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ABSTRACT

Since the spring of 2021, nearly 700 colleges and universities in the U.S. have mandated that their students become vaccinated against the COVID-19 virus. We leverage rich data on colleges' vaccination policies and semester start dates, along with a variety of county-level public health outcomes, to provide the first estimates of the effects of these mandates on the communities surrounding four-year, residential colleges. In event study specifications, we find that, over the first 13 weeks of the fall 2021 semester, college vaccine mandates reduced new COVID-19 cases by 339 per 100,000 county residents and new deaths by 5.4 per 100,000 residents, with an estimated value of lives saved between $9.7 million and $27.4 million per 100,000 residents. These figures suggest that the mandates reduced total US COVID-19 deaths in autumn 2021 by approximately 5%.

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1 Introduction

Mandates requiring vaccination for COVID-19 are among the most controversial but widespread policies that have been implemented to control the spread of the SARS-Cov2 (COVID-19) virus. The motivation for these mandates is that COVID-19 is a highly-communicable and deadly disease, which creates sizable externalities associated with individual infections. These externalities increase the risk of infecting others, potentially leading to increases in hospitalizations and deaths. Clinical trials have demonstrated that vaccines approved by the U.S. Food and Drug Administration (FDA) help protect people from being infected with the SARS-Cov2 virus, and, conditional on being infected, they reduce the likelihood of hospitalization and death (Baden et al. 2021; Falsey et al. 2021; Polack et al. 2020). Widespread vaccination thus can reduce the public health costs associated with the COVID-19 pandemic, but opponents of these mandates raise concerns about forced medical interventions and curtailments of individual freedom. Understanding how vaccine mandates impact community-wide COVID-19 infection rates, hospitalizations, and deaths is a critical aspect of this debate, providing direct information on the benefits of these policies that one can weigh against the associated costs. We provide the first evidence in the literature on this question, focusing on the context of colleges and universities.

Our study examines the effect of college- and university-imposed COVID-19 vaccine mandates for students on county-level COVID-19 infections, hospitalizations, deaths, and other health outcomes. We focus on college mandates for several reasons. First, other decisions made by higher education institutions during the COVID-19 pandemic have had large effects on both their students and their local communities. For example, colleges that brought students back to campuses following spring break in March 2020 saw increased levels of COVID-19 spread in their counties (Mangrum and Niekamp 2020), and those that opened in-person during the fall 2020 semester contributed to increased case rates and hospitalizations (Andersen et al. 2021). Students interact with those in the local community, so college vaccine mandates on the student population may affect those living near colleges and universities.

Because of their age, college students themselves have a considerably lower risk for severe outcomes, conditional on COVID-19 infection, than the surrounding population (Levin et al. 2020). This is despite the fact that they tend to live in congregate settings that are ripe for the spread of contagious diseases. Thus, one of the primary arguments for college vaccine mandates comes from externalities imposed by infection among students spreading to other members of the community, rather than benefits to the students themselves.[1] Furthermore, college-aged individuals have consistently had lower take-up of the COVID-19 vaccine —as of August 15, 2021, only 47% of US residents aged 18-24 were fully vaccinated, compared to 61% of 40-49 year olds and 84% of 65-79 year olds —leaving substantial room for these mandates to impact vaccination rates.[2] The college context therefore offers a powerful lens through which to understand how vaccine mandates, and the act of vaccination itself, can affect health externalities from infectious disease.

Second, extensive variation across colleges in their vaccine mandate policies provides a source of identification. As the fall 2021 semester approached and vaccines became more widely available, 668 two-year and four-year institutions mandated that students, and sometimes faculty and staff, be vaccinated against SARS-Cov2 (Botelho et al. 2021). In some cases, these mandates were driven by institutional decisions, and in others, they were state-level decisions. As a result, there is variation among observationally-similar people who live near postsecondary institutions in terms of whether the college students in their community had to be vaccinated.

We study the effects of college vaccine mandates on local public health outcomes by leveraging several rich sources of data. We obtain information on vaccine mandates for the fall 2021 semester, along with institutions' semester start dates, mask mandates, and required COVID-19 testing policies from the College Crisis Initiative (C2i) at Davidson College (Botelho et al. 2021; Berick et al. 2021). C2i's staff collected vaccine mandate information through a combination of data-scraping and directly visiting colleges' websites between July 21, 2021 and August 5, 2021 —just prior to the start of colleges' fall semesters —with follow-up collection in late October and early November. These data are then merged with publicly available information from the Centers for Disease Control and Prevention (CDC) on county-level COVID-19 case rates, vaccinations,

[1] Carlin et al. 2022 find that even private returns to the COVID-19 vaccine were undervalued in the US population, including among 18-39 year-olds. While externalities are one argument for vaccine mandates, it also is possible to justify such mandates in a behavioral model with undervalued private returns.

[2] https://covid.cdc.gov/covid-data-tracker/#vaccination-demographics-trends.

hospitalizations, and deaths. We also acquire data on county test positivity rates from CovidActNow.org, data on doctors' visits from insurance claims, and data on individual vaccination status from the Census Bureau's Household Pulse Survey. [3]

We estimate event study specifications that examine how these outcomes evolve before and after students return to campus by whether counties contained colleges that had a vaccination mandate. The identification assumption underlying our approach is that areas without college vaccine mandates provide an accurate counterfactual for what COVID-19 outcomes would have been absent the college mandates. Of primary concern is that counties with colleges that decided to implement vaccine mandates have other protective policies in place or have populations that were otherwise more likely to be vaccinated or that more stringently followed public health advice. There are strong geographic and political components to vaccination rates, public health measures, and compliance with these measures (Murthy et al. 2021; Yuan et al. 2021; Gollwitzer et al. 2020; Ye 2021; Clinton et al. 2021; Adolph et al. 2021; Fraser, Juliano, and Nichols 2021). Hence, we include not only county and calendar week fixed effects in our models but also region-by-week fixed effects, interactions between week fixed effects and the Democratic vote share in the 2016 presidential election, and interactions between week fixed effects and the baseline county vaccination rate (measured during the last week of June 2021, before any college in our data began fall classes). Furthermore, we present evidence that our results are (1) robust to controlling for differences in colleges' masking and testing policies, and (2) unlikely to be confounded by other policy or behavioral changes that alter community-level vaccination rates or mobility, as neither of these outcomes differentially change in counties with vaccine mandates after college semesters begin.

Our results show consistent evidence that college vaccine mandates reduced COVID-19 cases and deaths in the surrounding population. In order to summarize our results, we sum estimates over 13 weeks, beginning with the week prior to semester start when students are likely to return to college campuses and ending about two-thirds of the way through the fall term, prior to the Thanksgiving holiday. In our preferred specifications, a college vaccine mandate imposed by a res-

[3] All data on outcomes are publicly available. College vaccine mandate data can be requested from C2i.

idential, four-year college reduces total new cases in a county by 339 per 100,000 (approximately 10% of the baseline mean) over these 13 weeks. This estimate is significantly different from zero at the 5% level and is largest in areas where we would expect mandates to have the largest effects on local public health: counties where colleges have low predicted vaccination rates based on their demographic composition and where colleges are large relative to the county population.

Hospital-based measures, such as the number of ICU patients and hospitalizations, contain error because they are based on hospital locations rather than patients' counties of residence. Our findings for these measures are generally statistically indistinguishable from zero, though ICU estimates are consistently negative. Deaths are measured by county of residence and likely contain less noise. We document that vaccine mandates led to 5.4 fewer deaths per 100,000 in the county, an estimate that is also significant at the 5% level. Again, this effect is larger in counties where we would expect college vaccine mandates to have the largest effect on student vaccination rates, and therefore, on local public health.

Taken together, these results suggest that college COVID-19 vaccine mandates had meaningful and statistically significant effects on infections and health outcomes. We calculate that four-year college vaccine mandates during the 13 weeks we consider avoided approximately 7,300 deaths, which is about 5% of total deaths from COVID-19 during this period. The value gained from saved life-years is substantial. Estimates for the average years of life lost when a person dies from COVID-19 range from 9 to 14.5 (Elledge 2020; Quast et al. 2021; Goldstein and Lee 2020; Arolas et al. 2020). Aldy and Viscusi (2008) estimate a value of a statistical life-year (VSLY) at age 62 of $350,000. Given that in 2021, 69% of COVID-19 deaths were for people over age 65,[4] we approximate that the value of lives saved from college COVID-19 vaccine mandates is between $17 million and $27.4 million per 100k residents in a county —or $19.8 to $31.8 million total for the average-sized county in our sample.[5] This is likely an upper bound estimate given the life-year value is for someone aged 62. If we instead assume a lower VSLY of $200,000, we estimate that the value of lives saved from college COVID-19 vaccine mandates is between $9.7 million and

[4] `https://www.cdc.gov/nchs/covid19/mortality-overview.htm`

[5] These calculations are based on our estimates in Table 2 of 5.4 deaths per 100k people prevented over 13 weeks following semester start multiplied by $350k $\times$ a lower bound of 9 years of life saved and an upper bound of 14.5 years of life saved. We scale the estimates by the average population of counties in our sample, which is 116,191.

$15.7 million per 100,000 residents in a county, or $11.3 to $18.2 million for the average county.

Our paper contributes to multiple strands of the literature. First and foremost, while there are estimates of how vaccine mandates have affected health outcomes for other diseases (Carpenter and Lawler 2019; Lawler 2017), to our knowledge we are the first to estimate the causal effect of COVID-19 vaccine mandates on public health. Given the enormous cost of the ongoing COVID-19 pandemic and the contentious nature of vaccine mandates, this is an important contribution.

We also contribute to a growing body of work that examines the interaction between postsecondary education and COVID-19.[6] Mangrum and Niekamp (2020) show that institutions that had earlier spring breaks at the onset of the pandemic experienced higher growth rates of cases due to more infections from spring break travel. Andersen et al. (2021) show that college re-openings led to higher student mobility and increased infection rates.[7] Our paper extends these analyses to identify the mitigating effects of vaccine mandates when students returned to campus.

Finally, our work contributes to the literature examining vaccine mandates more broadly. Vaccine mandates, especially in schools and colleges, are not new: students across the US are required to be vaccinated against a variety of illnesses, such as smallpox, measles, and polio.[8] Carpenter and Lawler (2019) show that the introduction of the Tdap mandate in middle schools had a large effect on vaccine take-up and significantly reduced the incidence of pertussis. The mandate also induced positive spillovers to the take-up of other vaccines. Lawler (2017) presents evidence that school mandates for the hepatitis A vaccine increased take-up and reduced population incidence of the disease. Abrevaya and Mulligan (2011) show positive effects of chickenpox vaccine mandates on take-up, however the take-up effects dissipate over time. Additionally, Holtkamp et al. (2021) uses the staggered rollout of smallpox vaccine mandates in the late 19th and early 20th centuries in the US and finds that the mandates increased vaccine take-up and had large long-run effects on affected students.

We contribute to this research along two dimensions. First, we provide novel evidence on the ef-

[6] An expanding literature also examines the effect of the COVID-19 pandemic on K-12 schooling, showing that it changed the demand for different types of schooling environments (Chatterji and Li 2021; Musaddiq et al. 2021; Bacher-Hicks, Goodman, and Mulhern 2021), reduced academic achievement (Azevedo et al. 2021; Bailey et al. 2021; Kilbride et al. 2021), and reduced bullying (Bacher-Hicks et al. 2022). See Hinrichs (2021) for a review of the literature on COVID-19 and schooling.

[7] In the K-12 sector there is evidence that under certain conditions, in-person schooling led to more COVID-19 spread relative to remote schooling (Courtemanche et al. 2021; Ertem et al. 2021; Goldhaber et al. 2020; Harris, Ziedan, and Hassig 2021).

[8] See Hodge Jr and Gostin (2001) for a history of school-based vaccine mandates.

fect of vaccine mandates for COVID-19, which presents unique challenges due to the politicization of support for vaccination. Second, our analysis is rather unique in the literature in showing the effects of vaccine mandates on infections and health outcomes of the broader population not affected by the mandate. With a highly-infectious disease such as COVID-19, estimating the spillover and population health effects of vaccine mandates are of primary importance.

Our results indicate that college vaccine mandates for COVID-19 have sizable positive effects on the health of the population living near colleges and universities. These benefits must be balanced against curtailments of individual freedoms associated with these mandates as well as any adverse effects of the vaccines themselves. Our results show that these costs must be substantial in order to overcome the large public health benefits of COVID-19 college vaccine mandates.

2 Data

2.1 Data Sources

We obtain information on college-level vaccine mandates (Botelho et al. 2021), semester start dates (Berick et al. 2021), and masking (Bernhardt et al. 2022b) and testing (Bernhardt et al. 2022a) policies as of the start of the fall 2021 semester from C2i. The vaccine mandate data were first collected between July 21, 2021 and August 5, 2021, with follow-up collection between November 5, 2021 and November 24, 2021. We define an institution as having a vaccine mandate if they announced a mandate prior to the start of their fall 2021 semester.[9] We merge these data with institutional characteristics, such as location, enrollment, and public/private control, from the National Center for Education Statistics' Integrated Postsecondary Education Data System (IPEDS).

We further combine these college-level data with county-level COVID-19 cases, emergency room visits, hospitalizations, deaths, and vaccination counts by county and week from the Center for Disease Control and Prevention (CDC).[10] In addition, we collect county-week-level data on

[9]If an institution announced a vaccine mandate between the summer and fall data collection periods, we hand-collected information on the announcement date from their website to determine the timing of the announcement relative to the start of the fall 2021 semester.

[10]These data are publicly available at `https://data.cdc.gov`.

test positivity rates from CovidActNow.org. Together, these data sources provide rich weekly information on public health outcomes at the local level throughout the summer and fall of 2021.

While we have access to extensive information on county-level health outcomes, we do not observe vaccination or COVID-related outcomes specifically for the student body on each college campus. Due to this data limitation, we cannot directly measure the "first-stage" effect—the effect of college vaccine mandates on the number of vaccinated students relative to the county population. Instead, we use a more indirect approach to demonstrate that our results are driven by the first-stage effect of the mandates: we show that the reduced-form effect of mandates on local health outcomes is larger for counties in which we expect mandates to have a larger first-stage effect, i.e., where we would expect the college student population to have a lower vaccination rate. The details of this exercise are described in Section 3.2. To determine which colleges have the largest expected first-stage effect, we use the Census Bureau's Household Pulse Survey, which collects vaccination attitudes and outcomes along with demographic characteristics at the individual level. We combine this information with demographic information on colleges' student bodies from both IPEDS and Opportunity Insights.

2.2 Analysis Sample

Our analysis sample includes all U.S. counties with at least one four-year college that offers on-campus residential facilities in states where at least one four-year residential college mandated COVID-19 vaccinations for the fall 2021 semester.[11] We further restrict the sample to counties where the first fall 2021 semester start date fell between August 7^{th} and September 9^{th}.[12] In addition, we omit counties in Colorado and Hawaii due to a lack of accurate, county-level COVID-19 vaccination data. We then distinguish between "mandate" and "non-mandate" college counties by whether any four-year college in the county had a COVID-19 vaccination mandate for students.[13] To ensure clean comparisons between these mandate and non-mandate counties, we drop 38 coun-

[11] No colleges in Alaska, Alabama, Arkansas, Florida, Kansas, Mississippi, Montana, North Dakota, New Mexico, Nevada, Oklahoma, South Dakota, Utah, or Wyoming mandated vaccinations prior to the fall 2021 semester.

[12] Only 24 out of 763 counties (3.1%) with four-year residential colleges have start dates outside of this window.

[13] Although it is possible that different colleges in the same county can make different mandate decisions, 84% of colleges in mandate counties have a mandate, and these mandates cover 85% of students in these counties. Appendix Figure A.2 shows the counties in our sample by the percent of students covered by a mandate. We also estimate specifications that omit counties where some colleges mandated vaccination and others in the same county did not and find similar results.

ties that do not have any college mandates, but in which colleges offered incentives for students to get vaccinated. Appendix Figure A.1 shows the counties in our data by mandate status, and Appendix Figure A.3 shows students with a vaccine mandate as a share of the county population.

Table 1 summarizes the 269 counties with a mandate and the 284 counties without a mandate in our sample. The table shows large and statistically significant differences in the demographic, geographic, and college-level characteristics between the mandate and non-mandate counties. Mandate counties, on average, are more populous, more urban, have a larger non-white population, have higher average incomes, and have higher educational attainment than do non-mandate counties. The baseline vaccination rate, defined as the vaccination rate in the last week of June 2021, also is higher in mandate counties, which are more likely than non-mandate counties to be located in the Northeast, Mid-Atlantic, and West. Moreover, counties with mandates tend to lean more liberal than non-mandate counties. On average, mandate counties are home to 2.5 four-year colleges, while non-mandate counties are home to 1.2 colleges. This difference corresponds to more college students in mandate counties (18,067) than in non-mandate counties (7,650). Mandate counties are also much more likely than non-mandate counties to have at least one college that required regular COVID-19 testing or required masking indoors for at least some students at the start of the fall 2021 semester. Among mandate counties, 20.8% have a college that requires testing of some students, and 94.8% have a college that requires masks indoors for some students. For non-mandate counties, these numbers are 3.9% and 69%, respectively.

Given these differences in county and college characteristics, our empirical approach compares within-county *changes* in COVID-19 outcomes between mandate and non-mandate counties, before and after the fall 2021 semester begins. In the section that follows, we discuss how the time-invariant demographic and geographic differences in mandate and non-mandate counties may affect trends in health outcomes over time and the steps we take to account for these correlations.

3 Empirical Strategy and Identification

Our goal is to estimate the causal effect of college COVID-19 vaccine mandates on COVID-related health outcomes in college counties. The reduced-form effect of a vaccine mandate on local outcomes derives from a two-stage process: first, the mandate affects student vaccinations, then student vaccinations reduce the local spread of COVID-19 as students mix with county residents after semesters begin. We focus on the reduced-form effect of a mandate policy, but also demonstrate that our estimated reduced-form effects are consistent with this two-stage mechanism.

