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Original article

Spatially refined time-varying reproduction numbers of SARS-CoV-2 in Arkansas and Kentucky and their relationship to population size and public health policy, March – November 2020

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ABSTRACT

Purpose: To examine the time-varying reproduction number, R_t, for COVID-19 in Arkansas and Kentucky and investigate the impact of policies and preventative measures on the variability in R_t.
Methods: Arkansas and Kentucky county-level COVID-19 cumulative case count data (March 6-November 7, 2020) were obtained. R_t was estimated using the R package 'EpiEstim', by county, region (Delta, non-Delta, Appalachian, non-Appalachian), and policy measures.
Results: The R_t was initially high, falling below 1 in May or June depending on the region, before stabilizing around 1 in the later months. The median R_t for Arkansas and Kentucky at the end of the study were 1.15 (95% credible interval [CrI], 1.13, 1.18) and 1.10 (95% CrI, 1.08, 1.12), respectively, and remained above 1 for the non-Appalachian region. R_t decreased when facial coverings were mandated, changing by -10.64% (95% CrI, -10.60%, -10.70%) in Arkansas and -5.93% (95% CrI, -4.31%, -7.65%) in Kentucky. The trends in R_t estimates were mostly associated with the implementation and relaxation of social distancing measures.
Conclusions: Arkansas and Kentucky maintained a median R_t above 1 during the entire study period. Changes in R_t estimates allow quantitative estimates of potential impact of policies such as facemask mandate.

Introduction

Coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-COV-2), was first reported in humans in Wuhan in December 2019. From the early stages of the pandemic to November 2020, there has been a rise in both cases and deaths among states that contain large rural areas in the United States (US) [1]. Arkansas, one of eight states that did not implement a stay-at-home order, and Kentucky, a state that has been more proactive from the beginning of the pandemic, are two southern states that have very similar COVID-19 morbidity and mortality rates, yet differed in their approach in addressing this pandemic. Both states have regions that are classified as rural (the Delta in Arkansas and Appalachia in Kentucky), which face higher percentages of health disparities and socioeconomic stress compared to their respective state counterparts.

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In both states, disparities in rurality, poverty, health conditions, and healthcare access have a significant role. In Arkansas, 41% of Arkansans live in rural counties [2], compared to only 14% of the US population who live in nonmetropolitan counties. In Kentucky, 25.3% of individuals in Appalachia live in poverty compared to 15.3% in non-Appalachia [3]. These rural communities face challenges with the pandemic and may be unsuited to handle large surges within their healthcare systems [4,5]. Fifty percent of rural residents are at a higher risk of hospitalization and serious illness if they became infected with COVID-19 compared to 40% of metropolitan residents because of pre-existing health conditions [6]. Rural residents are more likely to be older, poorer, and have more comorbidities including obesity, diabetes, hypertension, heart disease, and chronic lower respiratory disease than urbanites [6–10].

The states of Arkansas and Kentucky were chosen for this study's time period due to the increasing incidence of COVID-19 in the southern US. We also wanted to highlight two southern states that share similar cultural heritages, but are of different political climates in 2020 (a Republican governor in Arkansas and a Democratic governor in Kentucky). The time-varying reproduction number, R_t, represents a pathogen's changing transmission potential over time. As the average number of secondary cases per case at a certain time *t*, $R_t>1$ indicates sustained transmission and <1 epidemic decline [11–13]. Examining the R_t among these two states will provide a better indication of COVID-19 transmission, especially among vulnerable rural areas. Our study aimed to estimate the R_t for COVID-19 within Arkansas and Kentucky and to compare the R_t among the two states, as well to determine if it differs among the urban and rural areas of each state, and to investigate the impact of policies, and preventative and relaxation measures on the R_t.

Methods

Data acquisition

Using data from the New York Times GitHub data repository [14], we downloaded the cumulative confirmed case count from March 6 – November 7, 2020, for Arkansas and Kentucky, including the counties located in each state. We used the Delta Regional Authority [15] and the Appalachian Regional Commission [16] to classify the counties in Arkansas as Delta and non-Delta, and Appalachian and non-Appalachian in Kentucky. A detailed list of all 75 and 120 counties of Arkansas and Kentucky are provided in *Supplementary Tables 1* and *2*. The first case in Arkansas was reported on March 11, 2020, and the first case in Kentucky was reported on March 6, 2020. The study cutoff point was November 7, 2020. The management of negative incident case counts is described in *Appendix A*. We merged the county-level data to obtain the regional-level data (Delta, non-Delta, Appalachian, and non-Appalachian). To generate R_t, from the reported cumulative case count numbers, we utilized the daily number of new confirmed COVID-19 cases. We accessed 2019 county-level population data for Arkansas and Kentucky from the U.S. Census Bureau [17].

