Comment on Sen, Karaca-Mandic, and Georgiou on Stay-at-Home Orders and COVID-19 Hospitalizations in Four States

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LINK TO ABSTRACT

The *JAMA* research letter "Association of Stay-at-Home Orders with COVID-19 Hospitalizations in 4 States," by Soumya Sen, Pinar Karaca-Mandic, and Archelle Georgiou (2020; hereafter the authors are referred to as SKG), should not be used to make any claims about the effects of stay-at-home orders because its statistical method is flawed. The letter shows that, after the effective date of stay-at-home orders in Colorado, Minnesota, Ohio, and Virginia, actual hospitalizations were well below the putative forecast from a univariate exponential time trend.

The effects of stay-at-home orders on COVID-19 hospitalizations cannot be determined by only comparing actual hospitalizations to forecasts of hospitalizations from an exponential trend model within a state with a stay-at-home order. That method suffers from the lack of any comparison to control data. Unfortunately, the SKG research letter did not examine whether actual COVID-19 hospitalizations were also lower than a similar forecast of exponential growth in states without stay-at-home orders.

This paper shows that the SKG method fails the following placebo tests. In three states without stay-at-home orders, cumulative COVID-19 hospitalizations do not continue to grow at the initial estimated exponential rate. Actual COVID-19

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cumulative hospitalizations are substantially lower than the forecast from a univariate exponential model in Iowa and North Dakota. In South Dakota, COVID-19 hospitalizations fall below the projections from a univariate exponential model in May. Actual COVID-19 cases are significantly below a projection of exponential growth in Arkansas, another state without a stay-at-home order. A reduction in actual hospitalizations below projections of exponential growth in states without statewide or local stay-at-home orders should not be attributed to non-existent stay-at-home orders.

SKG's methods and results

SKG estimate separate univariate linear and exponential time trend models using statewide cumulative COVID-19 hospitalizations in four states, Colorado, Minnesota, Ohio, and Virginia, with stay-at-home orders. They favor the exponential model because its goodness of fit is better than that of the linear model.

The exponential time trend model is $y = ae^{bt}$, where y is cumulative COVID-19 hospitalizations and t is a time trend. SKG estimate this model using data from the beginning of a state's available data until twelve days after the state's stay-at-home order to allow for reported medians of five days from infection until symptoms and seven days from symptoms until hospitalization.

SKG interpret the deviation of actual hospitalizations from the projected exponential growth in cumulative hospitalizations as evidence of an association between stay-at-home orders and reduced hospitalizations. They include this remark: "Other factors that potentially decreased the rate of virus spread and subsequent hospitalizations include school closings, social distance guidelines, and general pandemic awareness" (SKG 2020, 2522–2523). They also note that other factors were not modeled, and "data on only 4 states were available" (ibid., 2523).

Problems with SKG's analysis

In general, without the use of any control group it is not possible to identify the effects of a single policy intervention during the COVID-19 pandemic by fitting a univariate exponential time trend to cumulative COVID-19 events in a state from the beginning of the pandemic and viewing the difference between the exponential forecast and subsequent observed data as the treatment effect of the policy intervention.

The exponential functional form ignores Farr's Law. Farr (1840) observed that the flow—infections, hospitalizations, or deaths—of an infectious disease

could be approximated by a normal bell curve (Bregman and Langmuir 1990). Cumulative counts of disease events, like hospitalizations, may be approximated by a sigmoid (s-shaped) function, such as the logistic function. In contrast, the exponential functional form assumes constant exponential growth. Actual cumulative disease events will tend to fall below exponential growth forecasted from initial data, without any intervention, when cumulative disease events follow Farr's Law.

SKG do not explain why they favor fitting an exponential function over a sigmoid function. The univariate exponential functional form would only be appropriate when there is a credible argument that the initial exponential trend would continue in the absence of the policy intervention.

Data and methods

In this paper I implement the SKG method by estimating univariate exponential models for four states where either COVID-19 hospitalizations or cases are a function of time during the curve fitting period shown in Table 1.

There were five states without stay-at-home orders at either the state or local level: Arkansas, Iowa, Nebraska, North Dakota, and South Dakota (Mervosh, Lu, and Swales 2020). Nebraska is excluded because cumulative hospitalization data is not available until June 1. Each of these four remaining states did have other official state actions, including school closings, intended to reduce interactions that could spread the virus. Arkansas, Iowa, North Dakota, and South Dakota are not a random selection of states. They are more agricultural, rural, and centrally located than a typical state.

