Original Research

College reopening and community spread of COVID-19 in the United States

C.-N. Chang [a], [*], H.-Y. Chien [b], L. Malagon-Palacios [a]

[a] *Life Span Institute, University of Kansas, USA*
[b] *Department of Educational Psychology, Texas A&M University, USA*

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ABSTRACT

Objective: After months of lockdown due to the COVID-19 outbreak, the US postsecondary institutions implemented different instruction approaches to bring their students back for the Fall 2020 semester. Given public health concerns with reopening campuses, the study evaluated the impact of Fall 2020 college reopenings on COVID-19 transmission within the 632 US university counties.
Study design: This was a retrospective and observational study.
Methods: Bayesian Structural Time Series (BSTS) models were conducted to investigate the county-level COVID-19 case increases during the first 21 days of Fall 2020. The case increase for each county was estimated by comparing the observed time series (actual daily cases after school reopening) to the BSTS counterfactual time series (predictive daily cases if not reopening during the same time frame). We then used multilevel models to examine the associations between opening approaches (in-person, online, and hybrid) and county-level COVID-19 case increases within 21 and 42 days after classes began. The multigroup comparison between mask and non-mask-required states for these associations were also performed, given that the statewide guidelines might moderate the effects of college opening approaches.
Results: More than 80% of our university county sample did not experience a significant case increase in Fall 2020. There were no significant relationships between opening approaches and community transmission in both mask-required and non-mask-required states. Only small metropolitan counties and counties with a non-community college or a higher percentage of student population showed significantly positive associations with the case number increase within the first 21-day period of Fall 2020. For the longer 42-day period, the counties with a higher percentage of the student population showed a significant case increase.
Conclusion: The overall findings underscored the outcomes of US higher education reopening efforts when the vaccines were still under development in Fall 2020. For individual county results, we invite the college- and county-level decision-makers to interpret their results using our web application.

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Introduction

The COVID-19 pandemic has severely disrupted the functioning of global postsecondary institutions since 2020. In late March 2020, more than 1300 colleges and universities in the United States suspended in-person classes and closed campuses,[1] resulting in many students moving back to their hometowns to complete their coursework remotely. After months of lockdown, institutions started implementing different instruction approaches (in-person, online, and hybrid) to bring their students back for the Fall 2020 semester. At the same time, it also concerns that college campuses could potentially become COVID-19 spreaders for the community.[2] The present study aimed to evaluate the causal effect of college reopening on county-level COVID-19 cases for Fall 2020. This study provides one of the first national evidence on whether and to what extent the US higher education reopening efforts could prevent disease spread and the occurrence of an outbreak without any vaccine.

The US Centers for Disease Control and Prevention (CDC) found the links between large institution openings and COVID-19 community incidence.[3] Their research findings through a Difference-in-Difference (DD) analysis indicated that in comparison with the 21-day periods before and after the Fall 2020 semester started,

* Corresponding author. Life Span Institute, University of Kansas, 1000 Sunnyside Ave, Lawrence, KS 66045, USA. Tel.: +1-785-864-1797.
E-mail address: cnchang@ku.edu (C.-N. Chang).

counties with large universities with online instruction (n = 22) experienced a decrease in COVID-19 incidence, whereas those with in-person instruction (n = 79) experienced an increase in confirmed cases. However, little attention has been paid to the investigations on hybrid instruction and other sized institutions. In addition, studies have shown days from symptom onset to diagnosis could be up to 42 days.[4,5] It is also necessary to investigate the college opening impacts within a 42-day time frame.[6]

Building on the US CDC research, this study used Bayesian Structural Time Series (BSTS) models to evaluate the causal effects of Fall 2020 college reopenings on the county-level COVID-19 cases in 632 US counties (approximately 20% of the US counties) and examined the associations between opening approaches (in-person, online, and hybrid) and county-level incidence within the first 21- and 42-day period after the Fall 2020 classes began. Importantly, compared with the classical DD designs testing the difference before and after the intervention, BSTS is a machine learning approach to investigating a causal effect evolving over time.[7] This approach has started being applied in analyzing the casual impact of lockdown during the COVID-19 outbreak around the world.[8]

Methods

Data

The data for this study include the US county-level daily COVID-19 confirm cases (data version: January 29, 2021),[9] university's Fall 2020 reopening date (collected from each university website in December 2020 and January 2021), university's Fall 2020 opening approach (Data version: November 10, 2020),[1,10] university types,[1,10,11] university's enrollment in 2018 (most recent data),[12] county urban—rural classification,[13] and state-level mask requirements (August to September 2020).[14]