For sensitivity analysis, statewide hospitalization data for Arkansas and Kentucky, were downloaded from the COVID Tracking Project [18]. The first date of report was April 1, 2020 for Arkansas and April 10, 2020 for Kentucky. Due to an observed weekend effect, the 3-day moving average was applied to both hospitalization datasets before they were further analyzed.

We downloaded the executive orders from the governors' offices of each state and identified the date of the implementation and relaxation of public health interventions in each state respectively (**Table 1**).

Statistical analysis

R_t was estimated using the instantaneous reproduction number method as implemented in the R package 'EpiEstim' version 2.2–3. This measure was defined by Cori et al. [11] as the ratio between I_t, the number of incident cases at the time *t*, and the total infectiousness of all infected individuals at the time *t*. This method has been implemented worldwide in multiple studies to estimate the R_t of SARS-CoV-2 and is briefly described in *Appendix B* [19–26]. We shifted the time series by 9 days backward (assuming a mean incubation period of 6 days and a median delay to testing of 3 days) [27] for generating R_t by the assumed date of infection [13], and we specified the serial interval (mean=4.60 days; standard deviation=5.55 days) [28]. Besides using the 7-day sliding window, we also analyze R_t by the different non-overlapping time periods when different combinations of non-pharmaceutical interventions have been implemented, known as policy change R_t (PCR_t) thereafter. We estimated the 1-week sliding window R_t and PCR_t for both states at the state and regional levels. We calculated the median R_t difference percentage changes and the 95% credible interval (CrI), comparing with the previous policy interval, by bootstrapping (1000 random samples for each R_t distribution) for each state-level PCR_t, each respective state region, and the hot-spot analyses for each state (*Supplementary Tables 3–6*).

We also performed the similar analysis at the county-level in which we identified as hot spots based on the reported data and local news (*Appendix C*). For Arkansas, we analyzed data from Washington, Benton, Lincoln, and Yell Counties, respectively, and combined data from Washington County and adjacent Benton County for analysis as they are one metropolitan area (*Supplementary Figure 1*). For Kentucky, we analyzed Jefferson, Shelby, Elliott, and Warren Counties, respectively, and combined data from Jefferson County and adjacent Shelby County for analysis as they are one metropolitan area (*Supplementary Figure 2*).

A sensitivity analysis was performed to estimate 1-week sliding window R_t utilizing statewide hospitalization data (*Appendix D*).

We conducted linear regression between the $\log_{10}$-transformed per capita cumulative case count and the $\log_{10}$-transformed population size [29,30], at four different dates: May 7, July 7, September 7, and November 7. See *Appendix E* for details and results.

Statistical analysis was performed using R 4.0.3 (R Core Team, R Foundation for Statistical Computing, Vienna, Austria). Maps were created using ArcGIS Pro-Version 2.4.0 (Esri, Redlands, CA, USA), with color codes arranged according to quintiles of the values.

Ethics

The Georgia Southern University Institutional Review Board made a non-human subjects determination for this project (H20364) under the G8 exemption category.

Results

As of November 7, 2020, there were 119,057 cumulative confirmed COVID-19 cases in Arkansas (57,836 for Delta and 61,221 for non-Delta) and 122,024 cases in Kentucky (27,480 for Appalachian and 94,544 for non-Appalachian). *Supplementary Figures 3* and *4* present the spatial variation of cumulative case count and cumulative incidence per 100,000 population by county in Arkansas and Kentucky at four different dates: May 7, July 7, September 7, and November 7, 2020, respectively.

R_t estimates at the state and regional level

Overall, the median R_t for Arkansas and Kentucky at the end of the study were 1.15 (95% CrI, 1.13, 1.18) and 1.10 (95% CrI, 1.08,

Table 1
COVID-19-Related Policies and Measures Implemented in Arkansas and Kentucky, March – October 2020.

