# The Health and Employment Effects of Employer Vaccination Mandates

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**Abstract**

Background: Many employers implemented COVID-19 vaccination mandates to protect employees and customers. This study estimates the health and employment effects of 13 chain-level (581 facilities) employer vaccination mandates in the nursing home industry, where low staff vaccination coverage may have posed a risk to patients.

Methods: Using administrative data, we performed a retrospective cohort study using an event study design that compared changes in clinical and employment outcomes occurring around the time of mandate announcement at nursing homes that implemented mandates to contemporaneous changes in nursing homes without a mandate.

Findings: Nursing homes implementing a vaccination mandate increased staff vaccination coverage by 13.7 percentage points (95%CI:8.7,18.7) relative to comparison facilities. After mandate announcement, nursing homes experienced a small reduction in staffing levels of 0.45 certified nursing assistants (CNAs) per 100 beds (95%CI:-0.9,-0.0) and approximately two minutes of CNA care per resident day. Nursing homes also saw a small increase in separations on the week of enforcement (0.06 additional separations per 100 beds; 95%CI:0.0,0.1) that were partially offset by new hires. In the six months following mandate announcements, nursing homes with mandates had 3.5 (95%CI:-4.8,-2.3) fewer total staff COVID cases per 100 beds and 4.4(95%CI:-5.3,-3.5) and 0.5 (95%CI:-0.8,-0.1) fewer resident COVID cases and deaths per 100 beds, respectively.

Interpretation: Employer vaccination mandates were effective at increasing staff vaccination rates, reducing the number of staff and resident COVID cases, and reducing the number of resident COVID deaths, with limited adverse staffing effects.

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Vaccines have been highly effective at reducing COVID-19 infection, disease severity, and viral transmission[1–5]. As COVID-19 vaccines became widely available in early 2021, many organizations in healthcare and other industries considered mandating vaccination for their workers or even customers rather than waiting for government mandates[6–9]. Organizations considering such "employer mandates" worried that these mandates could lead to substantial turnover and staffing shortages if employees chose to quit rather than comply. In the absence of a government-imposed mandate, staff subjected to an organizational mandate from their current employer could find alternative employment from a competitor without a mandate.

The tension between the costs and benefits of employer mandates were particularly salient in the healthcare industry, where close contact entails risks for both patients and providers. Nowhere was this more true than in nursing homes where there have been over 3 million COVID-19 cases and roughly 168,000 COVID related deaths among residents and staff[10,11]. Vaccination against COVID-19 has been critical for preventing COVID-19 cases and deaths[12–14] among residents and staff in nursing homes, particularly before the Omicron variant wave. Although a substantial majority of nursing home residents were quickly vaccinated (80%), many staff remained unvaccinated months after vaccines became available[15].

Although education and outreach could plausibly increase vaccination uptake among nursing home staff, one randomized control trial found that such interventions did not increase vaccination rates[16]. In response, COVID vaccination mandates for health care workers have been implemented at several levels over the course of the pandemic, including at the employer, state, and federal levels[17,18]. To our knowledge, there have been no evaluations on the impact of employer mandates. Available evidence on state mandates suggests that these were effective at increasing vaccination rates in nursing homes without creating staff shortages, but the effect of mandates on staff separations is unknown[17]. Even modest increases in staff separations because of mandates are concerning given the industry's challenges with high rates of turnover and widespread staffing shortages[19–21].

We addressed this gap in knowledge about private mandates by leveraging detailed data on staffing, vaccination, and COVID-19 outcomes in the nursing home industry to examine the relationship between employer vaccination mandates implemented at a chain level and detailed employment outcomes, staff vaccination rates, and COVID-19 outcomes among staff and residents.

## Methods

*Data sources*

The primary data sources for this retrospective cohort study of U.S. nursing homes were the Centers for Medicare and Medicaid Services (CMS) Payroll-Based Journal (PBJ) database and Centers for Disease Control and Prevention's National Healthcare Safety Network (NHSN) data. The PBJ database contains a record of all individual staff shifts at the daily level. In addition to hours worked, the PBJ data also details the worker's role (e.g., certified nursing assistant, licensed practical nurse, or registered nurse) and employment type (wage, salary, or contract), and shifts for all 15,419 CMS-certified nursing facilities in the United States (5.1 million staff members, 489 million shifts). The NHSN data contain weekly COVID-19 outcomes for residents and staff at all U.S. nursing homes, including cases, deaths, and vaccination coverage. Nursing homes are required to report these aggregate facility measures into NHSN on a weekly basis, and the NHSN data are widely used to study COVID outcomes in nursing homes.

We collected data on chain-level COVID-19 staff vaccination mandates from an online publication for senior living (McKnights) that reported mandate announcements made by nursing home chains, defined as

an organization operating more than one nursing home. For mandates announced from December 28, 2020 to August 31, 2021, we compiled information about the dates on which the mandates were announced and the dates on which the mandates went into effect. We did not include any chains with mandates that offered a test-out option in lieu of vaccination. Additional details about the data collection of these vaccination mandates are discussed in Supplementary Appendix, Section 1.1. We merged this detailed information about vaccine mandate policies with the PBJ and NHSN data.

*Study Sample*

Our study sample consists of 581 nursing homes operated by 13 chains that implemented employer-imposed vaccination mandates and 9,242 control nursing homes where staff were not subject to any employer-imposed vaccination mandate. We excluded nursing homes owned by chains that implemented mandates with a test-out option in lieu of vaccination. We also restricted our sample to nursing homes with high-quality reporting in the PBJ and exclude any data when facilities are subject to a state vaccine mandate (see Supplementary Appendix, Section 1.3).

Vaccinations and employment outcomes are measured from the week ending on June 28, 2020 through the week ending on November 6, 2021. The study period ended on November 6, 2021 to avoid confounding from the federal vaccination mandate, which was formally released on November 4, 2021 and had an initial targeted enactment date of December 6, 2021[22]. Additional details about these dates are discussed in Supplementary Appendix, Section 1.1. COVID-19 outcomes are measured June 28, 2020 to January 2, 2022. This longer follow-up period was implemented to capture the lag between vaccination and potential increases in immunity that can reduce COVID-19 cases and death.

*Study Outcomes*

STAFF VACCINE COVERAGE

Staff vaccine coverage is measured as the weekly percentage of all health care staff who received at least one dose of an authorized COVID-19 vaccine (Moderna, Pfizer-BioNTech, or Janssen), as reported in the NHSN data.

EMPLOYMENT OUTCOMES

Our main analysis focused on employment outcomes among certified nursing assistant (CNA) employees. This group represents the majority of direct care staff in nursing homes as CNAs comprised 53% of all staff in the PBJ data. Additionally, CNAs had substantially lower COVID vaccination rates relative to other nursing home staff[15]. We examined other direct care staff, including LPNs and RNs, and present these findings in the appendix.

The employment outcomes we examined include the following measures constructed using PBJ data: staff size (defined as the total number of unique employees working in a nursing home each day), staffing levels (measured as the number of hours per resident day), separations (measured as the number of employees that are last seen in a facility each day), and hires (measured as the number of employees that are first seen in a facility each day). Staffing outcomes were winsorized at the 2.5 and 97.5 percentiles to address outliers that may reflect reporting error.

COVID-19 OUTCOMES

COVID outcomes are measured at the weekly level and include resident COVID cases and deaths per 100 beds and staff COVID cases per 100 beds. We examined COVID outcomes per 100 beds because we require

a non-time varying measure for the denominator (see Supplementary Appendix, Section 1.2 for additional details). We did not study staff deaths, as they were rare during our study window.

*Statistical Analysis*

To estimate the association between employer-imposed vaccination mandates and staff vaccination coverage, employment, and COVID-19 outcomes, we estimated event study models that included fixed effects for each facility and calendar week. We estimated these event studies both around the week of announcement ("announcement week") and around the week in which each mandate took effect ("enforcement week"). This approach estimates the change in the outcomes of interest for mandate nursing homes after the mandate's announcement or enforcement week compared with the changes experienced in non-mandate nursing homes during the same time period. The key assumption for an event study is parallel trends—i.e., that nursing homes experiencing a mandate would otherwise have proceeded under the same trend as the non-mandate control nursing homes. Our event study estimates are presented as relative to a baseline week. When studying mandate announcement, the baseline week is the week prior to mandate announcement. When studying mandate enforcement, the baseline week is four weeks prior to enforcement since employees intending to achieve full vaccination prior to enforcement may need to receive their first dose up to four weeks in advance. We used a 13-week event study window for vaccination and employment outcomes and a 26-week event study window for COVID outcomes, to capture the lag between vaccination and potential increases in immunity that can reduce COVID-19 cases and death. Standard errors were clustered at the chain level because we examined mandates that were introduced at the chain level[23]. We also estimate additional event studies using new methods robust to concerns about negative weighting in the Supplementary Appendix, Section 2.3[24].

While chains are unlikely to have implemented mandates in response to changes in staffing, a key concern when studying COVID outcomes is that chains may have elected to implement mandates in response to recent outbreaks. This could violate the parallel trends assumption. To address this, when examining COVID outcomes, we used a matched event study analysis where nursing homes with a staff vaccination mandate were matched to non-mandate nursing homes based on county and resident COVID case rates in the weeks prior to announcement. Full details of this approach are described in Supplementary Appendix, Section 2.2.

We performed several robustness checks, including restricting to the matched sample of facilities for the vaccination and employment outcomes, restricting our sample to nursing homes owned by chains, categorizing staff based on number of hours worked (e.g., full-time, part-time, very part-time), and using new event study estimators that address potential bias due to staggered timing of treatment. See Supplementary Appendix, Section 2.3 for details.

**Results**

The sample consisted of 9,823 nursing homes, 581 of which were operated by 13 chains that implemented a vaccination mandate for employees (Table 1). The dates of mandate announcement ranged from December 28, 2020 through August 31, 2021 and the dates of enforcement ranged from February 1, 2021 through November 1, 2021 (Supplementary Appendix, Table S1). Nursing homes that imposed mandates differed slightly from those without mandates—for example, nursing homes with mandates had more white residents and fewer beds relative to comparison facilities—however, differences tended to be a small relative to the standard deviation. After applying our matching protocol, the sample was restricted to 335 mandate nursing homes and 1,096 matched comparators for COVID outcomes. Importantly, the mandate and non-mandate nursing homes in this matched sample are more comparable on recent COVID outcomes such as confirmed COVID cases among residents.