Study population

The population of this study is US counties that have higher education institutions. Among 3006 US counties,[15] only 1265 counties have at least one university or college.[1,10] Our study sample was selected from these 1265 counties based on the following steps. First, to avoid the interference of multiple college opening approaches (e.g. different instruction types and different first days of classes) within a county in examining a college opening effect, we only selected the counties with only one college or university (n = 733). Second, among these 733 institutions, we only included those institutions (n = 693) whose opening approach in Fall 2020 was clearly specified as in-person, online, or hybrid.[1,10] Third, if the effects estimated through BSTS models are identified as extreme values in a stem-and-leaf plot, these outliers will be excluded from the study sample. The final analytic sample ended up with 632 US counties.

Estimating a college opening effect

A BSTS model was performed in each county to investigate the causal effect of college reopening by comparing the observed time series (i.e. daily COVID-19 cases within 21 days after classes began) to the counterfactual time series (daily COVID-19 cases during the same period under the scenario of "if the college or university did not reopen"). The novel part is the simulation of the counterfactual time series using a large set of potential predictors (i.e. spike-and-slab prior). These predictors consisted of a set of time series of daily confirmed cases since January 22, 2020, from the other non-university counties in each state. As demonstrated in Fig. 1, the simulated predictions fit the actual cases before the Fall 2020 classes started. Within 21 days after classes began, the discrepancy between

observed data and counterfactual predictions is an estimated college opening effect in the county. The college opening effect can be quantified by the average relative effect: (21-day cumulative actual cases − 21-day cumulative predictive cases)/|21-day cumulative predictive cases|. This value suggests the actual percentage increase of county-level cases when opening a college in a given county compared with a counterfactual scenario (i.e. no college opening in the same county). A positive effect implies a case increase within the county during the first 21-day school reopening, whereas a negative effect stands for a case decrease. Ninety-five percent Bayesian posterior probability intervals would help identify the significance of the school opening effect. A web application was developed to display each of the county results. The web application, quick start guide, and our county sample may be accessed on https://sites.google.com/view/collegereopening.

Analytic strategies

A total of 632 BSTS models for 632 US counties were conducted. Each model was estimated using 10,000 Markov chain Monte Carlo samples in R.[16] The descriptive results for college opening effects in the first 21 days of Fall 2020 are plotted in Fig. 2 and presented in Table 1. Given the nested data structure (counties clustered within states), we used multilevel models to examine the associations between opening approaches (in-person, hybrid, and online) and county-level COVID-19 case increases (i.e. the college opening effect estimated from the BSTS models) within 21 and 42 days after classes began, controlling for the covariates including statewide public mask requirements in August and September 2020 (mask-required states/non-mask-required states), university sector (private/public), community college, college enrollment, percentage of college student population in a county, and county-rural classification.[3] Additional multigroup chi-square difference tests between mask and non-mask-required states for these associations were also performed, given that the statewide guidelines might moderate the effects of college opening approaches.

Results

County-level COVID-19 infection during the first 21 days of Fall 2020

Fig. 2 shows the college opening effect within the first 21 days of the Fall 2020 semester in each county. Each of these effects was estimated through a BSTS model, indicating the actual percentage increase of county-level cases when opening a college in a county, compared with a counterfactual scenario (i.e. no college opening in the same county). Counties filled in red indicate that the college openings in these counties might bring more COVID-19 confirmed cases, whereas counties in green show that the COVID-19 cases might be less than expected. Blue county means that the county's case number did not show a significant change. Overall, as shown in Table 1, 18% of counties (114/632) showed an 85.3% case increase within the first 21 days, whereas 21% of counties (133/632) showed a 50.3% case decrease during the first 21 days of Fall 2020. No significant case changes were found in the remaining 61% of counties (385/632).