Label in R_t policy plot	Date	Implemented policies and relaxation measures
Arkansas		
	March 17	Schools Closed.
A	March 19	Closed dine-in activities at bars and restaurants, gyms and indoor entertainment venues, and schools until April 17, 2020.
B	March 23	Restricted gatherings to 10 people or fewer.
C	April 4	Required businesses, manufacturers, construction companies, and places of worship to implement social distancing protocols, such as: limiting the number of people who might enter a facility at once, marking off six-foot increments if lines formed, providing hand sanitizer or other disinfectant at or near the entrance, using contactless payment systems if the business engaged in retail or disinfecting all portals and pens, and posting a sign at the entrance informing those who entered that they should maintain a six-foot distance and avoid entering if they had a fever or cough.
	April 30	Governor Hutchinson announced that gyms and fitness centers can reopen on May 4.
	May 1	Governor Hutchinson announced that barber, cosmetology, massage therapy, body art, and medical spa services may resume operations on May 6.
	May 5	Executive Order Regarding the Public Health Emergency Concerning COVID-19, For the Purpose of Renewing the Disaster and Public Health Emergency to Prevent the Spread of and Mitigate the Impact of COVID-19.
D	May 11	Dine-in operations continue for resturants.
	May 15	Governor Hutchinson announced that as of May 18, 2020, all businesses, with the exception of bars, will be permitted to open in the state.
	May 18	Governor Hutchinson announced that bars associated with restaurant facilities may open on May 19, 2020, while freestanding bars not associated with restaurants may open with restrictions on May 26, 2020.
	June 2	State of Emergency Declared.
E	June 10	Governor Hutchinson announced that the state will be moving into Phase 2 of reopening beginning on June 15, 2020. Under Phase 2, social distancing and facial coverings are still recommended, and restaurants and businesses will be allowed to operate at two-thirds capacity, as opposed to the one-third capacity allowed during Phase 1.
	June 18	Declared an End to the State of Emergency declared on June 2.
	June 29	Governor Hutchinson has paused further reopening of Arkansas businesses as the number of coronavirus cases in the state continue to spike.
	July 6	Cities permitted to implement ordinances requiring face coverings to help curb the spread of COVID-19. Previously, only the Governor could mandate the wearing of face coverings, as cities and counties could not take more restrictive measures than those issued by the state government, per Executive Order 20–37. Arkansas does not have a state-wide face covering mandate.
F	July 20	Required use of face coverings/masks in public.
	August 14	Executive Order to Renew the Disaster and Public Health Emergency to Mitigate the Spread and Impact of COVID-19.
G	August 24	Schools reopened for in-person instruction.
	October 13	Executive Order to Renew the Disaster and Public Health Emergency to Mitigate the Spread and Impact of COVID-19.
Kentucky		
	March 6	State of Emergency Declared.
A	March 16	Schools Closed. Resturants ceased in person dining.
	March 23	Closed all in-person retail businesses that were not lifesustaining. Ceased all elective medical procedures.
	March 26	Ceased all non-life-sustaining businesses in-person services.
	March 28	Governor Beshear announced that Kentuckians could still go to Tennessee for work, to take care of a loved one or even buy groceries if it was closer, but asked that unnecessary travel to Tennessee end.
B	March 30	Issued order that restricted out-of-state travel, with four exceptions: 1) traveling to other states for work or groceries, 2) traveling to care for loved ones, 3) traveling to obtain health care and 4) traveling when required by a court order.
	April 2	Expanded recent order restricting travel to include people from out of state coming into the commonwealth. Anyone from out of state had to follow the same travel restrictions as Kentuckians. If people wanted to stay in Kentucky with a family member or friend for the duration of the COVID-19 crisis, that would be okay, but they needed to quarantine for 14 days when they got here and would not travel anywhere else.
	April 3	All Kentucky State Parks would no longer be open for overnight stays.
C	April 4	Adopted on a voluntary basis the new guidance from the U.S. Centers for Disease Control and Prevention (CDC) recommending that people wear cloth masks in some situations.
	April 9	Ordered Natural Bridge and Cumberland Falls state resort parks to close.
	April 20	Governor Beshear advised the commonwealth's education leaders to keep facilities closed to in-person instruction for the rest of the school year.
	May 6	Governor Beshear issued new executive order that continued to ban anyone with a positive or presumptively positive case of COVID-19 from entering Kentucky, except as ordered for medical treatment. It also kept in place requirements of social distancing on public transportation. Those traveling from out of state into Kentucky and staying were being asked to self-quarantine for 14 days.
	May 11	Everybody working for an essential business that was reopening should be wearing a mask.
D	May 14	Groups of 10 people or fewer could gather.
E	July 9	Required use of face coverings/masks in public.
	July 20	Cabinet for Health and Family Services issued new order that pulled back on guidance covering social, non-commercial mass gatherings. The Kentucky Department of Public Health issued a new travel advisory that recommended a 14-day self-quarantine for travelers who went to any of eight states – Alabama, Arizona, Florida, Georgia, Idaho, Nevada, South Carolina and Texas – that were reporting a positive coronavirus testing rate equal to or greater than 15%. The advisory also included Mississippi, which was quickly approaching a positive testing rate of 15%, and the U.S. Commonwealth of Puerto Rico.