*Staff Vaccination*

Following the announcement of employer staff vaccination mandates, vaccination coverage among staff immediately began to increase in mandate nursing homes relative to nursing homes without employer mandates. Thirteen weeks after mandate announcement, staff vaccination rates increased by approximately 13.7 percentage points (95% CI: 8.7, 18.7) relative to the week prior to the mandate announcement, reflecting a 21% increase (Figure 1) relative to control nursing homes without employer mandates. We likewise found evidence of a rapid acceleration in staff vaccination coverage around the time of mandate enforcement (Figure 1). Staff vaccination rates across mandate nursing homes prior to mandate announcement was 65%, compared to 61% in non-mandate nursing homes. Neither mandate nursing homes nor control nursing homes reached 100% vaccination coverage following the enforcement date ($25^{th}$ percentile: 68.6%, median: 85.3%, $75^{th}$ percentile: 96.3%).

*Staffing Levels and Changes*

Mandate nursing homes experienced a small decline in the number of CNAs following mandate announcements amounting to less than 0.45 CNAs per 100 beds (95% CI: -0.86, -0.03, Figure 2) or an 8% relative change. This decline in the number of CNAs was concentrated among very part-time (less than 20 hours per week) and part-time (20-34 hours per week) employees rather than full-time employees (35+ hours per week) (Supplementary Appendix, Figure S8). The overall effect amounted to a decrease of less than two minutes of CNA care (0.03 hours, 95% CI: -0.07, 0.00) per resident day (Figure 2).

In the week when employer vaccination mandates were to be enforced, we observed a small but statistically significant increase of 0.06 CNA separations per 100 beds (95% CI: 0.02, 0.10, Figure 3). For the typical 90 bed facility, this constitutes an effect of 0.05 separations on average. Importantly, the increase in separations were brief and localized to the week when the mandate took effect. We also found that these additional separations were primarily among CNAs who worked less than 20 hours per week (Supplementary Appendix, Figure S9). Following the mandate enforcement, the temporary increase in staff separations was partially offset by an increase in new hires; facilities experienced an increase of 0.02 new CNA hires per 100 beds (95% CI: -0.02, 0.05 Figure 3) over the 13 weeks following mandate enforcement, reflecting an 21% relative increase compared to non-mandate nursing homes. Results for staffing levels and changes were robust to using a matched sample of facilities using pre-period resident COVID-19 cases rates as well as estimators that address staggered treatment timing (Supplementary Appendix, Figures S2 and S5).

Results for other staff types (LPNs and RNs) were similar. In the week when mandates were enforced, we observed a small but statistically significant increase of 0.02 RN separations per 100 beds (95% CI: 0.01, 0.03, Supplementary Appendix, Figure S13).

*COVID Cases and Deaths*

Matched mandate and non-mandate nursing homes had similar COVID trends in case and death rates prior to mandate announcement. Mandates were associated with 3.5 (95% CI: -4.8, -2.3) fewer cumulative staff COVID cases per 100 beds by the end of the 6-month follow-up period, as well as 4.4 (95% CI: -5.3, -3.5) and 0.5 (95% CI: -0.8, -0.1) fewer resident COVID cases and deaths per 100 beds, respectively. Relative to the sample means, these reductions represent 35% fewer staff cases, 61.1% fewer resident cases, and 64.9% fewer resident deaths (Figure 4).

**Discussion**

Employer vaccination mandates announced between December 2020 and August 2021 were effective at increasing nursing home staff primary vaccination coverage by 21%. This is in stark contrast to the efficacy of non-mandate interventions such as vaccination campaigns, which one randomized controlled trial found not to discernibly increase vaccination rates during this period[16,27]. Nursing homes that were subjected to a vaccination mandate achieved an average vaccination rate of 79%. Vaccination rates are likely below 100% because of medical and religious exemption clauses as well as imperfect enforcement of the employer mandates. Employer mandates may also be harder to enforce than government mandates, and even among nursing homes subject to a government vaccination mandate did not achieve vaccination rates of 100%[17].

Despite widespread concerns that mandates would result in large-scale staff departures, employer staff vaccination mandates yielded only a modest and transitory increase in staff separations during the week of mandate enforcement that primarily affected part-time employees. Furthermore, these separations were partially offset by increases in new staff hires, resulting in minimal declines in staff counts and resident care ratios. The sharpness of these minor employment effects around mandate announcement and enforcement suggest that we are capturing effects on staffing driven by a change around the timing of mandate announcement and enforcement. Although nursing home chains may have been implementing other confounding policies to reduce the spread of COVID, such as personal protective equipment requirements, such policies would only affect our estimates if they were implemented at the same time as mandate announcement and enforcement. Perhaps most importantly, the mandate-induced increases in staff vaccination were associated with fewer staff and resident COVID cases, as well as fewer resident COVID deaths. A back-of-the-envelope calculation suggests that, given the average nursing home in our sample is about 100 beds in size and that nursing homes with mandates had 0.5 fewer resident COVID deaths per 100 beds, roughly one life was saved per every two facilities that implemented a vaccination mandate.

Amid the emergence of new variants and waning vaccine efficacy, some employers are already considering or implementing booster mandates. For example, employers such as Goldman Sachs, Meta, and TJX require proof of booster shots for eligible employees[25,26]. Healthcare providers and especially nursing homes might consider such mandates as a crucial tool to increase protection for both staff and residents. Our findings suggest that such employer mandates may also be an effective policy level for increasing booster vaccination coverage without resulting in substantial staff shortages. We might expect that federal or state vaccination mandates to have a smaller effect than employer mandates on staff separations, since government mandates reduce options for alternative employment for employees who decline to be vaccinated. However, as the political appetite for employer mandates wanes, private mandates may become particularly important for companies and organizations hoping to increase coverage of COVID-19 boosters in their workforce.

This study has several limitations. Most importantly, while our estimates generally show parallel pre-trends, the assumption of parallel trends in the period after announcement or enforcement is not testable. Intuitively, our estimation approach assumes there were not contemporaneous factors or trends that changed at the same time when mandates were implemented. We cannot fully exclude the possibility that unmeasured confounders correlated both with a chain's decision to implement a vaccination mandate and the chain's vaccination, employment, and COVID-19 outcomes. Additionally, we evaluated how mandates affected staff vaccination rates, staffing levels, and clinical outcomes relative to the date on which the mandates were announced. Our results would be biased towards zero if staff were aware of these mandates prior to their announcement.

Healthcare employers may look to mandate vaccination in future pandemics or more regularly for other diseases such as influenza. Such mandates may be particularly effective for highly transmissible diseases as they can increase vaccination rates with minimal costs and have substantial benefits for individuals

receiving the vaccine and those interacting with them. These benefits may be particularly large for those working and living in close proximity, such as staff and residents at nursing homes, assisted living facilities, and hospitals, as well as non-healthcare settings such as prisons, mines, and manufacturing settings. This study contributes valuable knowledge that may be useful in understanding and forecasting the implications of employer-imposed mandates for vaccination coverage, employment, and health outcomes.

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Table 1. Summary Statistics of Mandate and Non-Mandate Nursing Homes

| | Vaccination and Employment Outcome Sample[a] | | COVID Outcome Sample[b] | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| | Mandate | Non-Mandate | Mandate (Matched) | Non-Mandate (Matched) |
| Staff Vaccinated (%) | 64.91+/- 15.13 | 61.99, +/- 19.00 | 65.11, +/- 15.28 | 66.63, +/- 18.96 |
| Staff size[c, e] | 18.12, +/- 5.32 | 19.05, +/- 6.79 | 17.82, +/- 5.36 | 18.61, +/- 6.80 |
| Hours per Resident Day[d, e] | 1.96, +/- 0.47 | 2.12, +/- 0.57 | 1.91, +/- 0.41 | 2.04, +/- 0.59 |
| Separations [e] | 0.10, +/- 0.15 | 0.11, +/- 0.16 | 0.09, +/- 0.14 | 0.10, +/- 0.15 |
| New Hires [e] | 0.08, +/- 0.14 | 0.09, +/- 0.16 | 0.08, +/- 0.15 | 0.09, +/- 0.16 |
| Staff Weekly Confirmed COVID-19 | 0.28, +/- 1.47 | 0.25, +/- 1.08 | 0.02, +/- 0/.15 | 0.05 +/- 0.33 |
| Residents Weekly Confirmed COVID-19 | 0.44, +/- 3.02 | 0.21, +/- 1.67 | 0.00, +/- 0.05 | 0.03 +/- 0.47 |
| Residents Weekly COVID-19 Deaths | 0.03, +/- 0.26 | 0.03, +/- 0.34 | 0.00, +/- 0.00 | 0.1, +/- 0.10 |
| Beds | 100.50 +/- 46.13 | 115.17, +/- 62.10 | 99.23, +/- 44.64 | 109.99, +/- 61.17 |
| Medicaid (%) | 60.05, +/- 23.08 | 61.30, +/- 21.43 | 56.38, +/- 24.56 | 59.06, +/- 24.95 |
| Medicare (%) | 14.28 +/- 12.65 | 12.26, +/- 10.65 | 15.03, +/- 13.30 | 12.76, +/- 12.79 |
| White (%) | 81.50, +/- 21.99 | 76.25, +/- 24.37 | 82.71, +/- 21.57 | 76.93, +/- 23.74 |
| Black (%) | 10.74, +/- 18.936 | 13.34, +/- 18.55 | 11.14, +/- 19.05 | 13.23, +/- 19.52 |
| For Profit (%) | 0.76, +/- 0.43 | 0.73, +/- 0.45 | 0.67, +/- 0.47 | 0.71, +/- 0.45 |
| Facilities | 581 | 9,242 | 335 | 1,096 |

[a] This sample consists of facilities with high-quality reporting in the PBJ (see Supplementary Appendix, Section 1.2).

[b] This sample consists of facilities identified by exact matching on county where the mandate facility was located and nearest neighbor matching on measures of pre-period resident COVID-19 case rates (see Supplementary Appendix, Section 2.2).

[c] Total number of unique staff working in a nursing home each day.

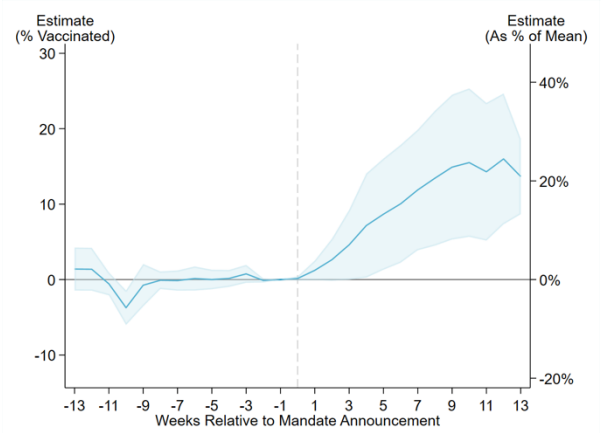
[d] Number of care hours worked by nursing staff per resident.