Table 1 also reveals the descriptive results for college opening effects by statewide public mask requirements, opening approaches, university sector, community college, college enrollment, percentage of the college student population within a county, and urban—rural classification. On average, counties in non-mask-required states showed a 12.7% increase in the case number, which was higher than the counties in mask-required states (1.6%). Counties with in-person college opening approaches showed a 10.2% increase in the case number, which was higher than the online (2.2%) and hybrid (−0.9%) approaches. Counties with private and public institutions showed
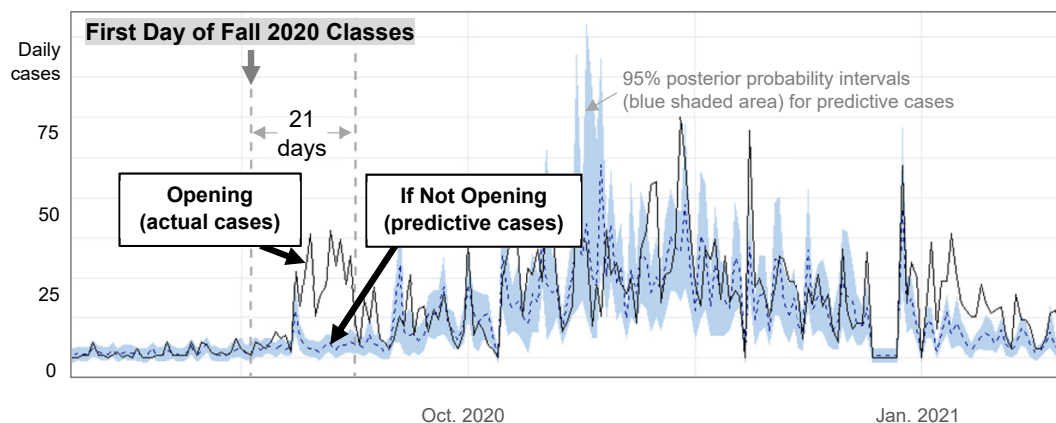
Fig. 1. Causal effect of a college reopening on COVID-19 case increase in an example county.
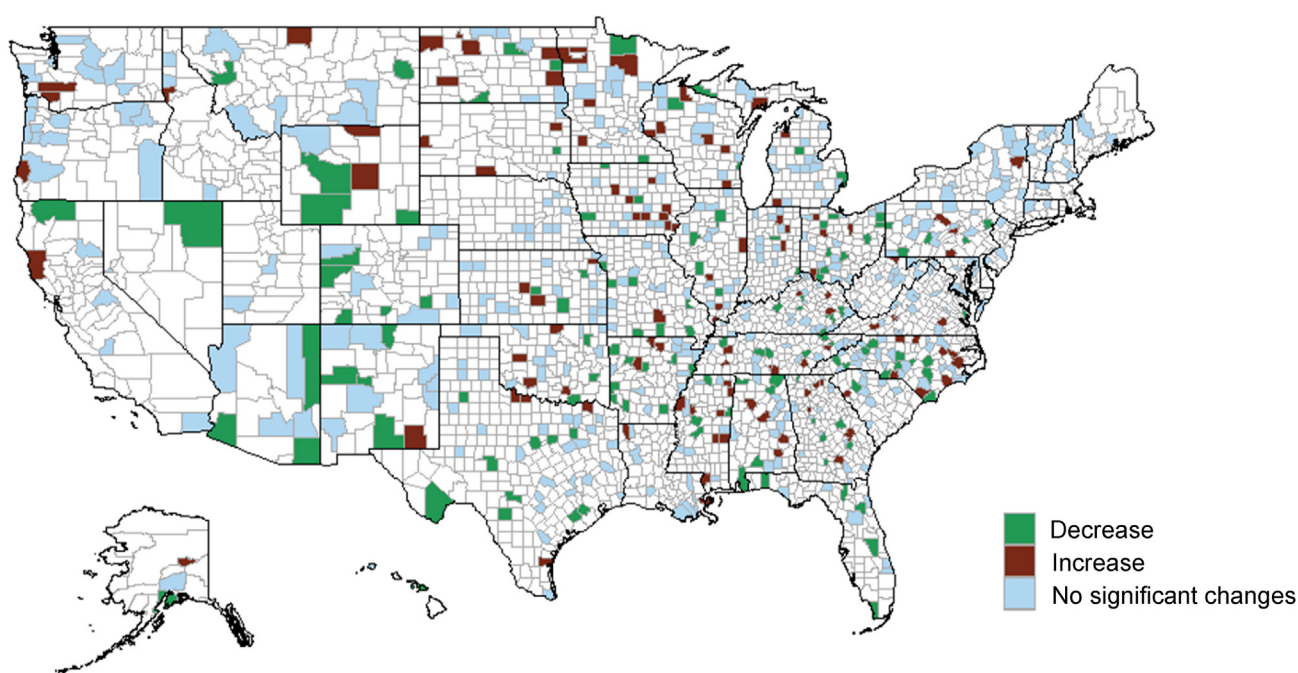

Fig. 2. County-level COVID-19 infection during the first 21 days of Fall 2020 semester. *Note.* Blank counties were excluded from our study, given the criteria of sample selection.

