonrural areas, we applied a series of the thresholds. We identified PUMAs with at least 20% and 50% of their population living in rural areas. We selected 20% as the threshold candidate because it corresponds to the approximate proportion of rural residents nationwide as measured and reported by the U.S. Census. We also performed a sensitivity analysis to ensure the validity and reliability of this definition of rural and nonrural PUMAs. To do so, we calculated and compared the socioeconomic profiles of rural and nonrural households by household car status using both a 20% threshold and a 50% threshold. Specifically, with the 50% threshold, we capture 52% of the rural population defined by the U.S. Census (31,221,919 out of 59,724,800), and with the 20% threshold, we capture 90% of the rural population defined by the U.S. Census (53,124,846 out of 59,724,800). Although patterns in the results were similar for both thresholds, the 20% threshold allows us to capture most of the rural population

defined by the U.S. Census. Thus, we report the results of applying the 20% threshold in the main text. The detailed descriptive statistics for both thresholds can be found in the supplementary information.

To further ensure the validity and consistency of our definitions of rural and nonrural areas derived from the two different data sources, we compared the sociodemographic characteristics of the people represented in rural areas in the NHTS to those represented in areas that we defined as rural in the PUMS data. When evaluating socioeconomic groups and levels of car access at the block group level, we found that both datasets capture similar proportions of people located in nonrural and rural areas (see Tables S3 and S4 in the supplementary material.)

The use of a binary rural definition is a limitation in our study. However, for the purposes of this study, our decision to evaluate a rural–nonrural classification was intentional, which allowed us to focus on the rural end of the urban/rural spectrum that has been limited in prior work.

Identifying socioeconomic and mobility variables

Through our review of the existing literature, we identified a set of socioeconomic factors that are associated with the status of having a household car and the degree of household car access. These factors are derived from the PUMS data and are available at either the individual or the household levels. Key individual characteristics include gender, age, race and ethnicity, language, citizenship, nationality, educational attainment, employment status, and marital status. Key household characteristics include household income, owner cost, rent cost, home ownership, single-parent household, presence of children, and presence of the elderly. For simplicity and clarity, in the main text, we report a subset of characteristics of importance: income, race and ethnicity, educational attainment, and housing cost burden. The remaining characteristics are included in the supplementary information.

We relied on both the PUMS and the NHTS to draw a comprehensive picture of how rural carless and car-deficit households and residents get around as well as the mobility barriers and burdens they face, relative to their nonrural counterparts. The PUMS data provides travel data on transportation modes for work trips (driving alone, carpooling, public transit (including bus, subway or rail), biking or walking, and others), while the NHTS data provides the mobility indicators of self-reported financial burden, trip duration, and unmet travel need.

Our measure of mobility barriers (or unmet travel need) is estimated based on the reason for no travel indicated by survey respondents who did not make a trip on the surveyed travel day. Ten reasons for no trips were provided, including the options that reflect a lack of need as well as one that we focus on as an indication of unmet need: lack of transportation options. The financial burden outcomes are measured directly based on responses to a question in the NHTS data asking respondents to indicate their level of agreement with the statements “getting from place to place costs too much” using a five-level Likert-type scale. Table 1 below provides a summary of the socioeconomic and mobility variables evaluated.

Table 1 Socioeconomic and mobility characteristics examined

Characteristics	Definitions	Unit of Analysis
Socioeconomic Variables (PUMS)		
Gender	Male or Female	Individual
Race and Ethnicity		Individual
Black or African American	Non-Hispanic Black or African American alone	
Native American	Non-Hispanic American Indian alone, Alaska Native alone, American Indian and Alaska Native tribes specified or American Indian or Alaska Native, not specified and no other races	
Hispanic or Latino	Hispanic or Latino (all races)	
Asian	Non-Hispanic Asian alone	
White	Non-Hispanic White	
Other	Non-Hispanic other races or multiple races	
Limited English proficiency	Does not speak English well or at all (aged 5 +)	Individual
Non-citizen	Not a citizen of the U.S	Individual
Foreign-born	Foreign born	Individual
Educational attainment	(aged 3 +)	Individual
Bachelor's or above	Bachelor's degree or above	
Some college or equivalent	Associates degree or some college	
High school or equivalent	High school diploma, GED, or alternative credential	
Less than high school	No high school diploma or equivalent	
Disabled	Disabled (aged 5 +)	Individual
Unemployed	Civilian unemployed in labor force (aged 16+)	Individual
Not married	Not married (aged 15+)	Individual
Household income	Household income in the past 12 months	Household
Owner cost (%)	Housing cost for owners as a % of household income in the past 12 months	Household
Gross rent (%)	Rental cost as a % of household income in the past 12 months	Household
Single-parent household	With children (18-) and no spouse/partner present	Household
Owned unit	Owns home with mortgage or loan or free and clear	Household

Table 1 (continued)

Characteristics	Definitions	Unit of Analysis
Presence of children	With children under 18 years old	Household
Presence of older adults	One or more persons aged 65 years old or above	Household
Mobility Variables (PUMS/NHTS)		
Mode to Work (PUMS)		
Drive alone	Drive alone	Individual
Carpool	Two-person or more carpool	
Public transit	Bus, subway, or elevated rail	
Bike and walk	Biking or walking	
Other	Other means of transportation	
Burdens & Barriers (NHTS)		
No trips (travel day)	No trips on surveyed travel day	Individual
No trips (no options) (unmet need)	No trips on surveyed travel day because no transportation options	
Financial burden	Travel is a financial burden (self-reported)	
Commute time	Trip duration (minutes) of all trips to work among these aged 18+	

Sources: 2015–2019 5-Year American Community Survey Original Codebook; 2017 National Household Travel Survey

Results

We now turn to presenting and interpreting the results of our analysis. We begin with the scope and scale of car access in rural and nonrural areas. Next, we highlight U.S. communities where rural carless and car-deficit residents and households are concentrated, and discuss socioeconomic and mobility differences by car access between and within rural and nonrural areas using the descriptive statistics and an ordinal logistic regression model. We then reveal new evidence on mobility inequity concerns that rural carless and car-deficit residents and households face, relative to their rural fully equipped and nonrural counterparts. We provide the detailed descriptive statistics in the supplemental information.

