



BMJ Open Association of stay-at-home orders and COVID-19 incidence and mortality in rural and urban United States: a population-based study

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ABSTRACT

Objective We examined the association between stay-at-home order implementation and the incidence of COVID-19 infections and deaths in rural versus urban counties of the United States.

Design We used an interrupted time-series analysis using a mixed effects zero-inflated Poisson model with random intercept by county and standardised by population to examine the associations between stay-at-home orders and county-level counts of daily new COVID-19 cases and deaths in rural versus urban counties between 22 January 2020 and 10 June 2020. We secondarily examined the association between stay-at-home orders and mobility in rural versus urban counties using Google Community Mobility Reports.

Interventions Issuance of stay-at-home orders.

Primary and secondary outcome measures Co-primary outcomes were COVID-19 daily incidence of cases (14-day lagged) and mortality (26-day lagged). Secondary outcome was mobility.

Results Stay-at-home orders were implemented later (median 30 March 2020 vs 28 March 2020) and were shorter in duration (median 35 vs 54 days) in rural compared with urban counties. Indoor mobility was, on average, 2.6%–6.9% higher in rural than urban counties both during and after stay-at-home orders. Compared with the baseline (pre-stay-at-home) period, the number of new COVID-19 cases increased under stay-at-home by incidence risk ratio (IRR) 1.60 (95% CI, 1.57 to 1.64) in rural and 1.36 (95% CI, 1.30 to 1.42) in urban counties, while the number of new COVID-19 deaths increased by IRR 14.21 (95% CI, 11.02 to 18.34) in rural and IRR 2.93 in urban counties (95% CI, 1.82 to 4.73). For each day under stay-at-home orders, the number of new cases changed by a factor of 0.982 (95% CI, 0.981 to 0.982) in rural and 0.952 (95% CI, 0.951 to 0.953) in urban counties compared with prior to stay-at-home, while number of new deaths changed by a factor of 0.977 (95% CI, 0.976 to 0.977) in rural counties and 0.935 (95% CI, 0.933 to 0.936) in urban counties. Each day after stay-at-home orders expired, the number of new cases changed by a factor of 0.995 (95% CI, 0.994 to 0.995) in rural and 0.997 (95% CI, 0.995 to 0.999) in urban counties compared with prior to stay-at-home, while number of new deaths changed by a factor of 0.969 (95% CI, 0.968 to 0.970) in rural counties and 0.928 (95% CI, 0.926 to 0.929) in urban counties.

Strengths and limitations of this study

- This study is among the first to examine the relative impact of stay-at-home orders on COVID-19 cases and deaths across urban and rural counties.
- For the co-primary outcomes of COVID-19 deaths and cases, this study uses an interrupted time-series analysis via mixed effects zero-inflated Poisson model with all 3142 US counties, with random effects by county.
- For the secondary outcome of mobility, this study examines the changes in different categories of indoor and outdoor mobility using available commercial data.
- This study does not take into consideration the heterogeneity of the stay-at-home orders issued by each county, nor does it look at hospitalisation/intensive care unit numbers, mainly due to lack of available data.

Conclusion Stay-at-home orders decreased mobility, slowed the spread of COVID-19 and mitigated COVID-19 mortality, but did so less effectively in rural than in urban counties. This necessitates a critical re-evaluation of how stay-at-home orders are designed, communicated and implemented in rural areas.

INTRODUCTION

As cases of COVID-19, caused by SARS-CoV-2, emerged in the United States in early 2020, pressure grew on federal, state and local governments to implement public health guidelines aimed at reducing its impact on the healthcare system and society. The most stringent and enforced of these initiatives were stay-at-home orders, which generally coincided with additional measures such as school and non-essential business closures and bans on social gatherings. However, the USA is not monolithic, and in the absence of a unified federal strategy,¹ the timing, duration, stringency and enforcement of stay-at-home orders varied widely across

municipalities.² Nearly one-fifth of the US population resides in rural areas.³ Resource availability, political affiliation and attitudes toward COVID-19 all differ between rural and urban areas,⁴ and, as such, public health guidance and implementation may need to be adapted to the unique needs and circumstances of each setting. Thus, while emerging evidence has demonstrated an overall effectiveness of physical distancing measures as enforced by stay-at-home orders,^{5–11} potential differences in their effectiveness and durability (ie, continued effectiveness even after the stay-at-home orders are lifted) between rural and urban areas have not been explored. Identification of such differences would call for closer examination of barriers to optimal implementation and effectiveness with the goal of developing more effective, adaptive and scalable public health guidelines going forward. With the more transmissible B.1.1.529 (Omicron) variant of SARS-CoV-2 virus now the dominant strain in the USA and the resurgence of cases,¹² there are discussions of new stay-at-home orders in many jurisdictions.^{13–15} As such, it is more important to consider the difference in efficacy of stay-at-home orders between geographical regions.

We focus on rural areas specifically because as COVID-19 first emerged in urban centres¹⁶ and only later spread throughout the country, rural perception of the pandemic and response to it may have differed from that of urban areas.⁴ For example, rural residents may have felt that public health regulations stemming from urban experiences do not equally apply to rural populations, which in turn, may have led to differences in the adoption of stay-at-home orders, the fidelity to physical distancing and ultimately to the spread of COVID-19 and mortality related to it.