3.1 Empirical Framework

Our main approach is to estimate event study models to identify the effect of a college vaccine mandate. We provide a general discussion of this framework and the associated identification concerns before moving to the specifics of our first-stage and reduced-form analyses. We limit the sample to counties with four-year, residential colleges, for which we observe outcomes for at least eleven weeks before and eleven weeks after the first college begins its fall semester.[14] Then, we use an event study approach in which we compare changes in outcomes for counties with colleges when colleges reopen by whether they had a vaccine mandate. Note that the "event" in these specifications is the college reopening, and all colleges experience this event. Fall 2021 coincided with the spread of the Delta variant, leading to high case rates from students moving back to campus at most colleges and universities. Our model examines how the effect of opening differs by whether a college in the county has a vaccine mandate.

Our event study specifications take the following form:

$$Y_{ct} = \sum_{\substack{k=-11 \\ k\neq -2}}^{11} \beta_k * 1\left[t - t_c^* = k\right] + \sum_{\substack{k=-11 \\ k\neq -2}}^{11} \gamma_k * 1\left[t - t_c^* = k\right] * Mandate_c + \theta_c + \delta_t + \varepsilon_{ct}, \tag{1}$$

where Y_{ct} is the outcome of interest in county c during week t, and t_c^* is the earliest week that a four-year, residential college in county c begins its fall semester. $Mandate_c$ is a dummy variable

[14] For the earliest college reopening counties in our sample, we observe outcomes beginning the week of May 21st. For the latest reopening counties, we observe outcomes through the week of November 19th. Thus, restricting the sample period to eleven weeks before and after college reopenings limits the likelihood that our results are affected by (1) the end of the spring 2021 semester or (2) student travel and changes in instructional mode following Thanksgiving in the fall 2021 semester.

equal to one if any four-year college in county c required vaccination as of the start of the fall semester.[15] We include both county fixed effects (θ_c), which capture time invariant differences between counties with and without college mandates, and week fixed effects (δ_t), which account for secular changes in COVID-19 health outcomes in college counties over time. Throughout the analysis, we cluster all standard errors at the county level.

The β_k coefficients trace how COVID-19 outcomes were changing in the eleven weeks before and after the start of colleges' fall semesters across all counties with four-year colleges. The γ_k coefficients then capture how these outcomes evolve differently in counties where colleges implemented vaccine mandates. For both sets of coefficients, we omit the period $k = -2$, i.e., two weeks before semesters begin. We anticipate that students may arrive on-campus prior to a college's official semester start date, which could generate treatment effects as early as period $k = -1$.

As with any difference-in-difference estimator, we invoke the identification assumption that counties without a college mandate are an accurate counterfactual for counties with a college mandate. This assumption can be broken down into two parts. The first is that counties with and without a mandate were on the same trend prior to college openings. The β_k coefficients for $k \leq 2$ provide a test of this assumption, showing pre-opening trends by mandate status. We expect these coefficients to be zero: the mandates should have no effect until students return to begin the semester.

The second part of the identification assumption is that there are no changes in unobserved determinants of our outcome measures that occur concurrently with college re-openings and that differentially affect mandate versus non-mandate counties. Violations of this assumption most likely come from three separate sources:

1. <u>Correlated COVID Shocks:</u> Mandate and non-mandate counties could be hit by COVID waves at systematically different times, possibly because they are not uniformly distributed across the country—non-mandate counties tend to be more concentrated in the South, Southwest, and the Midwest (see Table 1).

[15] We also estimates a version of this model in which we use the share of students in a county that are covered by a mandate, instead of the dummy variable for any mandate in the county.

2. College Selection of Mandate Policies: Colleges decide whether to impose vaccine mandates or not, and these decisions could potentially be driven by factors such as local COVID spread, the political environment on campus or in the community, or even the likelihood that students would be vaccinated without a mandate.[16]

3. Other Policies: Other local or college-level policies and social norms, such as masking and social distancing policies and compliance, could be correlated with mandates and have independent effects on the outcomes we examine. This pattern could result from the college selection discussed above or it could be generated through other mechanisms.

To address the identification concerns related to regional variation in COVID spread, we include region-by-week fixed effects, separating the country into eight regions defined by the Bureau of Labor Statistics (BLS). It still is possible that there is within-region variation in the timing of COVID waves that is systematically correlated with mandate status. We view this as unlikely given strong evidence of parallel trends in COVID outcomes across mandate and non-mandate counties prior to semester start, after accounting for region fixed effects and other controls. We discuss this evidence below.

To the extent that colleges are responding to student or community factors when making vaccine mandate decisions, underlying variation in baseline attitudes and behaviors among the student or community population may drive both mandate decisions and COVID outcomes. A few specific examples of this type of concern include: 1) a college could impose a mandate only if students are already favorable towards vaccination, or 2) colleges may impose mandates based on community concerns, which may be correlated with other local policies. To address these concerns in the regression analysis, we include weekly fixed effects interacted with the county's Democratic vote share in the 2016 presidential election. Because of the politicized nature of the response to the pandemic, the democratic vote share is strongly correlated with community behaviors and policies. It also is correlated with student behaviors to the extent that students sort into colleges with communities that match their political beliefs. In addition, we control for baseline vaccination

[16] Acton, Cook, and Luedtke (2022) and Collier et al. (2021) analyze factors that contribute to college instruction mode decisions in fall 2021, demonstrating that these decisions depend upon political preferences, local COVID severity, and peer institution decisions. Grossmann et al. (2021) show some similar influences in K-12 reopening decisions. College vaccine mandate decisions are likely to be influenced by similar factors.

rates interacted with weekly fixed effects. Communities in which there were more aggressive public health responses and where people followed public health guidelines more carefully had higher vaccination rates, especially in August 2021. These controls thus help capture community attitudes and behaviors around COVID as well. Any bias from unobserved policies or local behaviors must be orthogonal to *both* the Democratic vote share and the baseline COVID vaccination rate. While possible, we present evidence below that these controls account powerfully for local heterogeneity.

The third identification concern is that other local or college-level COVID-19 policies could be correlated with a college passing a mandate. As discussed above, the vote-share and baseline vaccination rate-by-week fixed effects help control for this unobserved heterogeneity. In the section that follows, we show that there are no differential trends in county-wide vaccination rates before or after the start of fall semesters in counties by college mandate status, suggesting that there were no concurrent policies implemented that increased vaccine take-up among the general public. Any other policies or unobserved heterogeneity residual to our controls would have to impact outcomes without being correlated with vaccination rates of the county populations. We also find no evidence from placebo tests that 2021 mandates are associated with differences in outcomes surrounding semester starts in fall 2020 among colleges that were operating in person. Since other norms and policies, such as masking and social distancing, are likely to have been in effect over that time period as well, these findings further suggest that we are not picking up latent differences in how communities addressed the risk from COVID-19. Further, we control directly for institutions' mask and testing policies during the fall 2021 semester and find that doing so makes little difference in our cumulative estimates.

Taking into account all of the controls discussed above, our final estimating equation is the following:

$$Y_{ct} = \sum_{\substack{k=-11 \\ k\neq-2}}^{11} \beta_k * 1\left[t - t_c^* = k\right] + \sum_{\substack{k=-11 \\ k\neq-2}}^{11} \gamma_k * 1\left[t - t_c^* = k\right] * Mandate_c \qquad (2)$$

$$+ \theta_c + \delta_t + \nu_t * Region_c + \mu_t * VoteShare_c + \phi_t * BaseVaxrate_c + \varepsilon_{ct},,$$

where we have augmented Equation 1 with week-by-region, week-by-2016 Democratic presidential vote share, and week-by-baseline vaccination rate fixed effects. We present results with and without the week-by-baseline vaccination rate controls to demonstrate that they do not substantially alter the results after accounting for regional and political differences in our outcomes over time. Given the close relationship between community COVID-19 responses and vaccination rates, this evidence strongly supports our claim that our controls account for unobserved local heterogeneity in other policies and prevention behavior.

3.2 First-Stage

Ideally, we would estimate the first-stage effect of vaccination mandates on vaccination rates among students using our event-study framework with student vaccination rates as the outcome measure. This is infeasible, however, because we cannot observe vaccinations among the student population specifically. We do observe weekly vaccination rates in the county population surrounding a college, but age-specific data at the county level are not available. Furthermore, since most mandates were announced prior to students' arrival on campus and often required students to get vaccinated before arrival, a large portion —potentially a substantial majority —of students would have been vaccinated in a county other than the one in which their college is located. Although we are unable to directly assess how mandates affected college student vaccination rates, we highlight two findings that are suggestive of a strong first-stage: 1) college vaccination mandates had virtually no effect on vaccination rates among the local population, and 2) the reduced-form results indicate effects on outcomes that are consistent with a strong first-stage effect.

We begin our analysis by estimating whether vaccine mandates had any effect on vaccination rates in the broader local population.[17] We present the γ coefficients from Equation 2 for county-wide vaccination rates in Appendix Figure A.4. While there is some indication of a slight upwards trend in mandate relative to non-mandate counties prior to the start of the fall 2021 semester, the point estimates are very small —the estimate for vaccination rate differential in week -11 is only -0.002 percentage points. Ultimately, we see little impact of the mandates on county-wide vaccination rates. Summing across the 13 weeks following the start of the fall semester in our preferred

[17] Specifically, we use the countywide share of the population that received at least one dose of the COVID-19 vaccine.

specification with both vote share and baseline vaccination by week fixed effects, we estimate that mandate counties had 0.007pp lower vaccination rates than non-mandate counties. This estimate is not statistically significant at even the 10% level. Overall, we conclude that college vaccine mandates had a negligible impact on aggregate vaccinations in the county. This result is important because it suggests that, conditional on our controls, mandate and non-mandate counties were trending similarly in terms of vaccinations before and after college students returned to campuses. Since vaccination rates are correlated with other dimensions of response to COVID risk, the null result on overall vaccinations is consistent with our model identifying the causal effect of college vaccine mandates and not other policy or behavioral differences.

One feasible test of the first-stage is to assess whether our reduced-form estimates are heterogeneous in ways that are consistent with a strong first-stage. In particular, we examine patterns of heterogeneity to confirm that they align with the following hypotheses:

Hypothesis 1: *Vaccine mandates have a larger effect on local health outcomes where college students make up a larger share of the population.*

Hypothesis 2: *Vaccine mandates have a larger effect on local health outcomes where students are less likely to be vaccinated in absence of a vaccine mandate.*

Testing the first hypothesis is straightforward: we examine whether the estimated reduced-form effects are larger for counties where students make up a larger share of the population. Testing the second hypothesis is more difficult because we have to measure which colleges enroll students who are likely to be vaccinated in absence of a mandate. We perform this test in two ways. First, we estimate effects by college selectivity under the conjecture that mandates may be more effective at less-selective institutions. Second, we use information from the Census Bureau's Household Pulse Survey to estimate the relationship between vaccination status, race, and income and use this relationship along with college demographics to estimate counterfactual vaccine take-up rates in absence of a mandate. We then confirm that our reduced-form effects are stronger at institutions with lower predicted vaccine take-up.

For our analysis of the Pulse data, we use the sample of 18-24 year olds surveyed between July

21 and August 16, 2021. We estimate the following regression to identify the relationship between vaccination status, race, and income:

$$Vax_{jqr} = \alpha + \sum_q \beta_q Income_q + \sum_r \gamma_r Race_r + \sum_q \sum_r \pi_{rq} Income_q * Race_r + \varepsilon_{jqr}, \quad (3)$$

where Vax_{jqr} is a dummy variable indicating whether respondent j in household income quintile q and racial group r reports being fully vaccinated.[18] We use the coefficients from this regression to predict vaccination rates at each college using college-level income quintile shares from Opportunity Insights and racial shares from IPEDS.[19] For some analyses, we also present versions in which we only include income, or include income and race without their interactions.

Appendix Figure A.5 shows predicted vaccination rates by county using the full set of predictors. Appendix Figure A.6 shows the distribution of predicted vaccination rates by mandate status using either income alone, race and income, or race, income, and their interactions. In both figures, we caution that these predicted vaccination rates are likely higher than colleges' true vaccination rates at the start of the fall 2021 semester, due to the fact that the Household Pulse Survey overestimated U.S. vaccine take-up (Bradley et al. 2021). However, there is substantial variation in these predicted rates and, although college counties with no mandate have lower predicted vaccination rates than college counties with a mandate on average, there is considerable overlap in these distributions. Thus, we are able to estimate how vaccine mandates affect outcomes separately in counties with relatively low versus high predicted student vaccination rates.

[18] The Household Pulse Survey asks individuals "Have you received a COVID-19 vaccine?" and "Did you receive (or do you plan to receive) all required doses?" regarding vaccination status. Individuals can respond "1) Yes, received all required doses", "2) Yes, plan to receive all required doses", and "3) No, don't plan to receive all required doses". We assign a value of 1 to individuals who selected the first response, and 0 to all others. We aggregate income ranges from the Pulse survey to income quintiles based on the U.S. household income distribution in 2019 (`https://www.taxpolicycenter.org/statistics/household-income-quintiles`). The ranges of the income quintile bins are less than $25,000, $25,000 to $49,999, $50,000 to $74,999, $75,000 to $149,999, and $150,000 and above, respectively.

[19] The Opportunity Insights data use the universe of U.S. tax records to estimate the share of students from each income quintile at each higher education institution (Chetty et al. 2020). We use the most recent data available, which capture students enrolled in colleges and universities in 2013. For institutions with insufficient data to provide quintiles, we use the estimates from Chetty et al. 2020 of the income distribution among all students attending the colleges with insufficient data.

3.3 Raw Trends and Fixed Effects

Figure 1 presents average weekly per-capita cases at the county level by mandate status and region.[20] Our use of region-by-week fixed effects in the event study models means that we are identifying the main effects off of the within-region variation we show here. In each region, COVID-19 cases in mandate and non-mandate counties are moving along a similar trend but split off from each other after the semester start, suggesting that vaccine mandates generate a relative drop in case rates.

Our event-study estimates include the week-by-vote share and week-by-baseline vaccination rate effects discussed above. The variation we use after accounting for all of our fixed effects is shown in Appendix Figure A.7, where we plot the residuals from a regression of each COVID-19 outcome measure on all the fixed effects and interactions in Equation 2. After residualizing the data, differences in COVID-19 outcomes and vaccinations between mandate and non-mandate counties during the pre-opening periods are small and show little indication of non-parallel trends. It is important to note that the magnitudes themselves are very small: residualized average positivity rate gaps do not exceed 0.4% in any pre-opening period, while the COVID outcome gaps are less than 13 cases, 2 hospitalizations, and 0.5 deaths per 100k people per week. Our event-study estimates using 11 weeks prior to semester start confirm the lack of pre-trends.

4 Results

We now turn to assessing how college vaccine mandates affect the spread of COVID-19 and related health outcomes. We emphasize that all of our estimates provide the net effect of vaccine mandates on local outcomes of interest, inclusive of any changes in behavior or outcomes of college students themselves.

[20] For ease of exposition, we show figures for the six BLS-defined regions with the greatest number of mandate counties in our sample and omit figures for the Southwest (6 mandate counties) and Mountain-Plains (5 mandate counties) regions as they have very few mandate counties. No regions are omitted from the regression specifications.

4.1 Main Results

We present our main event study results in Figure 2.[21] Panel (a) shows the effect of vaccine mandates on cases. COVID-19 cases were trending similarly in mandate- and non-mandate college counties before students came back for the semester start. Beginning the week prior to semester start, cases decline in mandate counties relative to non-mandate counties. The difference is approximately equal to 50 cases per 100,000 in the fourth week after semester start, after which the difference is reduced somewhat. We note, however, that reported case counts are endogenous to the testing regime. If mandate counties engage in more testing, then the negative effects we find are even more striking. If they have less testing, then we should observe an increase in the test positivity rate. In Panel (b), we show that the test positivity rate —defined as the number of positive COVID-19 tests in a county divided by the total number of reported tests —was trending similarly in counties with and without college mandates prior to semester start dates. The positivity rate then began to *decline* in counties with mandates relative to counties without mandates in the weeks after the start of the semester, although the coefficients are not statistically different from zero. That both cases and the positivity rate decline strongly suggests that there were fewer infections in mandate relative to non-mandate counties after opening.

Panels (c) and (d) show the effects of college mandates on the number of new hospitalizations and the number of ICU patients with COVID-19. Both measures include suspected and confirmed cases of COVID-19. The results for hospitalizations in panel (c) are noisy but suggestive of a reduction in hospitalizations in weeks 2-4 following college re-openings. However, hospitalizations then rise after week 4. Panel (d) shows a reduction in the number of ICU cases per 100,000 county residents per week beginning the week after college semesters start. In Section 4.3, we show that these effects are much larger when we weight the regressions by county size, indicating that we see reductions in hospitalizations in larger counties. Hospitalization data reflect the locations where patients are hospitalized rather than where they reside. There is likely to be misclassification error in small counties with low hospital capacity, where severely ill patients may be hospitalized outside of their county of residence and thus reported as occurring in a different county. The unweighted

[21] Estimates are also available in tabular form in Appendix Table A.1.

hospitalization results therefore should be interpreted with caution.

Panel (f) shows the effects of colleges' vaccination mandates on COVID-19 deaths. As with prior figures, there is little evidence of a pre-opening trend in COVID-19 deaths per 100,000 residents prior to the start of colleges' fall semesters. There additionally is only a small effect on deaths at the beginning of the semester, which is unsurprising given the well-documented lag between COVID-19 cases and deaths (Testa et al. 2020; Jin 2021). The estimated effect then grows slightly to a reduction of approximately 0.5 deaths per 100,000 county residents per week in weeks 8 and 9 of the semester.

We summarize these event study estimates in Table 2. For all outcomes that are measured on a per capita basis, we sum the post-period event study coefficients ($k = -1$ to $k = 11$) to present a cumulative effect over the 13 weeks since students likely began returning to campus. For the test positivity rate, which is measured on a percentage basis, we present the average of the post-period event study coefficients.

The results in Panel A show the effects of having a vaccine mandate at any college in the county. Beginning with column (1), we find that college-level COVID-19 mandates reduced COVID-19 cases by 339 cases per 100,000 —an approximately 10% reduction off of the mean. There is no effect on the positivity rate, as shown in column (2). Aligned with Figure 2, columns (3) and (4) show noisy cumulative effects on hospitalizations and ICU patient counts. The results in column (5) indicate that college mandates reduce the total number of COVID-19 deaths in a county by 5.4 per 100,000 over thirteen weeks, a 12.8% decrease. Taken together, these findings demonstrate that colleges' vaccination mandates reduced the health-related toll of COVID-19 in their local communities during the fall 2021 semester.