Scope and scale of carlessness by rurality in the U.S.

The scope and scale of car access are derived from the PUMS data. Using our definitions of car access demonstrated above, we found 110 million U.S. households (91%), or 282 million people (94%), have at least one household car. However, about 10.5 million households (8.6%), or 18.6 million people (6.2%), do not have a household car, and 20.6 million households (17%), or 70 million people (23.3%), are in a car-deficit status. Together, in the U.S., carless and car-deficit households account for more than one quarter of total households, and carless and car-deficit residents account for about one-third of the total population.

Car access is not evenly distributed between rural and nonrural areas. In this study, we applied a binary classification of rurality to capture rural–nonrural differences in the scope and scale of car access. Our results show that in nonrural areas, about 14.3 million residents (7.3%) do not have a household car, and more than 50 million residents (26%) are in a car-deficit status. In rural areas, despite limited transportation options and low levels of accessibility to many destinations, the scope and scale of carlessness and limited car access are notable. Although 96% of rural residents have at least one car, 4% or more than 4.3 million rural residents, do not have a car, and 18% or about 19.3 million rural residents, are in a car-deficit status.

There are clear spatial patterns in the scope and scale of rural car access. Figure 1 shows differences in car access in rural areas across the U.S., with nonrural areas shown in gray. Rural areas with higher shares of carless and car-deficit households appear to be geographically concentrated. The Appalachian region, northern New England, portions of the coastal Southeast, the Mississippi Delta, southern Texas, and some Native American reservations and their surroundings have higher shares of rural carless households (Fig. 1a), while the Sunbelt area of the U.S., portions of northern New England, central South Dakota, and parts of Northern California tend to have higher shares of rural car-deficit households (Fig. 1b).

Rural–nonrural comparisons in who lacks car access

Both socioeconomic characteristics and living environments relate to car access. Disadvantages that rural carless and car-deficit households and residents face are further exaggerated by rural–nonrural differences in socioeconomic characteristics and car ownership. We present our findings drawn from the descriptive statistics and an ordinal logistic regression model below.

Fig. 1 Mapping of Rural Car Access Nationwide (Using our classification scheme of the 20% threshold, the gray areas in Fig. 1 are classified as nonrural areas, relative to rural areas. Figure 1 presents differences in car access in rural areas at the PUMA level). *Data Source* PUMS

Descriptive statistics

Disparities in socioeconomic characteristics between rural and nonrural areas among carless and car-deficit households and residents are derived from the PUMS data (Fig. 2). As expected, household income is one distinguishing characteristic associated with rural–nonrural disparities in carlessness and limited car access. Compared to their nonrural counterparts, rural carless and car-deficit households earn 40% and 28% less (i.e., calculated as the average household income), respectively (Fig. 2a).

Relative to their nonrural peers, rural residents are less likely to be carless or in a car-deficit status, but are more likely to be fully equipped across all racial and ethnic groups except rural Native Americans. Unlike every other race or ethnicity, the proportion of rural Native Americans who are fully equipped, is not greater than their nonrural counterparts (Fig. 2b).

Educational attainment is another factor that explains rural–nonrural disparities in carlessness. Compared to their nonrural peers, rural residents with less than a high school degree are 1.2 times more likely to be carless; rural residents with a high school degree are 1.3 times more likely to be carless or in a car-deficit status (Fig. 2c).

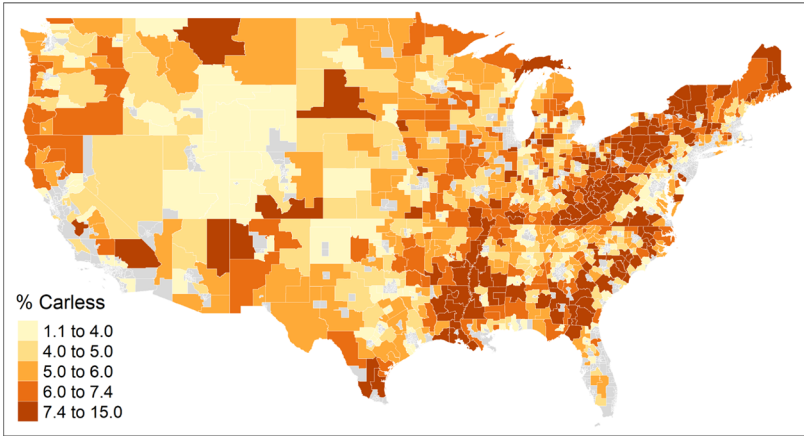
Not surprisingly, rural–nonrural differences in land and development prices contribute to differences in housing cost burdens by car access. Rural carless and car-deficit households experience relatively lower rental cost burdens but higher housing cost burdens for homeowners than their nonrural counterparts. Rural carless and car-deficit households spent 20% and 30% less on rent as a share of their income, respectively, than their nonrural counterparts. This difference is not surprising given higher affordability and lower demand for rental housing in rural areas compared to their nonrural counterparts. However, this trend is reversed for housing cost burdens for homeowners. Rural carless households in owned units spent 1.4 times as much on housing costs as a share of income as their nonrural counterparts, which may be a consequence of rural–nonrural differences in income levels, house types, and the sizes of owned units among carless households (Fig. 2d).

Importantly, compared to their nonrural peers, rural carless and car-deficit residents are about 1.5 times more likely to have a disability or to be unemployed. (See the supplemental information for detailed descriptive statistics.)

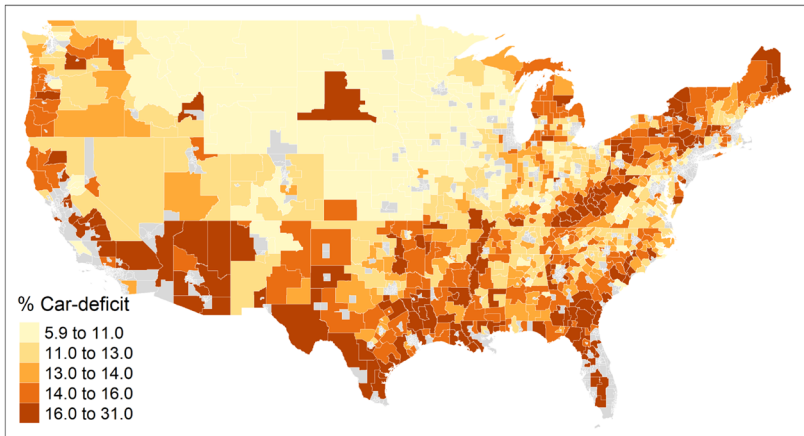
An examination of who does not have car access within rural areas reveals that socioeconomic disparities by car access in rural areas are in many cases more severe than nonrural disparities (Fig. 2). Rural carless and car-deficit households earn 64% and 16% less than their rural fully equipped counterparts, respectively, compared to 54% and 10% in the nonrural comparison (Fig. 2a).