[e] Reported means are for Certified Nursing Assistants (CNAs) only.

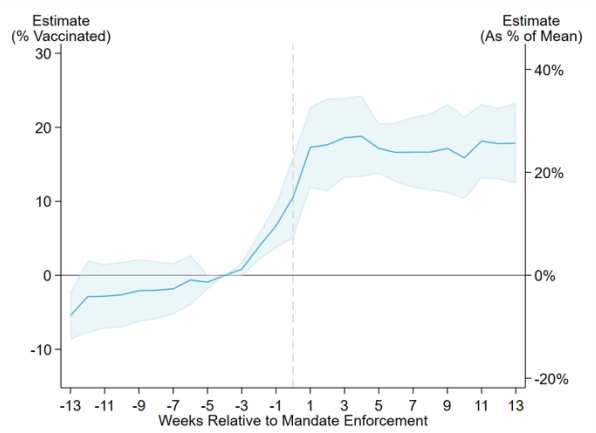
*Notes*: This table reports means of outcomes and nursing home characteristics followed by the standard deviation. For time varying measures such as health and employment outcomes, the reported means for mandate nursing homes (columns 1 and 3) pertain to the week prior to mandate announcement. Means for the non-mandate nursing homes (columns 2 and 4) are constructed to sample from the same distribution of weeks that the treatment (mandate announcements) occurred in. Data for the percentage of staff vaccinated, employment outcomes, and COVID outcomes are at the week level. Data for nursing home characteristics are at the year level.

Figure 1. Estimated Effect of Mandates on Staff Vaccination Rates

(A) Mandate Announcement



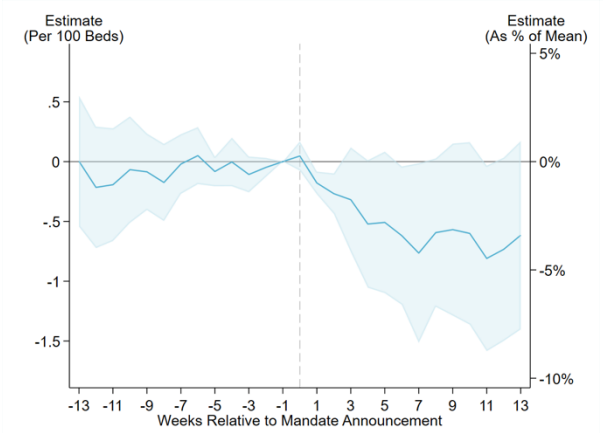

(B) Mandate Enforcement



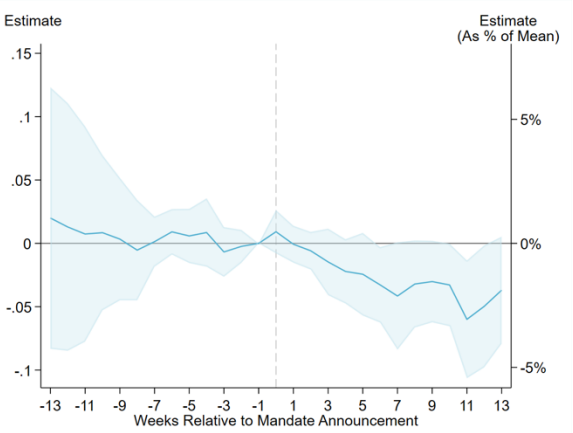

*Notes*: These figures plot event study regression estimates comparing treated nursing homes that implemented a vaccination mandate relative to control nursing homes that did not implement a vaccination mandate. Regressions include nursing home and week fixed effects. Standard errors are clustered at the chain level. Estimates in (a) are computed relative to a baseline one week prior to mandate announcement. Estimates in (b) are computed relative to a baseline week that is four weeks prior to the mandate becoming enforced. Four weeks was the authorized interval between first and second dose for the Moderna vaccine. The left axes present the estimates, and the right axes present the estimates scaled by the mean of the outcome variable for treated nursing homes in the baseline week. The mean staff vaccination rate in the week prior to mandate announcement was 65.4% (standard deviation [SD]=15.5). The mean staff vaccination rate in the four weeks prior to mandate enforcement was 69.6% (S.D=14.4).

Figure 2. Estimated Effect of Mandate Announcement on CNA Staffing Levels

(A) Staff Size



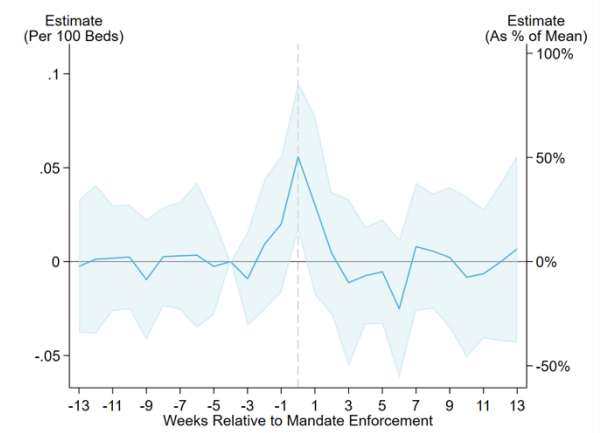

(B) Hours Per Patient Day



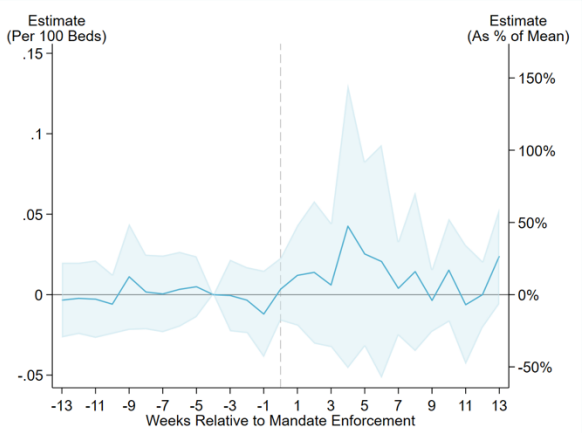

*Notes:* These figures plot event study regression estimates comparing treated nursing homes that implemented a vaccination mandate relative to control nursing homes that did not implement a vaccination mandate. Regressions include nursing home and week fixed effects. Standard errors are clustered at the chain level. Estimates in are computed relative to a baseline one week prior to mandate announcement. The left axes present the estimates, and the right axes present the estimates scaled by the mean of the outcome variable for treated nursing homes in the baseline week. The mean staff size per 100 beds in the week prior to mandate announcement was 18.1 (SD=5.3). The mean hours per patient day in the week prior to mandate announcement was 2.0 (SD=0.5).

Figure 3. Estimated Effect of Mandate Enforcement on CNA Separations and Hiring

(A) Separations



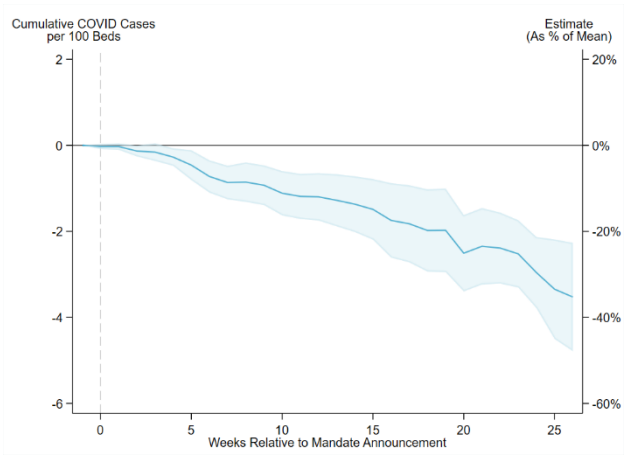

(B) Hires



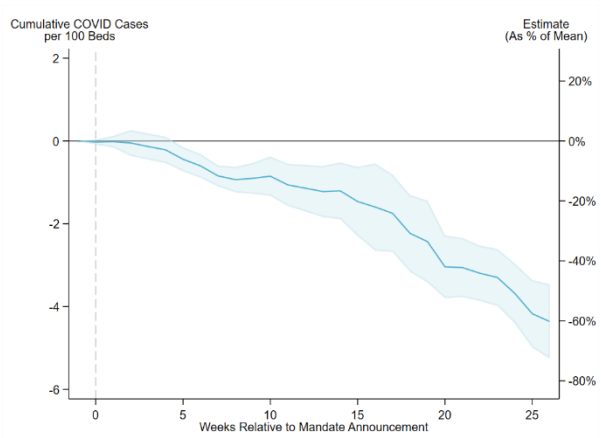

*Notes:* These figures plot event study regression estimates comparing treated nursing homes that implemented a vaccination mandate relative to control nursing homes that did not implement a vaccination mandate. Regressions include nursing home and week fixed effects. Standard errors are clustered at the chain level. Estimates are computed relative to a baseline week that is 4 weeks prior to the mandate becoming enforced. Four weeks was the authorized interval between first and second dose for the Moderna vaccine. The left axes present the estimates, and the right axes present the estimates scaled by the mean of the outcome variable for treated nursing homes in the baseline week. The mean number of separations per 100 beds in the week prior to mandate enforcement was 0.11 (SD=0.16). The mean number of hires per 100 beds in the week prior to mandate enforcement was 0.09 (SD=0.18).

Figure 4. Effect of Mandate Announcement on COVID-19 Cases and Deaths

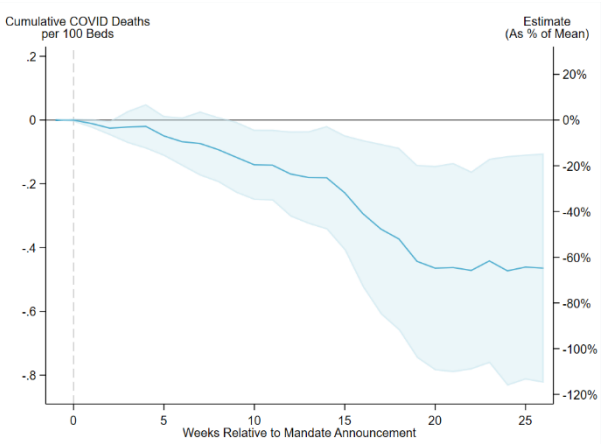
(A) Staff Cases




(B) Resident Cases




(C) Resident Deaths




*Notes:* These figures plot cumulative event study regression estimates comparing treated nursing homes that implemented a vaccination mandate relative to a matched control group of nursing homes from the same counties that did not implement a vaccination mandate but were comparable in their recent COVID-19 case rates to the treated facilities. More details on the matching and estimates from the non-cumulative event study, including pre-treatment estimates, are provided in the Appendix. Regressions include nursing home and week fixed effects. Standard errors are clustered at the chain level. Estimates are computed relative to a baseline one week prior to mandate announcement. The left axes present the estimates, and the right axes present the estimates scaled by the mean of the outcome variable for study sample in the last week of follow-up. The mean number of staff COVID-19 cases per 100 beds in the week prior to mandate announcement was 0.28 (SD=1.47). The mean number of resident COVID-19 cases and deaths per 100 beds in the week prior to mandate announcement was 0.44 (SD=3.02) and 0.03 (SD=0.26), respectively.