Thus far, we have measured vaccine mandate exposure by whether any four-year college in the county has a mandate. In Panel B of Table 2, we instead use as the treatment variable the percentage of students in the county covered by a college vaccine mandate. The resulting estimates thus show the effect of mandating that 100% of students in a county receive the vaccine. Since 84% of colleges in mandate counties have a mandate, and these mandates cover 85% of students in these counties, it is not surprising that the estimates in Panel B are qualitatively and quantitatively similar to those in Panel A. Covering 100% of students leads to 488 fewer cases per 100,000, 5.7 fewer deaths per 100,000, and 15.1 fewer ICU patients per 100,000. The first two estimates are statistically significant at the 5% level, while the latter is significant at the 10% level. Broadly, the results in both panels of Table 2 show sizable public health benefits of college vaccine mandates regardless of how we measure mandate exposure.

We motivated our analysis by suggesting that college student vaccinations may have spillover effects on the non-college population. In Figure 3, we test this assertion by estimating effects on cases by age group. While we do not have data on cases by detailed ages and week, we are able to examine effects at the monthly level for three broad age groups: 0-17, 18-64, and 65+. We estimate a monthly event study by age group using the same controls as the weekly event studies, except with month fixed effects substituted for week fixed effects. The outcome is measured as cases per 100k population within the relevant age group. The results in Figure 3 indicate that rates decline for all age groups in mandate counties relative to non-mandate counties after the semester starts. Hence, the reduction in cases we document above is not solely driven by differences in case levels among the college student population. Furthermore, 99.5% of COVID deaths are among those over the age of 24. The reductions in deaths we document hence come almost entirely from the non-college population.

4.2 Heterogeneity

In this section, we test whether heterogeneity in the estimated effects of vaccine mandates aligns with our hypotheses surrounding the "first-stage" effect of mandates on student vaccination rates. We do not observe vaccinations among students directly, so we are unable to implement a direct test of the first-stage effect. Instead, as discussed in Section 3.2, we test whether our reduced-form estimates are consistent with a strong first stage.

We first assess whether our estimated effects are larger at colleges where baseline vaccination take-up is likely to be low. Our primary approach to identifying colleges where vaccination rates would otherwise be lower is to use the Census Bureau's Household Pulse Survey to estimate a function relating vaccination status among 18-24 year olds to income and race and use this function to predict vaccination rates at the campus level (see Section 3.2 for details). We then split the sample by high (above median) and low (below median) predicted vaccination rates.

Figure 4 shows event study estimates by predicted vaccination rates using the Pulse Survey data. All of the outcomes provide evidence of stronger effects in counties where colleges are predicted to have lower underlying vaccination rates. The estimates for cases, ICU admissions, and deaths are particularly striking: all of the effects are driven by counties with colleges that are predicted to have low vaccination rates based on their demographic composition. Put differently, our results are strongest in areas with colleges that enroll a higher percentage of non-white and lower-income students, since students from these backgrounds tend to have lower vaccination rates on average. In order for this result to be affected by omitted variable bias, it would have to be the case that communities with such colleges are more likely to have other mitigating policies or have populations that more closely follow public health guidance.

Figure 5 shows cumulative event study estimates by predicted vaccination rates using three methods for the prediction: only income, income and race, and income, race, and their interactions. Regardless of the method chosen to predict vaccination rates, the estimated effects are much stronger for colleges with below-median predicted vaccination rates. Appendix Figure A.8 shows similar results by quartiles of predicted vaccination. Generally, the effects across our outcomes of interest are strongest for the counties that contain the lowest-quartile predicted vaccination colleges.

Because our results show that the effects are largest where predicted vaccination rates are lowest, and because increasing the percent of students who are vaccinated through means other than mandates (e.g., incentives or informational campaigns) may be of interest to policymakers, we quantify the effect of a one percentage point increase in the student vaccination rate on health outcomes. To do so, we estimate event study specifications where we interact the pre- and post-indicators with the expected vaccination rate of college students in a given county at the start of the semester. For institutions with mandates, we set this rate to 90%, 95%, or 100%, in order to illustrate the effect of different assumptions about mandate compliance.[22] For institutions without

[22]To inform these rates, we collected data on the final, reported vaccination rates for 145 randomly-selected institutions with vaccine mandates. For 106 of these institutions, we were able to find information on campuses' final vaccination rates. Within this sample, the median reported final

mandates, we set this rate to the predicted vaccination rate from the Pulse Survey data, using the most saturated predicted specification that includes race and income interactions. We also consider specifications where we subtract 30 percentage points from these predicted vaccination rates, because the average reported vaccination rates in the Pulse data are about 30 percentage points higher than the true vaccination rate in the 18-24 year old population at the time of the survey.[23] For counties containing multiple four-year colleges, we then average expected start-of-semester vaccination rates over colleges within a county, weighting by each college's enrollment.

Figure 6 displays the results from this exercise, summing the event study coefficients over the 13 post-period weeks in our data, beginning with the week before the semester begins, and dividing by 100. As such, the estimates display the expected effect of beginning the semester with a 1 percentage point higher vaccination rate among college students within a county. The effects are larger when we assume a smaller difference in vaccination rates between institutions with and without mandates but consistently show that an increase in the student vaccination rate reduces county-level cases and deaths by statistically significant amounts. Specifically, we estimate that a 1 percentage point increase in the college student vaccination rate reduces cumulative cases by 20-30.5 per 100,000 and cumulative deaths by 0.34-0.6 per 100,000 in specifications without the 30 percentage point adjustment. With such an adjustment, we find that a 1 percentage point increase in the college student vaccination rate reduces cumulative cases by 9.4-11.4 per 100,000 and cumulative deaths by 0.14-0.17 per 100,000.

We also examine heterogeneity by the size of the college population relative to the county population. We construct the following relative size measure:

$$RelativeSize_c = \frac{\sum_{Jc} Enrollment_j}{Population_c}, \tag{4}$$

where Jc represents the set of colleges located in county c. We divide the sample into counties that are above- and below-median by this measure and show differences in the estimated effects across these two sets of counties. We use this measure because it is likely that the externality

vaccination rate was 95.2%. The 25th and 75th percentiles were 91% and 98%, respectively.

[23] For the US adult population overall, Bradley et al. (2021) find that the Pulse Survey overstates vaccination rates by 14% in May 2021, with gaps widening between January and May.

effects of the vaccine mandates will be larger when students make up a larger share of the local population (e.g., "college towns"). Additionally, we use IPEDS data to characterize colleges by their average admission test scores and create a county-level weighted average admission test score across colleges within the county. The motivation for this measure is that more selective colleges are likely to enroll students who otherwise would be more likely to get vaccinated.

Table 3 presents estimates by above/below median predicted vaccination rate and student population share. While we lose precision with these sample splits, the estimates in Panel A suggest that effects are strongest for counties that have both below-median predicted vaccination rates and above-median student population share. For these counties, vaccine mandates reduce cumulative case counts by 950 per 100,000 and deaths by 23.1 per 100,000. The latter estimate is significant at the 5% level. We further observe reductions in hospitalizations of 57.7 per 100,000 and in ICU patients of 49.8 per 100,000, the latter of which is statistically significant at the 10% level. Effects for the other groups shown in the table are more modest and are not statistically significant at conventional levels, although generally they are in the same direction. Appendix Figure A.9 shows event studies for cases for each of these groups and aligns with the findings from Table 3.[24]

Appendix Table A.2 repeats this analysis splitting the sample by colleges' SAT scores and student share. The results indicate that vaccine mandates have the largest effect in counties where college students make up a large share of the population and where colleges are less selective (Panel A).[25] Indeed, the results in Panel A in Table A.2 are very close to those from Panel A in Table 3, where we split by predicted vaccination rate and student share. Together, these results show that the reduced-form effects of vaccine mandates are localized to the types of colleges where we would expect a larger first-stage effect. Although we are unable to identify the first stage directly, these estimates strongly support the validity of our approach and conclusions.

4.3 Robustness

The results presented in Sections 4.1 and 4.2 indicate that college-level COVID-19 mandates protected local public health during the fall 2021 semester. These findings rely on the assumption

[24] Event study figures for other outcomes are available from the authors upon request.
[25] Appendix Figure A.10 presents event study estimates of case counts for these groups.

that counties where colleges did not implement vaccination mandates serve as a valid counterfactual for those that did. We now present several tests of this assumption.

As previously discussed, a central identifying assumption in our event study approach is that our controls are sufficient to account for unobserved policies or behaviors that could be correlated with mandates but have independent effects on outcomes. To provide further evidence that our estimates are not being driven by these factors, we conduct a placebo test surrounding fall 2020 reopenings. In fall 2020, COVID-19 vaccines were not yet available to the public, but patterns of county-level heterogeneity with respect to alternative policies and behaviors were likely similar in fall 2020 and fall 2021. If these alternative policies and behaviors are sources of bias, they should differentially affect outcomes in fall 2020 as well, before vaccine mandates were in place.

Figure 7 shows the results of a placebo event study using the same specification as in our baseline event study but with COVID-19 outcomes measured in fall 2020. The sample is restricted to counties in which colleges re-opened for in-person instruction in fall 2020.[26] The results show no indication of differences in outcomes across mandate and non-mandate counties in 2020.[27] This evidence supports our identification strategy and indicates that mandate counties did not differ from non-mandate counties in terms of health outcomes in the first year of the pandemic, conditional on our set of controls.

To further ensure that our results are not driven by alternative policies or behaviors, we test the robustness of our results to the inclusion of additional week fixed effects interacted with college-level policies. Panel A of Table 4 shows the results from our preferred main specification, while Panel B shows the results when we include week fixed effects interacted with an indicator for remote re-opening in 2020.[28] This specification address the concern that mandate colleges may have systematically different attitudes and responses to COVID-19 than non-mandate colleges across both the 2020 and 2021 academic years. The estimates are very similar to those in Panel A, suggesting that this is not a relevant source of bias. Panels C and D of Table 4 then use data on

[26]We obtain data on colleges' fall 2020 instructional modes from C2i. We include all counties where at least 50% of colleges operated primarily or fully in-person in fall 2020.

[27]The contrast between the 2020 and 2021 results is not driven by the fact that we have limited our sample to colleges that re-opened in person in 2020. For comparison, Appendix Figure A.11 presents a version of our 2021 results in which the sample is limited to colleges that re-open in person in fall 2020. The estimates are similar to baseline.

[28]For computational ease, we dichotomize the choices of colleges within a county, interacting the week fixed effects with a dummy variable indicating that more than 50% of colleges in a county operated remotely in the fall 2020 semester.

college COVID-19 testing and masking requirements to control directly for such policies. In Panel C, we augment our baseline model with week fixed effects interacted with an indicator for whether the county has at least one college with an indoor mask requirement for at least some students. Adding these controls barely moves the estimated effect of the vaccine mandate. Similarly, adding week fixed effects interacted with COVID-19 testing policies does not change our results (Panel D). Taken together, these estimates provide strong evidence that our main results are driven by vaccine mandates themselves, as opposed to other correlated policies.

Variation in college masking policies also allows us to estimate the effect of college masking policies directly and determine whether impacts of these policies contaminate our vaccine policy estimates. Among college counties without vaccine mandates, 69% have a college with a mask requirement, while nearly all college counties with a vaccine mandate also have a masking requirement. Thus, we focus on the sample of 284 counties with no vaccine mandate to estimate the effect of a mask mandate. Using this sample, we estimate event studies analogous to our baseline model, but with a mask mandate indicator replacing the vaccine mandate indicator. We then sum the event study estimates to obtain the cumulative effect of college mask mandates. The results are shown in Table A.3. The estimated effect of mask mandates on all measures of COVID-19 spread are positive —the opposite direction of our estimates for vaccine mandates —and none is statistically significant at even the 10% level. These null results provide further evidence that our findings for vaccine mandates are not picking up the effects of masking policies.

In the remainder of Table 4, we test the sensitivity of our results to several specification choices. Panel E shows the results when we weight the regressions by the county population size. Panel F then weights the regressions by the student share of the county population. In both sets of weighted regressions, we obtain larger and in many cases more statistically significant effects for cases, ICU patients, hospitalizations, and deaths, while the positivity rate effects remain small and are not statistically significant at conventional levels.

Panel G shows the estimates when we drop any counties that have multiple colleges with different vaccine mandate statuses in fall 2021. Our results and conclusions are robust to excluding these counties. Panel F then shows how our estimates change if we drop counties with colleges that have staff mandates.[29] While we lose some statistical power, our estimates are similar in size and direction, suggesting that our effects are driven primarily by student mandates rather than faculty and staff mandates. Panel G drops colleges that announce a vaccination mandate mid-semester and again produces very similar results to our main specification.[30]

As an additional test of the assumption that our results are driven by mandates and not other policy or behavioral changes —such as business or K-12 school closures, establishment capacity limits, or voluntary changes in social distancing measures when students return to campuses —we estimate effects on a variety of measures related to mobility and economic activity. Table 5 shows the estimated cumulative effect of mandates on (1) weekly restaurant visits per 100,000 residents, (2) weekly consumer spending relative to January 2020, and (3) weekly visits to different types of establishments, also measured relative to January 2020.[31] Panel A shows that, across the full sample, counties with college COVID-19 vaccine mandates do not experience decreased economic activity after students return to campuses. Moreover, Panels B through E show that, even in counties where we document the largest effects of mandates on COVID-19 health outcomes (those that have low predicted vaccination rates of college students and large college student populations), mandates are not associated with a decline in mobility or spending. If anything, we observe a small *increase* in restaurant visits and use of public transit in these counties. Thus, it is unlikely that our results for health-related outcomes are driven by other contemporaneous policy or behavioral changes that may have reduced the local COVID-19 burden.

Next, Appendix Table A.4 addresses the concern that our results could be driven by one specific state. We estimate our main specification leaving out one state at a time for all states in the analysis. The table shows percentiles of the distribution of estimated cumulative effects. Hospitalizations continue to be a noisy measure —in some specifications the coefficient is positive —but on the whole, the results are consistent with our main specification.

Finally, our main specification relies on event studies from two-way fixed effect regressions

[29] Only two colleges in our sample have faculty/staff mandates but no student mandates.

[30] As an additional robustness test, we drop any observations with negative counts, reflecting data revisions. Estimates that drop these observations differ little from our main estimates. These results are available from the authors upon request.

[31] We obtain restaurant visit data from Carnegie Mellon University's Project Delphi (`https://delphi.cmu.edu/covidcast/export/`) and all other measures from Opportunity Insights, (`https://www.tracktherecovery.org/`), which in turn collects data on consumer spending from Affinity Solutions and data on mobility from Google.

with staggered adoption. This approach can be a problem if the treatment effects are dynamic and heterogeneous (Goodman-Bacon 2021; Sun and Abraham 2021). While openings are staggered, there is actually little difference in the timing of when semesters start as seen in Appendix Figure A.12. Indeed, about 90% of colleges started in a three week period between August 15 and September 7, making our setup closer to a more standard event study with uniform adoption timing.[32] Since we know the start dates of each institution regardless of whether they are treated with a mandate, a simple way to address this concern is to estimate our models separately by semester start week. These results are shown in Appendix Table A.5.[33] For each outcome, the estimates are qualitatively similar and, with the exception of hospitalizations, are in the same direction across semester start weeks. Furthermore, in column (6) we provide a weighted average of these separate start-week estimates, where the weights are equal to the share of counties whose first semester start date falls within each week. The results are very similar to our main estimates, indicating that our estimates are not affected by the use of staggered start dates.

5 Conclusions

Mandates for COVID-19 vaccination are politically controversial. While we have excellent experimental and population data on how vaccines themselves affect individual health outcomes, the justification for mandates relies primarily on the extent to which vaccinations can reduce the externalities imposed on others from communicable illness in terms of additional disease spread. To better understand the externality-correcting benefits of vaccine mandates, we focus on the context of colleges and estimate the impact of vaccine mandates at residential, four-year colleges and universities on a variety of community-level COVID-19 health outcomes. Residential colleges and universities provide an excellent case study of spillover effects from vaccine mandates as they contain large, concentrated populations of young individuals who are at relatively low individual

[32] While we define the start time of treatment as the start of the semester, it is worth noting that 8.1% of institutions in our analysis sample that began the fall semester without a vaccine mandate announced one by mid-November. We code these counties as not having a mandate (since they do not begin the semester with one), which likely biases our estimates towards zero because we are treating some post-opening periods with mandates as not having mandates. When we estimate models that drop any county whose first mandate is after the semester start (Panel I in Table 4), our results are very similar.

[33] For this analysis, we drop the 5% of institutions in our sample that began their semesters during week 32 or 36 of the calendar year. In the second column of Appendix Table A.5, we show that the main estimates do not change in a meaningful way when we restrict the sample in this way.

risk from serious COVID-19 complications themselves but may spread infections to the broader community. Individuals of college age also tend to have lower vaccination take-up generally, and hence there is substantial scope for mandates to improve these rates.

Our analysis uses an event study estimation strategy that compares counties with colleges and universities that had mandates to those that did not before and after fall 2021 semester start dates. To account for differences across counties in mitigation behaviors, regional variation in the timing of COVID waves, colleges' selection into mandate status, and variation in baseline community vaccination rates, we also include county and calendar week fixed-effects, and we interact the latter with region indicators, Democratic vote shares in the 2016 presidential election, and baseline vaccination rates.

Our primary focus is on the combination of direct and indirect effects of the mandates on health outcomes. We estimate that, over the first thirteen weeks after students returned to campus in fall 2021, cases of COVID-19 in counties with mandate colleges fell by 339 per 100,000 people relative to counties with non-mandate colleges. This reduction in cases, in turn, resulted in 5.4 per 100,000 fewer deaths. Overall, four-year college vaccine mandates over the 13 weeks of fall 2021 saved approximately 7,300 lives, reducing deaths from COVID-19 by about 5%.[34] A back-of-the-envelope calculation applying the value of a statistical life-year estimate at age 62 between $200,000 and $350,000 (Aldy and Viscusi 2008) and estimates of each COVID death resulting in 9 to 14.5 lost life years (Elledge 2020; Quast et al. 2021; Goldstein and Lee 2020; Arolas et al. 2020), we approximate that the value of lives saved from college COVID-19 vaccine mandates ranges from $9.7 million to $27.4 million per 100,000 residents in a county.