Data on cumulative hospitalization was downloaded from the COVID-19 Hospitalization Tracking Project website (**link**) for Iowa, North Dakota, and South Dakota. SKG have performed a valuable service by disseminating data on cumulative COVID-19 hospitalizations via that website. Iowa, North Dakota, and South Dakota have data on cumulative hospitalizations beginning on April 1, March 21, and March 30, respectively. Such data begins on March 10 for Colorado, March 17 for Ohio, and March 19 for both Minnesota and Virginia.

Cumulative COVID-19 case data for Arkansas was downloaded from the Arkansas Department of Health (**link**) because Arkansas did not have cumulative hospitalization data available until April 28. Arkansas data on cumulative COVID-19 cases begins on March 11.

I use a counterfactual stay-at-home placebo date of March 30, the same day Virginia issued its stay-at-home order, to determine the curve fitting period. The counterfactual stay-at-home placebo date of March 30 is my best guess of when a state would have enacted a stay-at-home order. It is two days after Minnesota's

stay-at-home order and the same day as Virginia's order.

Following SKG, I make the median effective date for hospitalizations in Iowa, North Dakota, and South Dakota twelve days later, to allow for a median of five days from infection until symptoms and a median of seven days from symptoms until hospitalization. The median effective date for COVID-19 cases in Arkansas is five days later to allow for five days from infection until symptoms.

Data on Iowa hospitalizations starts on April 1, resulting in an April 1–April 10 fitting period. Data on North Dakota hospitalizations starts on March 21, resulting in a March 21–April 10 fitting period. Data on South Dakota hospitalizations starts on March 31, resulting in a March 31–April-10 fitting period. Data on Arkansas cumulative COVID-19 cases starts on March 11, resulting in a March 11–April 3 fitting period.

Results

Actual COVID-19 cumulative hospitalizations are substantially lower than the forecasted exponential growth rates in Iowa and North Dakota. The difference becomes progressively larger with time. The 95% confidence intervals (c.i.) for forecasted cumulative hospitalizations shown in Figure 1 are relatively large.

TABLE 1. Cumulative hospitalizations or infections due to COVID-19 in Iowa, North Dakota, South Dakota, and Arkansas

State	COVID-19 data	Curve fitting period	Counterfactual stay-at-home placebo date	Median effective date	Cumulative count		Best exponential fit: $\ln(y)=\ln(a)+bt$		
					On first day of reporting	On April 28	$\ln(a)$ (95% CI)	b (95% CI)	R^2
Iowa	Hospital-izations	April 1–April 10	March 30	April 10	47	618	34.85 (29.40–41.32)	0.12 (0.09–0.15)	0.93
North Dakota	Hospital-izations	March 21–April 10	March 30	April 10	3	79	4.54 (3.40–6.08)	0.12 (0.10–0.14)	0.86
South Dakota	Hospital-izations	March 31–April 10	March 30	April 10	12	157	11.48 (10.06–13.10)	0.09 (0.07–0.11)	0.93
Arkansas	Cases	March 11–April 3	March 30	April 3	5	3146	8.19 (5.17–11.73)	0.22 (0.19–0.24)	0.94

In Iowa actual hospitalizations start falling below projected hospitalizations around April 20, ten days after the median effective date for the placebo stay-at-home order. By May 26 actual cumulative Iowa hospitalizations were 1,594, while forecasted cumulative hospitalizations were 29,000 (c.i. 5,300–162,000).

In North Dakota actual hospitalizations started falling under the forecasted cumulative hospitalizations around April 8, two days before the median effective

placebo date. The difference between actual and forecasted hospitalizations is not statistically significant on this date. On April 15 projected hospitalizations were 98 (c.i. 40–240), and actual hospitalizations were 44. This was five days after the median effective placebo stay-at-home date. By May 26 projected hospitalizations were 12,600 (c.i. 1,991–79,000) and actual hospitalizations were 156.

In South Dakota actual cumulative hospitalizations stayed around forecasted cumulative hospitalizations for most of April. South Dakota hospitalizations began falling below forecast around April 28. By May 26 projected hospitalizations were 2,200 (c.i. 586–8,600), and actual South Dakota hospitalizations were 378.

The exponential parameter b, in $y = ae^{bt}$, is estimated to be 0.012 in both Iowa and North Dakota and 0.09 in South Dakota. This is almost half the magnitude estimated in SKG. They find that b ranges from 0.178 in Virginia to 0.24 in Colorado. These differences show a slower rate of growth in cumulative hospitalizations in these three states than in the four states studied in SKG. This difference could be due to inherent differences among the states or the different dates of the fitting periods, especially the later start of the Iowa and South Dakota fitting periods.