(*continued on next page*)

Table 1 (*continued*)

Label in R_t policy plot	Date	Implemented policies and relaxation measures
	July 27	Announced the closing of bars for two weeks, effective, Tuesday, July 28. Announced that restaurants would be limited to 25% of pre-pandemic capacity indoors; outdoor accommodations remain limited only by the ability to provide proper social distancing. Recommended that public and private schools avoided offering in-person instruction until the third week of August.
	August 6	Extended the state's mandate requiring face coverings in some situations for another 30 days.
	August 10	Governor Beshear recommended that schools waited to begin in-person classes until Sept. 28.
	August 11	Issued an executive order allowing bars and restaurants to operate at 50% of capacity, as long as people could remain six feet from anyone who was not in their household or group. Bars and restaurants would be required to halt food and beverage service by 10 p.m. and close at 11 p.m. local time.
	August 12	Governor Beshear offered an update on his administration's travel advisory, which recommended a 14-day self-quarantine for Kentuckians who traveled to states and territories that were reporting a positive coronavirus testing rate equal to or greater than 15%. The current areas meeting this threshold included Florida, Nevada, Mississippi, Idaho, South Carolina, Texas, Alabama and Arizona.
	September 4	Extended the state's mandate requiring face coverings in some situations for another 30 days.
F	September 28	Schools reopened with in-person instruction.
	October 6	Extended the state's mandate requiring face coverings in some situations for another 30 days.

1.12), respectively. Between both states, the R_t estimates followed similar patterns. However, they were different when examining certain policy changes.

From March 11 to November 7, 2020, Arkansas revealed two major surges of new cases in July and October (**Fig. 1**). The 7-day sliding window R_t estimates in Arkansas was high at the beginning, nearing an R_t estimate of 3, dropping below 1 in mid-April, and having peaks above 1 for a few months before steadily staying around 1. At the end of the study, the median 7-day sliding window R_t estimate was 1.15 (95% CrI, 1.13, 1.18). In the Delta region, the 7-day sliding window R_t estimates had more pronounced decreased peaks in mid-May and mid-June, whereas the non-Delta region had two peaks below 1 in the early stages, an increased peak in mid-May that was above 1, and then stabilized around 1. At the end of the study, the Delta and non-Delta median 7-day sliding window R_t estimates were 1.14 (95% CrI, 1.10, 1.17) and 1.17 (95% CrI, 1.13, 1.20), respectively, with both regions demonstrating extensive community transmission of SARS-CoV-2, with a median $R_t > 1$.

At the beginning, the PCR_t estimates were high in Arkansas and both the Delta and non-Delta regions. The PCR_t estimates declined statewide (median R_t difference percentage: -53.56%, 95% CrI, -53.1%, -54.1%) and both Delta (-44.56%, 95% CI, -43.4%, -45.8%) and non-Delta regions (-62.67%, 95%, -62.4%, -63.0%) after schools closed on March 17. The PCR_t estimate remained stable statewide and in the Delta region when gatherings were restricted to 10 individuals or fewer on March 23, but declined by -10.81% (95% CrI, -26.9%, +8.35%) to below 1 in the non-Delta region. The PCR_t estimates increased statewide (+6.68%; 95% CrI, +5.58%, +7.75%) and the non-Delta region (+14.29%; 95% CrI, −5.14%, +23.68%) after May 11, when restaurant dine-in operations could resume. Both regions (Delta region: -12.08%; 95% CrI, -11.9%, -12.3%; Non-Delta region: -10.97%; 95% CrI, -10.6%, -11.3%), as well as Arkansas as a whole (-10.64%; 95% CrI, -10.60%, -10.70%), saw a decrease in the PCR_t estimate when face masks were required in public beginning on July 20. There was an increase in the PCR_t estimates statewide (+11.56%; 95% CrI, +9.88%, +13.27%) and both regions (Delta region: +9.07%; 95% CrI, +6.85%, +11.18%; Non-Delta region: +14.51%; 95% CrI, +12.3%, +16.7%) after August 24, when schools reopened with in-person instruction.

From March 6 to November 7, 2020, Kentucky's daily incidence data showed a steady increase (**Fig. 2**). In Kentucky, the 7-day sliding window R_t estimate was high in March and decreased in April. The R_t estimate had peaks that stayed around 1 and by the end of the study its median was 1.10 (95% CrI, 1.08, 1.12). Both regions (Appalachian and non-Appalachian) demonstrated an extensive community transmission of SARS-CoV-2, with a median 7-day sliding window R_t larger than 1. The Appalachian and non-Appalachian regions' median 7-day sliding window R_t estimates were 1.07 (95% CrI, 1.04, 1.11) and 1.11 (95% CrI, 1.09, 1.14), respectively, at the end of the study.