Stay-at-home orders are only effective if they translate to greater physical distancing and reduced mobility, particularly in indoor settings that pose the highest risk for COVID-19 transmission. Several studies have correlated changes in population-level mobility with COVID-19 infection rates^{6 17} and demonstrated reduced mobility with the passage of stay-at-home orders.^{2 18 19} Yet, public intent to comply with physical distancing regulations has varied widely across the USA, influenced by religious affiliation,²⁰ income,²¹ political ideology²² and local/state political leadership.²³ We hypothesise that it also differed between rural and urban areas, though this has not heretofore been explicitly assessed.

Better understanding of the spread of COVID-19 and of the effectiveness and durability of stay-at-home orders in rural areas, specifically, is important because rural populations are highly susceptible to severe manifestations of COVID-19.²⁴ Rates of obesity,²⁵ heart disease,^{26 27} chronic lung disease,²⁶ diabetes,²⁷ smoking²⁸ and multimorbidity are major risk factors for serious COVID-19 illness and are all higher in rural than urban settings.²⁸ Rural residents are also older than urban residents²⁸ and age is a major determinant of COVID-19 severity and mortality.²⁹ Furthermore, rural areas may have lower resiliency against the pandemic, with fewer intensive care unit (ICU) beds²⁸

and many small regional and critical access hospitals and clinics already facing financial hardship.³⁰

Thus, in the face of these unique challenges facing rural residents, identifying opportunities to improve the effectiveness of stay-at-home orders is critical as the nation faces resurgence of case numbers and new strains of COVID-19.³¹ The recent increases in case numbers in many states and across the nation have led policymakers to consider reinstating stay-at-home orders.³² In order to optimise the current iteration of stay-at-home orders and inform future infection control efforts, we examine the effectiveness of such orders in rural and urban areas of the USA. Specifically, we examine the mobility patterns and COVID-19 infection and mortality rates in rural and urban counties during and after stay-at-home orders, focusing specifically on how stay-at-home orders impacted rates of new infections, deaths and mobility in these areas.

METHODS

Data sources and study population

County-level daily COVID-19 case (incidence) and mortality data were acquired from the Centers for Disease Control and Prevention, courtesy of USAFacts.org, a non-partisan, non-profit government data repository.³³ The dataset contained cumulative county-level cases and deaths for all 3142 US counties and county-equivalents between 22 January and 10 June 2020. Each county was categorised as urban or rural using 2013 county-level Rural-Urban Continuum Codes (RUCC) per the Economic Research Service of the US Department of Agriculture and the Office of Management and Budget.³⁴ Urban counties were defined as having RUCC of 1–3 and rural counties as RUCC of 4–7. We chose to use the RUCC as a proxy for rurality as it considers both the population of a given county and its potential adjacency to a metropolitan area. This allows us to account for counties located near major population centres and ensure that counties designated as ‘rural’ are truly rural.

Start and end dates of stay-at-home orders were identified from data compiled and published by the *New York Times*,^{35 36} which was then manually verified for completeness and accuracy by the study team via internet search and review of state executive orders. A binary variable was created to indicate each day individual counties were under stay-at-home. When stay-at-home orders were issued by state governments, it was assumed that all counties in that state fell under that order. If individual counties issued their own stay-at-home orders (eg, Davis County, Utah³⁷), county-specific start and end dates were identified and applied. If stay-at-home orders were declared by individual cities (eg, Jackson, Wyoming,³⁸ Oklahoma City, Oklahoma³⁹), those stay-at-home order dates were applied to the rest of that county, as cities comprised the majority of that county’s population.

County-level mobility trends were identified from COVID-19 Community Mobility Reports between 15 February and 14 June 2020, available from Google.⁴⁰ This

data show daily changes in mobility in how often and how long visitors spent in specific categories of places compared with a baseline day. The baseline day is represented by a normal value for that day of the week based on the median value from the 5-week period between 3 January and 6 February 2020.

Outcomes

The co-primary outcomes were the number of new cases of and deaths attributed to COVID-19 per day per 100 000 people in each county. Lag periods of 14 days for cases and 26 days for deaths were used based on the duration of susceptibility to a new diagnosis of and death from COVID-19, respectively, after an initial exposure.^{41 42} Sensitivity analyses were performed for 5-day and 10-day lagged cases. Secondary outcomes were per cent changes in county-level mobility for the following categories: grocery/pharmacy, retail/recreation, residential and workplace. Transit and parks categories were not included due to insufficient data for all counties.

Independent variables

Independent variables included in the models were the primary exposure of county classification (rural vs urban), stay-at-home order status (before, during or after), days since start of follow-up (to account for time), days under stay-at-home orders and days after stay-at-home orders.