4.1% and 5.0% increases in the case number, respectively. Counties with community colleges showed a 1.5% decrease; however, the remaining counties with non-community colleges showed a 10.4% case increase. Counties with a larger college (enrollment $\geq$5000) showed a 9.8% case increase, and counties with a small-size institution (enrollment <5000) showed a 3.2% case increase. Similarly, for counties with a larger student population (>10% of total county population), the total confirmed cases increased about 12.1%, which was higher than the remaining counties' 2.1% case increase. The results also showed COVID-19 cases decreased in large metropolitan counties (-7.5% to -16.6%), but cases increased in medium metropolitan counties (2.9%), small metropolitan counties (15.4%), micropolitan counties (8.2%), and non-core counties (1.1%).

Associations between college opening approaches and county-level case increases

Multilevel analyses (Table 2) indicated weak associations between the college opening approaches and county-level case increases in the first 21 and 42 days of the Fall 2021 semester. The outcome, county-level case increase (i.e. college opening effect estimated through BSTS), was the actual percentage increase of county-level cases when opening a college in a county, compared with a counterfactual scenario (i.e. no college opening in the same county). For the first 21-day period, model 1 revealed that the in-person opening approach showed a marginally significant tendency ($P = .085$) toward a higher COVID-19 case increase than the online opening approach. After controlling for the state-level mask requirements and other county-level covariates, the in-person instruction mode was still not significant in Model 2. Instead, we found that small metropolitan counties and counties with a non-community college or a higher percentage of student population showed a significant case number increase. All the county-level variables could account for 4.6% (small effect) of the variance in county-level case number increase. There were no significant differences between hybrid and online opening approaches in models 1 and 2. For a longer term 42 days, there were also no significant differences between in-person, hybrid, and online approaches in models 3 and 4. The results showed that the county-level case increase within the 42 days was significantly found in those counties

Table 1
County-level COVID-19 infection within the first 21 days of Fall 2020 semester.

County characteristics	N (%)	Average effect
All counties	632 (100%)	4.7%
Case decrease	133 (21%)	−50.3%
Case increase	114 (18%)	85.3%
No significant changes	385 (61%)	−0.1%
Statewide public mask requirements		
Required	453 (72%)	1.6%
Not required	179 (28%)	12.7%
Opening approaches		
In person	257 (41%)	10.2%
Hybrid	148 (23%)	−0.9%
Online	227 (36%)	2.2%
Sector		
Private	165 (26%)	4.1%
Public	467 (74%)	5.0%
Community college		
Community	301 (48%)	−1.5%
Non-comm.	331 (52%)	10.4%
Enrollment		
<5000	486 (77%)	3.2%
≥5000	146 (23%)	9.8%
Percentage of student population		
<10%	468 (74%)	2.1%
≥10%	164 (26%)	12.1%
Urban−rural classification		
Large central metro	2 (0%)	−16.6%
Large fringe metro	90 (14%)	−7.5%
Medium metro	63 (10%)	2.9%
Small metro	92 (15%)	15.4%
Micropolitan	236 (37%)	8.2%
Noncore	149 (24%)	1.1%

Note. N = number of counties. % = the percentage of counties in 632 counties. No significant changes = the 95% posterior probability interval of the college opening effect includes zero. Non-comm. = non-community college.

with a higher percentage of student population, which could explain 2.9% (small effect) of variance.

Table 3 further indicated the association between college opening approaches and county-level case increase by statewide public mask requirements. There were no significant associations ($P < .05$) between college opening approaches and COVID-19 case increase within the communities in both mask and non-mask-required states. The percentage of student population in non-mask-required state counties might positively predict the county-level case increase within the first 21 days. The multigroup comparison tests summarized no significant differences between mask and non-mask-required states in their group-specific parameter estimates within the first 21 and 42 days of the Fall 2021 semester. In other words, the estimated effects shown in Table 3 did not significantly vary by the statewide public mask requirements.

