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Schools under mandatory testing can mitigate the spread of SARS-CoV-2

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We use event study models based on staggered summer vacations in Germany to estimate the effect of school reopenings after the summer of 2021 on the spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Estimations are based on daily counts of confirmed coronavirus infections across all 401 German counties. A central antipandemic measure in German schools included mandatory rapid testing multiple times per week. Our results are consistent with mandatory testing contributing to the containment of the viral spread. We find a short-term increase in infection rates right after summer breaks, indicating the uncovering of otherwise undetected (asymptomatic) cases through the testing. After a period of about 2 wk after school reopenings, the growth of case numbers is smaller in states that reopened schools compared with the control group of states still in summer break. The results show a similar pattern for older age groups as well, arguably as a result of detected clusters through the school testing. This means that under certain conditions, open schools can play a role in containing the spread of the virus. Our results suggest that closing schools as a means to reduce infections may have unintended consequences by giving up surveillance and should be considered only as a last resort.

COVID-19 | SARS-CoV-2 | school closures | school reopenings | event study

Significance

We provide causal evidence on the impact of opening schools in a situation under virus variants and substantial vaccination rates in the adult population. We show that schools under regular and mandatory rapid testing of the studentship mitigated the growth in case numbers leading to Germany's fourth pandemic wave in autumn 2021. Our results have important implications for the design of future nonpharmaceutical interventions to mitigate the spread of severe acute respiratory syndrome coronavirus 2 and comparable future diseases. Keeping schools open under mandatory testing rules can provide a means to track infection rates. Our results suggest that school closures, given substantial economic and societal costs, should be thought of as the "last resort," even if inevitable at some point.

Long after its global onset in early 2020, the spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) continues to cause large numbers of new infections, hospitalizations, and deaths worldwide. At the same time, the pandemic situation has substantially changed over time due to several major "game changers." About half of the world's population has been vaccinated against the disease; however, vaccination rates are much higher in rich compared with poor countries, and vaccines were not approved for children until very recently. Further, more contagious variants of SARS-CoV-2 (the "Alpha," "Beta," "Gamma," "Delta," and more recently, "Omicron" strains) have appeared, lowering the effectiveness of vaccines (1). Finally, new technologies, especially large-scale rapid testing, provided new measures to help contain the spread of the virus. Taken together, these factors once more bring schools to the center of the public debate; vaccination rates among adolescents and particularly, younger children lag behind those of adults, as population-wide vaccination campaigns among these age groups only started in summer 2021. This leaves children vulnerable to infection and through spillovers, may increase infection rates among their families and populations at large.

Up until now, there was no consensus about the role of schools in transmitting the virus. Association studies relying on before/after comparisons indicate zero to large effects on case rates after school openings. Yet, these studies lack a valid identification of the causal effect of open schools. Studies employing plausible quasiexperimental designs provide a more consistent picture. These show that under strict hygiene rules as well as testing and quarantining regimes, open schools contribute nothing or only little to rising case rates. Yet, it is questionable whether the existing evidence stemming from settings before the spread of new variants and with low or zero vaccination rates among adults extrapolates well to later situations.

Against this background, we provide causal evidence on the impact of opening schools in a situation with the dominant Delta strain and substantial vaccination rates. We do so by using data on official daily case counts by age group across all 401 German counties (Kreise). To identify a causal effect of school openings, we exploit the staggered timing of summer breaks across German federal states, with schools closing in June/July and reopening in August/September 2021 after having been fully closed for about 6 wk.* We implement an event study design, in which we compare changes in newly

*This research design was previously developed and applied on early data in 2020 in a situation without variants and vaccinations (2).

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confirmed cases in reopening states relative to the end of summer breaks. We keep mobility patterns as measured by Google Mobility Reports (3) statistically constant between treatment and control groups. This approach implies that we compare against the counterfactual situation of summer breaks ending but without students returning to in-class teaching (i.e., adopting distance learning arrangements). Since our setting is characterized by the staggered adoption of the treatment, applying a standard dynamic two-way fixed effects (TWFE) model may yield biased estimates. Therefore, we apply event study estimates robust to heterogeneous dynamic treatment effects (4).

Our results are consistent with the hypothesis that the combination of mandatory testing in schools and compulsory school attendance contributed to a containment of cases after the summer breaks. Relative to states still in the summer break, we observe an initial short-term increase in detected cases in states reopening schools, which is most pronounced among school-aged students. This is in line with the detection of (asymptomatic) cases and clusters that remained undetected during the summer breaks. Yet, school openings may lead to new actual infections by new contacts in schools as well. However, after a period of about 2 wk after school reopenings, the growth of case rates is smaller in states that reopened schools compared with the control group of states still in summer break. This pattern is most pronounced among school-aged children but appears to spill over to older age groups too, arguably as a result of detected clusters through the school testing.