Statistical analysis

Interrupted time-series analysis of county-level, 14-day lagged COVID-19 daily new cases and 26-day lagged COVID-19 daily new deaths examined the impact of stay-at-home orders on rural and urban counties. Models included the independent variables outlined above and interaction terms between each of the variables and rural/urban status. To account for differences between counties, we used a mixed effects models with random intercept by county.

A variety of mixed effects count data models were compared on the basis of model diagnostics, Akaike information criterion (AIC) and parsimony, in descending priority: Poisson, zero-inflated Poisson, zero-inflated Poisson with random intercept and slope, negative binomial, negative binomial with random intercept and slope and zero-inflated negative binomial. All used the same variables for the fixed effects to account for the time varying nature of stay-at-home orders and were offset by county population divided by 100 000 to standardise by population. Models were run using the *glmmTMB* package in R,⁴³ while model diagnostics examined the simulated quantile scaled residuals using the *DHARMA* package in R.⁴⁴ Models were assessed for over-dispersion, zero-inflation and distribution of residuals. For cases, the mixed effects zero-inflated Poisson model with random intercept by county was chosen as the best model, as it was not significantly zero-inflated, not over-dispersed, did not contain outliers and had the expected distribution of residuals. It was temporally autocorrelated by the

Durbin-Watson test, but this is unavoidable (additions of variance-covariance structures led to significant over-dispersion) and did not have a significant effect on the results because of the long follow-up time, the significance of the results and the large number of counties.⁴⁵ For deaths, we selected mixed effects negative binomial model with random intercepts by county and random slope by stay-at-home order period (before, during and after), selected on the basis of AIC, simplicity and parsimony.

Using offsets calculated from rural and urban population averages, we visualised the impact of stay-at-home orders by estimating the number of new COVID-19 cases and deaths in rural and urban counties for the start, end and duration of stay-at-home orders. We conducted sensitivity analysis surrounding the lag time for our regression. We conducted a 5-day and a 10-day lag and compared the results to that of our original 14-day lag. Detailed description of the methods is available in the online supplemental file. For differences between the rural and urban cohorts, we reported the incidence risk ratio (IRR). IRR is defined as ratio between two cumulative incidences of the urban counties and the rural counties.

Google Community Mobility Reports were analysed for differences in during and post-stay-at-home mobility between urban and rural counties using two-way repeated measures analysis of variance (ANOVA) via the *rstatix* package in R.⁴⁶ Before testing for significance, all of the mobility data were examined for outliers and normality. Outliers were classified as observations outside of 1.5 times the IQR of their respective distribution (mobility type and rurality). Grocery/pharmacy and workplace were the only categories with outliers, with eight outliers (4 days) and two outliers (1 day) removed for these categories, respectively. The two-way repeated measure ANOVA was conducted because a combination of scarcity and bias in the data; not every county was represented, and data suffer from voluntary bias as Google takes data from willing participants. These reasons led us to use the mobility data in a pseudo-qualitative manner, but it provides a reasonable estimation of mobility differences in these communities.

Difference in stay-at-home duration between county type was assessed using Wilcoxon rank sum test with continuity correction.

We generated a visual of the effects by inputting the estimates of fixed effects and the urban and rural averages of stay-at-home orders start and end dates. The outcome was divided by the offset to standardise the results per 100 000 population. The respective offsets for urban and rural counties were calculated using urban and rural counties respective population averages. Similarly, the extrapolations were generated by using the conditional model only with intercept and variables: Rurality, Days and Rurality*Days. The extrapolations represent continuation of the before stay-at-home order trends.

Table 1 Study cohort and stay-at-home implementation

	Urban counties	Rural counties	USA total
Count, n (%)	1166 (37)	1976 (63)	3142
Population, n (%)	282 176 462 (86.0)	46 063 061 (14.0)	328 239 523
Cases, n (%)	1 625 434 (91.0)	161 452 (9.0)	1 786 886
Cases per 100 000 persons	576.03	350.5	544.38
Deaths, n (%)	106 488 (94.8)	5807 (5.2)	112 295
Deaths per 100 000 persons	12.6	37.7	34.2
Counties stay at home, n (%)	1075 (92.2)	1854 (93.8)	2929 (93.2)
Median time before stay at home (days) (IQR)	66.0 (61–71)	68.0 (63–71)	68.0 (62–71)
Median stay at home length (days) (IQR)	54.0 (29–70)	35.0 (28–68)	42.0 (28–69)
Median days since stay at home elapsed (days) (IQR)	27.0 (11–42)	39.0 (14–45)	38.0 (13–42)
Median stay at home start date (day since 22/01/2020) (IQR)	67.0 (64–72)	69.0 (63–73)	69.0 (63–73)

Patient involvement

No patients were directly involved in setting the research question or the outcome measures, however, the study was motivated by the need to elucidate the urban–rural disparities in the implementation of stay-at-home orders. We hope that study results will inform public health officials and policymakers on the need to evaluate how stay-at-home orders are designed, communicated and implemented across varying geographies.