While we are unable to estimate the direct effect of vaccine mandates on student vaccination rates (the first-stage effect), we pursue multiple routes to demonstrate that our findings are consistent with a strong first stage. In particular, we show that our estimated effects are strongest for institutions that we predict to have low vaccination rates in absence of the mandates as well as in areas in which college students are a relatively larger share of the population and with less-selective

[34] We calculate that 7,319 lives were saved by multiplying the cumulative reduction in deaths per 100,000 (5.40 from Panel A of Table 2) by the average size of counties with a mandate (503,588 from Table 1) and by the number of mandate counties (269 from Table 1): 5.04*5.40*269=7,319. During this period (August 16 to November 14), there were 139,711 deaths from COVID-19 per CDC figures: 7319/139711=0.05.

postsecondary institutions.

In total, our findings indicate that college vaccine mandates led to substantial reductions in disease burden well beyond college campuses themselves. As of now, it is unclear how the COVID-19 pandemic will continue as new potential variants emerge. However, public health officials and governments likely will continue to need to be nimble in how they try to reduce disease burden. This study shows that vaccine mandates, even in a young population, can be an effective tool towards achieving that goal.

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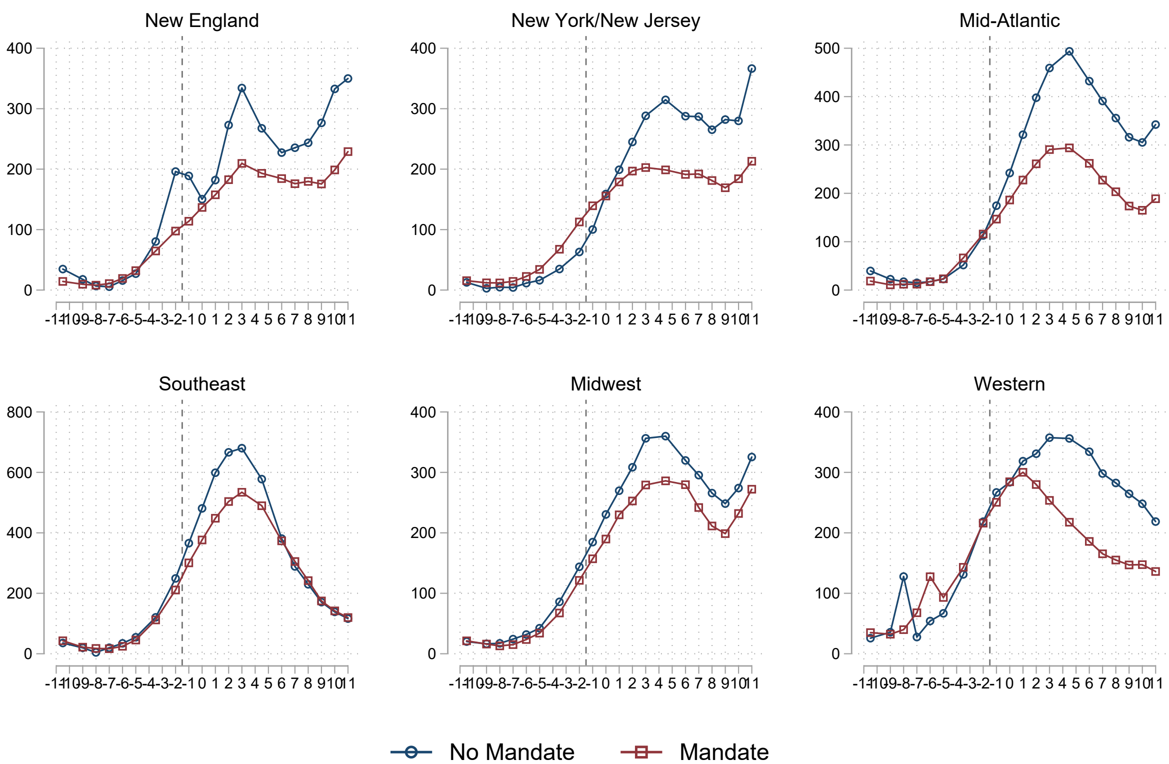
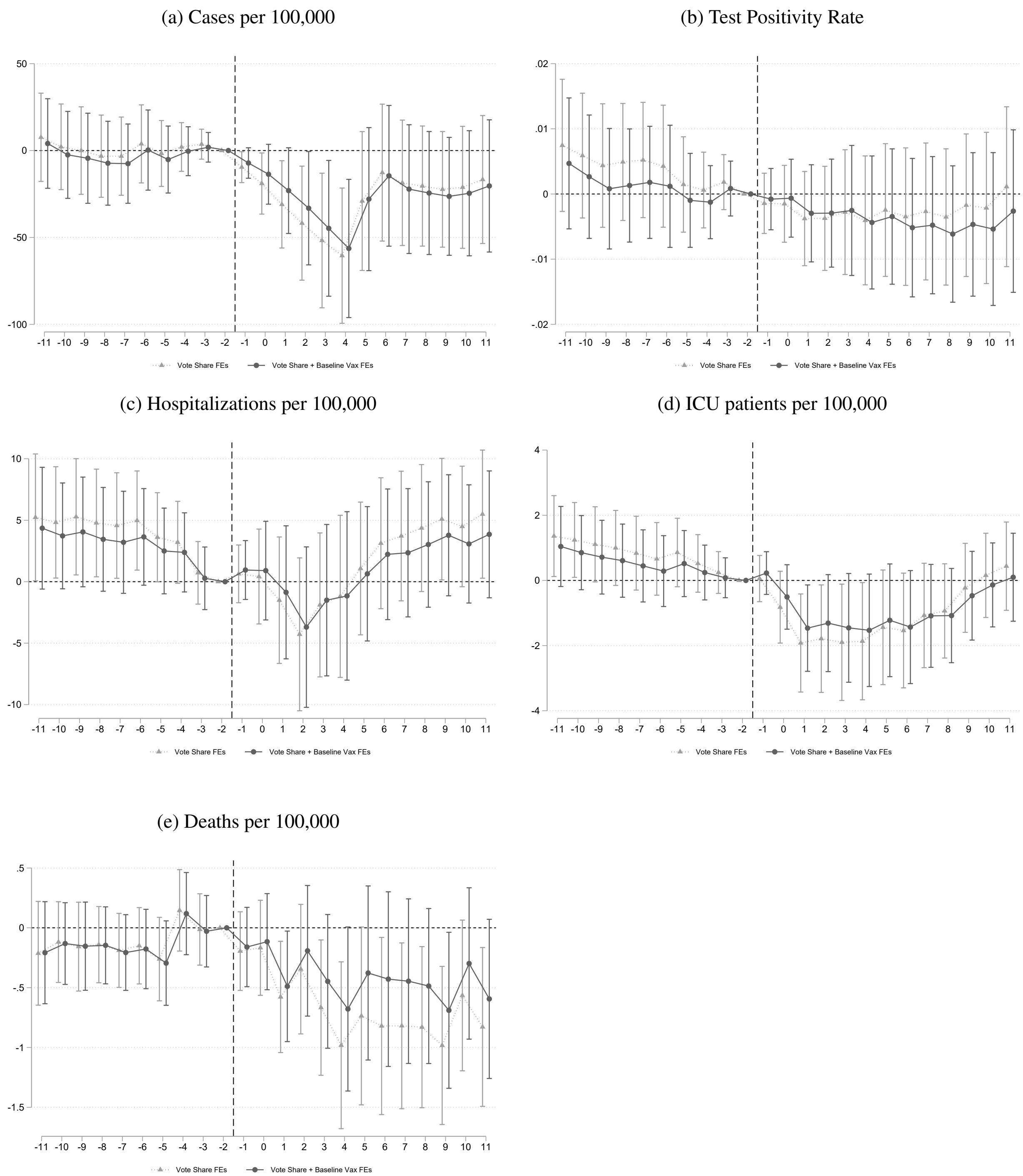
Figure 1: COVID-19 Cases by Region and Mandate Status



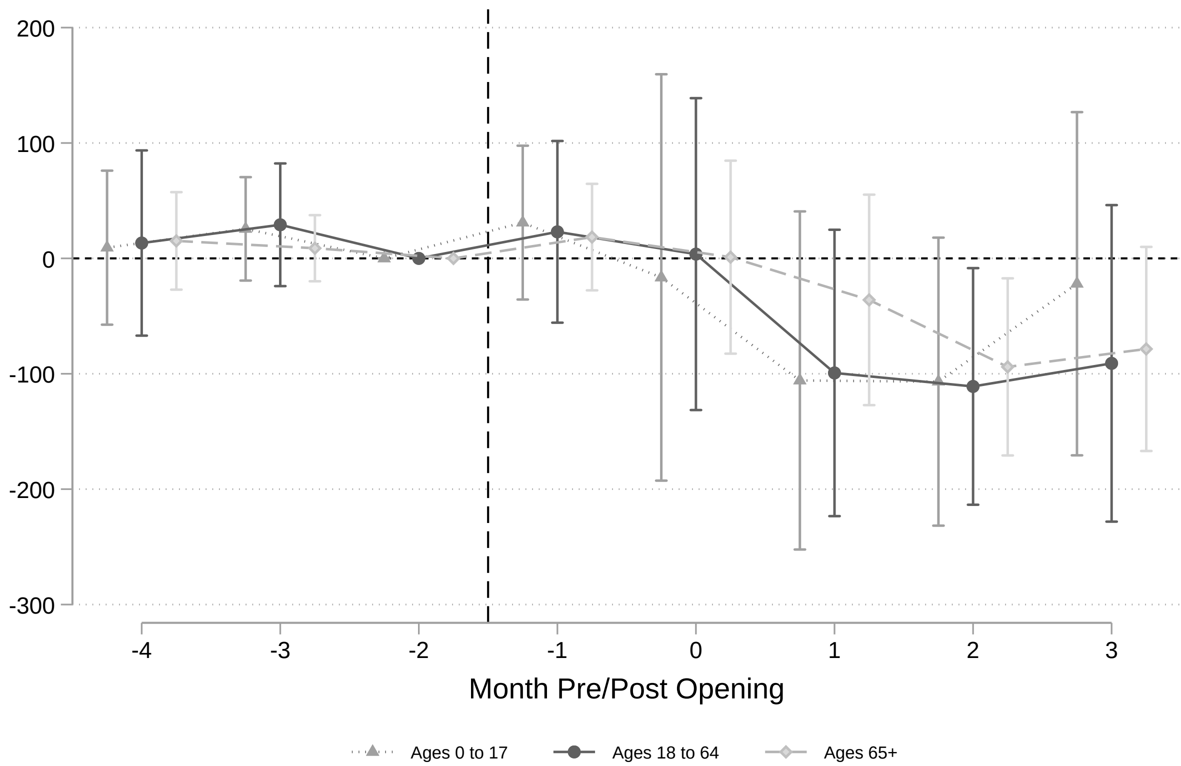
Note: These figures show average weekly COVID-19 cases per 100k population at the county level in the six BLS-defined regions with the greatest number of mandate counties in our sample. We omit figures for the Southwest (6 mandate counties) and Mountain-Plains (5 mandate counties) regions as they have very few mandate counties. The levels for college counties with (without) a mandate are given by the square (circular) markers.

Figure 2: Event Studies



Note: These figures show the results of event studies that include county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. The line shows the effect of the mandate relative to college counties without mandates. We cluster standard errors at the county level and include 95% confidence intervals. Panels are labeled by the outcome measure. Outcomes are measured on a weekly basis.

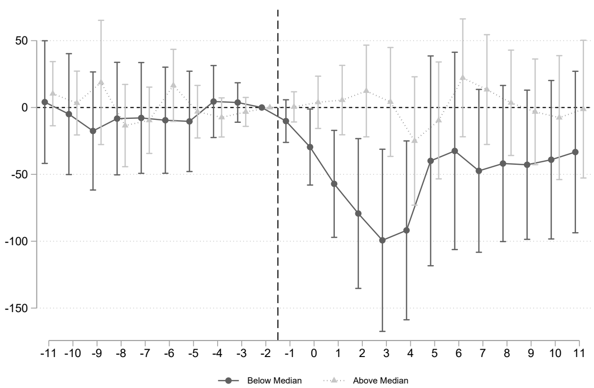
Figure 3: Event Study: Monthly Cases by Age



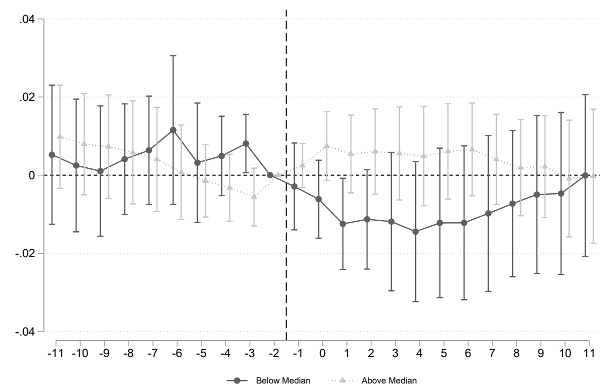
Note: This figure shows the results of an event study by age group with cases per 100k population (within age group) per month as the dependent variable. The event study includes county and month fixed effects, month-by-region fixed effects, month-by-baseline vaccination rate fixed effects, and month-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. The estimates show the effect of the mandate relative to college counties without mandates. We cluster standard errors at the county level and include 95% confidence intervals.

Figure 4: Event Studies by Predicted Vax Rates

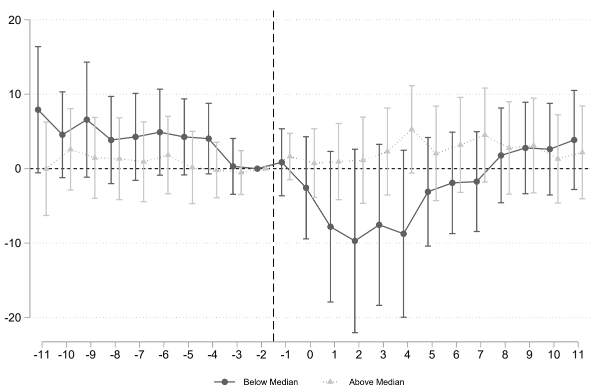
(a) Cases per 100,000



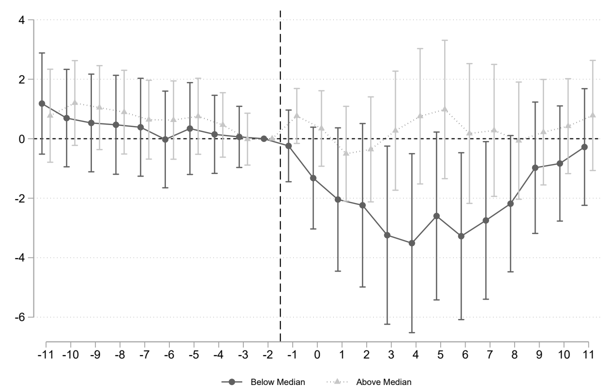
(b) Test Positivity Rate



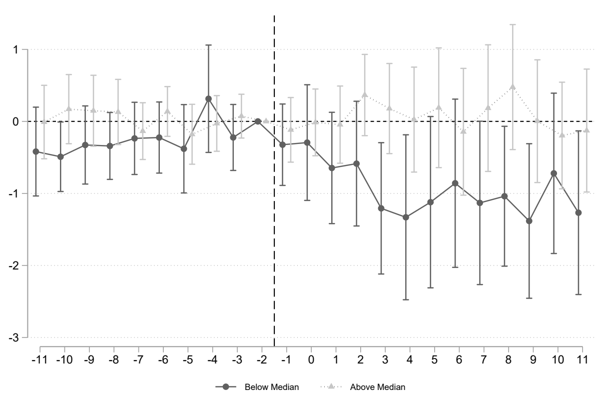
(c) Hospitalizations per 100,000



(d) ICU patients per 100,000



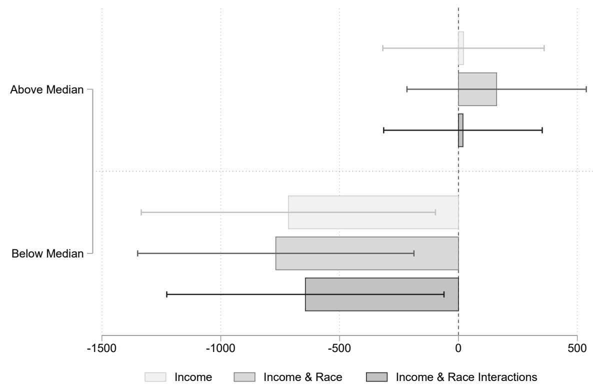
(e) Deaths per 100,000



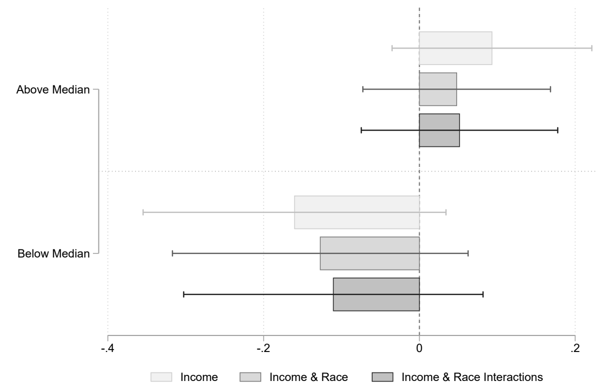
Note: These figures show the results of event studies that include county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. The lines show the effect of the mandate relative to college counties without mandates. The dark line with circular markers indicates the effects for counties with colleges that have below-median predicted student vaccination rates, while the light gray line with triangular markers indicates the effects for counties with colleges that have above-median predicted student vaccination rates (median = 76.7%). We cluster standard errors at the county level and include 95% confidence intervals. Panels are labeled by the outcome measure. Outcomes are measured on a weekly basis.