Our results have important implications for the design of future nonpharmaceutical interventions to mitigate the spread of SARS-CoV-2 and also, comparable future diseases. School closures were one of the most widely used nonpharmaceutical interventions during the first waves of the pandemic, with more than 1.6 billion students globally being affected at its peak. The extent to which school closures led to learning losses among the affected cohorts is subject to an active debate. Studies document substantial learning losses in the Netherlands concentrated among students from less educated homes (5); others do not find evidence for a major learning slide or widening learning gaps by family background in Denmark (6). A recent review (7) provides an overview of the emerging literature on learning losses during the school closures. They conclude that most evidence points to rather substantial learning losses and widening inequalities. Yet, effects of school closures go beyond direct effects on student achievement. Other studies point to detrimental effects on children's health and mental well-being (8), parental labor market outcomes (9), and domestic violence (10). Across these dimensions, these costs are borne primarily by low–socioeconomic status households, increasing inequality (11). Yet, empirical evidence on the effectiveness of school closures in containing infections is sparse, ambiguous, and based on data before the aforementioned game changers: variants and testing. Our results imply that schools under a set of hygiene rules and mandatory testing remained a safe place. These hygiene rules in our study setting include regular airing or the use of air filters and mandatory mask wearing. Mask mandates were a crucial feature of hygiene concepts in place during the weeks after the summer break but were relaxed or abandoned some weeks later by some federal states. More importantly, the combination of compulsory school attendance and mandatory rapid testing provides an important unbiased surveillance of the scope of the pandemic. This surveillance is crucial for the early detection and quarantining of clusters. The argument of a crucial role of rapid mandatory testing has been made before by complementary simulation studies in refs. 12 and 13.

Taken together, our results, therefore, strongly suggest not to consider school closures as a preferred nonpharmaceutical intervention under the current circumstances. However, our results are based on data covering the pandemic situation in Germany until early October 2021 (i.e., before the now dominant Omicron variant started spreading rapidly across the world and causing record infection rates, especially by largely evading immunity from past infection or vaccination) (14). In addition to increasing the risk of infections among schoolchildren, higher frequency of quarantining of teachers may severely hamper maintaining in-person education. Therefore, we acknowledge that the external validity of our findings may be limited given that we are faced with yet another game changer in the pandemic. New SARS-CoV-2 variants and new infectious diseases may appear in the future. To generalize to those situations, our results show that school closures are not an obvious measure of first choice against the population-wide spread of infections. Instead, keeping schools open under mandatory testing rules can provide a means to keep track of infection rates. Depending on case rates and infectiousness of a virus, keeping schools open under appropriate hygiene rules can even provide a way to reduce case rates, although these measures may have costs of their own in terms of disrupting the learning process. Yet, given the substantial economic and societal costs, comprehensive school closures are better thought of as the "last resort," even if inevitable at some point.

Background

Schools and SARS-CoV-2. School closures have been an effective strategy against earlier pandemics through the mechanical reductions in social contacts (15, 16), yet they come with substantial costs in learning, future wages, and physical and mental health as well as substantial spillovers to parental labor supply and well-being (17). These costs have to be carefully weighed against the positive effects of school closures in mitigating the spread of the virus (18). Whether or not school closures are an effective nonpharmaceutical intervention in the case of SARS-CoV-2 is debated heatedly.

Early evidence tracing specific outbreaks to school environments drew public attention to the role of schools (19). Contact-tracing studies in school environments confirmed that children are not exempt from transmitting the virus (20–22). The first systematic evidence on the impact of school closures was mainly relying on time series data and simple over-time comparisons. A systematic review described a large heterogeneity in results, with half of the studies documenting significantly reduced community transmission, while the remaining studies reported no association (23). A similar heterogeneity is displayed in prospective modeling and simulation studies. Results range from school closures being effective mitigating policies (24) to null results (25, 26). Simulation studies highlight the role of distancing measures (e.g., small group teaching) in containing school outbreaks (27).

A potential caveat of most of the association and simulation studies is that the underlying over-time variation does not allow for a causal identification of the effect of schools. In most cases, underlying empirical approaches boil down to before/after comparisons, with the main shortcoming that other simultaneous factors are not controlled for. Yet, proper quasiexperimental approaches are difficult to come by, with the COVID-19 crisis having a near-universal and worldwide influence on every aspect of life. A number of notable exceptions apply valid identification strategies to estimate the causal effect of school closures and reopenings. Several studies apply panel regressions based on longitudinal variation across United States counties. Studies showed that cases and deaths in counties with in-person or hybrid teaching substantially increased. The effect was found to be stronger for counties without any mask mandate for staff (28). In the US states of Washington and Michigan, school reopenings led to modest positive effects on case rates, primarily when preexisting case rates were high (29). No effects for school reopenings are found when case rates were low (30). Results for higher levels of case rates are inconclusive. For the state of Texas, where schools reopened under hardly any precautionary measures and under high levels of community spread, estimates indicate a strong positive effect on case rates and fatalities in the weeks after the school reopenings (31). In accordance with these very different effect patterns, event study designs for reopenings of schools in the northern United States find no effect but significant and sustained effects in the South, indicating a role of behavioral differences (32).