# Supplementary Appendix

June 20, 2023

# 1 Supplementary Details on Data

## 1.1 Vaccination Mandates

### 1.1.1 Chain Mandates

Data on chain mandates was collected from December of 2020 through September of 2021, following the first public announcement of a company-wide COVID-19 vaccination mandate on December 28, 2020. The process for identifying and verifying nursing home chains that implemented COVID-19 vaccination mandates for all employees was as follows. Given the groundbreaking nature of these mandates, a well-known online publication for senior living (McKnights) was reporting and updating such announcements weekly. Research staff reviewed this and other sites publishing vaccine mandate announcements for updated chain listings. They then searched and collected links to public announcements from each chain to verify, or searched the chain's website for additional information. When further information was not available for verification, the chain's mandate was not added to the verified listing and these chains were excluded from the analyses. The announcements and chain's websites were referred to for details about the COVID-19 vaccine mandate, including the announcement date, enforcement date, and that it was a mandate for all employees to be vaccinated (excluding medical and religious exemptions).

Table S1: Mandate Announcement and Enforcement Dates

| Chain | Announcement Date | Enforcement Date |
|---|---|---|
| A | December 28, 2020 | February 1, 2021 |
| B | March 15, 2021 | June 1, 2021 |
| C | March 23, 2021 | July 31, 2021 |
| D | March 31, 2021 | June 1, 2021 |
| E | May 13, 2021 | May 13, 2021 |
| F | June 1, 2021 | September 1, 2021 |
| G | July 1, 2021 | August 23, 2021 |
| H | July 14, 2021 | September 30, 2021 |
| I | July 22, 2021 | November 1, 2021 |
| J | August 2, 2021 | August 23, 2021 |
| K | August 9, 2021 | October 1, 2021 |
| L | August 16, 2021 | November 1, 2021 |
| M | August 31, 2021 | October 29, 2021 |

We obtained provider numbers associated with each chain that implemented a vaccination mandate, which allowed us to merge mandate announcement and enforcement dates with our Payroll-Based Journal (PBJ) and National Healthcare Safety Network (NHSN) data.

### 1.1.2 Federal Mandate

The Centers for Medicare and Medicaid (CMS) announced that they were developing emergency regulation of vaccination requirements for staff in nursing homes on August 18, 2021 and announced that they would enact this federal vaccination mandate for all nursing home workers on September 9, 2021, though the regulation was not released until November 4, 2021.[1,2]

## 1.2 Variable Construction

The staffing outcomes of our analysis include staff size (defined as the total number of unique staff working in a nursing home each day), staffing levels (measured as the number of hours per resident day), staff separations (measured as the number of employees that are last seen in a nursing home each day), and staffing hires (measured as the number of employees that are first seen in a nursing home each day).

The scope of our analysis includes CNA (Certified Nurse Aides), LPN (Licensed Practical Nurses), and RN (Registered Nurses). Based on the Technical Users' Guide by Centers for Medicare & Medicaid Services,[3] we combine multiple specific job codes for calculating the employment outcomes of each nurse type.

- CNA: Includes Certified Nurse Aides, Aides in Training, and Medication Aides/Technicians
- LPN: Includes Licensed Practical/Licensed Vocational Nurses with Administrative Duties and Licensed Practical/Vocational Nurses
- RN: Includes RN Director of Nursing, Registered Nurses with Administrative Duties, and Registered Nurses

All outcomes (with the exception of hours per resident day) are per 100 beds. We use the number of beds as the denominator specifically because this measure does not change over time. In contrast, a time varying denominator, such as nursing home occupancy, would be problematic because occupancy is likely to be impacted by outbreaks of COVID or other infectious diseases.

## 1.3 PBJ Data Inclusions and Exclusions

Our analyses of staffing outcomes pertain to nursing home employees since they accounted for the majority of staff; contract workers were excluded. We include nursing homes with 40 or more beds that reported data in the Payroll Based Journal (PBJ) database in 2020 and 2021.

We excluded nursing home with poor quality data reporting in the PBJ database. Table 2 documents the number of mandate and non-mandate nursing homes that were excluded due to poor quality data reporting in PBJ. Nursing homes were excluded if they implemented a software reset, missing 28+ days of data in 2021, zero values for staffing outcomes for 7+ days in 2021, or missing Minimum Dataset census

information. For mandate nursing homes, we also excluded nursing homes with no PBJ data available after mandate announcement. Additionally, we excluded all nursing homes belonging to three nursing home chains with a suspected chain-wide software reset in 2019 or 2020. Another chain with an employer vaccination mandate was excluded because of general data quality issues in late 2020.

Additionally, we dropped specific nursing home-days if data quality issues were observed (dropped nursing home-days with poor data quality as well as two days before and after). Such nursing home-days were excluded in 2020 if a nursing home was missing data regardless of length, zero values for all staffing outcomes for any period, temporary decrease in number of workers exceeding 80% from the previous day, MDS census value of zero or missing. Additionally, nursing home-days were excluded if there was missing data for less than 28 days in 2021. Finally, data was censored if a state-level vaccine mandate for healthcare workers in nursing homes was announced.

Table S2: Inclusion Criteria for Mandate & Non-Mandate Facilities

| | | Number of Mandate Facilities | Number of Non-Mandate Facilities | Total Number of Facilities (Mandate and Non-Mandate) |
|---|---|---|---|---|
| Inclusions | 40+ beds | 786 | 12,749 | 13,535 |
| | No missing quarters of data for 2020q2 - 2021q4 | 739 | 11,336 | 12,075 |
| Exclusions | PBJ/software reset | 663 | 9,685 | 10,348 |
| | 28+ days of missing data in 2021 | 663 | 9,478 | 10,141 |
| | Staffing outcomes = 0 for 7+ days in 2021 | 654 | 9,271 | 9,925 |
| | MDS census = missing for > 0 days in 2021 | 654 | 9,242 | 9,896 |
| | Suspected chain-wide software reset | 603 | 9,242 | 9,845 |
| | Missing PBJ data post mandate announcement | 583 | 9,242 | 9,825 |
| | Miscellaneous data quality issues | 581 | 9,242 | 9,823 |

# 2 Supplementary Details on Methods

## 2.1 Analysis

To estimate the association between employer-imposed vaccination mandates and staff vaccination coverage, employment, and COVID-19 outcomes, we estimated event study models. Event studies allow us to assess whether pre-treatment trends between mandate and non-mandate nursing homes were similar. Treatment occurs at time zero and a reference period prior to treatment is chosen. When studying mandate announcement, the reference week is the week prior to mandate announcement. When studying mandate enforcement, the reference week is four weeks prior to enforcement since employees intending to achieve full vaccination prior to enforcement may need to receive their first dose up to four weeks in advance. Coefficients that are close to zero in the pre-treatment period imply that the pre-treatment trends for both mandate and non-mandate nursing homes were similar. The coefficients post-treatment identify post treatment effects, which convey how outcomes evolved relative to before the mandates were announced (or enforced).

Equation 1 summarizes the main event study approach used to estimate the effect of nursing home chain staff vaccination mandates on staff vaccination coverage, staffing levels and changes, and COVID outcomes, relative to changes in outcomes experienced in nursing homes that were not subject to a vaccination

mandate over the same time period.

$$y_{i,t} = \eta_{t-\tau(i)} M_i + \gamma_i + \theta_t + \epsilon_{i,t} \quad (1)$$

$y_{i,t}$ represents the outcome of interest for nursing home $i$ in calendar week $t$. $\gamma_i$ is a nursing home fixed effect and $\theta_t$ denotes calendar week fixed effects. $M_i$ is an indicator for whether nursing home $i$ is subject to a vaccine mandate. $\tau(i)$ represents the announcement or enforcement date of the vaccination mandate, and $t - \tau_i$ represents the week of the mandate announcement (or enforcement) so that $t - \tau(i)$ signifies the event time during calendar week $t$. The coefficient $\eta_k$ represents the estimate of the effect of the mandate announcement (or enforcement) for event week $k$. Standard errors are clustered at the chain level since the mandates were determined at the chain level.

## 2.2 Matched Event Study

To address concerns that nursing home chains may adopt mandates in response to recent outbreaks, thereby violating the parallel trends assumption for analyses of COVID outcomes, we performed a matched event study to compare treatment and control facilities who were in the same county and had similar resident COVID-19 case rates and trends in the pre-mandate-announcement period.

Matching was conducted using exact matching on the county where the treatment facility is located and nearest neighbor matching on three measures of per-period resident COVID-19 case rates (defined as the weekly number of new COVID-19 cases divided by the number of beds in the facility): 1) resident COVID case rates in the 10-weeks prior to mandate announcement, 2) resident COVID case rates in the 2-weeks prior to mandate announcement, and 3) the change in cases between weeks -4 and -3 and -2 and -1. We applied calipers to limit matches to SNFs for whom matches where within 0.5 standard deviations of the Mahalanobis distance. A non-mandate facility could be matched to multiple treatment facilities if they were located within the same county.

After constructing matched cohorts, we estimated a similar event study regression model with the addition of separate week and facility fixed effects for cohort. Additionally these models controlled for resident COVID vaccination rates in weeks in which this information was available (i.e, event weeks corresponding to June 6, 2021 and later).

## 2.3 Sensitivity Analyses

We performed various sensitivity analyses to explore the robustness of our results.

First, for our vaccination coverage and staffing outcomes, we estimated event studies using the matched sample of facilities used for analyses of COVID cases and deaths. Although the analyses of COVID outcomes consisted of a sample of 1,431 nursing homes, the matched sample for analyses of staff vaccination, levels, and changes consisted of 989 nursing homes due to the exclusion of facilities with PBJ data quality issues.