The PCR_t estimates were high among Kentucky and both regions, as the pandemic began spreading through the states. Out-of-state travel restrictions were issued on March 30, decreasing the PCR_t estimate statewide and in the non-Appalachian region, yet PCR_t increased in the Appalachian region (+32.85%; 95% CrI, +30.3%, +35.8%). The PCR_t estimate decreased to below one in the Appalachian region (-53.51%; 95% CrI, -45.16%, -61.2%) and remained stable in the entire state, after April 4, when the state adopted on a voluntary basis guidance from the Centers for Disease Control and Prevention (CDC) recommending that individuals wear cloth masks in some situations. The PCR_t estimates statewide (+5.19%; 95% CrI, +4.47%, +5.91%) and both regions (Appalachian region: +33.46%; 95% CrI, +20.7%, +46.8%; Non-Appalachian region: +1.93%; 95% CrI, +1.3%, +2.51%) increased after gatherings of 10 or less were allowed on May 14. The PCR_t estimates decreased to near 1 statewide (-5.93%; 95% CrI, -4.31%, -7.65%) and both regions (Appalachian region: -13.34%; 95% CrI, -11.5%, -15.2%; Non-Appalachian region: -4.39%; 95% CrI, -2.56%, -6.33%) beginning on July 9, with the executive order requiring face coverings in public. There was an increase in the PCR_t estimates statewide (+8.97%; 95% CrI, +8.86%, +9.08%) and both regions after September 28, when schools reopened with in-person instruction (Appalachian region: +7.49%; 95% CrI, +7.48%, +7.51%; Non-Appalachian region: +9.39%; 95% CrI, +9.23%, +9.56%).

Discussion

The purpose of this paper was to estimate and compare state and county-level R_t trajectories of COVID-19 epidemics in Arkansas and Kentucky, focusing on differences between urban and rural areas. The implementation of preventative and relaxation measures impacted case burden and the direction of the R_t trajectories. We observed decreased R_t estimates when facial coverings were mandated, changing by -10.64% in Arkansas and -5.93% in Kentucky from the previous policy interval.

This paper uses R_t to examine the COVID-19 transmission over several months, as well as examine how it varied by public health interventions and policy changes. The R_t estimates provided public health policy makers near-real time indicators of the trajectory of the epidemic and whether their public health interventions were able to put the epidemic under control. Several studies have ex-