For countries beyond the United States, Swedish population data allow us to compare students of upper secondary schools in Sweden during the first wave who moved to online instruction with students of lower secondary schools, which remained open (33). Parents of in-school students experienced a small increase in confirmed infections. Stronger effects are found for directly exposed teachers. For Japan, no evidence for higher case rates after school reopenings is found based on a matching approach on the municipality level (34). Two studies apply quasiexperimental approaches for Italy. Comparing early reopening schools in Bolzano with a synthetic control group of comparable Italian provinces shows substantially higher case rates after school reopenings (35). A study of locally delayed reopenings of single schools on georeferenced cases in Sicily identified a modest increase of cases by 2% 2 wk after the school opening (36).

Finally, event study designs based on the staggered summer breaks in Germany during the first summer of the pandemic compare reopening states with states that are still in their summer breaks (2, 37). Results do not show evidence for increased case rates after summer breaks. Instead, slight and insignificant reductions in case rates may be attributable to strict hygiene measures and changes in parental behavior (2).

Taking stock of the quasiexperimental evidence, we conclude that the effect of school reopenings is context specific. Yet, while far from being unambiguous, the overwhelming part of the literature suggests that schools could have been reopened safely in 2020 if conditions, like hygiene rules, distance measures, mask wearing, and testing, were in place. Such strategies have been comprehensively described and discussed by scientists and practitioners alike (38, 39). Yet, several factors have changed since 2020. New and more aggressive variants of the virus have started appearing, starting with the Alpha variant in late 2020. These variants may change the picture. At the same time, other factors have changed as well. As of today, many Western countries have vaccinated substantial parts of their population, including older school-aged children. Scientific evidence on the virus's transmission has led to more targeted mitigation measures, such as the application of air filters and a more widespread adoption of mask wearing in classrooms. Finally, due to limited testing capacity, population-wide case rates were underestimated to a much greater extent in 2020 than they are now. Given these changes, it appears important to reanalyze the effect of school reopenings under the new contextual setting.

Testing, School Hygiene Measures, and Vaccinations. During our observation period, while in general, having autonomy about school policy, German federal states implemented similar and comparable measures against the spread of SARS-CoV-2 in schools. These measures comprised regular testing and quarantining of positive cases and suspects for infection as well as general hygiene measures. While general precautionary measures, like mask wearing inside school buildings, had already been implemented since the comprehensive school reopenings after the summer breaks in 2020 (2), the main innovation in terms of precautionary measures in 2021 was the implementation of comprehensive mandatory mass testing of schoolchildren and teachers. In addition, vaccination had been rolled out to the adult population starting in late December 2020, although vaccines were not yet approved for (younger) children at the time of school reopenings.

From the end of summer breaks in 2021 onward, both students and teachers were tested regularly (two or three times per week) using rapid antigen tests. In the weeks immediately after the reopening of schools after the summer break, testing was more frequent, up to daily depending on the state. Testing was mandatory, and opt out was not an option except for those who had been vaccinated or infected earlier.[†] Individuals with positive test results were isolated and had to undergo a PCR test in order to confirm whether the rapid antigen test was a true positive. In some states, namely North Rhine-Westphalia and later, Bavaria, pooled PCR tests were used to jointly test entire classes and to identify single positive cases only after. States further decided on a common set of quarantine rules. Positive tests led to immediate quarantining of the positively tested student. Peers, class members, or seat neighbors who were suspect of having potentially been infected too went into quarantine, which could be shortened with a negative test after 5 d.

Besides testing, a number of additional measures were kept in place. All states required that classrooms were aired frequently by opening windows or by means of mobile or fixed air filters. Mask wearing remained mandatory in the period immediately after the summer break, with mask regulations becoming heterogeneous between federal states, often tied to incidence numbers. During the observation period, schools remained open in all federal states. Full or partial school closures were planned for case rates reaching predefined thresholds, which did not happen during the observation period.

Population-wide vaccination rates in Germany increased over the observation period to 65% being fully vaccinated (with an additional 3% having received a first dose), which reflects a lower bound due to imperfect registration systems.[‡] Among children, vaccination rates remained markedly lower. The official advice by the German Standing Vaccination Committee to vaccinate those aged 12 to 17 was given on 16 August 2021. By the first week of October, the rate of fully vaccinated among this group was at around 35%. Vaccinations among younger children played no role during the observation period.

Summer Breaks in Germany. In Germany, the timing of the 6-wk-long summer break has varied across states since the 1950s. This varying schedule is supposed to avoid traffic congestion as well as excess demand for holiday accommodation in tourist regions if the entire German population went on holidays at the same time. The staggered timing of summer vacation periods follows long-term scheduling (currently up to 2030) and is decided by the Standing Conference of the Ministers of Education and Cultural Affairs (Kultusministerkonferenz [KMK]) (https://www.kmk.org/service/ferien.html), a consortium of state ministers responsible for education and schooling. Importantly, throughout the SARS-CoV-2 pandemic, the long-term scheduled summer break schedules in 2020 and 2021 remained unaffected by regional differences in case rates. Therefore, we can exploit

[†]Only in Thuringia, mandatory testing was abandoned after a few weeks; testing regimes were coupled to county incidence rates.