Second, we test the sensitivity of our results using a new estimator that addresses staggered implementation of the vaccination mandates. However, given that only 6% of facilities in our sample implement an employer vaccination mandate, our estimates are unlikely to be substantially biased from negative weighting due to dynamic treatment effect heterogeneity.[4] Still, we show robustness of our results to an alternative estimator that is robust dynamic treatment effect heterogeneity using the estimation procedure developed by Callaway and Sant'Anna (2021) that addresses variation in treatment timing.[5]

Third, we estimated overall mandate effects using a difference-in-differences (DID) approach rather than the event study approach specified in Equation (1). The estimating equation is

$$y_{i,t} = \beta Post_{i,t} + \gamma_i + \theta_t + \epsilon_{i,t} \tag{2}$$

where $Post_{i,t}$ is an indicator for calendar weeks following mandate announcement (or enforcement). $\beta$ represents the average change in the outcome of interest after mandate announcement (or enforcement) in mandate facilities relative to the changes observed in non-mandate facilities.

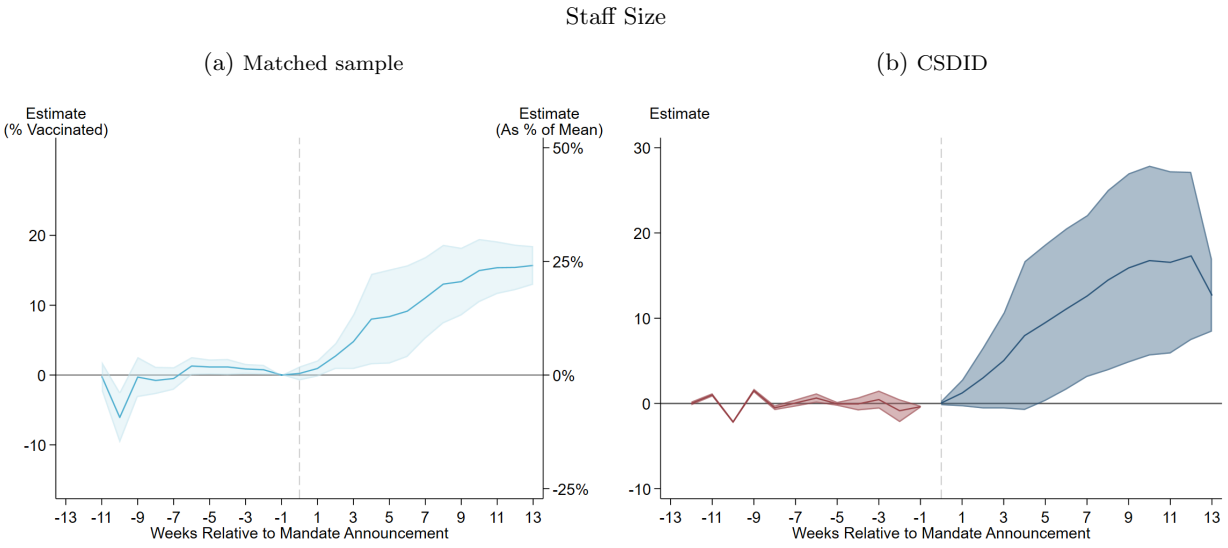
Third, we used the event study framework specified in Equation (1) to estimate the effects of the mandates using mandate enactment (for staff vaccination and staffing levels) and mandate announcement for staffing changes.

Finally, we examined the effects of the vaccination mandates separately for licensed practical nurses (LPNs) and registered nurses (RNs).

# 3 Additional Results

## 3.1 Sensitivity Analyses for CNAs

Figure S1: Estimated Effect of Mandate Announcement on Staff Vaccination Rates



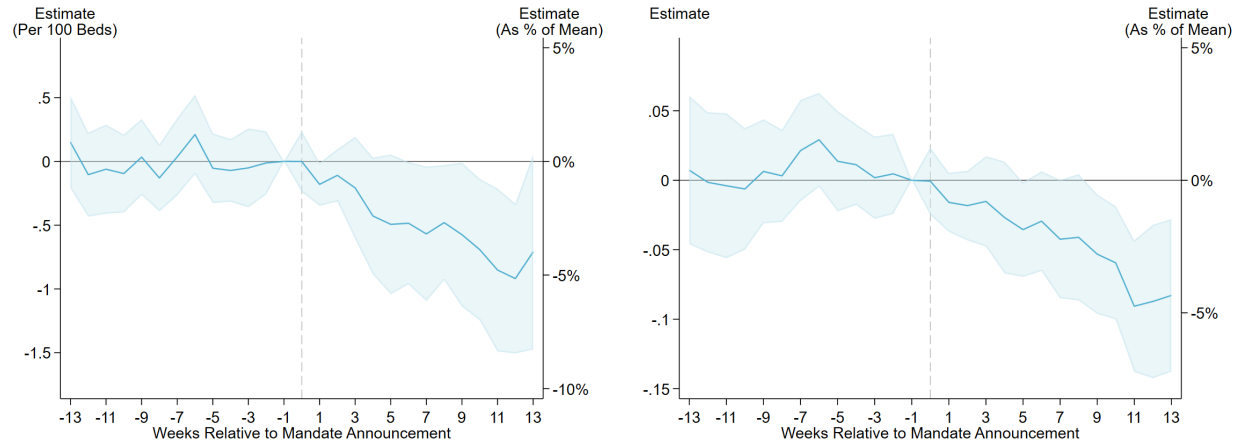

*Notes.* These figures plot event study regression estimates comparing treated facilities that implemented a vaccination mandate relative to control facilities that did not implement a vaccination mandate. Regressions include facility and week fixed effects. Standard errors are clustered at the chain level. Estimates are computed relative to a baseline one week prior to mandate announcement. The y-axis on the left-hand side shows the change for each outcome relative to to the week when vaccination mandates were announced. The y-axis on the right-hand side of panels (a) represents the estimate as percent change relative to the week prior to the mandate announcement week. The x-axis illustrates the event-time relative to the week in which the chain's vaccination mandate was announced.

Figure S2: Estimated Effect of Mandate Announcement on Staffing Levels

Matched Sample

(a) Staff Size

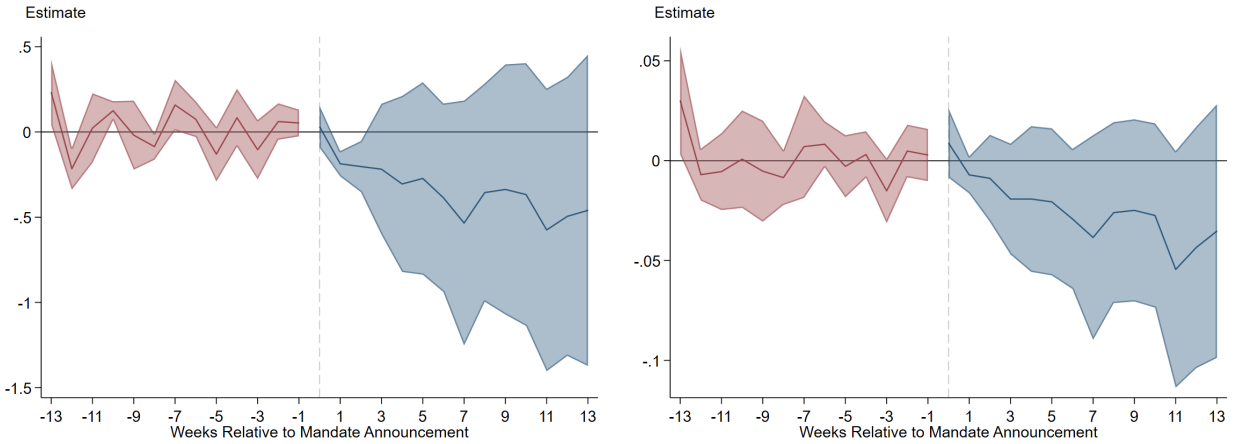
(b) Hour Per Patient Day




CSDID

(c) Staff Size

(d) Hour Per Patient Day

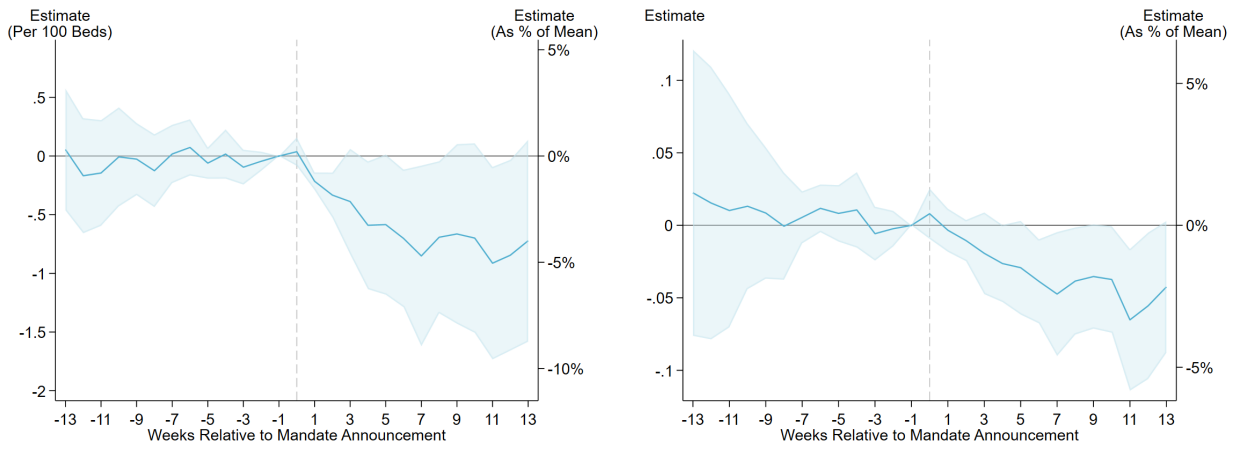



*Notes.* These figures plot event study regressions which compare treated facilities that implemented a vaccination mandate relative to control facilities that did not implement a vaccination mandate. Regressions include week and facility fixed effects. Standard errors are clustered at the chain level. The y-axis on the left-hand side shows the change for each outcome relative to to the week when vaccination mandates were announced. The y-axis on the right-hand side of panels (a) and (c) represents the estimate as percent change relative to the week prior to the mandate announcement week. The x-axis illustrates the event-time relative to the week in which the chain's vaccination mandate was announced.