As expected, the intersection of rurality and race and ethnicity points to disparities in car access in rural areas. Compared to their white peers, rural Black or African American people and Native Americans are 3 times more likely to be carless. Rural Black or African American people, Native Americans, Hispanic or Latino, and Asian people are 1.7 times, 2 times, 1.8 times, and 2 times more likely to be in a car-deficit status than their white peers, respectively (Fig. 2b).

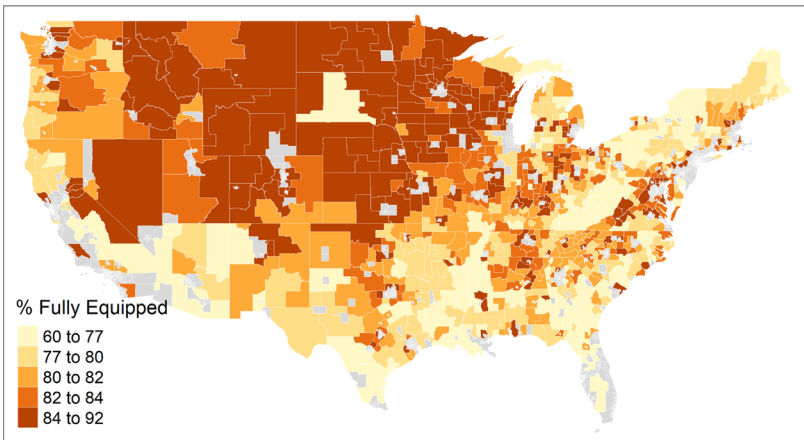
Educational attainment is another characteristic associated with car access in rural areas. Compared to their rural peers with at least a Bachelor's degree, rural residents with



(a) Rural Carless Households



(b) Rural Car-deficit Households



(c) Rural Fully Equipped Households

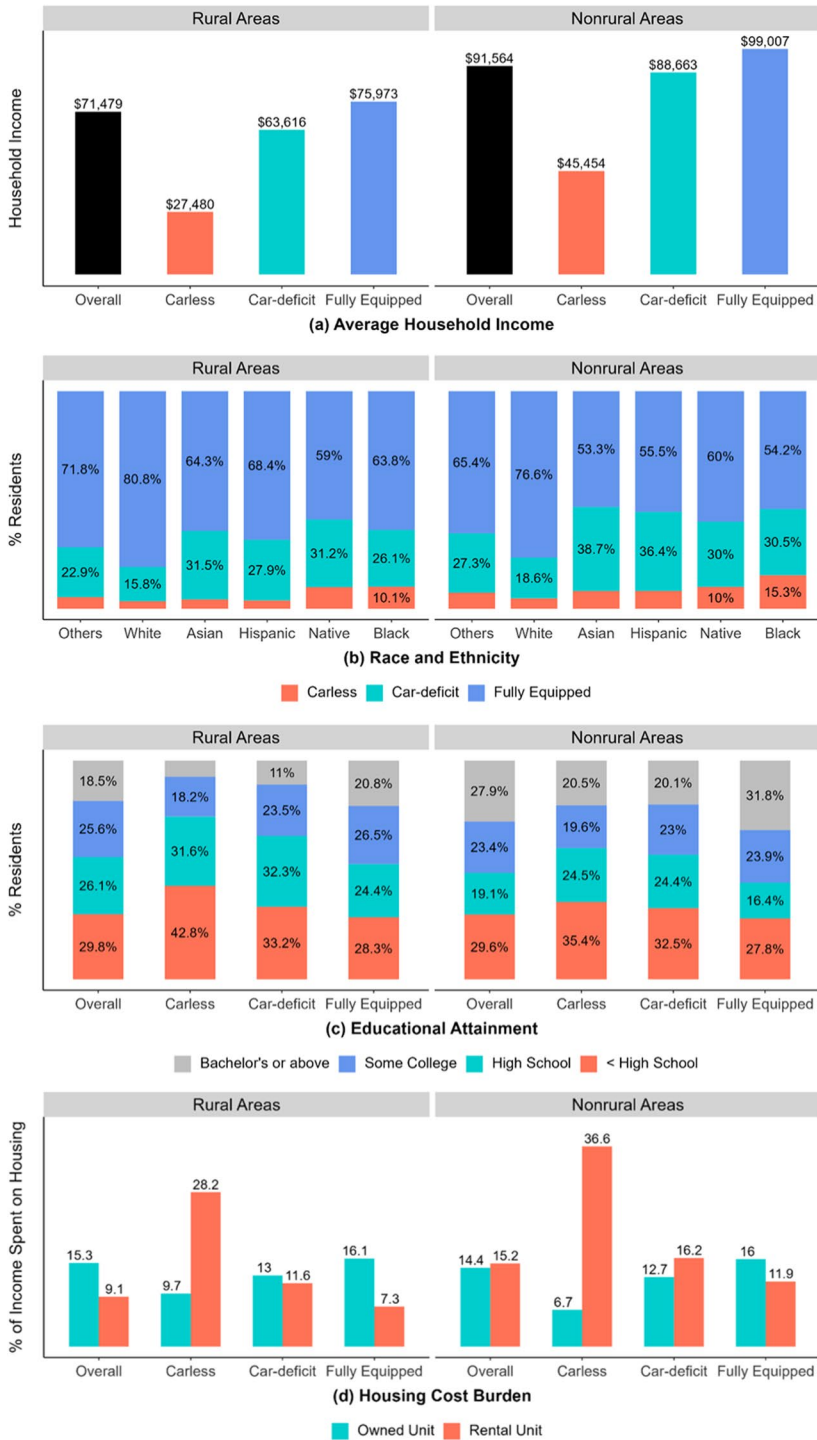


Fig. 2 Rural–Nonrural Differences in Socioeconomic Factors by Car Access (Data Source: PUMS)

less than a high school degree are 3.6 times and 1.9 times more likely to be carless or in a car-deficit status, respectively; rural residents with a high school degree are 3.1 times and 2.1 times more likely to be carless or in a car-deficit status, respectively; similarly, rural residents who completed some college but do not have a college degree are 1.8 times and 1.5 times more likely to be carless or in a car-deficit status, respectively (Fig. 2c).