[‡]Information is available at https://www.rki.de/DE/Content/InfAZ/N/Neuartiges_Coronavirus/Daten/Impfquoten-Tab.html (last accessed: 11 November 2021).

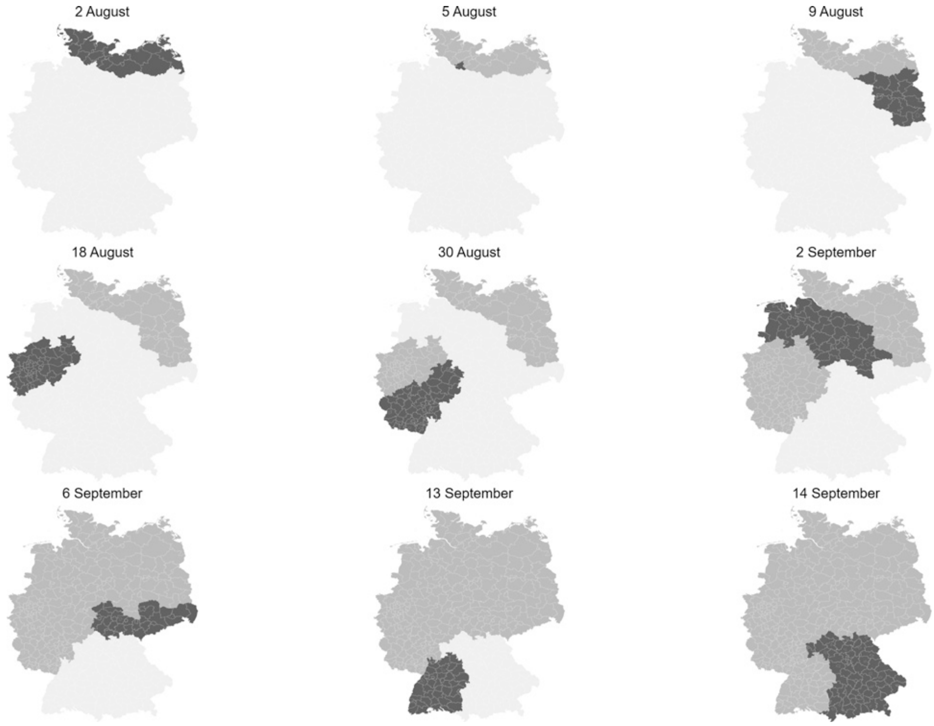

Fig. 1. School opening dates after summer vacation 2021 in Germany. This graph shows a map of German counties and highlights counties in states by the date of school opening after summer vacation 2021. Counties (states) highlighted in dark gray started the new school year on the respective date, while light gray indicates that they were still on summer vacation, and medium gray indicates that they had already reopened schools at an earlier date. School reopening dates are as follows: 2 August: Mecklenburg-Vorpommern and Schleswig-Holstein; 5 August: Hamburg; 9 August: Berlin and Brandenburg; 18 August: North Rhine-Westphalia; 30 August: Hessia, Rhineland-Palatinate, and Saarland; 2 September: Lower Saxony, Bremen, and Saxony-Anhalt; 6 September: Saxony and Thuringia; 13 September: Baden-Wuerttemberg; and 14 September: Bavaria. Information was sourced from KMK (https://www.kmk.org/service/ferien.html).

the exogeneity in the staggered timing of school reopenings after summer vacations across German states for causal identification of their impact on confirmed case rates. Fig. 1 shows the school starting dates after the summer breaks in 2021 across German states ranging from early August to mid-September 2021. Only on 2 d at the end of July 2021 were schools across all German states closed simultaneously due to summer breaks.

Results

We estimate the causal effect of the end of summer breaks and the associated school reopenings on the spread of SARS-CoV-2 by exploiting the staggered summer break schedule across federal states using an event study design. Estimations are based on daily new confirmed SARS-CoV-2 cases by county and age group from 27 July to 4 October 2021. Intuitively, we compare changes in case rates in reopening states with changes in case rates in states that have not yet reopened (*Materials and Methods* has details).