RESULTS

We analysed data for all 1976 rural (62.9%) and 1166 urban (37.1%) USA counties, home to 46 063 061 (14.0%) and 282 176 462 (86.0%) people, respectively (table 1). As of 10 June 2020, there were 1 786 886 cases of COVID-19 in the USA, of which 9.0% (n=161 452) were in rural counties, and there were 112 295 COVID-19 deaths in the USA, of which 5.2% (n=5807) were in rural counties. Adjusted for population, this translates to 350.5 cases and 37.7 deaths per 100 000 persons in rural counties and 576.0 cases and 12.6 deaths per 100 000 persons in urban counties. During the study period, 1854 (93.8%) rural counties and 1075 (92.2%) urban counties were covered by a stay-at-home order. The median start date for stay-at-home orders was 30 March for rural counties and 28 March for urban counties. The median duration of stay-at-home orders was 35 days (IQR 28–68) for rural counties and 54 days (IQR 29–70) for urban counties (p<0.001).

County-level mobility trends

Mobility across all categories prior to the implementation of stay-at-home orders was similar in rural and urban counties (figure 1). There was an approximately 25% increase in grocery/pharmacy mobility prior to implementation of stay-at-home orders, potentially reflecting anticipatory shopping prior to sheltering in place. This was preceded by a 15% increase and subsequent decline

in retail/recreation mobility. The increase in grocery/pharmacy mobility coincided with a 25% decrease in workplace mobility and a 10% increase in residential mobility, consistent with transition to working from home.

After implementation of stay-at-home orders, mobility in grocery/pharmacy, retail/recreation and workplace decreased 10%–40%, while residential mobility increased 10%–20%. These reductions in mobility were significantly more pronounced in urban compared with rural counties, with the average absolute differences of 6.89%, 4.43%, 5.76% and 2.67% for retail/recreation, grocery/pharmacy, workplace and residential locations, respectively (p<0.0001). After stay-at-home orders elapsed, all mobility began to increase toward baseline levels, more rapidly in urban than rural areas. Grocery/pharmacy mobility ultimately exceeded baseline mobility in rural areas.

County-level COVID-19 case trends

Estimated numbers of new COVID-19 cases in rural and urban counties before, during and after stay-at-home orders are depicted in figure 2, using median dates of stay-at-home order initiation and termination for visual demonstration. In rural counties, implementation of stay-at-home orders decreased the growth of daily new COVID-19 cases from 2.1% (95% CI, 2.1% to 2.2%) growth in cases per day to 0.3% (95% CI, 0.2% to 0.4%) growth per day. After stay-at-home orders expired, the daily new case increase was slower than before they were put in place, with 0.2% (95% CI, –0.4% to –0.1%) decline in new cases per day. However, stay-at-home orders were more effective at preventing the spread of COVID-19 in urban counties, where the changes in the number of new daily COVID-19 cases were 4.3% (95% CI, 4.2% to 4.4%) increase per day before stay-at-home, 0.7% (95% CI, –0.9% to –0.5%) decrease per day during stay-at-home and 1% (95% CI, –1.4% to –0.6%) decrease per day after the stay-at-home order period.