Disparities in housing burdens by car access appear to be more substantial in rural areas relative to nonrural comparisons. The proportions of income that rural carless and car-deficit households spent on rental costs are 3.9 times and 1.6 times as much as their rural fully equipped counterparts, respectively, relative to 3.1 times and 1.4 times in nonrural comparisons (Fig. 2d). Conversely, the proportions of income that rural carless households in owned units spent on housing costs are 40% less than their rural fully equipped counterparts, relative to 60% in nonrural comparisons (Fig. 2d). This pattern of relatively low housing cost burdens for homeowners but high cost burdens for renters in rural areas suggests more severe disparities in housing cost burdens that rural carless and car-deficit households in rental units face than their nonrural counterparts.

Other factors that are notable in explaining differences by car access in rural areas include disability status, employment status, marital status, homeownership, single-parent households, and presence of children or older adults. Compared to their rural fully equipped peers, rural carless residents are 3 times and 4 times more likely to have disabilities or are unemployed. Rural carless residents are more likely to be single adults (1.5 times) and live in households with at least one member aged 65 years old or above (1.3 times), than their rural fully equipped peers. Conversely, rural carless residents are about 50% less likely than their rural fully equipped counterparts to live in an owned unit or in a household with children. (See the supplemental information for detailed descriptive statistics.)

Ordinal logistic regression model

We then move to our findings from the regression model on rural–nonrural differences in the determinants of car access. Overall, our results using an ordinal logistic regression model are consistent with findings from the descriptive statistics. Table 2 presents the odds ratios of one being carless or in a car-deficit status (vs. fully equipped) within and between rural and nonrural areas. Overall, we find new evidence on rural–nonrural differences in the effects of determinants of car access, and disadvantaged groups in rural areas are further disproportionately impacted in many cases, after controlling for the other factors.

As expected, age, race and ethnicity, English proficiency, household income, and educational attainment are strong determinants of car access. Age is negatively and substantively associated with the likelihood of being carless or in a car-deficit status (vs. fully equipped). Compared to their peers aged between 18 and 24 years old, rural residents who are older have a much lower odds of being carless or in a car-deficit status (vs. fully equipped) by 42% (aged between 25 and 34), 53% (aged between 35 and 44), 52% (aged between 45 and 54), 58% (aged between 55 and 64), 59% (aged between 65 and 74), and 55% (aged 75 years old or above), respectively.

People of color in rural areas are more likely to be carless than their rural white peers, with one exception. Native Americans, Black, and Asian populations in rural areas have 2.1 times, 1.3 times, and 1.3 times the odds of being carless or in a car-deficit status (vs. fully equipped), respectively, relative to their rural Non-Hispanic white peers. Compared to their rural peers who speak English fluently, rural residents who have limited English have

Table 2 Rural–nonrural differences in the odds ratio of being carless or in a car-deficit status (vs. fully equipped) using ordinal logistic regression model

Characteristics	Rural areas			Nonrural areas			Rural–non-rural differences Ratio of odds ratio (Rural to Nonrural Area)
	Odds ratio	95% CI		Odds ratio	95% CI		
		2.5%	97.5%		2.5%	97.5%	
Female (vs. Male)	0.92	0.90	0.94	0.99	0.98	1.00	0.93
Age (ref.: 18–24)							
25–34	0.58	0.55	0.61	0.69	0.68	0.70	0.84
35–44	0.47	0.45	0.50	0.58	0.57	0.59	0.82
45–54	0.48	0.46	0.50	0.60	0.59	0.61	0.80
55–64	0.42	0.40	0.45	0.59	0.58	0.60	0.72
65–74	0.41	0.38	0.44	0.58	0.57	0.60	0.70
75+	0.45	0.40	0.51	0.73	0.69	0.77	0.62
Race and Ethnicity (ref.: Non-Hispanic White)							
Non-Hispanic Black	1.26	1.17	1.37	1.58	1.54	1.62	0.80
Native American	2.11	1.98	2.26	1.31	1.20	1.43	1.61
Hispanic or Latino	0.73	0.70	0.76	1.10	1.08	1.11	0.67
Non-Hispanic Asian	1.34	1.27	1.41	1.52	1.49	1.55	0.88
Non-Hispanic Others	1.22	1.12	1.34	1.35	1.29	1.40	NS
Limited English	1.25	1.21	1.29	1.45	1.43	1.47	0.86
Household Income (ref.: 25 k or less)							
25 k to 50 k	0.90	0.85	0.94	0.87	0.85	0.89	NS
50 k to 75 k	0.96 (NS)	0.91	1.02	0.89	0.87	0.92	NS
75 k to 100 k	0.94*	0.88	0.99	0.94	0.91	0.96	NS
100 k to 150 k	1.03 (NS)	0.97	1.09	1.03	1.01	1.15	NS
150 k to 200 k	1.10*	1.00	1.20	1.11	1.07	1.15	NS
200 k+	1.12	1.03	1.21	1.13	1.10	1.16	NS
Educational Attainment (ref.: Bachelor or above)							
Some college	1.26	1.22	1.31	1.12	1.11	1.14	1.12
High school	1.74	1.67	1.81	1.46	1.44	1.48	1.19
Less than high school	2.80	2.68	2.92	1.78	1.75	1.82	1.57
Rental Unit (vs. Owned)	1.74	1.69	1.79	2.36	2.33	2.39	0.74
Unemployed	1.69	1.62	1.76	1.60	1.57	1.64	NS
Disabled	1.21	1.16	1.27	1.21	1.18	1.24	NS
Not Married	1.12	1.08	1.15	1.16	1.15	1.17	NS
Presence of Children (ref.: two-parents household)							
Single-parent	0.72	0.67	0.78	0.87	0.84	0.90	0.83
No children	1.23	1.19	1.28	1.41	1.39	1.43	0.88
Ordered Responses	Intercepts			Intercepts			
Carless Car-deficit	26.63	24.32	29.15	32.45	31.40	33.54	
Car-deficit Fully equipped	2.30	2.11	2.50	2.55	2.47	2.63	
Performance Metrics							
Number of observations	211,905			1,247,596			
RMSE	2.37			2.26			