Figure S3: Estimated Effect of Mandate Announcement on Staffing Levels Among Chain Facilities Only

(a) Staff Size

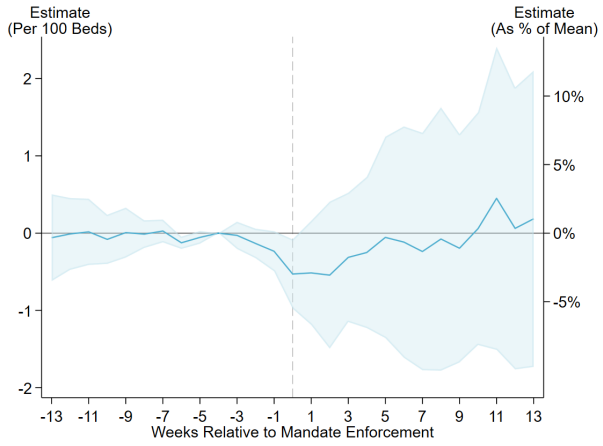
(b) Hour Per Patient Day



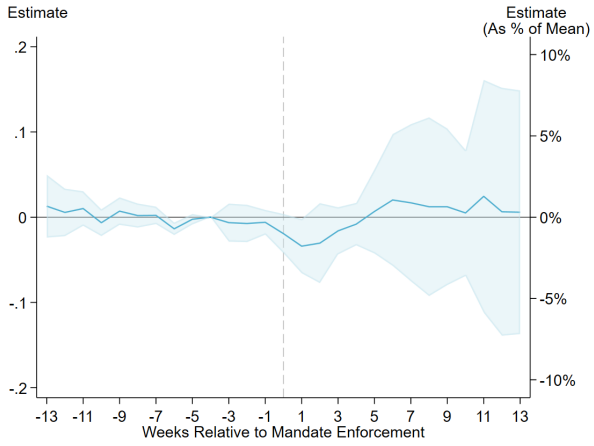

*Notes.* These figures plot event study regressions which compare treated facilities that implemented a vaccination mandate relative to control facilities that did not implement a vaccination mandate. Regressions include week and facility fixed effects. Standard errors are clustered at the chain level. The y-axis on the left-hand side shows the change for each outcome relative to to the week when vaccination mandates were announced. The y-axis on the right-hand side of panels (a) and (c) represents the estimate as percent change relative to the week prior to the mandate announcement week. The x-axis illustrates the event-time relative to the week in which the chain's vaccination mandate was announced.

Figure S4: Estimated Effect of Mandate Enforcement on CNA Staffing Levels

(a) Staff Size




(b) Hour Per Patient Day




*Notes.* These figures plot event study regressions which compare treated facilities that implemented a vaccination mandate relative to control facilities that did not implement a vaccination mandate. Regressions include week and facility fixed effects. Standard errors are clustered at the chain level. The y-axis on the left-hand side shows the change for each outcome relative to four weeks prior to the week when vaccination mandates were enforced. Four weeks prior to the mandate effective week is used as the reference period because of potential anticipation effects. The y-axis on the right-hand side represents the estimate as percent change relative to the four weeks prior to the mandate enforcement week. The x-axis illustrates the event-time relative to the week in which the chain's vaccination mandate was enforced.

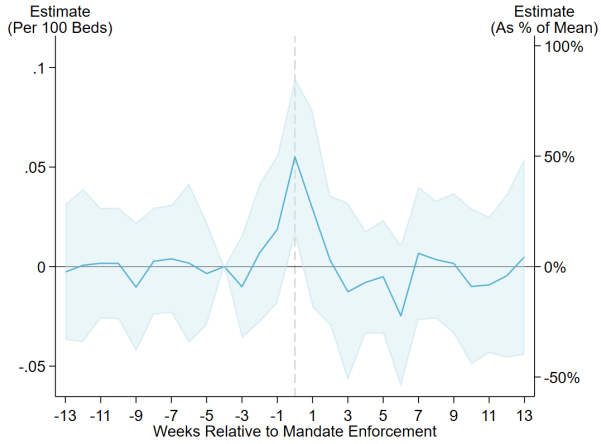
Figure S5: Estimated Effect of Mandate Enforcement on CNA Staffing Changes



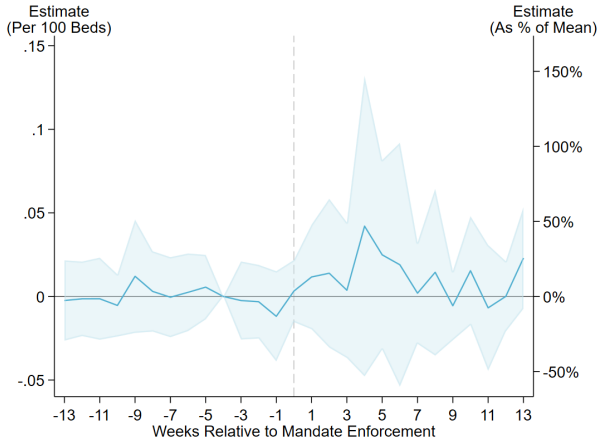

*Notes.* These figures plot event study regressions which compare treated facilities that implemented a vaccination mandate relative to control facilities that did not implement a vaccination mandate. Regressions include week and facility fixed effects. Standard errors are clustered at the chain level. The y-axis on the left-hand side shows the change for each outcome relative to four weeks prior to the week when vaccination mandates were in effect. Four weeks prior to the mandate effective week is used as the reference period because of potential anticipation effects. The y-axis on the right-hand side in panels (a) and (c) represents the estimate as percent change relative to the four weeks prior to the mandate enforcement week. The x-axis illustrates the event-time relative to the week in which the chain's vaccination mandate was enforced.

Figure S6: Estimated Effect of Mandate Enforcement on CNA Staffing Changes Among Chain Facilities Only

(a) Separations



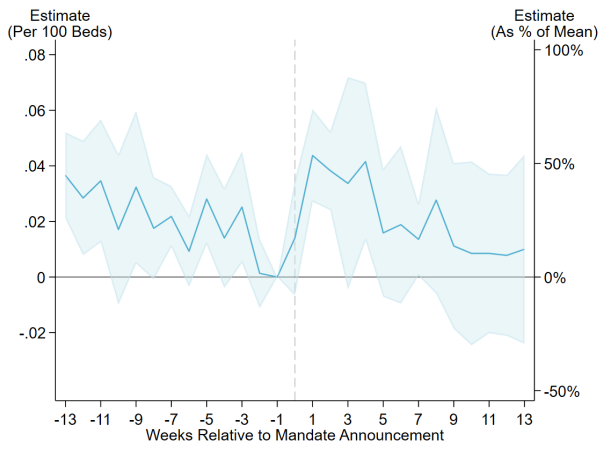

(b) Hires



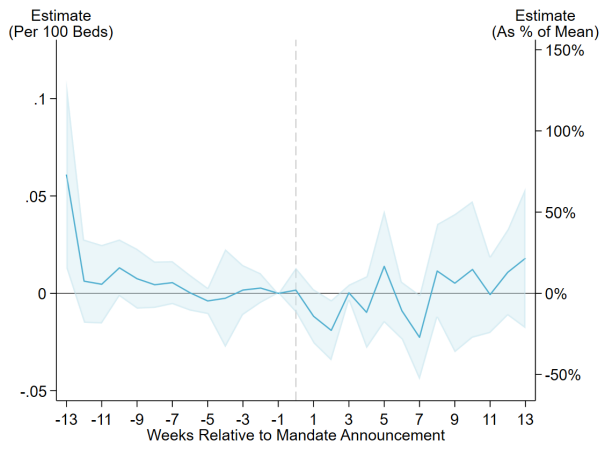

*Notes.* These figures plot event study regressions which compare treated facilities that implemented a vaccination mandate relative to control facilities that did not implement a vaccination mandate. Regressions include week and facility fixed effects. Standard errors are clustered at the chain level. The y-axis on the left-hand side shows the change for each outcome relative to four weeks prior to the week when vaccination mandates were in effect. Four weeks prior to the mandate enforcement week is used as the reference period because of potential anticipation effects. The y-axis on the right-hand side in panels (a) and (c) represents the estimate as percent change relative to the four weeks prior to the mandate effective week. The x-axis illustrates the event-time relative to the week in which the chain's vaccination mandate was enforced.

Figure S7: Estimated Effect of Mandate Announcement on CNA Staffing Changes

(a) Separations




(b) Hires



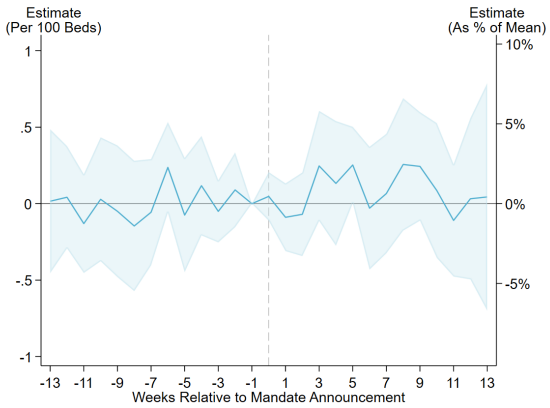

*Notes.* These figures plot event study regressions which compare treated facilities that implemented a vaccination mandate relative to control facilities that did not implement a vaccination mandate. Regressions include week and facility fixed effects. Standard errors are clustered at the chain level. The y-axis on the left-hand side shows the change for each outcome relative to to the week when vaccination mandates were announced. The y-axis on the right-hand side represents the estimate as percent change relative to the week prior to the mandate announcement week. The x-axis illustrates the event-time relative to the week in which the chain's vaccination mandate was announced.

## 3.2 Results for CNAs by Hours Worked

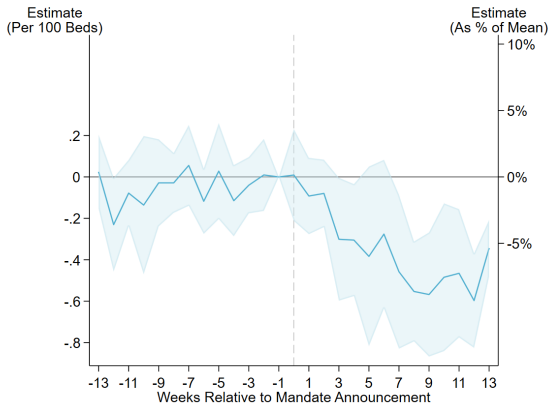
Figure S8: Estimated Effect of Mandate Announcement on CNA Staffing Levels