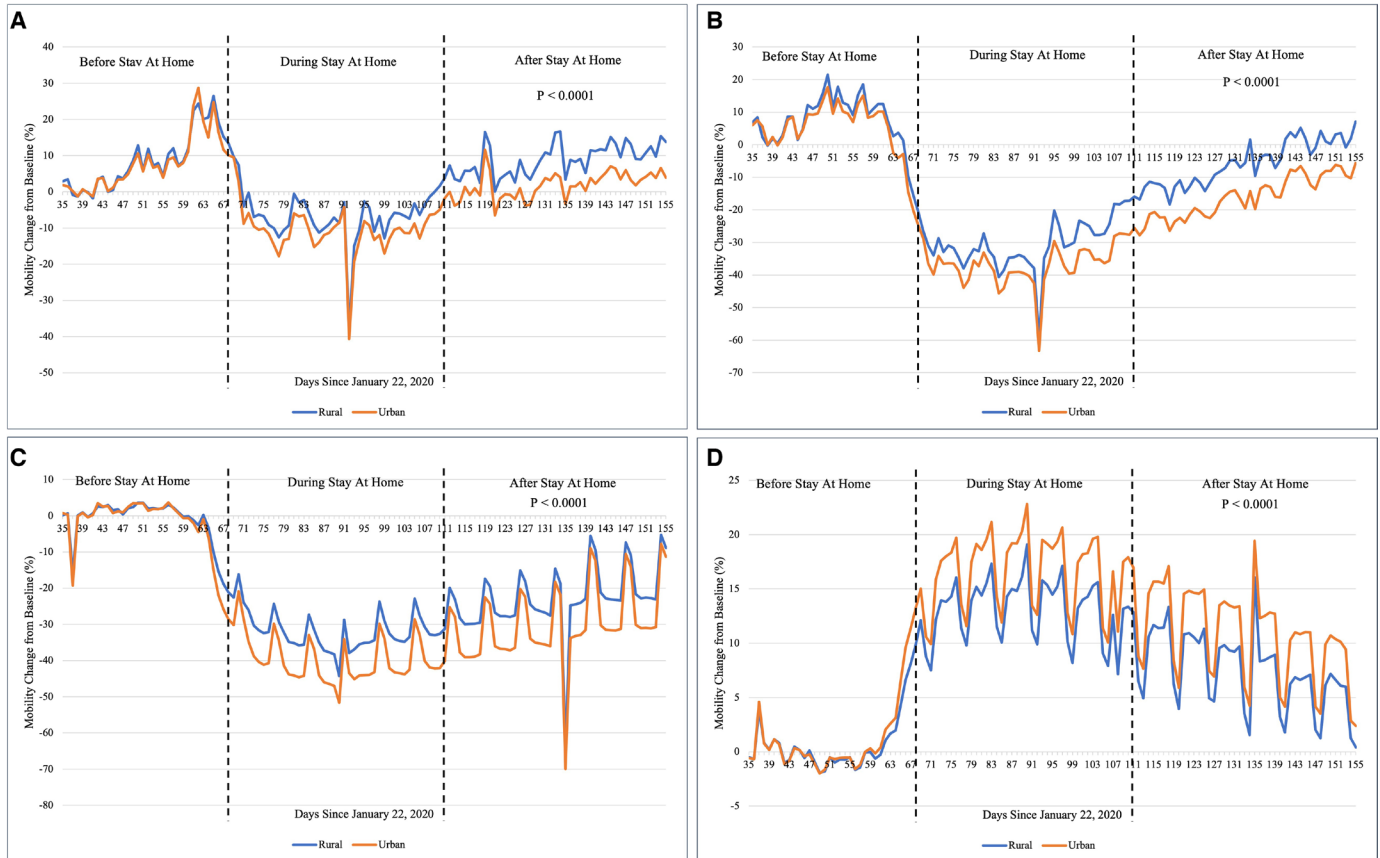


Figure 1 Changes in mobility in rural and urban counties. Per cent changes in mobility in (A) grocery and pharmacy, (B) retail and recreation, (C) work place and (D) residential areas were calculated for rural and urban counties compared with the referent period of 3 January and 6 February 2020. P values report the results of repeated measure analysis of variance (ANOVA).

The number of new COVID-19 cases increased from baseline to during stay-at-home orders by 60.4% (IRR 1.60; 95% CI, 1.57 to 1.64) in rural counties and by 35.9% (IRR 1.36; 95% CI, 1.30 to 1.42) in urban counties; [table 2](#). For each day under stay-at-home orders, the number of daily new cases slowed by a factor of 0.982 (95% CI, 0.981 to 0.982) in rural counties and 0.952 (95% CI, 0.951 to 0.953) in urban counties, that is, slowing down more in urban counties each day under stay-at-home.

After stay-at-home orders were lifted, rates of new COVID-19 infections were 39.8% greater (IRR 1.40; 95% CI, 1.36 to 1.44) than before they had been implemented in rural counties and 17.8% lower (IRR 0.82; 95% CI, 0.77 to 0.87) in urban counties, reinforcing the greater effectiveness of stay-at-home orders in urban than rural counties. Each additional day following the expiration of stay-at-home orders saw a reduction in the number of new COVID-19 cases by a factor of 0.995 in rural counties (95% CI, 0.994 to 0.995) and 0.997 in urban counties (95% CI, 0.995 to 0.999). That is to say that the rates of new cases were decreasing by 0.5% and 0.3% per day in rural and urban counties, respectively, after stay-at-home orders ended.

County-level COVID-19 death trends

In rural counties, implementation of stay-at-home orders was associated with a decrease in the growth of daily new

COVID-19 deaths from 4.6% (95% CI, 4.5% to 4.6%) growth per day to 2.2% (95% CI, 2% to 2.2%) growth per day. After stay-at-home orders expired, the daily new death increase rate was slower than before they were put in place, with a 0.9% (95% CI, 1.2% to 0.8%) decline in new deaths per day. In urban counties, however, stay-at-home orders were associated with a lower daily incident death rate than in rural counties, with the changes in the number of new daily COVID-19 deaths being 9.1% (95% CI, 8.9% to 9.2%) per day increase before stay-at-home, 2% (95% CI, 1.7% to 2.2%) per day increase during stay-at-home and 5.4% (95% CI, 5.8% to 5%) per day decrease after stay-at-home.

Thus, while stay-at-home orders were in place, the number of new COVID-19 deaths increased from baseline by 1321% (IRR 14.21; 95% CI, 11.023 to 18.338) in rural counties and by 193% (IRR 2.933; 95% CI, 1.824 to 4.726) in urban counties. For each day under stay-at-home orders, the number of daily new deaths slowed by a factor of 0.977 (95% CI, 0.976 to 0.977) in rural counties and 0.935 (95% CI, 0.933 to 0.936) in urban counties.