Table 2 (continued)

(1) All odds ratios presented are statistically significant at the level of $p < 0.001$ unless otherwise noted in which: * $p < 0.05$; ** $p < 0.01$, Not Significant (NS); (2) The odds ratios indicate the odds of one being carless and in car-deficit relative to fully equipped; (3) CI indicates Confidence Interval

1.3 times the odds of being carless or in a car-deficit status (vs. fully equipped). Note that rural residents who are Hispanic or Latino appear to have a 27% lower odds of being carless or in a car-deficit status (vs. fully equipped), which may be partially explained by the popularity of resource-based jobs (for instance agriculture, forestry) among rural Hispanic or Latino populations that often require car access (Cristancho et al. 2008; Lichter 2012; Rural Hispanics, USDA 2005). Yet, even after controlling for English proficiency, Hispanic or Latino populations in nonrural areas have 1.1 times the odds of being carless or in a car-deficit status (vs. fully equipped), compared to their Non-Hispanic white peers.

Not surprisingly, income is associated with car access. Yet, the relationship between incomes and car access appears to be nonlinear. One's status of being carless or in a car-deficit status (vs. fully equipped) is more sensitive to changes in household incomes among lower-income earners. Specifically, compared to those earning \$25,000 or less, rural households with an annual income between \$25,000 and \$50,000 have a 10% lower odds of being carless or in a car-deficit status (vs. fully equipped). However, as incomes continue rising, the probability of one being carless or in a car-deficit status (vs. fully equipped) among those earning up to \$150,000, are no longer substantively and significantly different from their rural counterparts who earn \$25,000 or less. These rural households who earn more than \$150,000 in rural areas are more likely to be carless or in a car-deficit status than their rural counterparts who earn \$25,000 or less.

Educational attainment is negatively and substantially associated with car access. Compared to their rural peers having a Bachelor's degree or above, rural residents who completed some college, high school, or less than high school, have a 1.3 times, 1.7 times, and 2.8 times the odds of being carless or in a car-deficit status (vs. fully equipped), respectively.

Other associated factors include homeownership, disability, employment status, marital status, gender, and presence of children. Compared to their rural peers, rural residents living in rental units, having disabilities, and who are unemployed or not married, have a 1.7 times, 1.7 times, 1.2 times, and 1.1 times the odds of being carless or in a car-deficit status (vs. fully equipped), respectively. The presence of children is positively associated with rural car access. Households having no children have a 1.2 times the odds of being carless or in a car-deficit status (vs. fully equipped) than their two-parents counterparts. However, relative to two-parents households, single-parent households have a 28% lower odds of being carless or in a car-deficit status. This difference in car access among rural households having children indicates the important role of car-sharing among household members in two-parents households and the necessity of car access for single-parent households. In rural areas, females are 8% less likely to be carless or in a car-deficit status (vs. fully equipped) than males.

Importantly, our results reveal new evidence on rural–nonrural differences in the associated factors of and the effects on one's status and degree of car access. We find that the likelihood of one being carless or in a car-deficit status that certain disadvantaged groups disproportionately face, is further exaggerated by living in rural areas. These exaggerated effects appear to be notable among rural Native Americans and these who completed less than a Bachelor's degree.

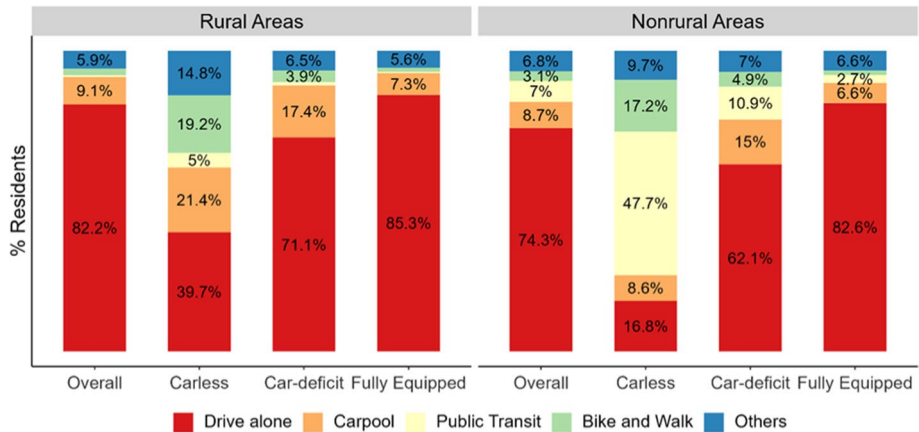


Fig. 3 Rural–Nonrural Differences in Modes for Work Trips by Car Access. *Data Source* PUMS

When compared to their nonrural peers, Native Americans in rural areas are more likely to be carless or in a car-deficit status than their white peers. Despite the necessity of having car access for one living in rural settings, rural Native Americans have a 2.1 times the odds of being carless or in a car-deficit status (vs. fully equipped) than their rural white peers, compared to 1.3 times in the nonrural comparison. Similarly, relative to their rural peers with a Bachelor’s degree, rural residents who completed some college, high school, and less than high school, are 1.3 times, 1.7 times, and 2.8 times more likely to be carless or in a car-deficit status, respectively, compared to 1.1 times, 1.4 times, and 1.8 times in nonrural comparisons. Consequently, these rural residents are left behind not only by car access but also by employment opportunities that require car access, which may contribute to increasing disparities in socioeconomic status between rural and nonrural carless households and individuals.

Conversely, elderly populations in nonrural areas have a much lower odds of being carless or in a car-deficit status (vs. fully equipped) by 42% (aged between 65 and 74 years old) and by 27% (aged 75 years old or above), respectively, than their nonrural reference group aged between 18 and 24 years old, compared to 59% and 55% in the rural comparisons. Not surprisingly, renters in nonrural areas have a 2.4 times the odds of being carless or in a car-deficit status (vs. fully equipped) than their nonrural peers, compared to 1.7 times in the rural comparison.