In Arkansas, actual cumulative cases started falling below projected cases around March 31, three days before the median effective placebo date. However, the March 31 difference between 612 actual cases and 783 projected cases was not statistically significant at a 95% confidence level. Actual cumulative cases were 1,146 on April 8, five days after the median effective placebo stay-at-home date, while projected cases were 4,400. By April 28 in Arkansas 342,000 cases were forecasted while there were only 3,146 actual cases.

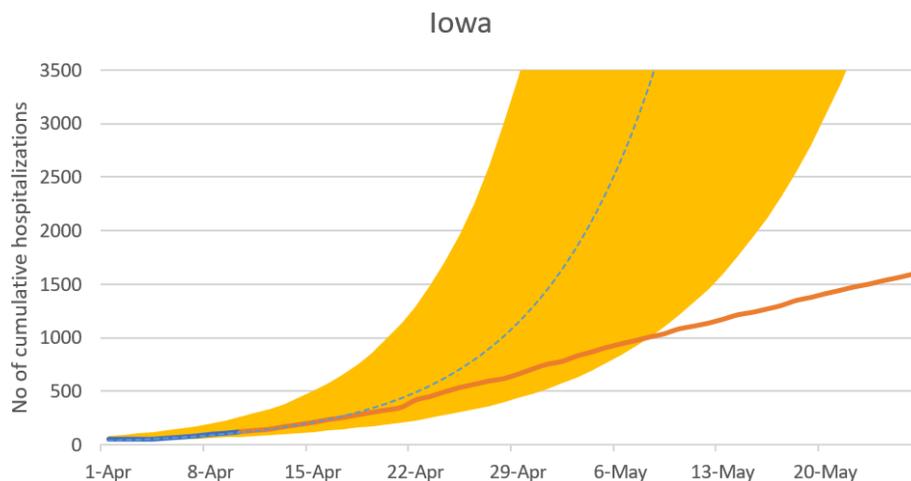**Figure 1**. Projected vs. observed COVID-19 events before and after placebo stay-at-home dates

Figure 1 (cont'd). Projected vs. observed COVID-19 events before and after placebo stay-at-home dates
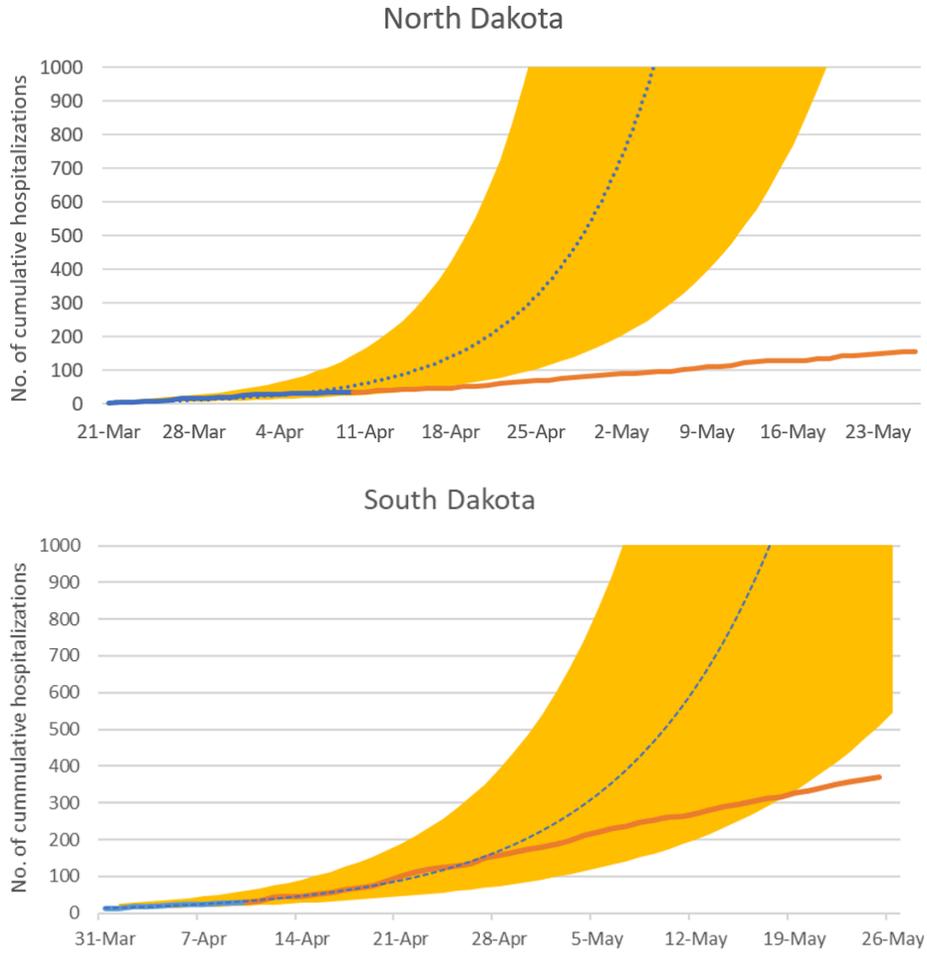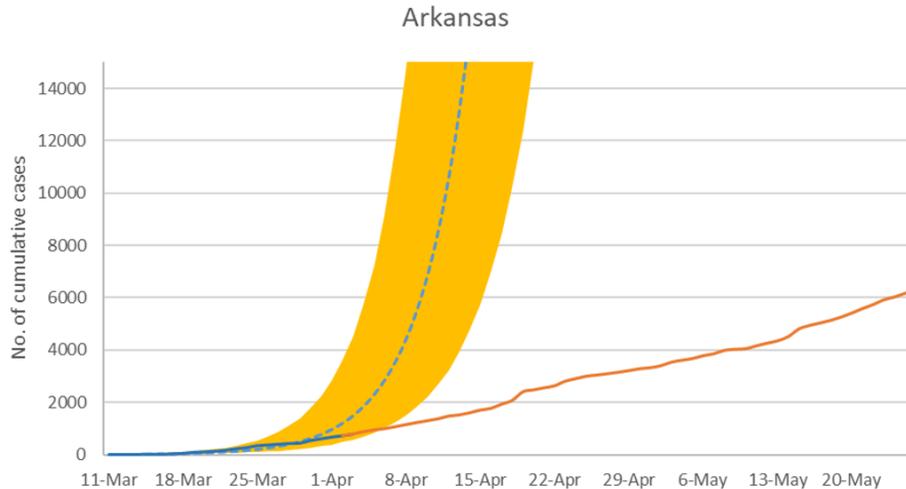
Figure 1 (cont'd). Projected vs. observed COVID-19 events before and after placebo stay-at-home dates