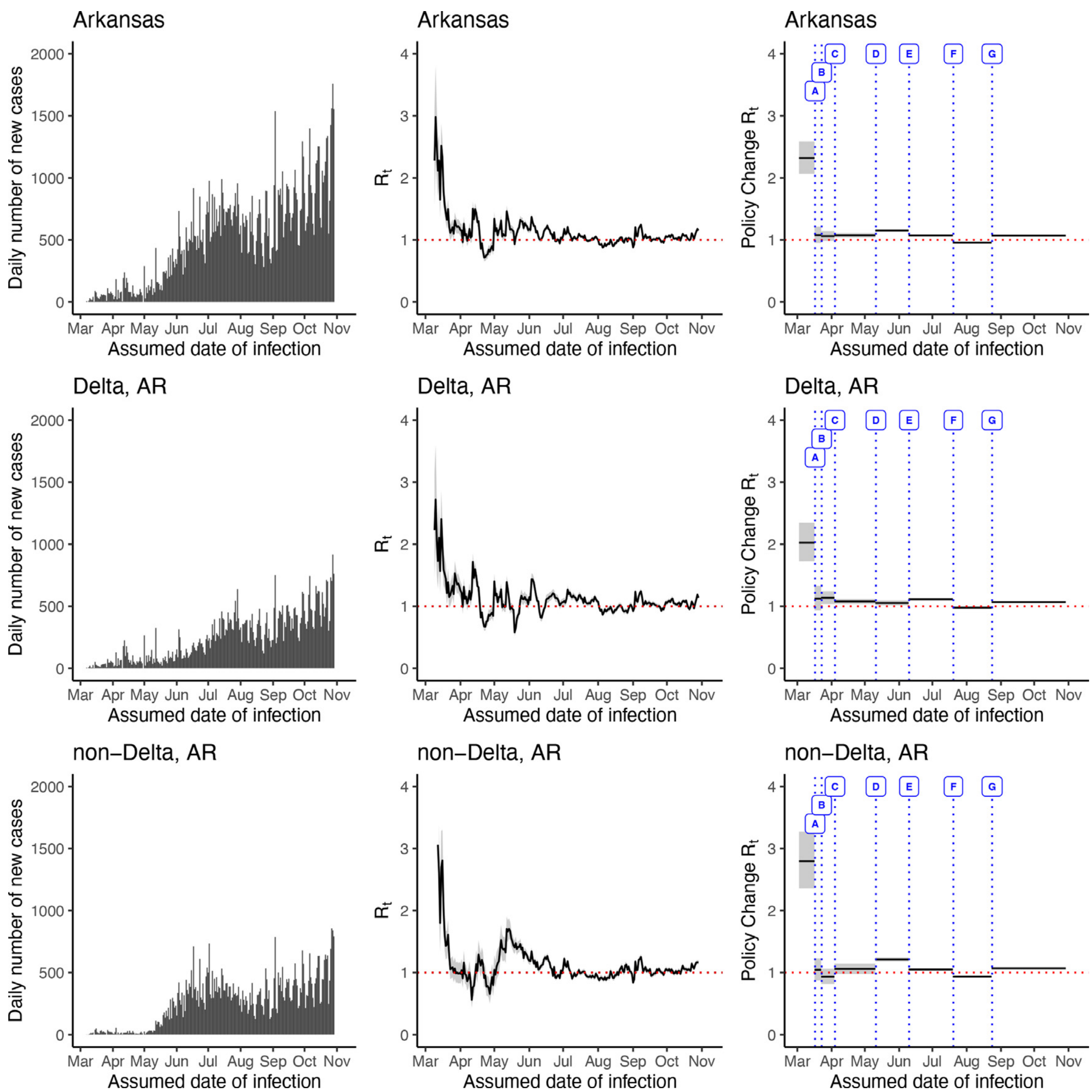

Fig. 1. The daily number of incidence (left panel), time-varying reproduction number (R_t) (middle panel), and R_t per policy change (right panel) in Arkansas, USA, March 6 – November 7, 2020 (date of report), estimated using the instantaneous reproduction number method implemented in the 'EpiEstim' package. (*A*) = Schools closed; (*B*) = Restricted gatherings to 10 people or fewer; (C) = Required businesses, manufacturers, construction companies, and places of worship to implement social distancing protocols; (*D*) = Phase One reopening of restaurants, dine-in operations may continue; (*E*) = Governor announced that Phase 2 of reopening would begin on Jun 15, 2020, allowing restaurants and businesses to operate at two-thirds capacity; (*F*) = Required use of face coverings/masks in public; (*G*) = Schools reopened for in-person instruction. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

amined the R_t estimates with respect to policy and interventions and used R_t estimates as predictive models and quantitative measures of epidemic growth or decline [31–33]. Here, the R_t trajectories of Arkansas and Kentucky differed among rural and urban areas, increasing or decreasing, depending on the implementation of preventative and relaxation measures. The R_t will be useful as the pandemic progresses to inform policymakers and public health professions of the direction of potential outbreaks, assisting in preventing health care surges and implementing more preventative measures and policies. For example, both Kentucky and Arkansas implemented mandated facial coverings or masks in July 2020, which was reflected by a decrease in COVID-19 transmission.

Our study sought to further examine if differences in COVID-19 transmission occurred among location, specifically urban versus rural, since we observed that the role of population size in counties has had a less significant effect on the spread of COVID-19. One study examined trends in the distribution of COVID-19 hotspot counties and found that more hotspot counties were occurring in the southern states of the US during summer months in 2020 [34]. This followed the trend and wave progression that occurred in the US, hitting the large metropolitan areas first, followed by spread in the Southern region and then in the Mid-West region. Another study found that many of the less vulnerable counties that had a low Social Vulnerability Index had slightly higher average incidence and death rates early in the pandemic, and as the pandemic progressed, the trends crossed, with many of the most vulnerable counties facing higher rates [35]. Many of the urban metropolitan areas and cities were impacted first, before spreading to the rural areas. This may be due to the linkage of metropolitan areas, through social, economic, and commuting relationships.

Arkansas, one of eight states in the US that did not implement a stay at home or lockdown order, lacked the immediate response, as seen by other states, could explain the higher R_t estimate, as it was at two or higher at the beginning of the pandemic [36]. Arkansas had 22 cases before the first preventative measure, the closing of schools on March 17, was implemented. Additionally, the only time