These rural–nonrural differences suggest that car access may play a more important role to get around for elderly populations and renters in rural areas than for their nonrural peers, as alternative services in rural areas are poor and even unavailable. Consequently, rural elderly populations with reduced health and cognitive ability and renters experiencing financial stress, may be forced to continue driving and to afford household cars, while their nonrural peers turn to alternative modes for safer and more affordable travels, which may contribute to increasing rural–nonrural disparities in health, travel safety, and mobility.

Adaptations of carlessness and modes for work trips

Living environments matter for how carless and car-deficit people get around. Differences in mobility characteristics by car access are distinct across rural and nonrural areas, with

potential mobility equity concerns for rural carless and car-deficit households and residents facing fewer transportation alternatives and greater travel burdens relative to their nonrural counterparts.

Differences in transportation modes used to get to work for rural residents with different degrees of car access are derived from the PUMS data (Fig. 3). Overall, despite limited transportation options in rural areas, the majority of rural carless (61%) and car-deficit (89%) residents rely on a car to travel, either driving alone or carpooling. This may signal that car access is essential in getting around rural areas. Not surprisingly, compared to their rural fully equipped peers (85.3%), rural carless (39.7%) and car-deficit (71.1%) workers are 50% and 20% less likely to drive alone for work trips, respectively.

To overcome the limitations of having no or limited car access, rural carless and car-deficit residents rely more heavily on transportation modes other than driving alone (Fig. 3).² Compared to their rural fully equipped peers, rural carless residents are 2.9 times, 12.5 times, and 12.8 times more likely to carpool, ride public transit, or bike and walk for work trips. Similar patterns exist among rural car-deficit residents but to a much lesser degree. Rural car-deficit residents are 2.4 times, 2.8 times, and 2.7 times more likely to carpool, ride public transit, or bike and walk for work trips than their rural fully equipped peers. These substantial differences in using modes other than driving alone for work trips show that in some rural areas, alternative modes play an important role in mobility for those without available household cars. (See the supplemental information for detailed descriptive statistics.) However, this data of modes used for work trips among rural carless and car-deficit residents does not provide an indication of the convenience or sufficiency of these alternative modes in rural areas.

Although alternative modes are an option for some people having no or limited household car access, rural–nonrural differences in the use of cars and alternative modes among carless and car-deficit residents appear to be substantial. Differences in transportation modes for work trips between rural and nonrural areas that carless and car-deficit travelers face are derived from the PUMS data (Fig. 3). Compared to their nonrural peers, rural carless and car-deficit residents are 90% less likely to ride public transit. These stark differences in the likelihood and proportion of using public transit between rural and nonrural areas, particularly among people having no or limited car access, are a likely consequence of a low proximity to destinations and limited availability of public transit service and infrastructure in most rural areas. For some of those who do walk, bike, or use transit in rural areas, it may not be an easy or a desirable option.

Notably, rural carless residents are 2.4 times and 2.5 times more likely to drive alone or carpool for work trips than their nonrural peers, while these rural–nonrural differences appear to be much less among rural car-deficit residents who have limited car access. This may correspond to prior findings that carless people living in high density areas are more likely to be those who voluntarily forgo cars (or are carfree), compared to their carless peers in other areas (Mitra and Saphores 2017). A slightly larger proportion of rural carless residents bike or walk for work trips (19.2%) compared to their nonrural peers (17.2%), which may indicate that rural carless residents adapt to carlessness and the need for car travel by finding employment options close to their homes.

² In rural areas, the percentages for modes used for work trips that are smaller than 2% (not shown in Fig. 3 for clarity of the visualization) include: Rural car-deficit residents who ride public transit—1.1%; Rural fully equipped residents who ride public transit—0.4%, and who bike and walk—1.5%.

Mobility barriers and burdens and rural carlessness

Mobility barriers and burdens of carlessness

Importantly, having no or limited car access appears to pose greater mobility barriers and burdens to rural carless and car-deficit travelers than to their nonrural peers. Disparities in mobility barriers and burdens between rural and nonrural areas among carless and car-deficit travelers are derived from the NHTS data (Table 3). When compared with their nonrural peers, rural carless and car-deficit travelers are 1.9 times and 1.4 times more likely to make no trips, respectively. Similar patterns exist among fully equipped travelers, but to a lesser degree (1.3 times). This may be due to the nature of the transportation and land use environment in rural areas which may act as a deterrent, or it may be related to sociodemographic differences between rural and nonrural areas.

Evidence further reveals that this rural–nonrural difference in making no trips among carless and car-deficit travelers can be partially explained by disparities in the availability of transportation options between rural and nonrural areas. Rural carless and car-deficit travelers are 2.3 times and 2.5 times more likely to report not traveling due to lack of transportation options than their nonrural peers, respectively. These disparities highlight the critical role that car access plays in meeting travelers' daily essential travel needs in rural settings.

Rural fully equipped and car-deficit travelers are slightly more likely (15% and 11%, respectively), than their nonrural peers to report that travel is a financial burden. This may be attributable to differences in perceptions of travel costs relative to income and other costs as well as higher costs of car ownership and maintenance in rural areas where people drive longer distances. In contrast, rural carless travelers are actually less likely (14%) to report that travel is a financial burden than their nonrural carless peers. Again, this may relate to perceptions of travel costs relative to income and other costs, and it may also relate to differences in whether and how rural carless residents travel.

Disparities in commute times between rural and nonrural areas are striking for carless travelers: rural carless travelers on average spend 1.4 times per trip as long as their nonrural peers (48 min vs. 35 min). Differences among car-deficit travelers between rural and nonrural areas are much smaller. In the case of car-deficit travelers, rural residents travel for slightly less time per trip than nonrural residents (26.5 min vs. 28.4 min). Longer commute times among rural carless residents may stem from longer travel distances, a reliance on non-auto modes even when they are relatively low-quality options, or negotiations of car-sharing and carpooling among commuters without ready access to a household car.