Discussion

The public health concerns about school closures and reopenings during the pandemic are continually discussed.[2,3,17–19] The present study evaluated the impact of college reopenings in Fall 2020 on COVID-19 transmission within the 632 university counties in the United States. We found that 18% of these counties had a significant case increase during the first 21 days of the Fall 2020 semester. These counties showed an 85% case increase on average, compared with the counterfactual scenario if not reopening the campus in these counties. We discovered some case increase patterns in non-mask-required states, small metropolitan counties, micropolitan counties, counties with an in-person college reopening, a non-community college, a large enrollment size institution, or a higher percentage of the student

Table 2
Associations between college opening approaches and county-level COVID-19 case increase.

Independent variable	21 days after classes began		42 days after classes began	
	Model 1	Model 2	Model 3	Model 4
Fixed effects				
State level				
Mask required[a]		−.09 (.06)		.004 (.06)
County level				
Opening approaches[b]				
In person	.09 (.05) †	.08 (.05)	.09 (.06)	.08 (.06)
Hybrid	−.02 (.06)	−.03 (.06)	.01 (.07)	.01 (.07)
Covariates				
Private[c]		−.05 (.06)		−.01 (.08)
Community college[d]		−.12 (.05) *		−.07 (.06)
Enrollment (per 1000)[e]		−.001 (.01)		.003 (.01)
Percentage of student population[e]		.76 (.26) **		.78 (.33) *
Urban−rural level[f]				
Large metro[g]		−.02 (.08)		−.12 (.09)
Medium metro		.07 (.08)		−.03 (.10)
Small metro		.17 (.08) *		.05 (.09)
Micropolitan		.10 (.06) †		−.03 (.07)
Intercept	.02 (.04)	.03 (.09)	.07 (.04)	.058 (.088)
R^2 (county level)	0.7% (.007)	5.3% (.018) **	0.4% (.005)	3.3% (.014) *
R^2 change (county level)		4.6%		2.9%
Random variance components				
Intercept (τ_{00})	.01 (.01)	.01 (.01)	.003 (.01)	.004 (.01)
σ^2	.29 (.02) ***	28 (.02) ***	.42 (.03) ***	.41 (.02) ***

Note. Model 1 and Model 3 included the opening approach variables. The state-level mask requirement and county-level covariates were added further in Model 2 and Model 4. Values are unstandardized estimates and standard errors (in parentheses).
†$P < .10$,*$P < .05$, **$P < .01$,***$P < .001$.
[a] Reference group: not required.
[b] Reference group: online.
[c] Reference group: public.
[d] Reference group: non-community college.
[e] Continuous variable.
[f] Reference group: non-core.
[g] This category includes large central metros and large fringe metros because only two counties are large central metros.

Table 3
Associations between college opening approaches and county-level COVID-19 case increase by statewide public mask requirements.

Independent variable	21 days after classes began		42 days after classes began	
	Mask-required states	Non-mask-required states	Mask-required states	Non-mask-required states
Fixed effects				
County level				
Opening approaches[a]				
In person	.03 (.06)	.20 (.11) †	.04 (.08)	.16 (.12)
Hybrid	−.01 (.07)	−.04 (.12)	.05 (.08)	−.07 (.14)
Covariates				
Private[b]	−.11 (.08)	.10 (.13)	−.04 (.09)	.03 (.11)
Community college[c]	−.11 (.07) †	−.12 (.11)	−.03 (.07)	−.18 (.11)
Enrollment (per 1000)[d]	−.002 (.01)	.01 (.01)	.01 (.01)	−.01 (.01)
Percentage of student population[d]	.59 (.32) †	.99 (.44) *	.62 (.38)	1.03 (.62)
Urban−rural level[e]				
Large metro[f]	.02 (.09)	−.11 (.16)	−.16 (.11)	.03 (.18)
Medium metro	.11 (.10)	−.09 (.17)	−.002 (.11)	−.16 (.20)
Small metro	.14 (.09)	.21 (.14)	.05 (.11)	.08 (.17)
Micropolitan	.12 (.07) †	.07 (.11)	−.08 (.08)	.11 (.13)
Intercept	−.03 (.08)	−.11 (.17)	.07 (.10)	.02 (.20)
R-square (county level)	3.3% (.02) †	15.3% (.05) **	3.3% (.02) *	9.9% (.04) *
Random variance components				
Intercept (τ_{00})	.01 (.01)	.01 (.02)	.004 (.01)	.001 (.03)
σ^2	.27 (.02) ***	.29 (.03) ***	.41 (.03) ***	.37 (.04) ***
Multigroup comparison[g]				
Chi-squared (*df*)	12.55 (10)		12.37 (10)	