Figure 5: Cumulative Estimates by Predicted Vaccination Rate

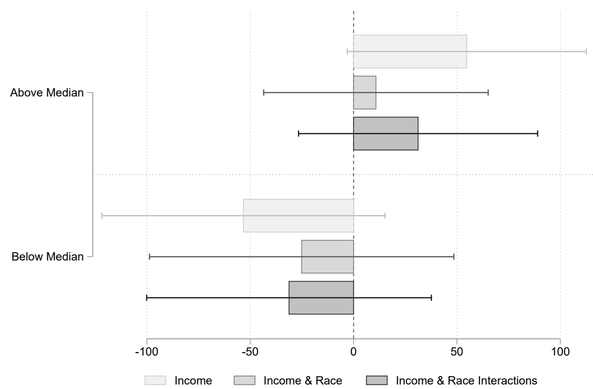
(a) Cases



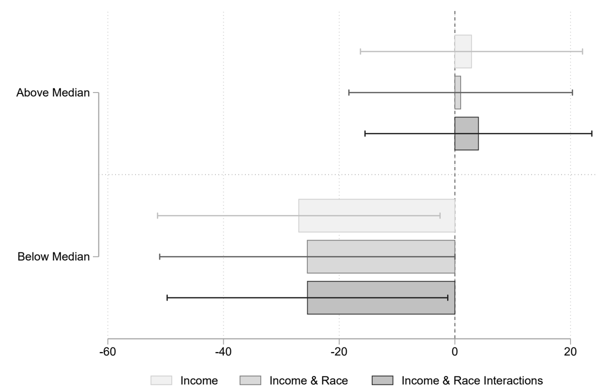
(b) Test Positivity Rate



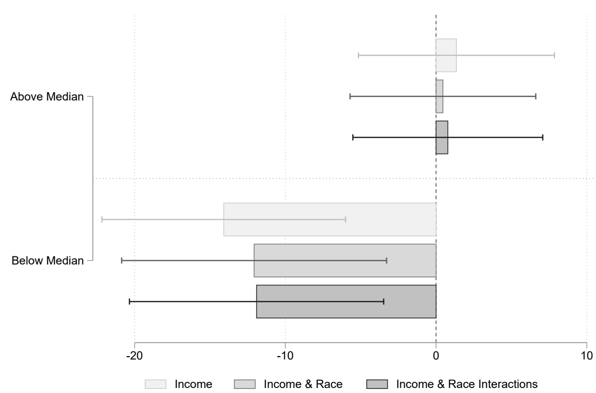
(c) Hospitalizations



(d) ICU patients

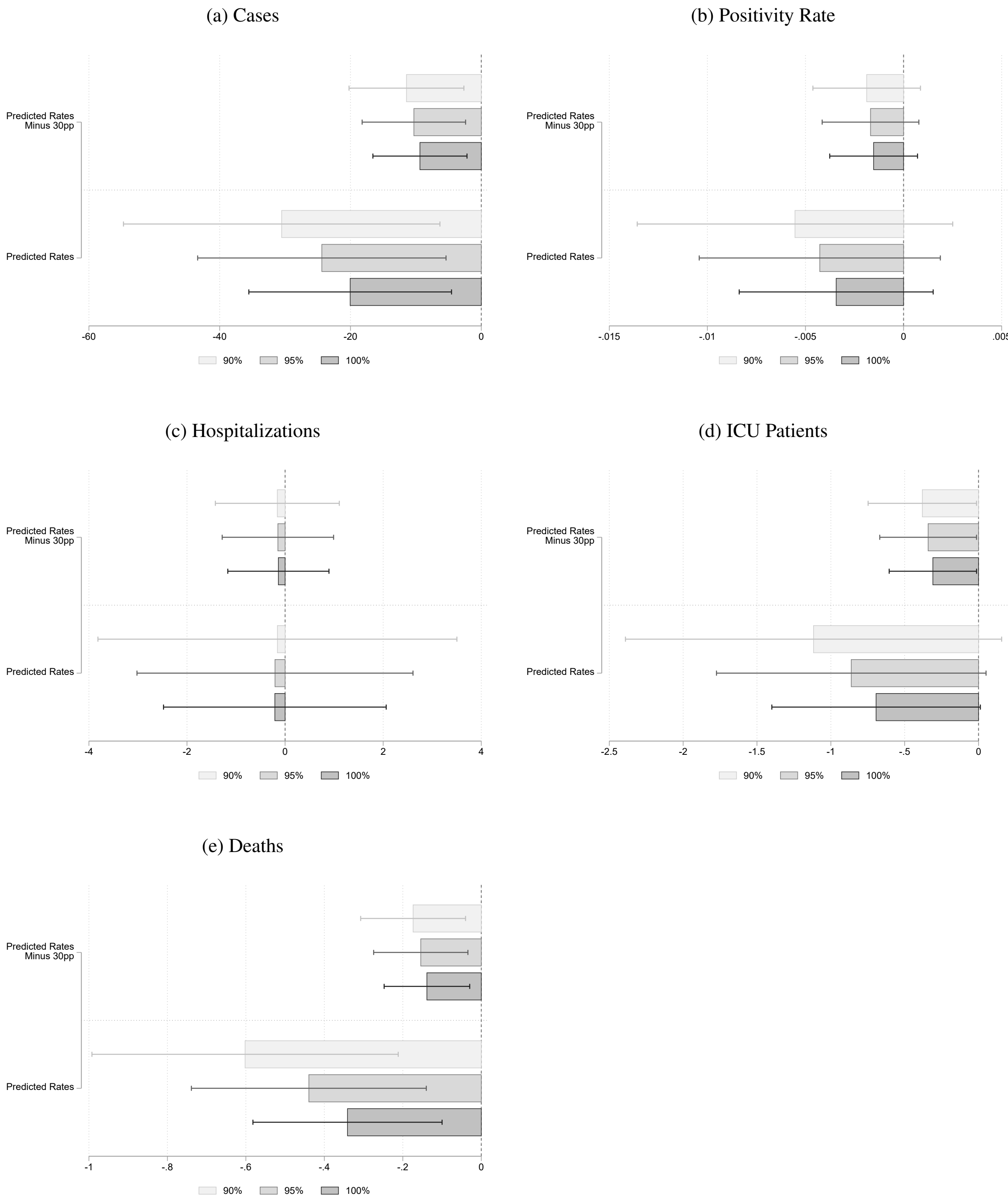


(e) Deaths



Note: These figures show cumulative and average effects of vaccine mandates on COVID-19 outcomes from the week prior to semester start through the 12^{th} week of the semester. These effects are computed separately for college counties with above- or below-median predicted student vaccination rates (median = 76.7%). The predicted vaccination rates are based on the regression shown in Equation 3, where the included regressors are either income, income and race, or income and race plus their interactions, as labeled in the figure. All values per 100k are sums of the event study estimates from -1 through 11. All percentage values are averages of these coefficients. The event studies include county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. We cluster standard errors at the county level and include 95% confidence intervals. Panels are labeled by the outcome measure. Outcomes are measured on a weekly basis.

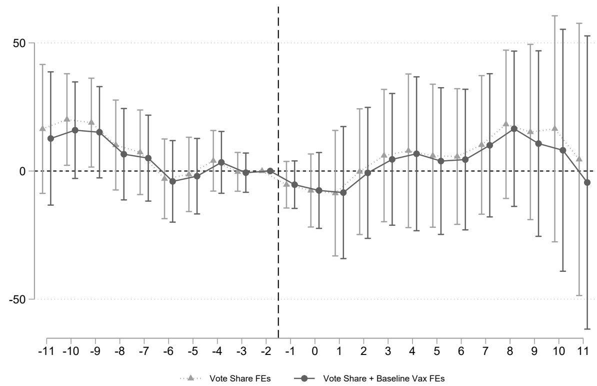
Figure 6: Effect of Increasing the Student Vaccination Rate



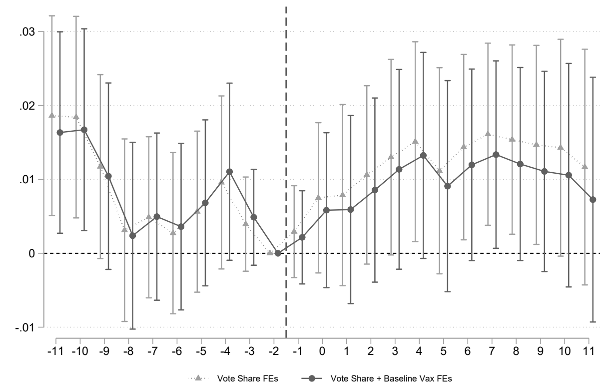
Note: The figures show the effect of a 1pp increase in student vaccinations on each outcome under multiple assumptions. The shading indicates the assumption about vaccination mandate compliance:—either a 90%, 95%, or 100% vaccination rate in the mandated student population. We also show two different assumptions about the vaccination rate in absence of the mandate. The predicted rate is the prediction from the Household Pulse Survey using income, race, and their interactions. This survey overstates vaccination rates relative to other data sources for this age group by approximately 30pp, so we show an alternative set of estimates that assumes vaccination rates without a mandate are 30pp lower than those predicted by the Pulse Survey regressions. We cluster standard errors at the county level and include 95% confidence intervals. Panels are labeled by the outcome measure. Outcomes are measured on a weekly basis.

Figure 7: Placebo Test: 2020 Outcomes for Colleges That Opened In Person

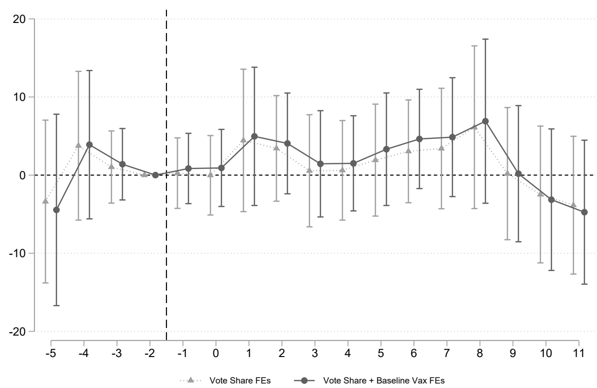
(a) Cases



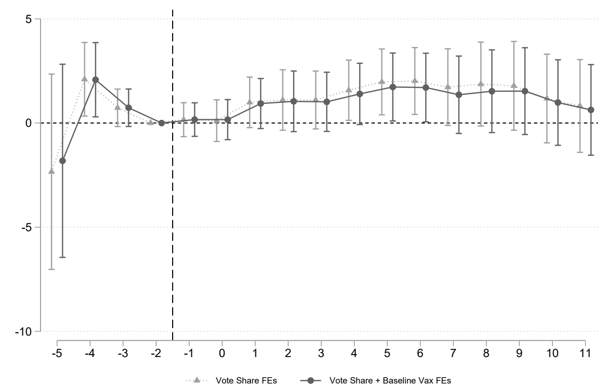
(b) Positivity Rate



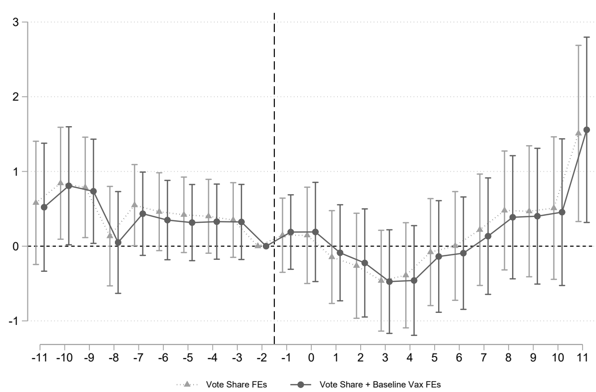
(c) Hospitalizations



(d) ICU Patients



(e) Deaths



Note: These figures show the results of a placebo event study in which we regress 2020 outcomes on 2021 mandates, for colleges that re-opened in person in 2020. All regressions include county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. The line shows the effect of the mandate relative to college counties without mandates. We cluster standard errors at the county level and include 95% confidence intervals. Panels are labeled by the outcome measure.

Table 1: Summary Statistics

	Mandate	No Mandate	Difference	
Population	503,588	188,553	315,035	(57,903)
Population Density	1710	281.1	1,429	(344.6)
% White	77.300	81.981	-4.681	(1.326)
Median Household Income	66,258	53,476	12,781	(1,256)
% Bachelor's Degree	33.737	25.951	7.786	(0.823)
Baseline Vaccination Rate	0.532	0.398	0.134	(0.010)
2016 Democrat Vote Share	0.528	0.377	0.151	(0.013)
New England	0.145	0.007	0.138	(0.022)
New Jersey/New York	0.186	0.007	0.179	(0.024)
Mid-Atlantic	0.227	0.106	0.121	(0.031)
Southeast	0.100	0.320	-0.22	(0.033)
Midwest	0.178	0.324	-0.146	(0.036)
Southwest	0.022	0.148	-0.126	(0.023)
Mountain Plains	0.019	0.056	-0.038	(0.016)
West	0.123	0.032	0.091	(0.023)
Number of Four-Year Colleges	2.524	1.218	1.306	(0.157)
% of Colleges w/ Mandate	84.3	0.0	84.3	(1.5)
% of Colleges Remote in 2020	40.9	20.4	20.5	(3.4)
Number of College Students	18,067	7,650	10,417	(1,786)
Students as Share of Population	0.060	0.072	-0.012	(0.007)
% of Students w/ Mandate	85.1	0.0	85.1	(1.7)
% of Students Remote in 2020	44.4	20.7	23.7	(3.5)
% of Students Living On-Campus	51.1	48.7	2.4	(2.4)
% with Any College Testing Requirement	20.8	3.9	16.9	(2.7)
% with Any College Mask Requirement	94.8	69.0	25.8	(3.1)
	269	284	553	

Note: This table presents mean characteristics of the counties in the analysis. Mandate counties are those with at least one four-year college with a vaccine mandate. Non-mandate counties are home to at least one four-year college, but none of these colleges mandate a COVID-19 vaccine. Standard errors of the difference between mandate and non-mandate counties are given in parentheses. The baseline vaccination rate is measured on August 1, 2021, which is prior to any start date in our sample. It is the vaccination rate for the entire county, not just the student population.

Table 2: Cumulative Results

	Cases per 100k (1)	**Positivity Rate (2)**	**Hosp. per 100k (3)**	**ICU patients per 100k (4)**	**Deaths per 100k (5)**
Panel A. Effect of any vaccine mandate in county					
Effect	-338.6**	-0.004	13.58	-11.37	-5.403**
	(171.9)	(0.004)	(26.64)	(7.426)	(2.599)
Obs.	12,437	12,297	11,864	11,358	12,437
Panel B. Effect of 100% mandate coverage of college students					
Effect	-487.6**	-0.006	2.346	-15.13*	-5.733**
	(194.6)	(0.005)	(29.45)	(7.734)	(2.902)
Obs.	12,437	12,297	11,864	11,358	12,437
Mean	3426.6	0.099	380.10	98.43	42.30
Estimate Type	Sum	Average	Sum	Sum	Sum

Note: The table shows cumulative effects of vaccine mandates on COVID-19 outcomes from the week prior to semester start through the 12^{th} week of the semester. The cumulative measure of the positivity rate, which is the percentage of positive tests, is an average over the event study estimates through week 11. For other outcomes, the cumulative measure is the sum of the event study coefficients. The specification in Panel A considers the effect of having any vaccine mandate in a county, while Panel B considers the share of college students in a county covered by a mandate. Both specifications include county, week, week-by-region, week-by-baseline vaccination rate, and week-by-vote share fixed effects. All standard errors are clustered at the county level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 3: Cumulative Estimates by Predicted Student Vaccination Rate and Student Population Share

	Cases per 100k (1)	**Positivity Rate (2)**	**Hosp. per 100k (3)**	**ICU patients per 100k (4)**	**Deaths per 100k (5)**
Panel A. Below-Median Vax, Above-Median Student Population Share					
Effect	-949.9	-0.012	-57.72	-49.81*	-23.07**
	(481.7)	(0.014)	(65.56)	(22.72)	(7.643)
Obs.	3,053	3,051	2,790	2,675	3,053
Panel B. Below-Median Vax, Below-Median Student Population Share					
Effect	-318.9	-0.005	-4.183	0.476	0.384
	(283.8)	(0.008)	(33.39)	(14.03)	(5.261)
Obs.	3,171	3,171	3,056	2,917	3,171
Panel C. Above-Median Vax, Above-Median Student Population Share					
Effect	-30.05	0.002	10.58	3.381	-3.194
	(225.0)	(0.007)	(38.27)	(13.44)	(4.746)
Obs.	3,192	3,123	3,050	3,004	3,192
Panel D. Above-Median Vax, Below-Median Student Population Share					
Effect	16.51	0.004	65.42	8.677	2.452
	(236.7)	(0.007)	(46.14)	(11.70)	(4.042)
Obs.	2,940	2,871	2,886	2,679	2,940

Note: The table shows cumulative effects from event studies by predicted student vaccination rate (median = 76.7%) and student population share (median = 3.84%). The predicted vaccination rates are based on the regression shown in Equation 3, where the dependent variables include income and race plus their interactions. All event study regressions include county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. All standard errors are clustered at the county level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 4: Cumulative Estimates from Robustness Checks

	Cases per 100k (1)	**Positivity Rate (2)**	**Hosp. per 100k (3)**	**ICU patients per 100k (4)**	**Deaths per 100k (5)**
Panel A. Main Specification					
Effect	-338.6**	-0.004	13.58	-11.37	-5.403**
	(171.9)	(0.004)	(26.64)	(7.43)	(2.599)
Obs.	12,437	12,297	11,864	11,358	12,437
Panel B. Remote in 2020-by-Week FEs					
Effect	-330.5**	-0.003	14.19	-11.54	-5.511**
	(167.7)	(0.004)	(26.64)	(7.50)	(2.621)
Obs.	12,437	12,297	11,863	11,357	12,437
Panel C. Mask Requirement-by-Week Controls					
Effect	-333.4*	-0.004	6.32	-13.46*	-5.381**
	(170.8)	(0.004)	(27.38)	(7.71)	(2.670)
Obs	12,437	12,297	11,864	11,358	12,437
Panel D. Test Requirement-by-Week Controls					
Effect	-342.6**	-0.004	11.62	-11.06	-5.426**
	(174.2)	(0.004)	(26.79)	(7.39)	(2.659)
Obs.	12,437	12,297	11,864	11,358	12,437
Panel E. Weighted by County Population					
Effect	-418.1***	-0.004	-18.45	-7.36	-6.014***
	(161.3)	(0.005)	(19.38)	(6.37)	(2.291)
Obs.	12,437	12,297	11,864	11,358	12,437
Panel F. Weighted by % Students					
Effect	-617.0***	-0.007	-58.52	-29.31**	-12.242**
	(218.0)	(0.007)	(52.10)	(13.50)	(5.488)
Obs.	12,437	12,297	11,864	11,358	12,437
Panel G. Drop Partially Treated					
Effect	-555.3**	-0.008	3.13	-16.92**	-6.833**
	(218.3)	(0.005)	(32.65)	(8.55)	(3.254)
Obs.	10,319	10,225	9,774	9,383	10,319
Panel H. Drop Staff Mandates					
Effect	-222.5	-0.004	6.65	-13.99	-6.303*
	(240.1)	(0.006)	(28.44)	(8.94)	(3.682)
Obs.	8,594	8,593	8,100	7,778	8,594
Panel I. Drop Mid-Semester Mandates					
Effect	-372.2**	-0.003	19.25	-10.57	-5.588**
	(179.4)	(0.004)	(27.98)	(7.65)	(2.748)
Obs.	11,724	11,584	11,174	10,829	11,724
Estimate Type	Sum	Average	Sum	Sum	Sum