Rural carlessness, disparities, and inequities

Rural carless and car-deficit travelers are also less mobile and experience higher travel burdens and barriers than their rural fully equipped peers. Disparities in mobility barriers and burdens by car access are derived from the NHTS data (Table 3). Compared to their rural fully equipped peers, rural carless and car-deficit travelers are 2.7 times and 1.8 times more likely to make no trips on the travel day, respectively. These disparities in making no trips by car access in rural areas appear to be more severe than their nonrural counterparts.

In order to understand the extent to which fewer trips reflect a burden, we focus on those who cite a reason for not making a trip that reflects their limited ability to do so, which we

Table 3 Rural–nonrural differences in mobility barriers and burdens by car access

Barriers and burdens	Car access		Rural areas		Nonrural areas		Rural–nonrural differences	
			N (Weighted %)	Ratio of weighted % (vs. fully equipped)	N (Weighted %)	Ratio of weighted % (vs. fully equipped)	Ratio of weighted % (Rural to nonrural area)	Ratio of weighted % (Rural to nonrural area)
No Trips (Travel Day)	Carless		270 (47%)	2.7	1672 (24.2%)	1.8	1.9	
	Car-deficit		451 (31%)	1.8	1416 (21.8%)	1.6	1.4	
	Fully Equipped		5,311 (18%)		12,769 (13.7%)		1.3	
No Trips (No Options)	Carless		48 (4.8%)	28.0	174 (2.11%)	12.4	2.3	
	Car-deficit		45 (1.9%)	10.8	111 (0.75%)	4.4	2.5	
	Fully Equipped		75 (0.2%)		216 (0.17%)		1.0	
Travel is a Financial Burden	Carless		407 (48%)	1.1	3747 (56%)	1.4	0.86	
	Car-deficit		1,896 (52%)	1.2	7365 (47%)	1.2	1.1	
	Fully Equipped		20,735 (45%)		51,402 (39%)		1.2	
Barriers & burdens	Car access		N (Mean, unit: mins)	Ratio of weighted % (vs. fully equipped)	N (Mean, unit: mins)	Ratio of weighted % (vs. fully equipped)	Ratio of weighted % (Rural to nonrural area)	Ratio of weighted % (Rural to nonrural area)
Commute Time (mins)	Carless		50 (47.9)	1.7	1,263 (35.0)	1.3	1.4	
	Car-deficit		391 (26.5)	0.9	2,537 (28.4)	1.1	0.93	
	Fully Equipped		9,582 (28.6)		37,798 (26.7)		1.1	

The ratios are calculated based on the original weighted percentages rather than the rounded values which are listed in Table 3 for simplicity and clarity
 Data Source: NHTS

consider a measure of unmet need. Looking at this unmet need, we find that rural carless and car-deficit travelers are 28 times and 10.8 times more likely to make no trips due to lack of transportation options (Table 3). This difference may also be attributed to differences in the built environment—for instance fewer destinations in rural areas than nonrural areas (Voulgaris et al. 2016)—as well as differences in the sociodemographic characteristics between rural carless and car-deficit residents and their rural fully equipped peers.

Rural carless and car-deficit travelers are slightly more likely than their rural fully equipped peers to report that travel is a financial burden; differences appear to be more severe for rural car-deficit travelers (15%) than rural carless travelers (7%). This may be attributable to differences in perceptions of travel costs relative to income and other costs as well as higher costs of car ownership and maintenance in rural areas where people drive longer distances, particularly among rural car-deficit residents, relative to their rural peers. The commute time for rural carless travelers is nearly 1.7 times as long as the commute time for their rural fully equipped peers (Table 3), which may be attributed to the longer distances to destinations as well as the use of slower modes, with about half of rural carless residents carpooling, riding public transit, biking, or walking to get to work compared to 2% of their rural fully equipped peers (Fig. 3).

Discussion and conclusions

One difficult but critical question that has attracted the attention of transportation practitioners and scholars is who needs what access options, as well as where and when. For instance, whether people walk or bike for transportation is not only a representation of individual characteristics (e.g., age, income, gender, and ability to walk or bike), but also a reflection of place characteristics of where they live (e.g., infrastructure, land use types that make walking or biking more feasible). Moreover, the confluence of socioeconomic characteristics and uneven distributions of transportation infrastructure may further exaggerate mobility inequity issues that disadvantaged groups face—for instance carless people who are Native Americans and live in rural areas. However, attention to the intersection of socioeconomic factors, car access, transportation options, and rural–nonrural status, is limited.

This study contributes to scholarly literature and practice in the following respects. This study advances our understanding of the scope and scale of household car access, extending prior literature that has primarily focused on localities to a nationwide perspective, as well as revealing who lacks a car, and whether and how carless households and residents get around when household car access is not an option. Importantly, we further provide evidence on rural–nonrural differences in socioeconomic and mobility characteristics among carless and car-deficit households and residents as a combination of disparities in the status and degrees of car access, socioeconomic disadvantages, alternative transportation options, and travel barriers and burdens, within and between rural and nonrural areas.

Findings show that mobility inequities that carless and car-deficit residents and households face are pervasive and are exacerbated by living in rural areas due to longer travel distances between destinations and limited transportation options, compared to their counterparts in nonrural areas or the nation as a whole. We find that although 76% of carless residents are concentrated in nonrural areas, more than 4% of the rural population in the U.S., or 4.3 million residents, do not have a car. Compared to their rural fully equipped counterparts, rural carless households and residents earn 64% less. After controlling for other factors, rural Native Americans, Black, and Asian people have a 2.1 times, 1.3 times,

and 1.3 times the odds of being carless or in a car-deficit status than their rural white peers, respectively, and rural residents with a less than high school degree have a 2.8 times the odds of being carless or in a car-deficit status than their rural peers with a Bachelor's degree or above. Disadvantages that rural carless households and residents face are further exaggerated by rural–nonrural disparities in other socioeconomic characteristics, with rural carless households earning 40% less compared to their nonrural counterparts. Rural Native Americans have a 2.1 times the odds of being carless or in a car-deficit status than their rural white peers, compared to 1.3 times in the nonrural comparison.