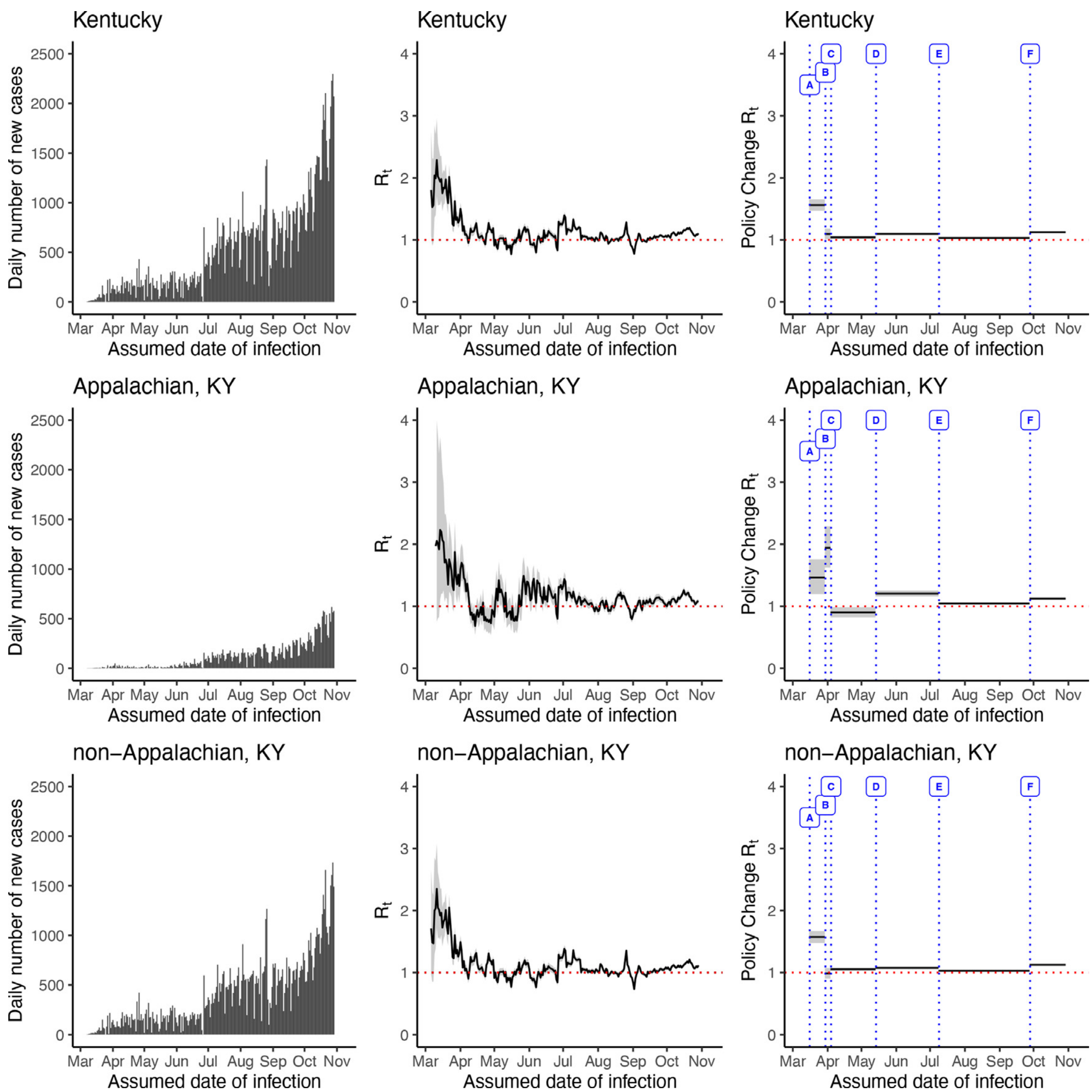

Fig. 2. The daily number of incidence (left panel), time-varying reproduction number (R_t) (middle panel), and R_t per policy change (right panel) in Kentucky, USA, March 6 – November 7, 2020 (date of report), estimated using the instantaneous reproduction number method implemented in the 'EpiEstim' package. *(A)* = School closure and restaurants cease in-person dining; *(B)* = Order issued to restrict out-of-state travel; (C) = Adopted on a voluntary basis the new guidance from the U.S. Centers for Disease Control and Prevention (CDC) recommending that people wear cloth masks in some situations; *(D)* = Groups of 10 people or fewer may gather; *(E)* = Required use of face coverings/masks in public; *(F)* = Schools reopened with in-person instruction. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the PCR_t estimate was below one was when face coverings were implemented in July, demonstrating a decrease in COVID-19 transmission. One of the biggest drivers in COVID-19 transmission in Arkansas was the poultry plant outbreaks that occurred among employees and spread through community transmission [37]. In Lincoln County, Arkansas, many COVID-19 cases were attributable to the correctional facility outbreak, rather than community transmission [38]. Additionally, there was an increase in mass testing at the correctional facility in Lincoln County, which could explain the large peaks in R_t estimates that we observed [39]. One study conducted among a correctional facility in Arkansas observed that if testing for COVID-19 was only among symptomatic individuals, then fewer cases would have been detected, allowing for a greater transmission of disease to occur [40].