Note: The table shows cumulative effects from the robustness checks described in Section 4.3. All regressions include county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. All standard errors are clustered at the county level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 5: Cumulative Estimates for Economic Outcomes

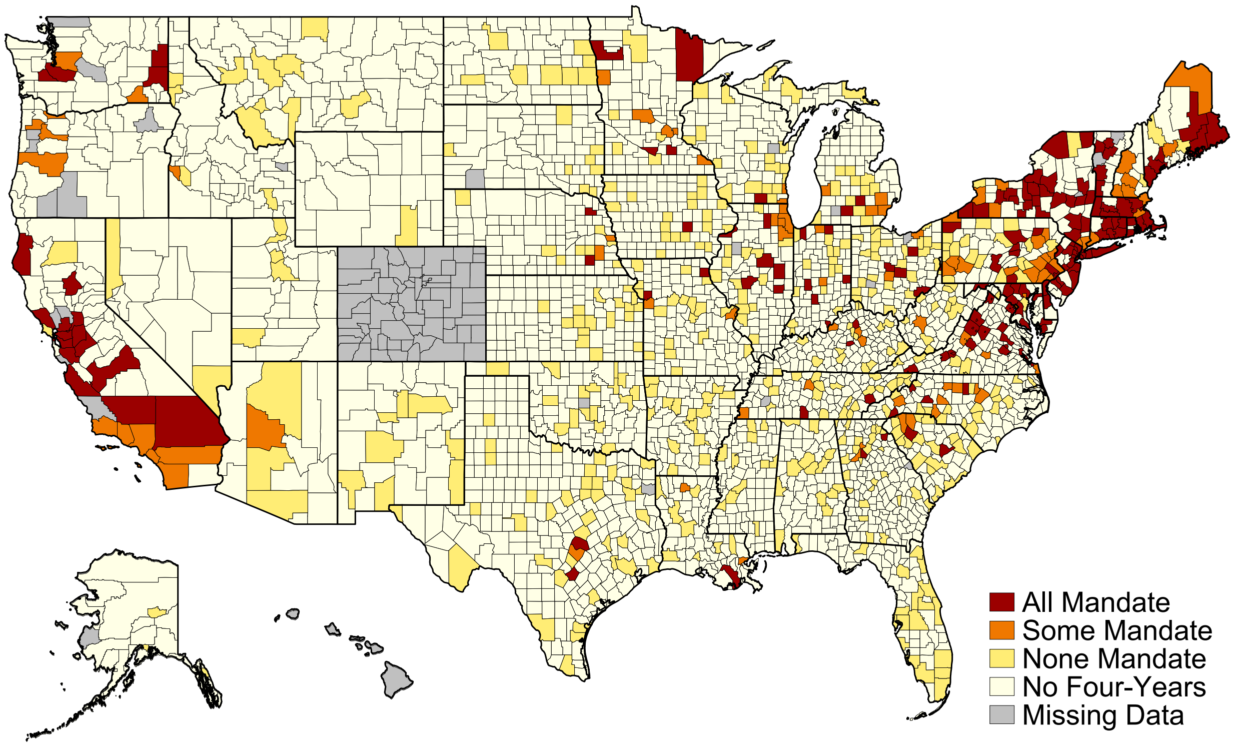
	Restaurant Visits (1)	Cons. Spend. (2)	GPS Retail (3)	GPS Grocery (4)	GPS Parks (5)	GPS Transit (6)	GPS Work (7)	GPS Resid. (8)	GPS Not Home (9)
Panel A. Main									
Effect	306.328	0.011	-0.000	0.000	0.013	0.018	-0.006*	-0.001	0.001
	(696.812)	(0.011)	(0.006)	(0.005)	(0.044)	(0.012)	(0.003)	(0.001)	(0.001)
Obs.	12,003	9,134	11,478	10,909	6,013	8,036	11,908	11,588	11,588
Panel B. Below-Median Vax, Above-Median Student Population Share									
Effect	1509.693	-0.003	-0.005	-0.010	0.038	0.059*	-0.010	-0.005	0.008
	(1999.143)	(0.028)	(0.018)	(0.015)	(0.079)	(0.025)	(0.012)	(0.004)	(0.005)
Obs	2809	1984	2235	2414	547	1253	2708	2521	2521
Panel C. Below-Median Vax, Below-Median Student Population Share									
Effect	1242.032	0.033	0.017	0.031*	0.154*	0.049	-0.002	-0.001	0.001
	(1250.598)	(0.019)	(0.011)	(0.013)	(0.067)	(0.030)	(0.004)	(0.002)	(0.002)
Obs	3060	2545	2848	3033	1486	2011	3079	3036	3036
Panel D. Above-Median Vax, Above-Median Student Population Share									
Effect	-1493.911	-0.018	-0.010	-0.023*	-0.164**	0.021	-0.017*	0.001	-0.001
	(1088.884)	(0.024)	(0.009)	(0.009)	(0.060)	(0.033)	(0.007)	(0.001)	(0.002)
Obs	3133	2232	2823	3054	1795	2261	3100	3008	3008
Panel E. Above-Median Vax, Below-Median Student Population Share									
Effect	-878.099	0.022	0.000	-0.009	0.034	-0.008	0.000	0.001	-0.002
	(1429.334)	(0.017)	(0.008)	(0.008)	(0.091)	(0.017)	(0.003)	(0.001)	(0.001)
Obs	2922	2275	2892	2894	2098	2402	2940	2940	2940

Note: The table shows cumulative effects on economic outcomes from event studies by predicted student vaccination rate (median = 76.7%) and student population share (median = 3.84%). The predicted vaccination rates are based on the regression shown in Equation 3, where the dependent variables include income and race plus their interactions. All event study regressions include county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. All standard errors are clustered at the county level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Online Appendix

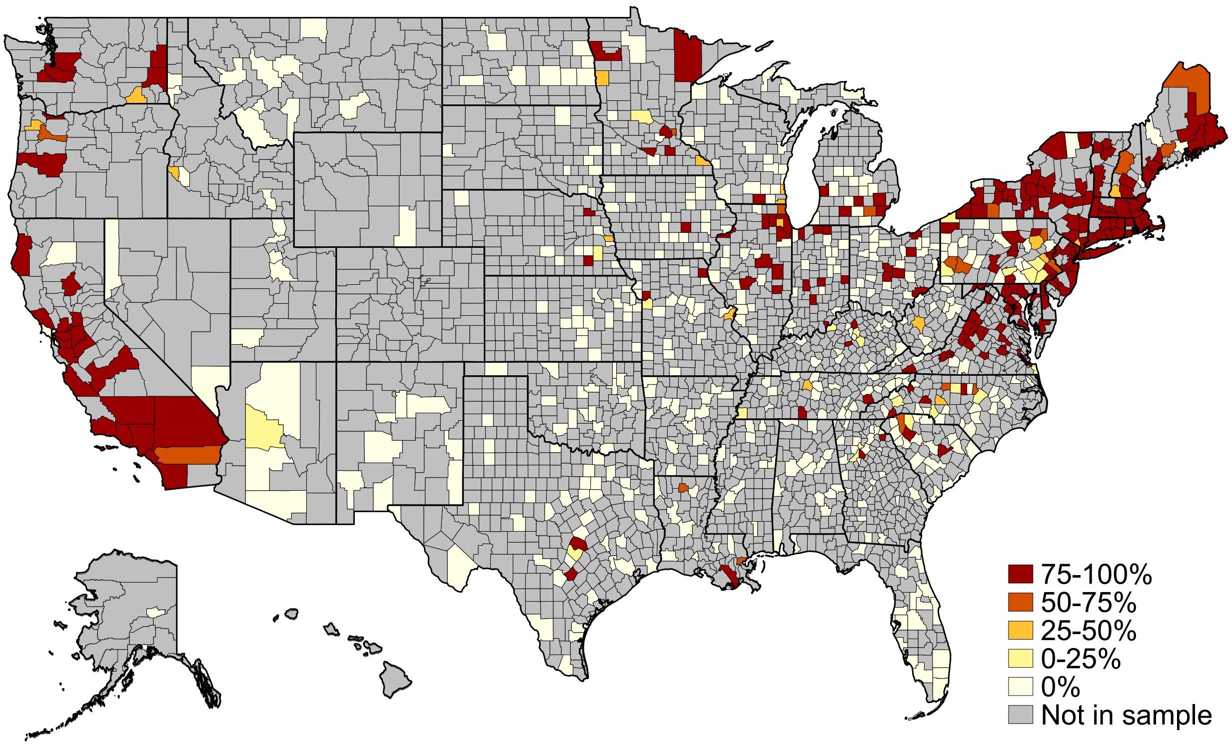
A Additional Figures & Tables

Figure A.1: Map of College Vaccine Mandates



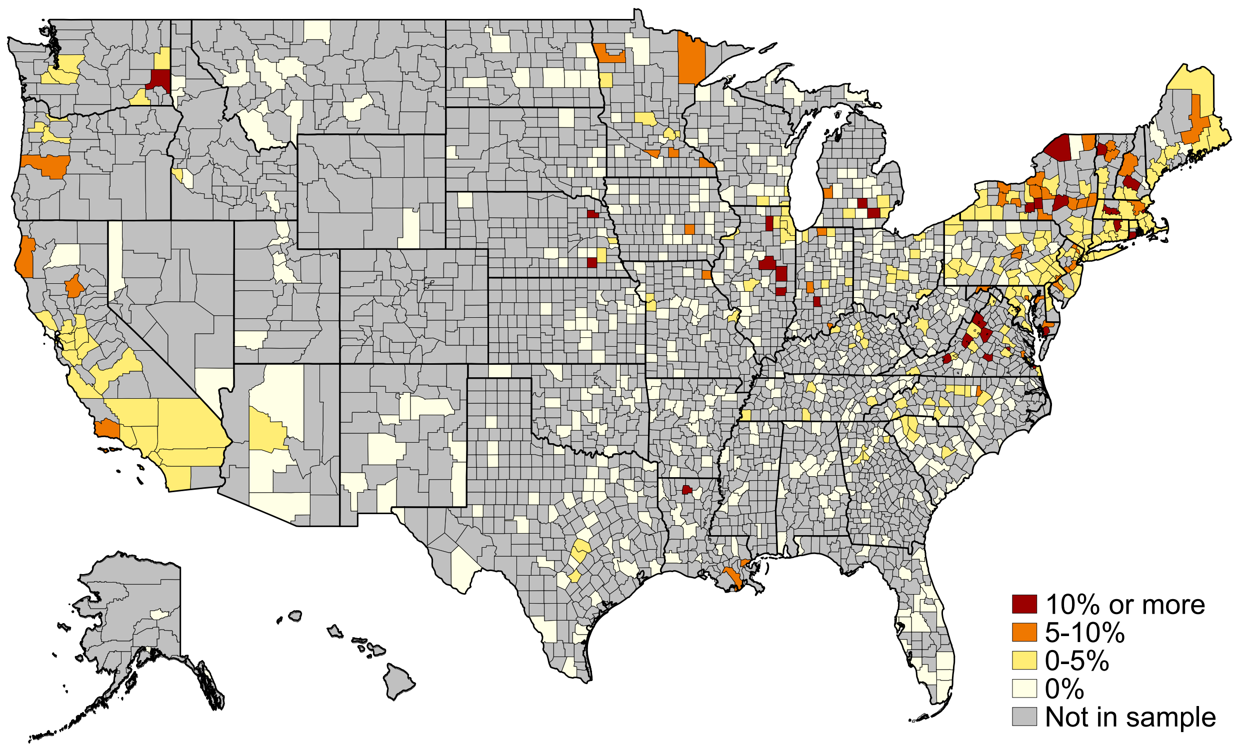
Note: This county-level map shows whether the county has a four-year college in the sample, and whether any of these colleges had a vaccine mandate. Counties with incomplete or inconsistent vaccination data are excluded. In the analysis, states that have no counties with vaccine mandates are excluded as well.

Figure A.2: Share of Students Covered by Vaccine Mandates



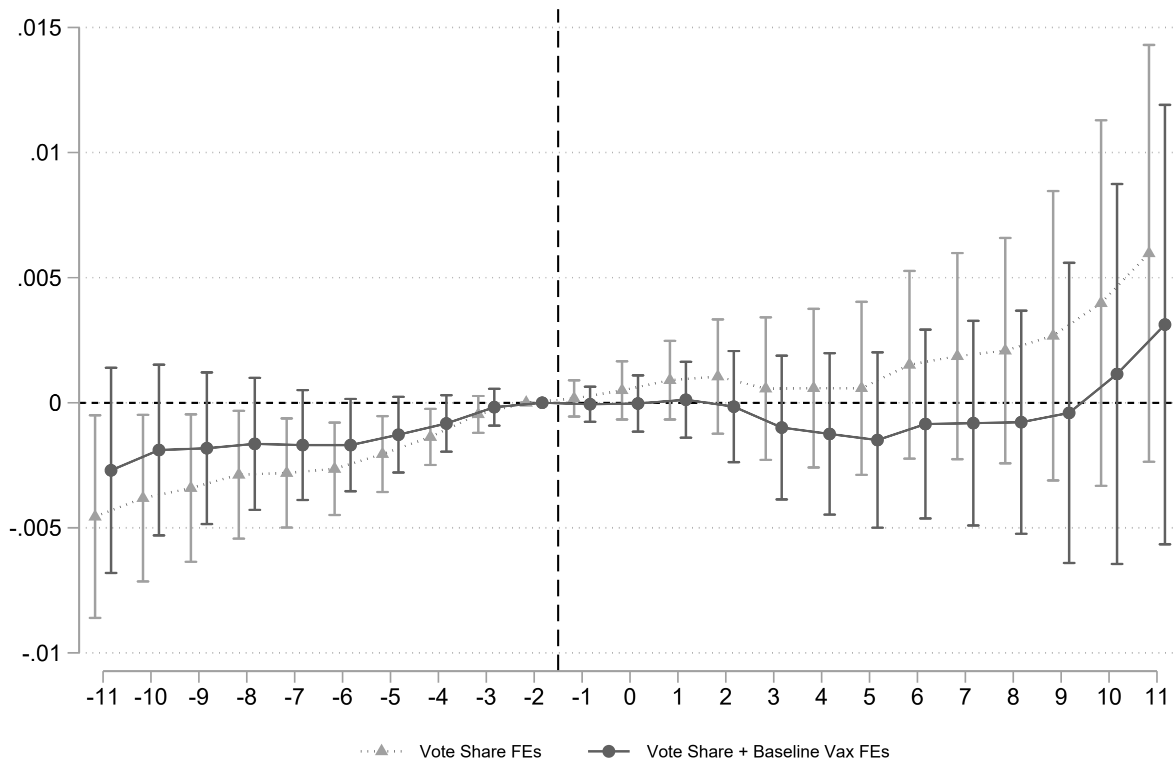
Note: This county-level map shows the proportion of four-year students covered by a mandate in each county. Counties that do not have four-year colleges and counties with incomplete or inconsistent vaccine data are excluded. In analysis, we also exclude the states that have no colleges with mandates.

Figure A.3: Mandate-Covered Students as Share of Total Population



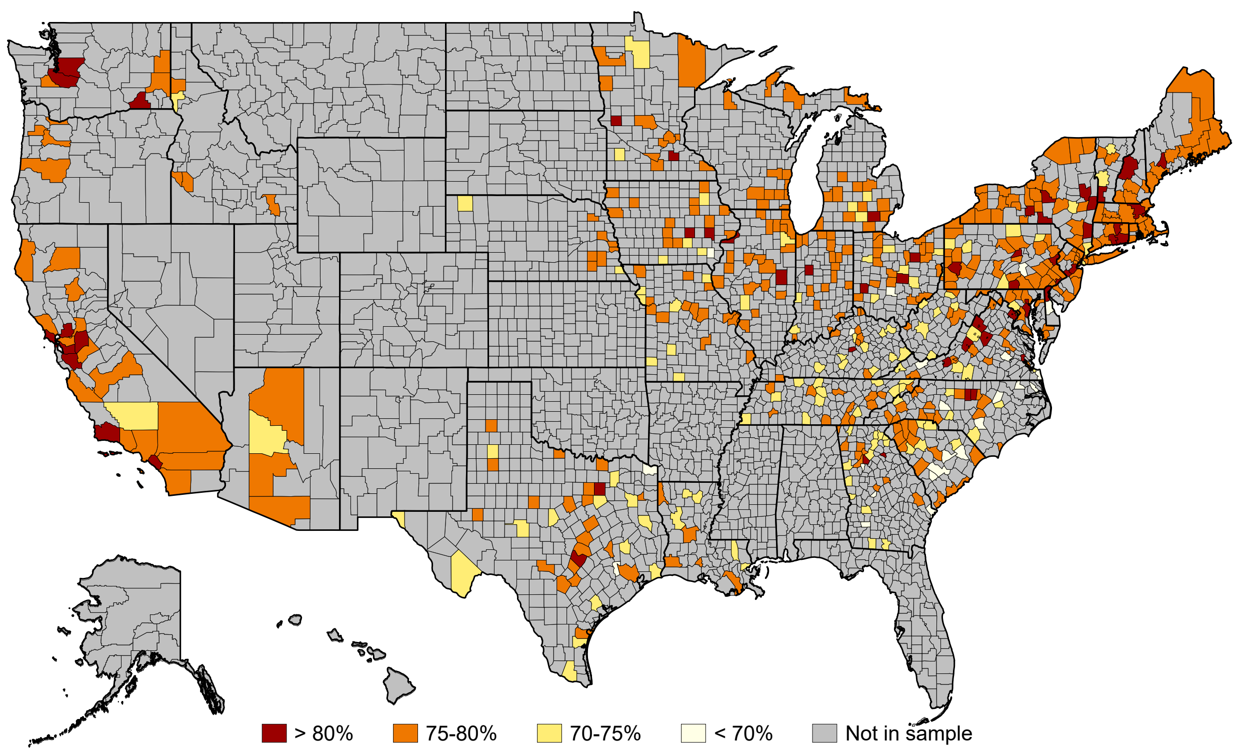
Note: This county-level map shows the four-year students covered by a mandate as a fraction of population in each county. Counties that do not have four-year colleges and counties with incomplete or inconsistent vaccine data are excluded. In analysis, we also exclude the states that have no colleges with mandates.