Table 1 summarizes case rates over the period of observation by age group and separately for periods before, during, and after the summer breaks. Two features are apparent that highlight the difference in the situation of 2021 compared with the situation 1 y earlier (2). While in 2020, cases were concentrated in older and vulnerable age groups, now (in all periods) confirmed cases peak in the youngest age group of 5 to 14 y. This reflects the impact of increasing vaccination rates as well as the increased availability of testing, which likely especially affected detection rates among those age groups in which infections often remain asymptomatic. Second, case rates are on average five times higher than in the same period surrounding the end of summer breaks in 2020. The descriptive data also display the strong dynamics over the summer breaks. While average cases per 100,000 are at just 1.0 case/d before the summer breaks, they increase to 9.9 cases/d after the summer breaks. This pattern is similar over all age groups. *SI Appendix*, Table S1 displays average case numbers (by age group) and population counts by state for the last week before the reopening of schools. Fig. 2 depicts this dynamic development

Table 1. Summary statistics—confirmed cases of SARS-CoV-2 (by county and day)

	Full Period		Before Summer break		During Summer break		After Summer break	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age group								
5–14	10.8	20.1	1.6	4.9	7.2	13.8	24.3	27.6
15–34	8.7	12.0	1.9	3.6	9.2	11.7	14.6	14.0
35–59	4.7	6.9	0.9	1.8	4.4	6.4	8.7	8.4
60+	1.6	3.4	0.3	1.1	1.3	3.0	3.2	4.5
All ages	5.3	7.1	1.0	1.5	4.9	6.2	9.9	8.6
Observations	45,600		17,100		22,375		22,375	

This table summarizes means and SDs of daily confirmed cases of SARS-CoV-2 normalized by 100,000 population by county and age group. The full observation period covers 13 June 2021 to 4 October 2021. Information was sourced from the RKI and the Statistical Office. (40, 41)

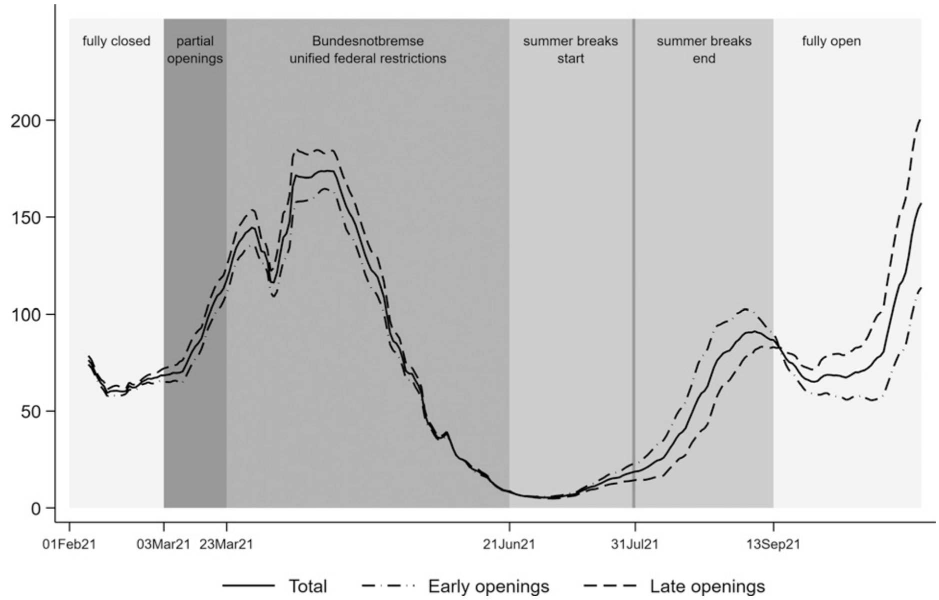

Fig. 2. Time line of the COVID-19 pandemic and school closures and openings in Germany. This graph shows the evolution of the number of new confirmed cases per 7 d of SARS-CoV-2 infections per 100,000 inhabitants for Germany as a whole (solid line) and by states with summer breaks ending up until 18 August 2021 (early reopening states) and states with summer breaks ending thereafter (late reopening states). The shaded areas describe the different phases of school closures and reopenings in Germany. Information was sourced from the RKI, Statistical Office (40, 41) and our own presentation.

over the period around the summer breaks. During the aftermath of the SARS-CoV-2 wave in the spring, schools were only partially open, and case rates decreased strongly. Yet, coinciding with the beginning of summer breaks, they slowly started to rise again, peaking shortly after the first states had reopened their schools and then, falling back again. While several reasons may be brought up for this particular development, we test whether school reopenings with their accompanying regular and mandatory testing have contributed to this pattern.

We proceed with presenting the main estimation results from the event study model (Eq. **1** in *Materials and Methods*). Fig. 3 shows estimated effect patterns separately by age group. The black solid lines connect the point estimates that display the difference between reopening and control states relative to this same difference on the last day of summer breaks ($t = 0$). The figure shows that pretrends are precisely estimated and display insignificant coefficients close to zero. These flat trends rule out concerns about several sources of potential confounders. First, the flat trends speak against any time-variant influences spuriously correlated with the timing of summer breaks and the pandemic course. Second, flat trends speak against early and late openers being at different stages of the pandemic producing spurious effects of school reopenings. This argument is further supported by the descriptive evidence in Fig. 2, which shows