After stay-at-home orders were lifted, rates of new COVID-19 fatalities were 3413% greater (IRR 35.128; 95% CI, 25.997 to 47.56) than before they had been implemented in rural counties and 284% greater (IRR 3.842; 95% CI, 2.138 to 6.91) in urban counties. Each

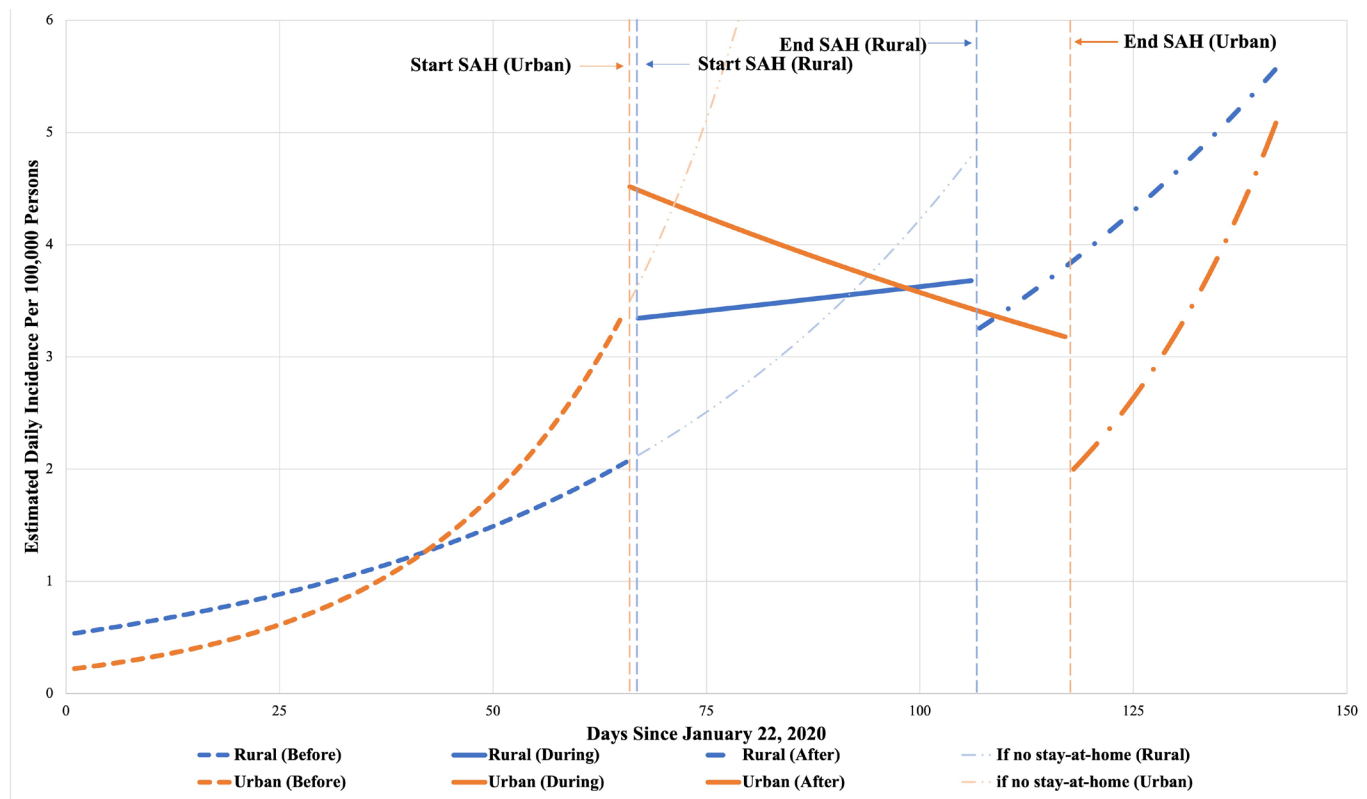


Figure 2 Estimated population-standardised daily new cases of COVID-19 in rural and urban counties. Estimated numbers of new COVID-19 cases per day were modelled using median dates for the start and end of stay-at-home orders in rural and urban counties. We also extrapolated the predicted numbers of new daily COVID-19 infections in rural and urban counties had stay-at-home orders not been implemented to demonstrate the potential impact of these orders. SAH, stay-at-home.

additional day following the expiration of stay-at-home orders was associated with a reduction in the number of new COVID-19 deaths by a factor of 0.969 in rural counties (95% CI, 0.968 to 0.97) and 0.928 in urban counties (95% CI, 0.926 to 0.929).

Sensitivity analyses

We examined the impact of stay-at-home orders on 5-day and 10-day lagged new cases of COVID-19 (online supplemental file p. 16). None of the study conclusions or inferences changed with either of these two different lag periods.

DISCUSSION

Physical distancing and other infection control efforts are essential to containing the spread of COVID-19. Our analysis of COVID-19 infection spread in rural and urban areas of the USA before, during and after the implementation of stay-at-home orders revealed important successes and opportunities for improvement of this public health approach. Urban areas, which, on average, implemented stay-at-home orders earlier and maintained them longer, were able to effectively slow the growth of COVID-19 cases and deaths both while stay-at-home orders were in place and after they expired. Implementation of stay-at-home orders in rural areas was also associated with slowed the spread of COVID-19 cases and deaths, but the observed

decreases in rural areas were significantly smaller than in urban areas and the COVID-19 case and mortality loads rebounded much faster after stay-at-home orders expired. These differences in the effectiveness and durability of stay-at-home orders between rural and urban areas may be driven by greater mobility of rural as compared with urban residents that we observed both during and after the stay-at-home period, as well as overall rigour of stay-at-home order enforcement.