Figure A.4: County Vaccination Rate Event Study



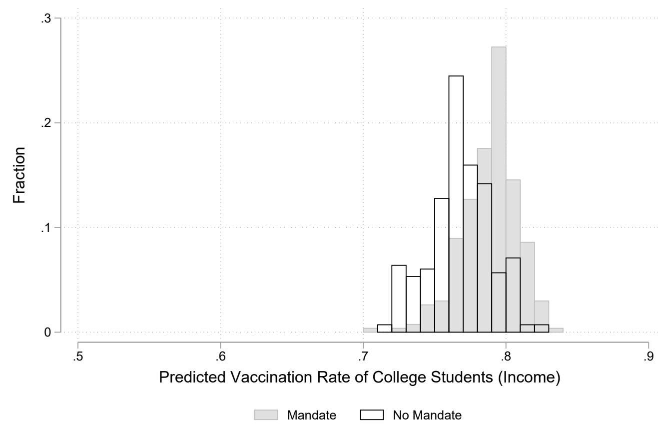
Note: The dark line in this figure shows the results of an event study that includes county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. The light gray line shows the estimated effects when we exclude the week-by-baseline vaccination rate fixed effects. The estimates show the effect of the mandate relative to college counties without mandates. The outcome measure is the vaccination rate in the county. We cluster standard errors at the county level and include 95% confidence intervals.

Figure A.5: Predicted Vaccination Rates by County

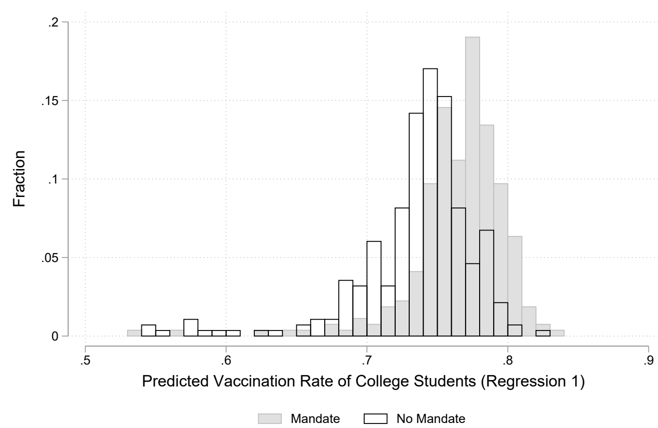


Note: This map shows the predicted vaccination rate among college students based on a regression of Pulse Survey vaccination responses on income, race and interactions as described in Section 3.2

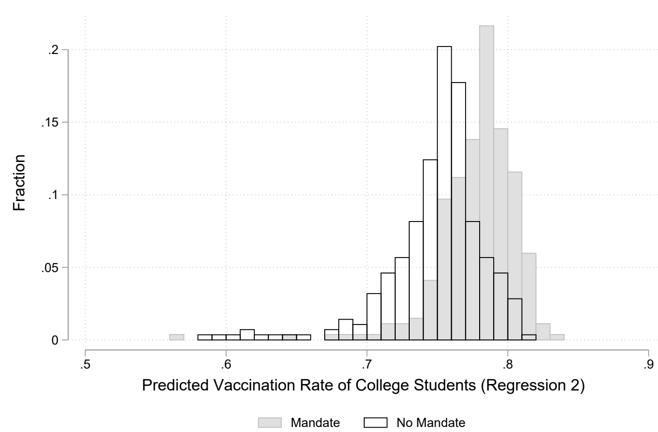
Figure A.6: Distribution of Predicted Vaccination by Mandate Status



(a) Prediction Based on Income Only



(b) Prediction Based on Income and Race

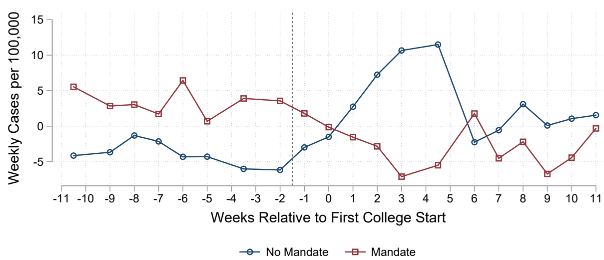


(c) Prediction Based on Income, Race, and Interactions

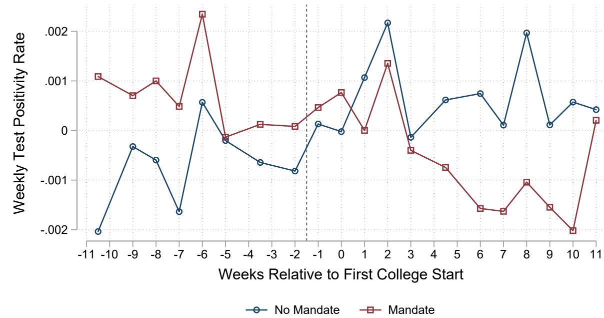
Note: The figures show the distribution of the predicted vaccination rate among college students based on regressions of Pulse Survey vaccination responses on income, race and interactions as described in Section 3.2. The three panels vary in the characteristics included in the regression. In Panel (a), the regression includes only income. In Panels (b) and (c), we add race and the interactions between race and income, respectively.

Figure A.7: Residual Plots

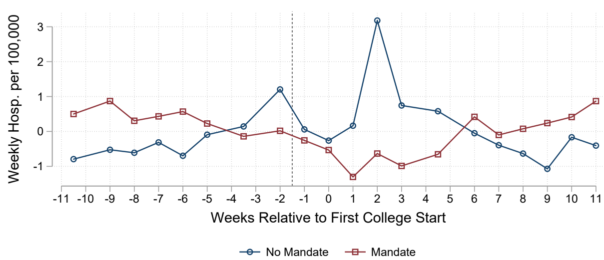
(a) Cases Residuals



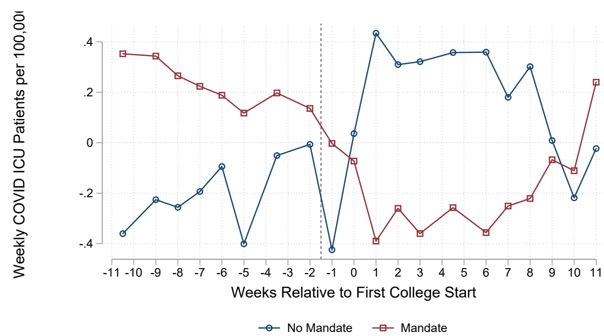
(b) Positivity Rate Residuals



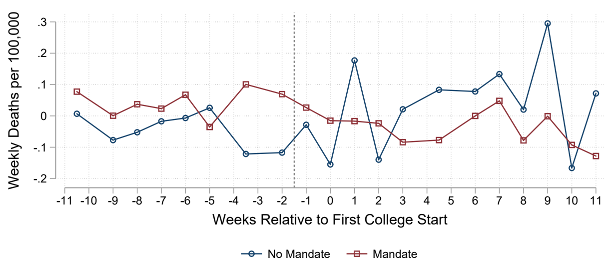
(c) Hospitalizations Residuals



(d) ICU patients Residuals



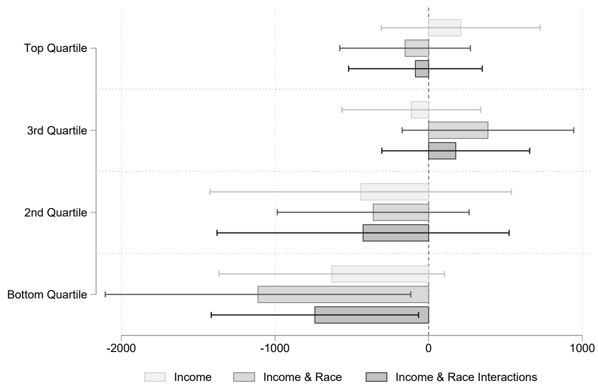
(e) Deaths Residuals



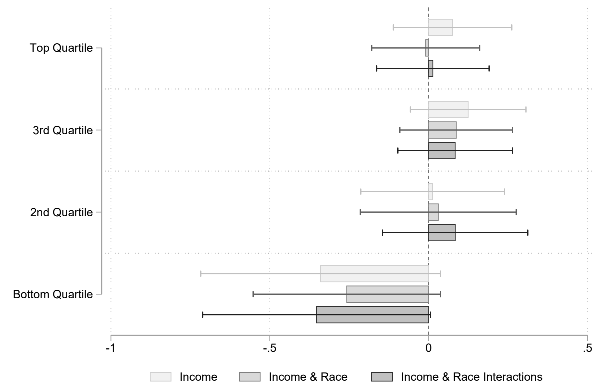
Note: These figures plot the residuals from a regression of COVID-19 outcome measures on county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. The levels for college counties with (without) a mandate are given by the square (circular) markers. Captions provide the outcome measure for each panel.

Figure A.8: Cumulative Estimates by Predicted Vax Rate Quartiles

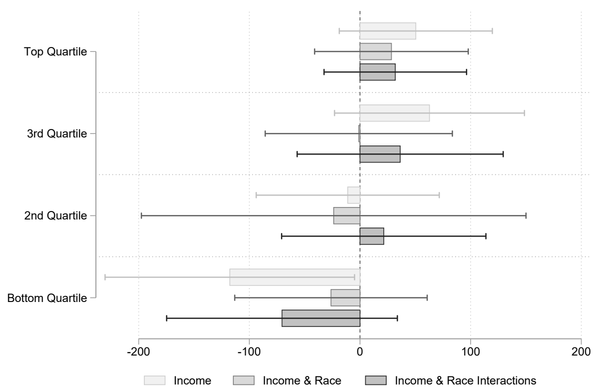
(a) Cases



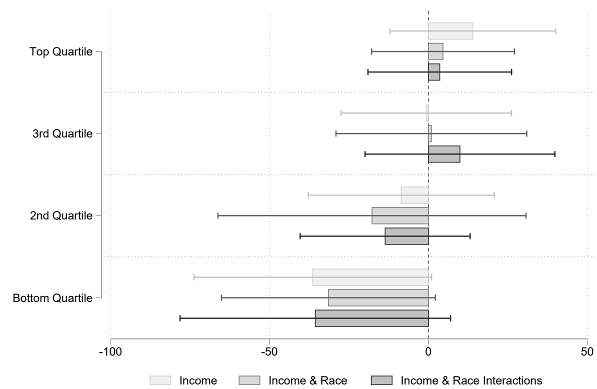
(b) Test Positivity Rate



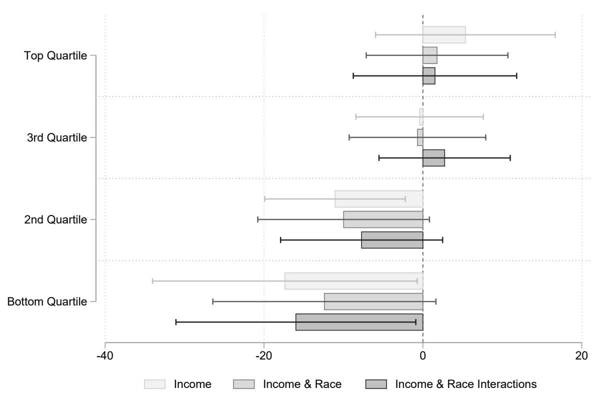
(c) Hospitalizations



(d) ICU Patients



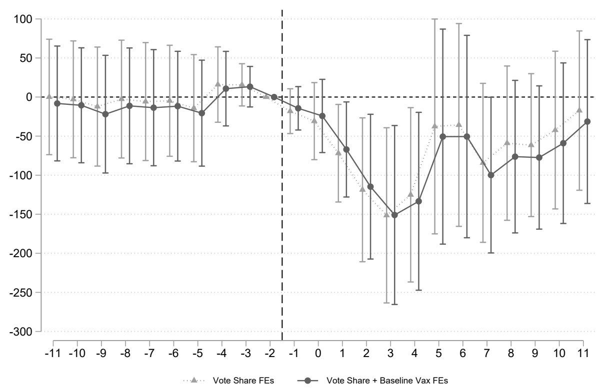
(e) Deaths



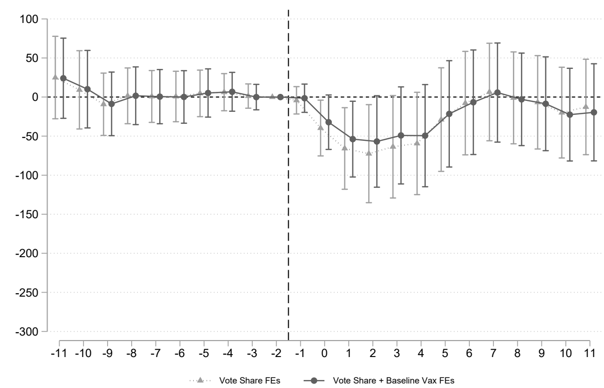
Note: These figures show cumulative and average effects of vaccine mandates on COVID-19 outcomes from the week prior to semester start through the 12^{th} week of the semester. These effects are computed separately for college counties by quartile of predicted vaccination rate. The predicted vaccination rates are based on the regression shown in Equation 3, where the included regressors are either income, income and race, or income and race plus their interactions, as labeled in the figure. All values per 100k are sums of the event study estimates from -1 through 11. All percentage values are averages of these coefficients. The event studies include county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. We cluster standard errors at the county level and include 95% confidence intervals. Panels are labeled by the outcome measure. Outcomes are measured on a weekly basis.

Figure A.9: Event Study: Cases, by Predicted Student Vaccination Rate and Student Population Share

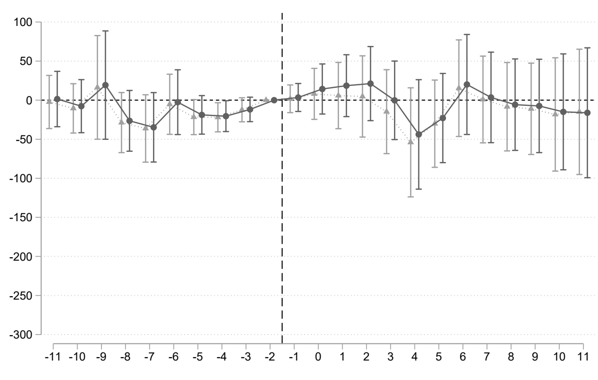
(a) Below-Median Vax, Above-Median Student Pop. Share



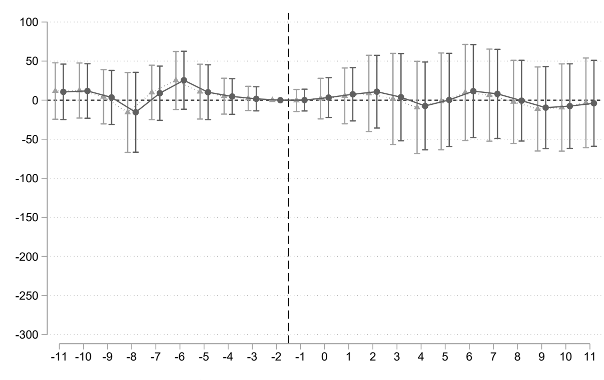
(b) Below-Median Vax, Below-Median Student Pop. Share



(c) Above-Median Vax, Above-Median Student Pop. Share



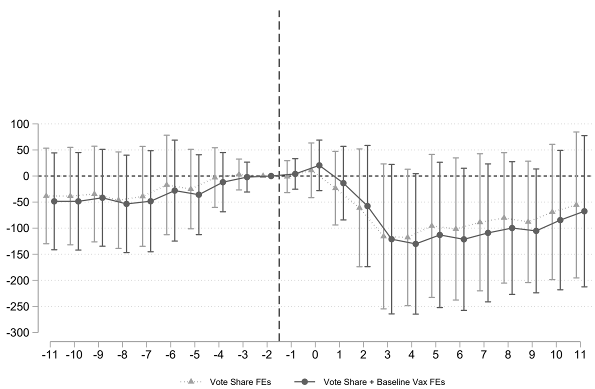
(d) Above-Median Vax, Below-Median Student Pop. Share



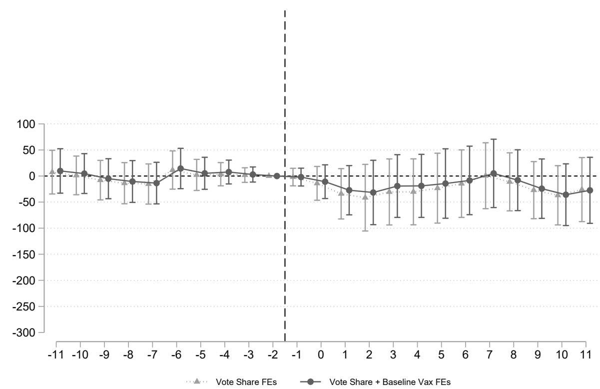
Note: These figures show the results of event studies with cases per 100k as the outcome measure, splitting the sample into above- vs. below-predicted student vaccination rates (median = 76.7%) and above- or below-median student population share (median = 3.84%). Predicted vaccination is based on income, race and the interactions of income and race. Each event study includes county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. The lines shows the effect of the mandate relative to college counties without mandates. We cluster standard errors at the county level and include 95% confidence intervals.