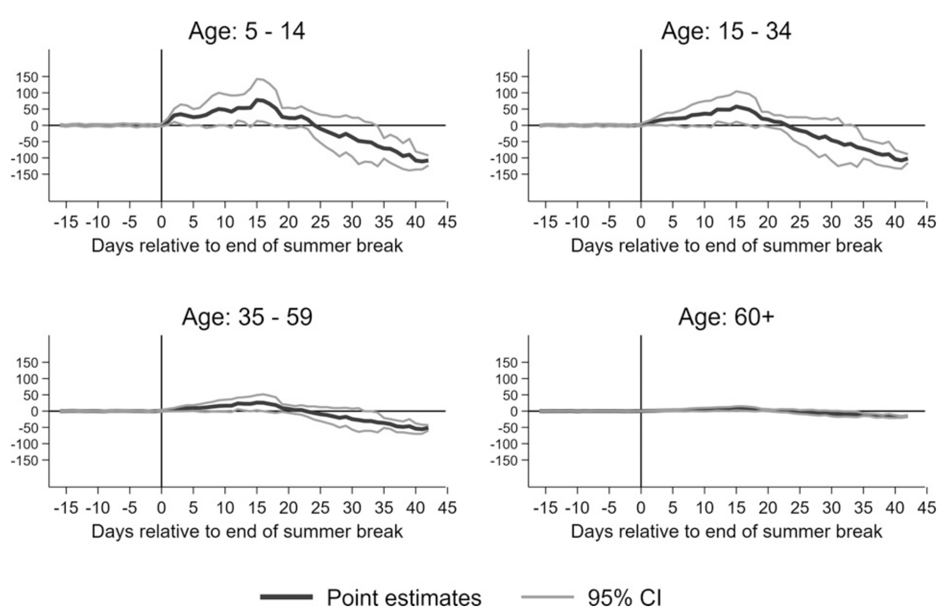

Fig. 3. The effect of the end of summer breaks on confirmed cases by age groups. This graph shows the point estimates ($\hat{\beta_\tau}$, $\tau \in [-15, 42]$) and corresponding 95% CIs of the event study model as defined in Eq. **1** separately estimated for cases by age groups 5 to 14, 15 to 34, 35 to 59, and 60+. The dependent variable is always the daily count of confirmed cases per 100,000 population per county and age group. The vertical lines at $\tau = 0$ indicate the day before school reopening. The regressions include fixed effects on the county and day levels as well as time-varying controls for mobility, cumulative case rates, and local vaccination rates. SEs are clustered at the federal state level. Information was sourced from the RKI, the Statistical Office, and Google Mobility Reports (3, 40, 41).

that early and late opening states display parallel developments that are only set apart by the average distance in summer break schedules. Third, the flat trends speak against a strong role of travel returnees in producing our result patterns, mechanically increasing case rates right before the end of summer breaks, which would result in diverging trends right before $t = 0$. Taken together, the flat trends empirically support that the identification assumption of parallel trends in the absence of school reopenings is plausible.

After schools reopen, we observe a very distinct pattern. Growth in confirmed cases in reopening states increases sharply relative to control states. After 15 d, the initial increase in growth reverses. About 5 wk after school reopening, case rates are even significantly lower than in control states. This qualitative pattern is similar across all age groups, yet it is especially pronounced in the age group of 5 to 14 y and less so in older age groups.

This effect pattern of an initial spike right after school reopenings can only be, to some degree, explained by new infections through additional social contacts in reopening schools. Especially the very early increase in confirmed cases during the first week after reopening is in line with schools under mandatory testing acting as a "screening device" and cannot be attributed to actual new infections, which would take time to manifest. Especially the youngest age group aged 5 to 14 y consists almost entirely of school-aged children. These were rarely tested during summer breaks, but became exposed to regular testing after the end of summer breaks.[§] Yet, we acknowledge that schools may lead to new actual infections by new contacts in schools as well. After 25 d, detection and quarantining of asymptomatic cases among children slowed down the growth in case rates below the growth levels of control states in the age group 5 to 14; this was earlier in older age groups. Additional evidence on deaths related to a SARS-CoV-2 infection suggests an analogous reduction in fatalities in the vulnerable age group 60+ (*SI Appendix*, Fig. S1).

The similar yet less pronounced spikes in older age groups are likely attributable to two different mechanisms. First, the age group 15 to 34 includes older high school students who are subject to the same screening mechanism described above.[¶] In addition, across all age groups, teachers are exposed to the same regular testing as students. Overall, about 1% of the German population works as teachers in primary and secondary schools.

Second, effects of early testing and quarantining are likely to have spillovers outside of schools as well. Positively tested students can uncover previously undetected clusters and trigger additional tests as well as cautious behavior among household members, relatives, and neighbors. This fits with the slowdown in case rate growth in older age groups.

Taken together, the particular pattern of sharply rising case rates immediately after school reopenings is in line with schools under mandatory testing being an important measure to screen the population. While participation in indoor activities was largely restricted to vaccinated, formerly infected, or tested persons, the demand for rapid testing was declining rapidly over the summer of 2021 as more and more people got vaccinated.