Stay-at-home orders, while they were in place, were associated with higher population-adjusted daily new cases and deaths in rural than urban areas, driven by both delayed implementation of stay-at-home orders and their shorter duration. Our analysis suggests that each additional day under stay-at-home restrictions was associated with a significant decrease in the rate of new COVID-19 infections and deaths. After stay-at-home orders expired, urban areas continued to see a much slower rate of COVID-19 case and mortality growth than before restrictions were implemented, while rural areas returned near to the pre-stay-at-home baseline. This effect is likely driven by a range of individual, systemic and political factors. Recent research suggests that the strongest determinants of the timing, issuance, enforcement and adherence of stay-at-home orders are political affiliations of the population within the county and geography.^{18 23 47-50} Rural areas are more likely to be politically conservative

Table 2 Model estimates

Variable	Daily incidence				Daily mortality			
	Estimate	2.5% CI	97.5% CI	P value	Estimate	2.5% CI	97.5% CI	P value
	(IRR)	(IRR)	(IRR)		(IRR)	(IRR)	(IRR)	
Intercept	-0.645 (0.525)	-0.712 (0.491)	-0.578 (0.561)	<0.0001	-8.026 (0.0003)	-8.373 (0.0002)	-7.679 (0.0005)	<0.0001
Urban (vs rural)	-0.905 (0.404)	-1.003 (0.367)	-0.808 (0.446)	<0.0001	1.479 (4.389)	1.073 (2.924)	1.885 (6.586)	<0.0001
Period during stay-at-home (vs before)	0.473 (1.604)	0.451 (1.570)	0.494 (1.640)	<0.0001	2.654 (14.211)	2.400 (11.023)	2.909 (18.338)	<0.0001
Period after stay-at-home (vs before)	0.335 (1.398)	0.305 (1.357)	0.365 (1.440)	<0.0001	3.559 (35.128)	3.258 (25.997)	3.862 (47.560)	<0.0001
Days elapsed since 22/01/2020	0.021 (1.021)	0.020 (1.021)	0.021 (1.022)	<0.0001	0.045 (1.046)	0.044 (1.045)	0.045 (1.046)	<0.0001
Per day under stay-at-home orders	-0.018 (0.982)	-0.019 (0.981)	-0.018 (0.982)	<0.0001	-0.023 (0.977)	-0.024 (0.976)	-0.023 (0.977)	<0.0001
Per day after stay-at-home orders	-0.005 (0.995)	-0.006 (0.994)	-0.005 (0.995)	<0.0001	-0.031 (0.969)	-0.032 (0.969)	-0.030 (0.970)	<0.0001
Urban county interaction with period during stay-at-home (vs before)	-0.166 (0.847)	-0.189 (0.828)	-0.143 (0.866)	<0.0001	-1.578 (0.206)	-1.799 (0.165)	-1.356 (0.258)	<0.0001
Urban county interaction with period after stay-at-home (vs before)	-0.531 (0.588)	-0.562 (0.570)	-0.499 (0.607)	<0.0001	-2.213 (0.109)	-2.498 (0.082)	-1.929 (0.145)	<0.0001
Urban county interaction with days elapsed since 22/1/2020	0.022 (1.022)	0.021 (1.021)	0.022 (1.022)	<0.0001	0.042 (1.043)	0.042 (1.043)	0.043 (1.044)	<0.0001
Urban county interaction with per day under stay-at-home orders	-0.031 (0.970)	-0.032 (0.969)	-0.030 (0.970)	<0.0001	-0.044 (0.957)	-0.045 (0.956)	-0.043 (0.958)	<0.0001
Urban county interaction with per day after stay-at-home orders	0.002 (1.002)	0.001 (1.001)	0.003 (1.003)	<0.0001	-0.044 (0.957)	-0.045 (0.956)	-0.043 (0.958)	<0.0001
Urban county period during stay-at-home (vs before)	0.307 (1.359)	0.262 (1.300)	0.351 (1.421)	<0.0001*	1.076 (2.933)	0.601 (1.824)	1.553 (4.726)	<0.0001*
Urban county period after stay-at-home (vs before)	-0.196 (0.822)	-0.257 (0.773)	-0.135 (0.874)	<0.0001*	1.346 (3.842)	0.760 (2.138)	1.933 (6.910)	<0.0001*
Urban county days elapsed since 22/1/2020	0.043 (1.043)	0.041 (1.042)	0.044 (1.044)	<0.0001*	0.087 (1.091)	0.086 (1.090)	0.088 (1.092)	<0.0001*
Urban county per day under stay-at-home orders	-0.049 (0.952)	-0.051 (0.951)	-0.048 (0.953)	<0.0001*	-0.067 (0.935)	-0.069 (0.933)	-0.066 (0.936)	<0.0001*
Urban county per day after stay-at-home orders	-0.003 (0.997)	-0.005 (0.995)	-0.001 (0.999)	<0.001*	-0.075 (0.928)	-0.077 (0.926)	-0.073 (0.930)	<0.0001*
Model diagnostics								
AIC:	2 220 521.000				AIC:	873 199.8		
BIC:	2 220 730.000				BIC:	873 409		