Note. Values are unstandardized estimates and standard errors (in parentheses).
†$P < .10$, *$P < .05$, **$P < .01$, ***$P < .001$.
[a] Reference group: online.
[b] Reference group: public.
[c] Reference group: non-community college.
[d] Continuous variable.
[e] Reference group: non-core.
[f] This category includes large central metros and large fringe metros.
[g] Difference test between mask and non-mask-required states.

population. The multilevel models revealed that only small metropolitan counties and counties with a non-community college or a higher percentage of student population showed significantly positive associations with the case number increase within the first 21-day period. For the longer 42 days after Fall 2020 began, we only found the link between the counties with a higher percentage of the student population and the county-level case increase.

Although recent studies indicated in-person opening approach increased the risk of COVID-19 spread within communities for some of the large-size universities,[2,3] our study did not find a significant association between the instruction type and case increase in the 632 diverse US university counties, even controlling for other county-level covariates and state-level public mask requirements. The multigroup comparison results indicated our findings were consistent in both mask and non-mask-required states. As higher education institutions developed campus reopening plans (e.g. COVID-19 testing, mask mandates, social distancing, etc.) based on the CDC and local government guideline,[20,21] it is not a surprise to see there were no significant differences among in-person, hybrid, and online approaches in community transmission. Especially, 82% of the 632 university counties did not show a significant community spread of COVID-19. These findings underscored the reopening efforts and outcomes of US higher education institutions when the vaccines were still under development in Fall 2020.

As expected, given a large number of college students moving back from their hometowns in Fall 2020, the potential virus spread was more likely to happen in small metropolitans and counties with a higher percentage of the student population or a non-community college. Although we found these significant associations, these factors only showed small effects on the county-level COVID-19 case increase. There might be other factors and

different contexts in each county that could potentially boost the case number during the campus opening. We invite the US college-level and county-level decision-makers to interpret their college opening effects and outcomes using our web application (https:// sites.google.com/view/collegereopening). This web application includes all the 1265 US counties with at least one university or college. One can select their state and county, college opening date in Fall 2020, and the days after the semester started to run a BSTS model and test if the actual case number is higher than the counterfactual predictive case number within the selected period.

There are some limitations to our study. First, our study relied on the public use data. Some covariates (e.g. the testing rate in each county before the semester started) that were not publicly accessible might be omitted. Although we could not include all possible covariates in the models, we still did not find a significant linkage between college opening approaches (in-person, hybrid, and online) and community transmissions. Second, our study sample was the 632 US counties with only one higher education institution. The findings might not be able to generalize to the US counties with multiple colleges. Third, this study provides macro trends and insights based on the evidence collected from these 632 counties, but we could not interpret individual county results. Only the county-level and college-level decision-makers with contextual data (e.g. county-level public health policy, local/residential case outbreak, college reopening plan implementation, etc.) could explain their BSTS results. Future studies could investigate the best practice of college openings during the pandemic by qualitatively and quantitatively linking the prevention plan and community transmission.

Despite these limitations, this study makes several methodological and practical contributions to public health, higher education, and crisis response literature. At the methodological level, this study is one of the first to analyze the linkage between college

openings and county-level COVID-19 confirmed cases with a large-scale US county sample. Our findings have greater generalizability than the prior studies with smaller sample sizes.[2,3] More importantly, compared with CDC's DD design,[3] our study using the BSTS models demonstrated methodological advantages in examining the evolution of a causal effect over time.[7] At the practical level, our empirical evidence showed only 18% of 632 US counties experienced a COVID-19 case increase during the first 21 days of Fall 2020. There was also no significant association between the in-person opening approach and the community spread of COVID-19 in both mask and non-mask-required states. These findings highlight the college reopening efforts in Fall 2020, which could potentially reduce the risk of disease spread without any vaccine.

Conclusion

This study found that 82% of US university counties did not experience a significant increase in county-level COVID-19 cases during the first 21 days of Fall 2020. Although the virus was more likely to spread within the small metropolitan counties and the counties with a higher percentage of student population or a non-community college, there were no significant relationships between opening approaches (in-person, online, and hybrid) and community transmission in both mask and non-mask-required states. The findings showed the outcomes of US higher education reopening efforts when the vaccines were still under development in Fall 2020.

Author statements

Acknowledgements

Ethical approval

This study is an analysis of secondary data and therefore does not require ethical approval.

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Competing interests

None declared.

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