In this situation, the transition from the summer break setting to an environment with comprehensive and compulsory testing apparently led to the sudden and sustaining detection of asymptomatic infections among school-aged children that would otherwise have remained undetected. Detected cases as well as direct contacts (defined either as seat neighbors or as whole classes) were sent into quarantine. Beside testing and quarantining, strict hygiene rules of mask wearing and venting were in place. As a result, reopening states experienced a relative decrease in the growth of case rates compared with control states. A counterfactual situation in which schools would have remained closed after summer breaks would have arguably led to a faster increase in case rates in early autumn.

Robustness. We conducted four additional analyses. First, *SI Appendix*, Fig. S2 shows results when SEs are clustered at the county instead of the state level. Estimates become much more precise in this specification, so that the pattern of results becomes more pronounced. Second, we run our main analyses without controlling for vaccination rates to alleviate potential concerns that these might be endogenous to changes in case rates. *SI Appendix*, Fig. S3 shows that leaving out this covariate does not qualitatively change the result patterns. Third, we omit the controls for daily mobility patterns. In the main specification, we controlled for relative stay durations in groceries, parks, home, retail and recreation, transit stations, and workplaces. Including these covariates in our main specification implied that our estimates should be interpreted as a comparison against a situation in which schools had not opened but all other mobility (relative stay durations in groceries, parks, home, retail and recreation, transit stations, and workplaces) would have been unaffected. *SI Appendix*, Fig. S4 shows that results remain robust once we no longer control for mobility patterns. Finally, we conduct similar analyses as our main ones but this time, focus on the start rather than the end of the summer holidays. Before the summer holidays, antipandemic measures in schools were similar to those after the holidays. Mandatory testing was in place and was mostly done twice weekly. Over this observation period, however, case rates were much lower than afterward. *SI Appendix*, Fig. S5 shows that the increase in case rates over the summer period tracked school holidays across the various federal states. Compared with states were schools were still open, incidences started increasing some days after school holidays began. This first happened among the school-aged groups and was somewhat later followed by increases among older age groups. This is not due to altered mobility patterns relating to the start of the holiday season, as we again control for the set of mobility measures. Instead, the explanation for the pattern of results again fits with the story line behind the earlier results. When the combination of mandatory testing and compulsory schooling fell away during the summer holiday, this led to a decrease in detection capability among children. If undetected, infected children are more likely to subsequently infect others.

Discussion

We study the effect of school openings and closures on SARS-CoV-2 case rates in German counties using the staggered timing of summer holidays across federal states. Applying an event study model and controlling for changes in mobility patterns coinciding with the end of summer holidays, we provide causal evidence of the isolated role of reopening schools in transmitting the virus.

After summer breaks, schools reopened under strict hygiene measures and implemented a mandatory rapid testing and quarantining system. Our results confirm the success of this policy. Our estimations suggest that testing and quarantining in schools

[§]Mandatory schooling in Germany starts in the year a child turns 6. The last year of kindergarten/preschool is free of charge and almost universally attended.

[¶]Unfortunately, age bins are provided by the Robert Koch Institut (RKI) and do not allow for a sharp distinction between students and older population groups.

substantially contributed to uncovering asymptomatic cases that would have otherwise remained unobserved. The testing led to a pronounced spike in observed cases during the first week after reopening. Observed cases decreased gradually during the following weeks, being statistically indistinguishable after 2 wk and decreasing further after that. We further observe in prime-aged age groups, comprising older students, teachers, and parents, that case rates steadily decrease below the counterfactual levels that would have prevailed if schools were kept closed. This suggests that early detection of infections by testing school-aged children reduces infections among their parents as well. Case rates among the most vulnerable age group of ages 60+ were affected less strongly in an absolute sense.

Our results are in line with simulation-based evidence, highlighting the important role of population-wide rapid testing (12, 13). Only the combination of compulsory schooling and mandatory testing allows for an unfiltered and unbiased look into the state of the pandemic (12). Our results suggest that increased infections through in-school contacts are more than offset by this surveillance effect of mandatory testing, spilling over into lower case rates in older age groups.

The results from this study stem from a time period when infection rates were moderately low and during which the Delta strain of the SARS-CoV-2 was dominant. This variant was more infectious than the wild type of the virus that was dominant during the observation period of most previous studies on the effects of school openings and closures. However, it was less infectious than the currently dominant Omicron variant. Measures against present and future variants of SARS-CoV-2 and other viruses should be tailored to infectiousness, virulence, and current infection rates. Our results suggest that school closures are not an obvious first choice as a measure to contain infection rates. Depending on the current viral situation and combined with appropriate in-school measures, such as ventilation and mask wearing, keeping schools open under mandatory testing regimes may help reduce infection rates.

At the same time, keeping schools open can have a secondary benefit. True infection rates are known to have been considerably underestimated during the early stages of the current pandemic but also, during later stages. Tracking infection rates across all social strata is generally hard to attain yet is highly important to develop appropriate policy responses. Mandatory testing combined with compulsory schooling may provide one feasible way to attain such an indispensable unbiased surveillance.