Figure A.10: Event Study: Cases, by SAT and Student Population Share

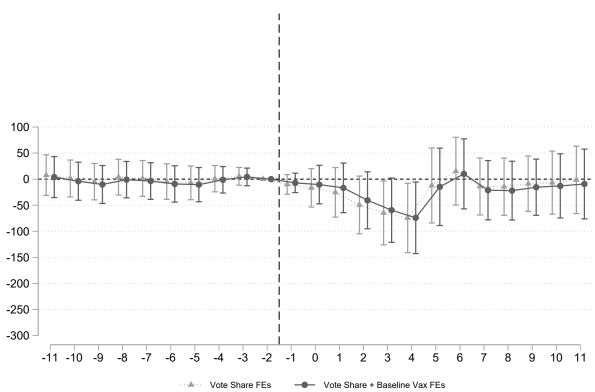
(a) Below-Median SAT, Above-Median Student Pop. Share



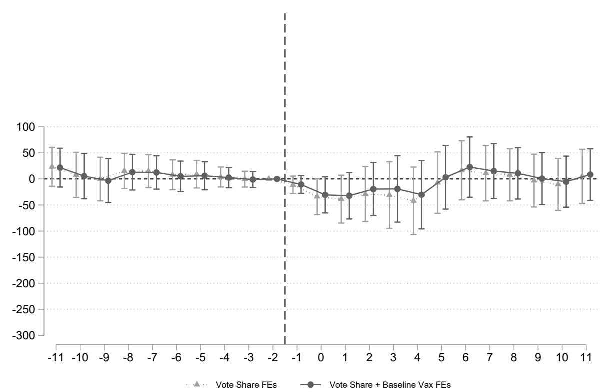
(b) Below-Median SAT, Below-Median Student Pop. Share



(c) Above-Median SAT, Above-Median Student Pop. Share



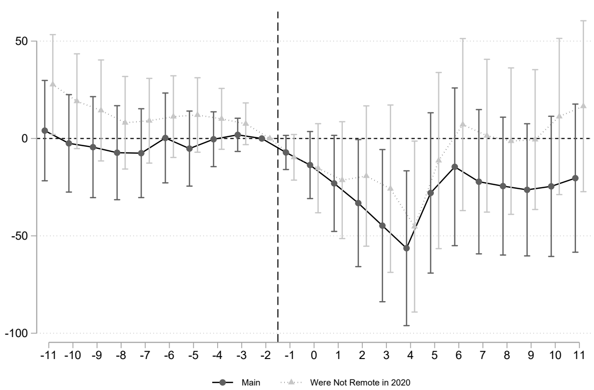
(d) Above-Median SAT, Below-Median Student Pop. Share



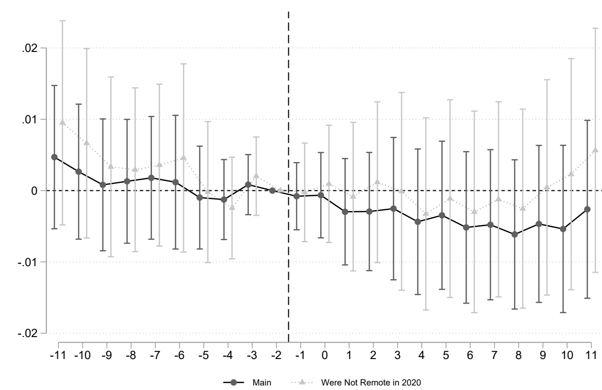
Note: These figures show the results of event studies with COVID-19 cases per 100k as the outcome measure, splitting the sample into above- vs. below- median county-average SAT score (median = 1108) and above- or below-median student population share (median = 3.84%). Each event study includes county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. The line shows the effect of the mandate relative to college counties without mandates. We cluster standard errors at the county level and include 95% confidence intervals.

Figure A.11: 2021 Event Studies by 2020 Instruction Mode

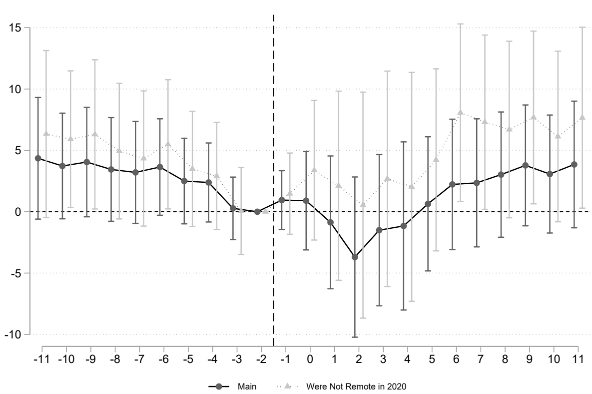
(a) Cases



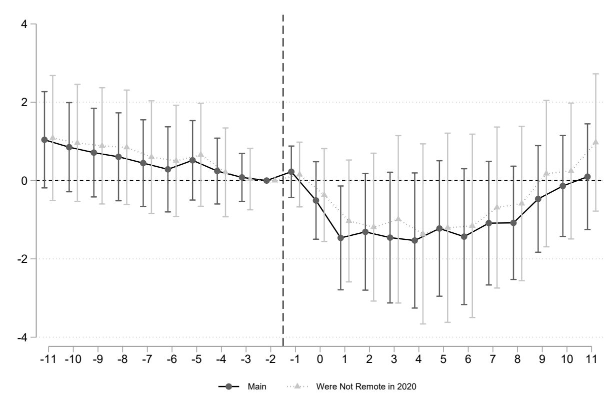
(b) Positivity Rate



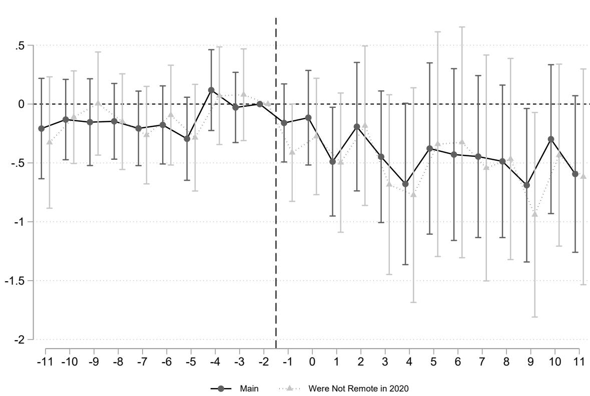
(c) Hospitalizations



(d) ICU Patients

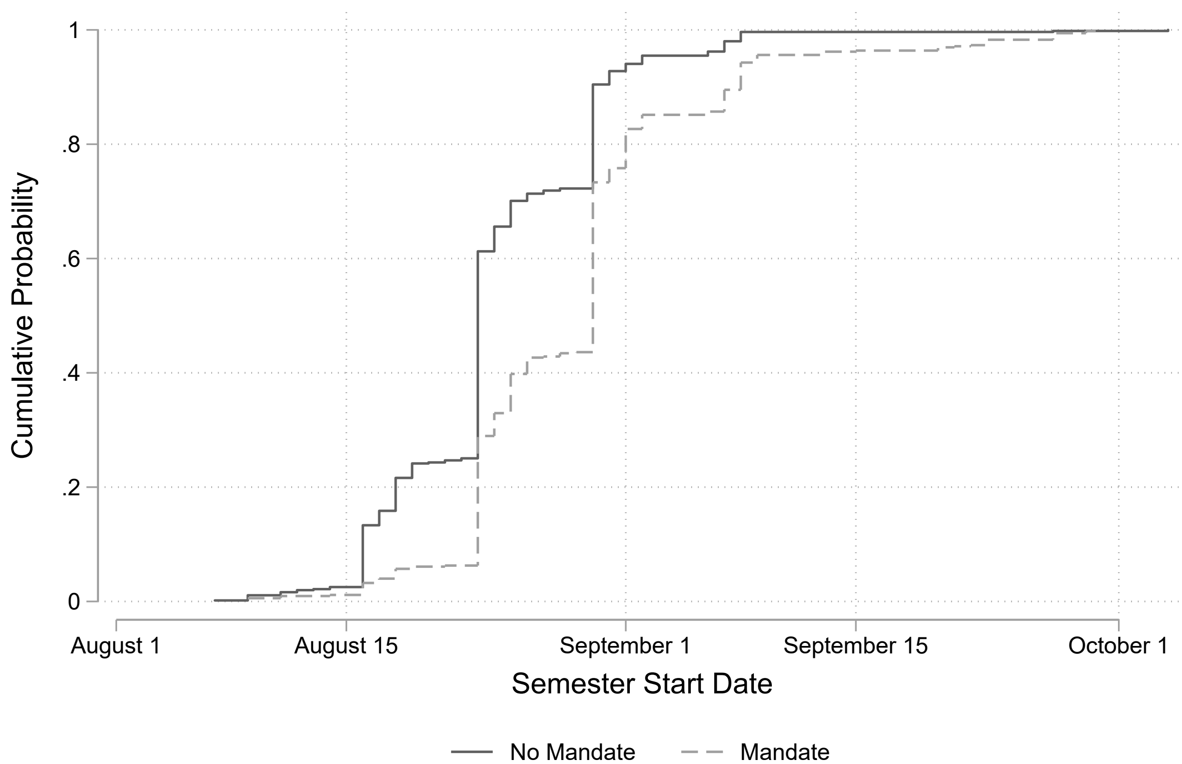


(e) Deaths



Note: These figures show the results of a placebo event study in which we regress 2020 outcomes on 2021 mandates, for colleges that re-opened in person in 2020. All regressions include county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. The line shows the effect of the mandate relative to college counties without mandates. We cluster standard errors at the county level and include 95% confidence intervals. Panels are labeled by the outcome measure.

Figure A.12: Semester Start Dates



Note: This figure shows the cumulative probability that a college's semester has started by the date indicated on the X axis, among colleges with and without a mandate.

Table A.1: Event Study Estimates

	Cases per 100k (1)	**Positivity Rate (2)**	**Hosp. per 100k (3)**	**ICU patients per 100k (4)**	**Deaths per 100k (5)**
Pre: -11	4.047	0.005	4.353*	1.042*	-0.208
	(13.118)	(0.005)	(2.522)	(0.625)	(0.217)
Pre: -10	-2.493	0.003	3.727*	0.852	-0.132
	(12.734)	(0.005)	(2.192)	(0.579)	(0.174)
Pre: -9	-4.439	0.001	4.048*	0.714	-0.154
	(13.199)	(0.005)	(2.271)	(0.576)	(0.188)
Pre: -8	-7.299	0.001	3.446	0.607	-0.146
	(12.291)	(0.004)	(2.150)	(0.571)	(0.164)
Pre: -7	-7.538	0.002	3.205	0.446	-0.206
	(11.611)	(0.004)	(2.114)	(0.563)	(0.161)
Pre: -6	0.273	0.001	3.643*	0.286	-0.177
	(11.743)	(0.005)	(2.000)	(0.553)	(0.169)
Pre: -5	-5.183	-0.001	2.501	0.517	-0.295
	(9.807)	(0.004)	(1.775)	(0.516)	(0.180)
Pre: -4	-0.385	-0.001	2.384	0.243	0.119
	(7.165)	(0.003)	(1.638)	(0.428)	(0.175)
Pre: -3	1.875	0.001	0.276	0.082	-0.029
	(4.339)	(0.002)	(1.296)	(0.312)	(0.152)
Post: -1	-7.174	-0.001	0.949	0.226	-0.160
	(4.464)	(0.002)	(1.219)	(0.334)	(0.169)
Post: 0	-13.636	-0.001	0.901	-0.508	-0.116
	(8.766)	(0.003)	(2.043)	(0.504)	(0.205)
Post: 1	-23.058*	-0.003	-0.866	-1.464**	-0.489**
	(12.557)	(0.004)	(2.754)	(0.675)	(0.235)
Post: 2	-33.181**	-0.003	-3.696	-1.310*	-0.192
	(16.607)	(0.004)	(3.323)	(0.757)	(0.278)
Post: 3	-44.751**	-0.003	-1.504	-1.456*	-0.448
	(19.890)	(0.005)	(3.136)	(0.849)	(0.285)
Post: 4	-56.344***	-0.004	-1.158	-1.530*	-0.679*
	(20.234)	(0.005)	(3.488)	(0.878)	(0.349)
Post: 5	-27.954	-0.003	0.643	-1.224	-0.377
	(20.951)	(0.005)	(2.782)	(0.880)	(0.370)
Post: 6	-14.543	-0.005	2.228	-1.432	-0.429
	(20.609)	(0.005)	(2.705)	(0.883)	(0.372)
Post: 7	-22.197	-0.005	2.353	-1.087	-0.446
	(18.859)	(0.005)	(2.656)	(0.803)	(0.350)
Post: 8	-24.449	-0.006	3.026	-1.079	-0.486
	(18.015)	(0.005)	(2.597)	(0.736)	(0.330)
Post: 9	-26.358	-0.005	3.776	-0.469	-0.689**
	(17.270)	(0.006)	(2.507)	(0.693)	(0.332)
Post: 10	-24.579	-0.005	3.072	-0.138	-0.298
	(18.324)	(0.006)	(2.447)	(0.656)	(0.322)
Post: 11	-20.361	-0.003	3.851	0.098	-0.594*
	(19.362)	(0.006)	(2.627)	(0.687)	(0.339)
Constant	175.161***	0.082***	27.319***	5.196***	1.734***
	(12.293)	(0.004)	(3.292)	(0.913)	(0.200)
Obs.	12,437	12,297	11,864	11,358	12,437
R-squared	0.775	0.814	0.717	0.720	0.570

Note: This table shows the event study estimates that correspond to those shown in Figure 2. The rows are labeled by the number of weeks pre- or post-semester start. The estimates are relative to non-mandate college counties. All regressions include county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election.

Table A.2: Cumulative Estimates by SAT and Student Population Share

	Cases per 100k (1)	**Positivity Rate (2)**	**Hosp. per 100k (3)**	**ICU patients per 100k (4)**	**Deaths per 100k (5)**
Panel A. Below-Median SAT, Above-Median Student Population Share					
Effect	-998.4	-0.022	-135.3*	-41.26	-16.38*
	(640.4)	(0.014)	(62.73)	(27.17)	(7.563)
Obs.	2,342	2,342	2,104	1,989	2,342
Panel B. Below-Median SAT, Below-Median Student Population Share					
Effect	-222.9	-0.006	71.59	5.109	1.727
	(272.7)	(0.007)	(52.87)	(13.85)	(5.762)
Obs.	3,029	3,006	2,960	2,707	3,029
Panel C. Above-Median SAT, Above-Median Student Population Share					
Effect	-294.2	-0.003	-13.70	-20.87	-8.887
	(242.0)	(0.007)	(40.91)	(12.37)	(5.113)
Obs.	3,883	3,812	3,718	3,672	3,883
Panel D. Above-Median SAT, Below-Median Student Population Share					
Effect	-86.686	0.001	58.316	3.816	2.319
	(244.8)	(0.006)	(45.38)	(12.58)	(4.269)
Obs.	3,146	3,100	3,050	2,958	3,146
Estimate Type	Sum	Average	Sum	Sum	Sum

Note: The table shows cumulative effects from event studies by county-average college SAT score (median = 1108) and student population share (median = 3.84%). All event study regressions include county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. All standard errors are clustered at the county level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table A.3: Cumulative Estimates of the Effect of College Mask Mandates

	Cases per 100k (1)	**Positivity Rate (2)**	**Hosp. per 100k (3)**	**ICU patients per 100k (4)**	**Deaths per 100k (5)**
Effect	186.6	0.009	60.61	13.30	2.938
	(234.1)	(0.006)	(43.00)	(12.93)	(3.703)
Obs.	6,474	6,473	6,129	5,876	6,474
Estimate Type	Sum	Average	Sum	Sum	Sum

Note: The table shows the cumulative effect of college mask mandates, estimated using the sample of college counties with no vaccination requirement. The cumulative effects are calculated by summing event study coefficients from the week prior to semester start through the 12th week of the semester. All event study regressions include county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. All standard errors are clustered at the county level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table A.4: Distribution of Effects with One State Left Out

Outcome	**max**	**p75**	**p50**	**p25**	**min**
Cases	-172.1	-326.9	-334.4	-346.5	-422.7
	(127.9)	(186.1)	(172.1)	(177.0)	(175.1)
Positivity Rate	-0.002	-0.003	-0.004	-0.004	-0.005
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Hospitalizations	22.18	16.97	13.81	12.58	-6.331
	(27.66)	(28.52)	(26.66)	(26.78)	(25.42)
ICU Patients	-7.471	-10.90	-11.38	-11.94	-14.40
	(7.497)	(7.617)	(7.433)	(7.424)	(7.452)
Deaths	-3.868	-5.161	-5.419	-5.56	-6.639
	(2.655)	(2.636)	(2.577)	(2.654)	(2.694)

Note: The table shows percentiles from the distribution of estimated effects using our main specification but leaving out one state from the analysis at a time. All standard errors are clustered at the county level.

Table A.5: Difference in Differences Estimates by Week of Semester Start

	Main **(1)**	**Weeks 33-35** **(2)**	**Week 33** **(3)**	**Week 34** **(4)**	**Week 35** **(5)**	**Weighted Avg.** **(6)**
Panel A. Cases						
Effect	-338.6**	-374.9**	-721.4	-194.0	-18.06	-267.2*
	(171.9)	(180.9)	(496.5)	(179.1)	(238.1)	(150.4)
Obs.	12,437	11,751	2,530	6,440	2,737	11,753
Panel B. Positivity Rate						
Effect	-0.046	-0.030	-0.103	-0.018	-0.015	-0.036
	(0.054)	(0.055)	(0.169)	(0.077)	(0.091)	(0.058)
Obs.	12,297	11,611	2,530	6,392	2,645	11,613
Panel C. Hospitalizations						
Effect	13.56	-4.604	-98.09*	1.806	77.08	-2.122
	(26.64)	(25.40)	(58.29)	(24.00)	(93.80)	(27.51)
Obs.	11,864	11,260	2,369	6,255	2,592	11,262
Panel D. ICU patients						
Effect	-11.37	-15.71**	-48.16**	-1.516	-9.361	-13.54**
	(7.426)	(7.495)	(18.754)	(8.707)	(13.037)	(6.714)
Obs.	11,358	10,754	2,300	5,864	2,546	10,756
Panel E. Deaths						
Effect	-5.403**	-5.998**	-5.747	-4.231	-4.209	-4.556
	(2.599)	(2.689)	(8.983)	(3.035)	(5.859)	(2.801)
Obs.	12,437	11,751	2,530	6,440	2,737	11,753

Note: The table shows cumulative effects by the week of semester start as described in Section 4.3. All regressions include county and week fixed effects, week-by-region fixed effects, week-by-baseline vaccination rate fixed effects, and week-by-vote share fixed effects, where the vote share is the county-level Democratic vote share in the 2016 presidential election. All standard errors are clustered at the county level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.