Staff Size

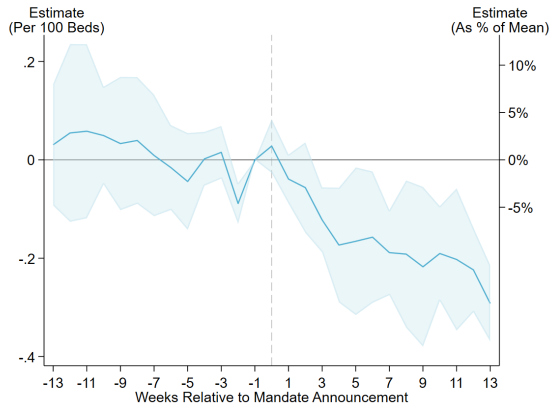
(a) Full-time Staff




(b) Part-time Staff

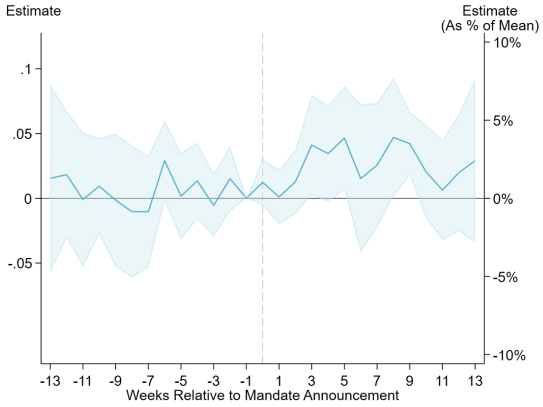



(c) Very Part-time Staff

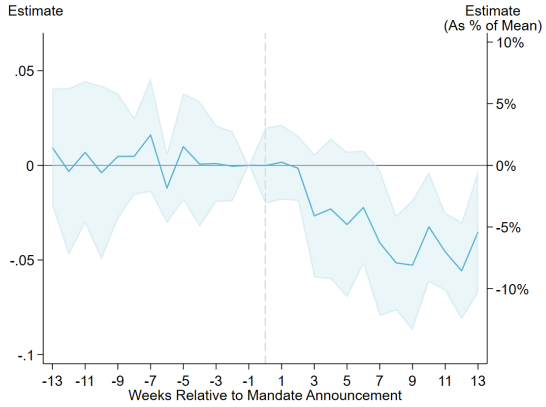



Hour Per Patient Day

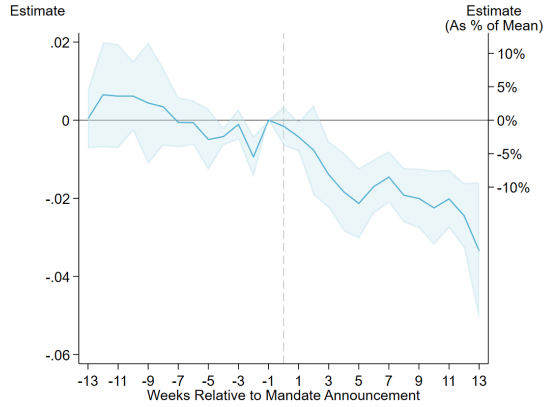
(d) Full-time Staff




(e) Part-time Staff




(f) Very Part-time Staff

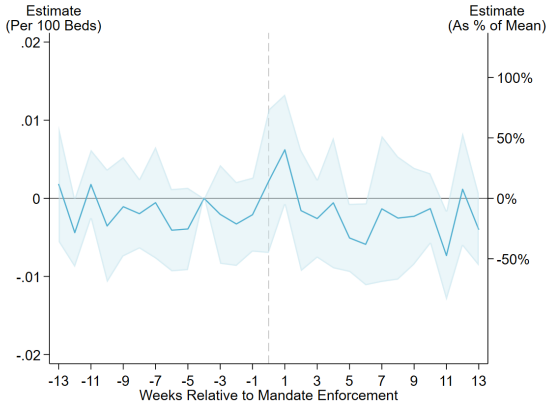



*Notes.* These figures plot event study regressions which compare treated facilities that implemented a vaccination mandate relative to control facilities that did not implement a vaccination mandate. Regressions include week and facility fixed effects. Standard errors are clustered at the chain level. The y-axis on the left-hand side shows the change for each outcome relative to to the week when vaccination mandates were announced. The y-axis on the right-hand side of panels (a) represents the estimate as percent change relative to the week prior to the mandate announcement week. The x-axis illustrates the event-time relative to the week in which the chain's vaccination mandate was announced.

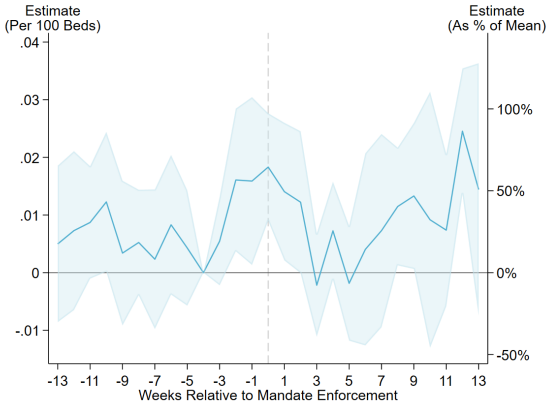
Figure S9: Estimated Effect of Mandate Enforcement on CNA Staffing Changes

Separations

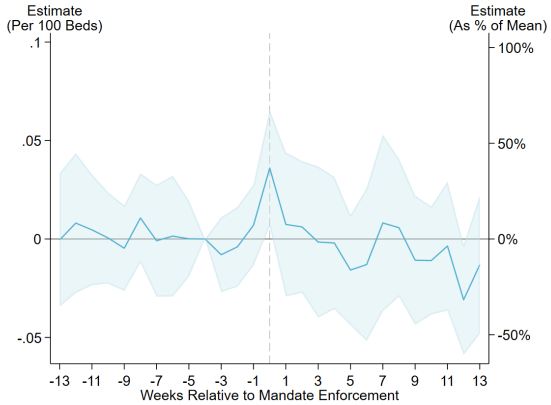
(a) Full-time Staff




(b) Part-time Staff

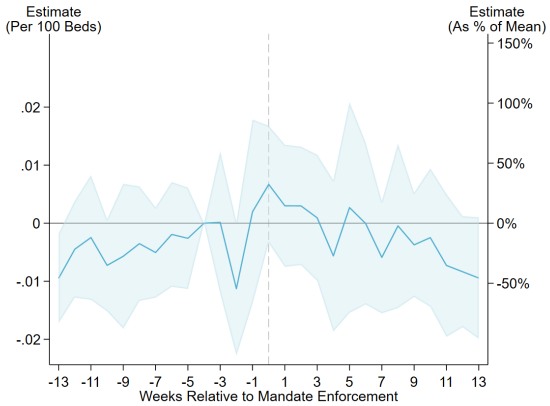



(c) Very Part-time Staff

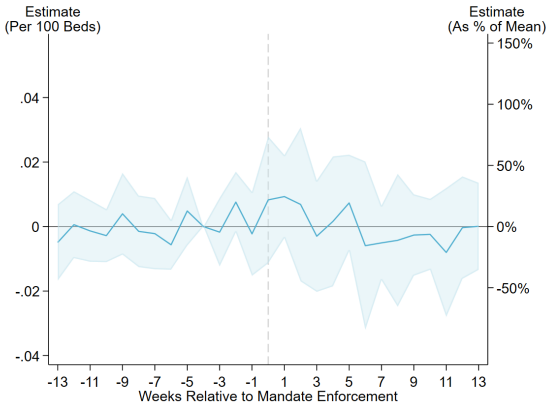



New Hires

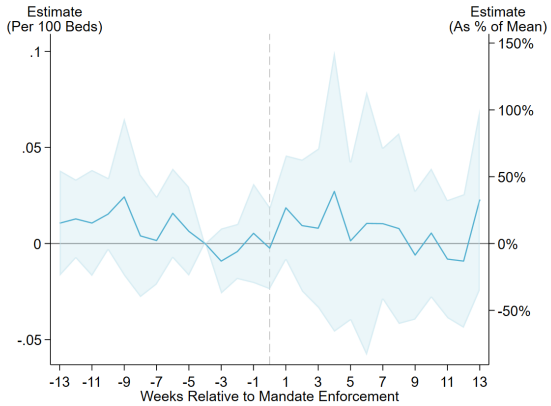
(d) Full-time Staff




(e) Part-time Staff




(f) Very Part-time Staff



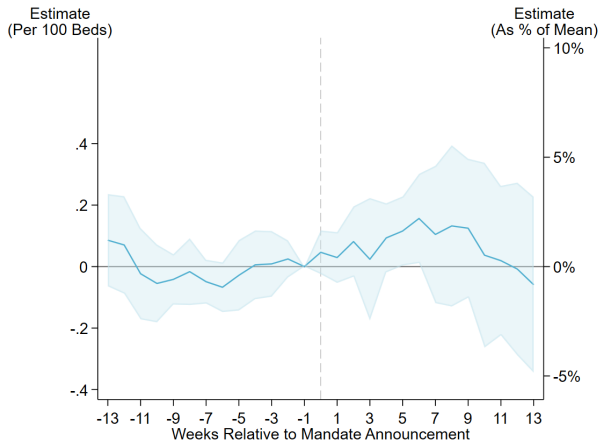

*Notes.* These figures plot event study regressions which compare treated facilities that implemented a vaccination mandate relative to control facilities that did not implement a vaccination mandate. Regressions include week and facility fixed effects. Standard errors are clustered at the chain level. The y-axis on the left-hand side shows the change for each outcome relative to four weeks prior to the week when vaccination mandates were in effect. Four weeks prior to the mandate effective week is used as the reference period because of potential anticipation effects. The y-axis on the right-hand side represents the estimate as percent change relative to the four weeks prior to the mandate effective week. The x-axis illustrates the event-time relative to the week in which the chain's vaccination mandate was effective.