Yet, while the precautionary measures allow schools to being kept open during the pandemic, it is noteworthy that they do not come without costs of their own. The strict testing and quarantining regime that was applied in German schools might have induced substantial disruptions for students and teachers. Regular switching between in-person, distance, and hybrid modes of teaching in response to quarantined students may have adversely impacted student learning but also, parental labor supply and well-being. To the best of our knowledge, no evidence on the learning costs of quarantine rules and further nonpharmaceutical interventions in schools exists up to today. These costs have to be considered, too, when evaluating the cost–benefit effectiveness of the applied measures.

We conclude that the benefits of closing schools during pandemics are not obvious. Although there are certainly situations in which the closure of schools is sensible, such a decision should not be taken without sound deliberation. This is especially true considering the drastic immediate and short-term costs for children and their parents associated with school closures.

Materials and Methods

Data. Estimations are based on daily new confirmed SARS-CoV-2 cases by age group (5 to 14, 15 to 34, 35 to 59, 60+) by all 401 German counties recorded on the date the local public health authorities became aware of a case. Case numbers are normalized by 100,000 population by county and age group. Data on the observation window from 27 July to 4 October were collected from the publicly available database of the RKI (40).

To account for changes in individual mobility that might contribute to changes in infection patterns, we keep mobility constant by controlling for state-level mobility information from the Google Mobility Reports (3). The data contain relative stay durations in groceries, parks, home, retail and recreation, transit stations, and workplaces.

Empirical Strategy. We apply an event study approach that intuitively compares changes in case rates in reopening states with changes in case rates in states that will only reopen in the future. To interpret this difference as the causal effect of school reopenings, we assume that case rates in reopening states would have changed similarly to those in the control states in the unobservable counterfactual situation of schools not being reopened after summer breaks. While we cannot directly test this assumption, insignificant differences between groups of states indicate a parallel development of case rates before school reopenings, which strongly supports the causal interpretation of our estimates.

This estimation strategy follows in spirit earlier work (2), but it incorporates recent advances in TWFE methodology (3, 42–44), which appear to be especially relevant in the present application. Simple TWFE models may be inappropriate in a setting such as ours characterized by a staggered treatment assignment across regions. Posttreatment coefficients rely in part on comparisons of just-treated units (changers) with already-treated units. This kind of comparison may lead to biased conclusions in the case that treatment effects are time varying (i.e., increasing or decreasing with time from treatment) (4, 43, 44). The bias can be avoided if an estimator is chosen that carefully avoids invalid control groups. Specifically, we apply the estimator described in ref. 4 as an extension of the estimator described in ref. 42 applicable to staggered settings (Stata command did_multiplegt is provided in ref. 45). Intuitively, in our setting, this estimator compares observed changes in case rates between states that end their summer breaks with case rates of not yet reopening states, while all states started the observation window within their respective summer breaks. Thus, the estimator avoids "forbidden comparisons" of reopening states with states that already reopened in the past.

Keeping the particularities of the above-mentioned methodology in mind, we express our empirical model in the form of a standard event study:

$$\mathrm{CoV}_{it} = \sum_{\tau=-15,\tau\neq 0}^{42} \beta_\tau \mathit{SchoolsOpen}_{s(i),t-\tau} + \alpha_i + \mu_t + X_{it}'\gamma + \varepsilon_{it}. \quad \textbf{[1]}$$

The outcome CoV_{it} describes new confirmed SARS-CoV-2 infections by county i and date t normalized per 100,000 population. The model is estimated separately by age group. The indicator $SchoolsOpen_{s(i),t-\tau}$ describes the binary treatment for day t relative to the end of summer breaks in county i in state s with lag τ. We consider an effect window of 2 wk before and 6 wk after the summer breaks. We do not prolong the effect window further to avoid confounding by the then starting autumn holidays. All observations before and after the respective state-specific event window are aggregated into bins at the end points (46). We consider $\tau = 0$, the last day before the end of summer breaks, as our comparison period. County-specific time-invariant confounders, such as population structure, are captured by county fixed effects α_i. Time-variant confounders, such as the global state of the pandemic and federal restrictions, are captured by date fixed effects μ_t. Time-varying variables X_{it} include mobility patterns by Google Mobility Reports (3), the county's vaccination rate 14 d ago, and cumulative case rates over the past 14 d. Keeping mobility patterns statistically constant between treatment and control group implies that we compare against the counterfactual situation of summer breaks ending but without including students returning to in-class teaching (i.e., adopting distance learning arrangements). *SI Appendix*, Fig. S4 shows that our main results are robust to not controlling for mobility patterns. SEs in all estimations are clustered at the federal state level.

Data Availability. Publicly available data on case numbers and deaths (41) and Google Mobility Reports have been deposited in Harvard Dataverse (https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/TRIHJJ) (47).

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