At the beginning of the pandemic, many states in the South and Midwest of the US observed increased COVID-19 infection rates, yet Kentucky's rate was notably low [41]. Kentucky took a very conservative method in their approach, as was observed by the policies and measures implemented, to slow the transmission of COVID-19. A decrease in COVID-19 transmission was seen in the Appalachian region, when the state adopted the guidance from the CDC recommending that people wear cloth masks in some situations and when Kentucky passed an executive order requiring face coverings in public. The Kentucky Appalachian region has high rates of comorbidities, especially respiratory diseases due to the coal industry, but saw an increase in mask wearing when required [42]. In Jefferson, Shelby, and Warren Counties in Kentucky, a decrease in PCR_t was observed in transmission towards the beginning of the pandemic, when an order was issued to restrict out-of-state travel. This decrease in transmission may have been due to less travel that occurred across state lines, as Warren County is near the Tennessee border and Nashville, the Tennessee capital, and Jefferson and Shelby Counties border Indiana, and is near Cincinnati in Ohio [43].

During the study period, both Arkansas and Kentucky maintained a median R_t above 1. These two states had different political parties in charge of the governor's office in 2020, yet share similar cultural and heritage histories. Additionally, within both of these states, we found that mandated face coverings were associated with a decreased R_t estimate and reopening of schools were associated with an increased R_t estimate. There are a few similarities of R_t estimates and PCR_t estimates among these two states on a statewide level, which may suggest underlying factors, such as COVID-19 variants and pathology, rather than social determinants of health. However, once we examine regional level, and even county level, we find both similarities (decreased COVID-19 transmission with mandated face coverings) and differences (increased COVID-19 transmission with gatherings of 10 or less allowed). The findings of this study among two similar southern states also relates to many other regions. Among different regions in the US, face coverings mandates and reopening of schools also showed a decreased and increased, respectively, of COVID-19 transmission. In the Western states (North Dakota, Montana, and Wyoming), it was found that the R_t estimate decreased following a face covering mandate [44]. An increase in COVID-19 transmission was observed in South Carolina following the reopening of schools (15.3%) [45].

While the R_t differed among rural and urban areas at the beginning of the pandemic, as the pandemic progressed, the R_t was similar across the urban and rural counties in both states. Although population size has been found to have a less significant effect on COVID-19 spread than hypothesized at the early pandemic, it is still important to discuss the disparities that occur between rural and urban locations and the implications the pandemic has on rural locations. Rural areas have had lower testing rates, as well as poorer health care infrastructures to handle cases [46]. Rural health care and public health systems are more vulnerable and have struggled to respond to the COVID-19 crisis [47]. Additionally, most healthcare systems do not have the capacity to handle surges in cases, and only one percent of the nation's intensive care unit beds are located in rural areas [48]. Many care and patient populations are different in rural communities and it is an important aspect to understanding the spread of COVID-19. Although policy and preventative measures are statewide, it does show differences among rural and urban communities. One study found that rural Americans were less likely than urban Americans to follow most recommended COVID-19 prevention behaviors [49].

There were several limitations in this study. One limitation was the lack of data on superspreading events that occurred in each state (for example, within prisons [50] and nursing homes [51], as well as in religious settings, schools and sport camps, and social events [52]). The lack of testing data, as well as hospitalization data, by county level may lead to testing bias. This would have provided further insight into the rural and urban disparities that may be present. Many of the counties located in both Arkansas and Kentucky contained large prison populations. The counties of Lincoln, Arkansas and Elliot, Kentucky, both contain county correctional facilities and prisons [38,53]. The reason for the unstable R_t in these counties may stem from disease amplification in prison outbreaks rather than community spread. However, it is difficult to pinpoint certain related outbreaks, and there is limited county-level data specific to correctional facilities. Additionally, there were 1755 unknown county-level cumulative cases in Arkansas. These cases were included in our state-level data analysis, but they were excluded from the Delta, non-Delta, and county-level hot spots analyses. Kentucky had all county-level data and all reported cases were used in all analyses.

This study observed that both Arkansas and Kentucky, as well as the respective regions, had an extensive spread of COVID-19, since both states maintained a median R_t above 1. The direction of the trend of the R_t estimates were reflected by the implementation of preventative measures and their subsequent relaxation as the pandemic progressed. This study was able to examine the changing transmission potential of COVID-19 over time in rural and urban areas in two socio-demographically similar Southern states. Further research is needed to examine the rural and urban differences in the spread of the COVID-19 pandemic in the US.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.annepidem.2021.12.012.

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