Notes: Blue and orange lines for Iowa, North Dakota, and South Dakota show actual cumulative COVID-19 hospitalizations (including those currently hospitalized and those discharged) up to each day. Blue and orange lines for Arkansas show actual cumulative COVID-19 cases up to each day. The dashed blue line shows the best fit exponential curves for cumulative COVID-19 events for the curve fitting period: the first day of reporting up to and including the median effective date (panel A: y=34.85exp(0.12t), R^2=0.93; panel B: y=4.54exp(0.12t), R^2=0.86; panel C y=11.48exp(0.09t), R^2=0.93, Panel D y=2.10exp(0.22t), R^2=0.94). Shaded regions indicate the 95% prediction bands of the exponential growth curves.

Discussion

If the SKG method was sound, states without stay-at-home orders should have experienced exponential growth in COVID-19 hospitalizations and cases—but they experienced COVID-19 events below exponential forecasts. Actual COVID-19 cumulative hospitalizations fall below the projections from a univariate exponential time trend model in Iowa, North Dakota, and South Dakota. Actual COVID-19 cases were significantly below an exponential time trend forecast in Arkansas. The timing of when these deviations occur does vary by state.

The best available conclusion from observing that COVID-19 hospitalizations fall below the forecast from a univariate exponential time trend in states with and without stay-at-home orders is that nothing should be concluded about the effect of stay-at-home orders on COVID-19 hospitalizations from the evidence in

SKG or in the present comment.

This does not mean that stay-at-home orders do not have an effect on COVID-19 hospitalizations. Whether or not stay-at-home orders play a role in reducing hospitalization is impossible to determine using this method. And the findings certainly do not mean that not enacting a stay-at-home order is associated with reduced COVID-19 hospitalizations in Iowa, North Dakota, and South Dakota or reduced COVID-19 cases in Arkansas.

Finally, a brief discussion of the history of related work is needed to credit the contributions of other people. Paul Novosad first publicized concerns with SKG's method in a Twitter thread on May 27, 2020 (**link**), when the SKG research letter was first published. I then collaborated with Mufaddal Baxamusa and Paul Novosad on an unsuccessful submission of a research letter to *JAMA* that served as the core of this comment. The *JAMA* editor suggested that we could submit a comment on the SKG research letter. Our submission of an online comment on the SKG research letter was also rejected. We then made that comment available online (Baxamusa, Novosad, and Spry 2020). Separately, Joe Gibson (2020) and Arnab K. Ghosh and Nathaniel Hupert (2020) also raised methodological concerns with SKG. Ghosh and Hupert especially criticized SKG's use of exponential functions.

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About the Author

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