Similar patterns are evident for rural–nonrural mobility disparities. Our analysis shows that rural carless residents must adapt their travel modes by relying on traveling by car-pooling, biking, and walking rather than driving alone more frequently than their rural fully equipped peers (60% vs. 15%), while a significantly smaller proportion of rural carless residents bike, walk, or take transit for work trips when compared to their nonrural peers (39% vs. 75%), which may indicate underinvestment or infeasibility of using alternative modes in some rural areas. Evidence also shows that rural carless travelers are 28 times and 2.3 times more likely to make no trips due to a lack of transportation options than their rural fully equipped peers and nonrural peers, respectively. Moreover, rural carless travelers take a much longer time to make their daily commute trips (48 min) when compared with their rural fully equipped peers (29 min) and their nonrural peers (35 min). These findings together suggest that the confluence of lack of car access and rural settings are compelling indicators of mobility barriers and burdens and that disparities in who is burdened are pervasive across rural and nonrural areas, with these disparities presenting as more severe in rural areas in many cases.

When we consider whether people did not travel on the travel day for any reason or due to lack of transportation options, we observe the importance of car access. Across all levels of car access, people who reside in rural areas are more likely to not travel on the surveyed travel day. This supports prior work that finds that rural residents typically make fewer but longer trips because getting places is more challenging with longer distances between destinations and fewer transportation options. We then compare the rates at which rural and nonrural travelers with different levels of car access did not travel on the travel day. We find that rural travelers with limited car access are more likely to make no trips, relative to their nonrural peers. Rural carless travelers are almost twice as likely to make no trips than their nonrural carless peers.

Lower rates of trip making among rural carless and car-deficit travelers, compared to their nonrural peers, may stem from less need (which may be correlated to a lack of car access) or greater unmet need. Extending this analysis to whether people do not travel on the travel day due to lack of transportation options provides an indication of the cause of these travelers' lower trip rates. We find no difference in the rate at which rural and nonrural fully equipped travelers do not travel due to lack of transportation options. However, rural carless and car-deficit travelers are more than twice as likely not to travel due to lack of options than their nonrural peers. Within rural areas, we observe a substantial disparity in the rates at which carless and car-deficit travelers do not travel due to lack of options, relative to their rural fully equipped peers. Rural carless and car-deficit travelers are 28 times and 10.8 times more likely to not travel due to lack of options than their rural fully equipped peers, respectively. This gap is twice the disparity that exists between nonrural fully equipped travelers and their carless peers in nonrural areas.

Evaluating perceptions of the financial burden of travel, we find that compared to their nonrural peers, rural fully equipped and car-deficit travelers are slightly more likely to report that travel is a financial burden; in contrast, rural carless travelers are actually less

likely to report that travel is a financial burden. When we couple our analysis of financial burden with our mobility-related burdensome travel outcomes, we better understand the implications of rural car access. We posit that rural households and residents are faced with a choice: either meet mobility needs and undertake the financial burden of car access or alleviate the financial burden of car ownership and suffer reduced mobility. There may be a host of factors that influence this decision, such as medical need, employment, or presence of children, but the decision of owning a car (or not) has substantial mobility and financial implications that are intensified in rural areas.

In short, we find that lack of car access is strongly tied to unmet travel need among rural residents, consistent with a controlled analysis described elsewhere (Espeland and Rowangould 2023). Almost half (47%) of all rural carless travelers did not leave their home on the surveyed travel day. Of all rural carless travelers, 1 in 20 did not travel on the travel day due to lack of options, which equates to approximately 100,000 people nationwide. This inability to travel may preclude people from visiting important destinations such as employment or school, the doctor, a food outlet, or social and recreational destinations. Though they are relatively rare occurrences, it is important to consider the scale of these events and their potentially deep impact on those who are affected.

Without targeted interventions that are designed for rural areas, rural households and residents having no or limited car access are likely to be left behind in a transition to sustainable communities that focus on reductions in car travel by increasing walking, biking, transit, and carpooling, as these alternatives are often not widely available in rural communities. At the same time, a push for electric vehicle adoption to address greenhouse gas mitigation goals risks leaving behind rural households and residents who may not be able to drive or afford a newer vehicle and who also face fewer (or no) alternatives compared to their nonrural counterparts. Thus, rural carless and car-deficit households and residents merit additional attention in research and practice and proactive policy interventions. This study highlights the importance of addressing rural–nonrural disparities, and particularly barriers and challenges that rural carless households and residents face when seeking to improve mobility, accessibility, and equity, and ensuring a smooth transition to sustainable and innovative transportation systems.

This study includes some limitations. First, despite the profound rural–nonrural disparities in socioeconomic characteristics and mobility outcomes for carless and car-deficit households and residents observed, the use of a binary indicator to distinguish rural and nonrural areas is a simplification of the variation that occurs across rural contexts, which can include centralized communities such as small cities and towns, as well as medium and low-density dispersed settlements (Isserman 2005; Mattioli 2014; Millward and Spinney 2011). Future work should use a more comprehensive and nuanced indicator of rurality. Although it is not our focus, the simplification of nonrural areas (including large cities, mid-sized cities, suburbs, etc.) also obscures some of the patterns in comparisons with nonrural areas. Second, this study focuses on understanding the scope, scale, and degrees of car access between and within rural and nonrural areas at a nationwide scale, revealing characteristics of carless and car-deficit households and residents and their travel outcomes, and importantly quantifying differences in socioeconomic disadvantages and mobility inequities that rural carless and car-deficit households and residents face relative to their nonrural peers. Future work should address the prediction strength of associated characteristics that are found to be influential in this study, including socioeconomic disadvantages, transportation options, rural status, and the confluence of person and place characteristics, to one's status and degrees of car access. Lastly, due to data limitations, our findings on transportation modes by car access and rural–nonrural disparities derived from the PUMS

data, are restricted to work trips. The small sample size of rural data from the NHTS limits the power of the statistical analysis.

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Author contributions The authors confirm contribution to the paper as follows: study conception and design: JMB, DR, WW, and SE; data collection: WW and SE; analysis and interpretation of results: WW, SE, JMB, and DR; draft manuscript preparation: WW, SE, JMB, and DR. All authors reviewed the results and approved the final version of the manuscript.

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Data availability The data and materials used in the study are publicly available.

Declarations

Conflict of interests The authors declare no competing interests.

Ethical approval Not applicable.

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