* These variables are linear combinations meant to show the effect of multiple covariates. The p values here were calculated using the confidence intervals and are not unique terms in the model.
AIC, Akaike information criterion; BIC, Bayesian Information Criterion.

and under Republican leadership^{51–53} leading to stay-at-home orders being delayed, cut short, or both, and with less enforcement of mobility restrictions. Furthermore, rural residents tend to have an older population,⁵⁴ which may affect how vulnerable rural populations are to the virus. In addition, rural areas have a lower return to education,^{55–57} and especially in science, technology, engineering and math fields, which may have contributed to the spread of COVID-19 through lack of health and science literacy.⁵⁸

Moreover, for stay-at-home orders to be effective and have a durable effect on infection control, individuals need to alter their daily routines and reduce high risk behaviours. Residents of rural areas consistently had higher mobility at high-risk indoor locations such as grocery stores, pharmacies and places of retail and recreation, rendering stay-at-home orders less efficacious. This is consistent with an earlier study showing that pandemic-era declines in restaurant visits was nearly double in urban areas as compared with rural areas.⁵⁹ Political affiliation of rural residents may have dampened their adherence to physical distancing regulations.^{18 23 50} Local news coverage of COVID-19 as a problem mainly affecting urban areas may have also diminished rural citizens' intentions to comply.⁶⁰ Finally, rural residents are frequently employed in fields not amenable to telework, such as agriculture, manufacturing and service industries,⁶¹ and hence may be unable to fully comply with stay-at-home orders.⁶²

As states are considering implementing a new round of stay-at-home orders, our findings reveal several ways to improve the implementation, enforcement and adherence. First, they should be implemented earlier and maintained longer for optimal effectiveness. There was marked heterogeneity in the timing and duration of stay-at-home orders and our data reinforce the need for multi-jurisdictional, ideally federal, infection control mandates.⁶³ Any new stay-at-home orders should be gradually implemented to avoid the pre-stay-at-home surge of mobility and subsequent spike in COVID-19 cases. To better encourage and facilitate compliance, leaders at all levels need to use scientific evidence to advocate for the importance of stay-at-home orders, set personal examples and develop employment, housing, educational and healthcare assistance for the most vulnerable.⁶²

While our study is the first to examine the effects of stay-at-home orders on rural and urban areas, it has limitations. We focused on stay-at-home orders without considering the heterogeneity of what constituted these orders on the local level and did not separately weigh the impacts of additional measures such as school closures, non-essential business closures, prohibition of large gatherings and mandatory masking. However, it would be difficult to separate these effects as most restrictions were implemented concurrent with, and worked in tandem to, stay-at-home orders. COVID-19 case data may be biased by differences in testing availability, and therefore we also analysed mobility data to eliminate testing bias. Use of

Google Community Mobility Reports to test our hypothesis of the differences in mobility between urban and rural counties has limitations, though is the most robust data source for different mobility categories available at the county level. The data for the counties are incomplete and not every county has a data point. Previous studies have shown that the Google data do not indicate which individuals were represented by the mobility trends, nor do we know exactly how mobility was calculated.^{64 65} However, for our analysis, we averaged trends by urban and rural counties and used all relevant indoor mobility data at locations where the risk of transmission is expected to be high. This analysis provides sufficient evidence that there was a difference in mobility between urban and rural counties. Our study does not take into account potential residual or unmeasured confounders that may explain the difference in infection rates between rural and urban counties outside of stay-at-home order implementation. We accounted for this by using a random intercept in our analysis, but due to the absence of granular data at the county-level, potential confounding would be impossible to eliminate completely. Lastly, researchers and politicians should be cognizant of how generalisable the result of this study is to other countries. While the evidence is clear that there is a difference in the implementation and effectiveness of stay-at-home orders across the urban–rural continuum, the results here only reflect data from the USA. We suspect that such a difference exists in other countries as well, but further research is needed to investigate specific differences using data from other countries.

High rates of COVID-19 in rural counties, along with the suppressed effect of stay-at-home orders relative to urban counties, are very concerning. Residents of rural counties are older and have higher rates of chronic health conditions that place them at high risk for severe COVID-19 disease and death.^{24 28 29} Rural areas also lack the resources of urban areas to care for patients with COVID-19, with fewer hospitals, ICU beds, infectious disease specialists and public health professionals.^{24 30} This may explain the high rate of COVID-19-related mortality we observed in rural areas. They may also have fewer support systems for people disabled by post-COVID-19 complications,⁶⁶ leading to longer-term disability and personal and financial hardship.

CONCLUSION

Shorter duration and lower effectiveness of stay-at-home orders in rural areas have led to the greater spread of COVID-19 cases and deaths in rural as compared with urban areas when standardised for population. This calls for urgent re-evaluation of how stay-at-home orders are designed, communicated and implemented in rural areas and throughout the USA.

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