## 3.3 Results for Licensed Practical Nurses (LPNs)

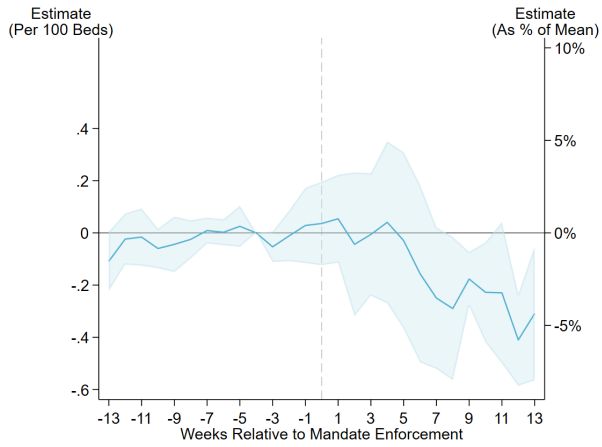
Figure S10: Estimated Effect of Mandates on LPN Staffing Levels

Staff Size

(a) Mandate Announcement

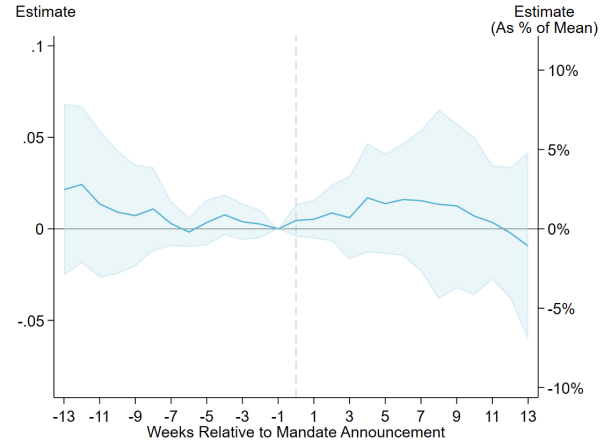



(b) Mandate Enforcement

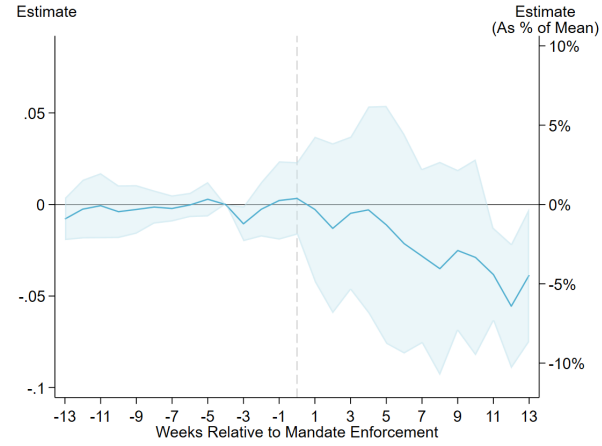



Hour Per Patient Day

(c) Mandate Announcement




(d) Mandate Enforcement

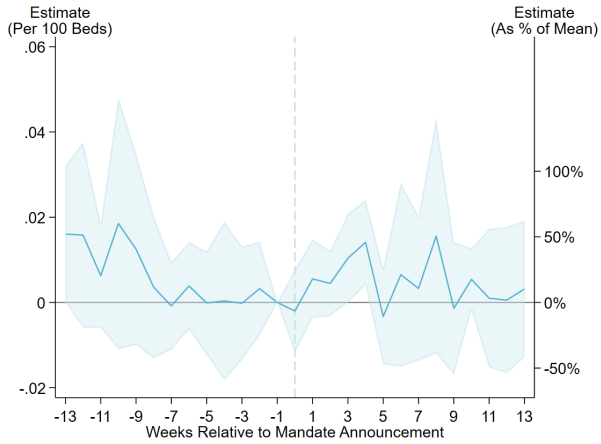



*Notes.* These figures plot event study regressions which compare treated facilities that implemented a vaccination mandate relative to control facilities that did not implement a vaccination mandate. Regressions include week and facility fixed effects. Standard errors are clustered at the chain level. The y-axis on the left-hand side shows the change for each outcome relative to to the week when vaccination mandates were announced in panels (a) and (c) and relative to four weeks prior to the week when vaccination mandates were enforced in panels (b) and (d). Four weeks prior to the mandate effective week is used as the reference period because of potential anticipation effects. The y-axis on the right-hand side of panels (a) and (c) represents the estimate as percent change relative to the week prior to the mandate announcement week. The y-axis on the right-hand side of panels (b) and (d) represents the estimate as percent change relative to the four weeks prior to the mandate enforcement week. The x-axis illustrates the event-time relative to the week in which the chain's vaccination mandate was enforced.

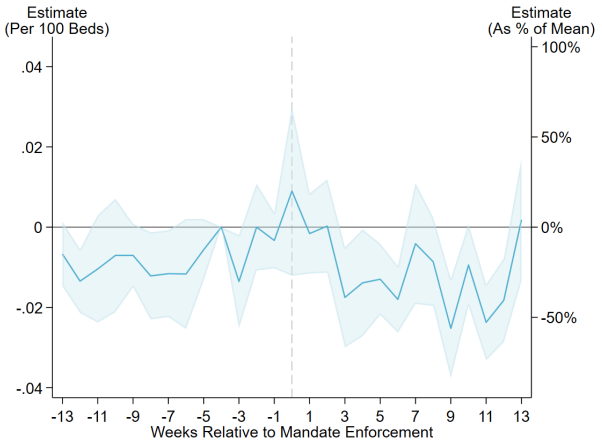
Figure S11: Estimated Effect of Mandates on LPN Staffing Changes

Separations

(a) Mandate Announcement

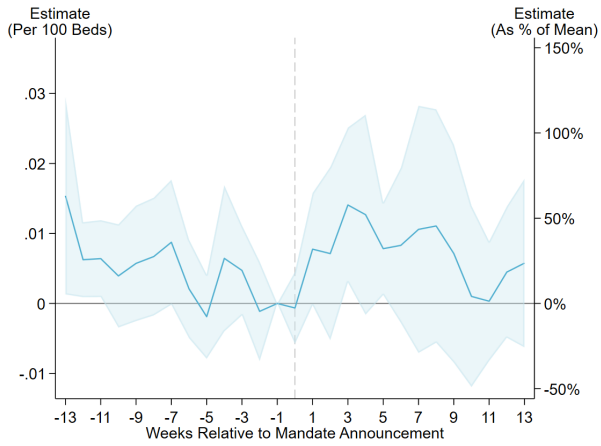



(b) Mandate Enforcement

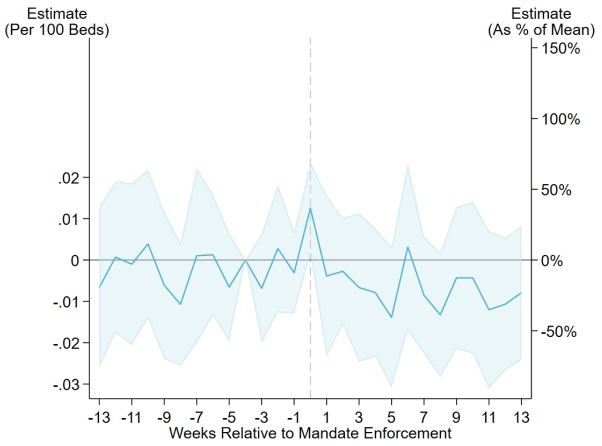



Hires

(c) Mandate Announcement




(d) Mandate Enforcement



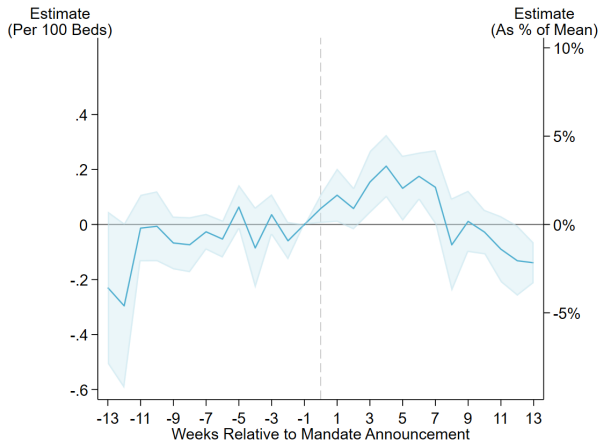

*Notes.* These figures plot event study regressions which compare treated facilities that implemented a vaccination mandate relative to control facilities that did not implement a vaccination mandate. Regressions include week and facility fixed effects. Standard errors are clustered at the chain level. The y-axis on the left-hand side shows the change for each outcome relative to to the week when vaccination mandates were announced in panels (a) and (c) and relative to four weeks prior to the week when vaccination mandates were enforced in panels (b) and (d). Four weeks prior to the mandate enforcement week is used as the reference period because of potential anticipation effects. The y-axis on the right-hand side of panels (a) and (c) represents the estimate as percent change relative to the week prior to the mandate announcement week. The y-axis on the right-hand side of panels (b) and (d) represents the estimate as percent change relative to the four weeks prior to the mandate effective week. The x-axis illustrates the event-time relative to the week in which the chain's vaccination mandate was enforced.

## 3.4 Results for Registered Nurses (RNs)

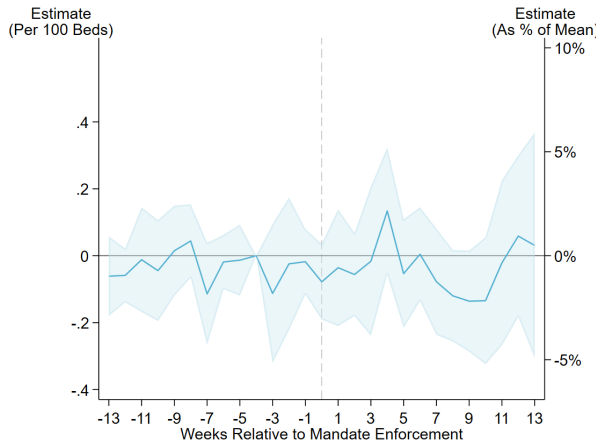
Figure S12: Estimated Effect of Mandates on RN Staffing Levels

Staff Size

(a) Mandate Announcement

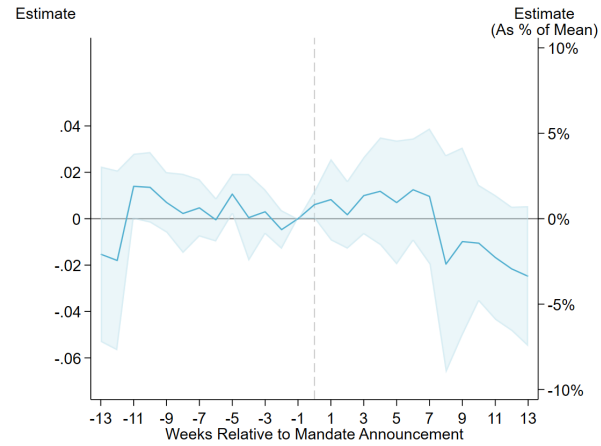



(b) Mandate Enforcement

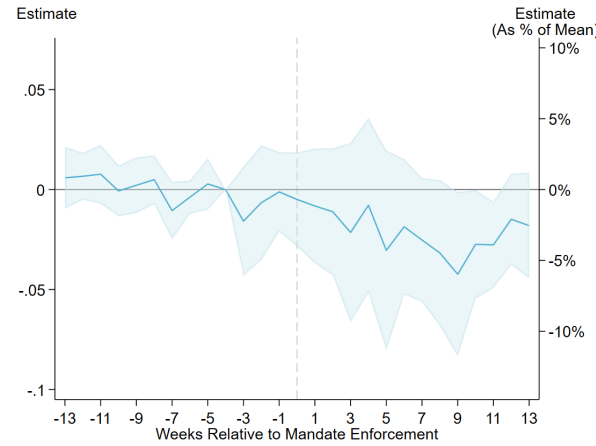



Hour Per Patient Day

(c) Mandate Announcement




(d) Mandate Enforcement

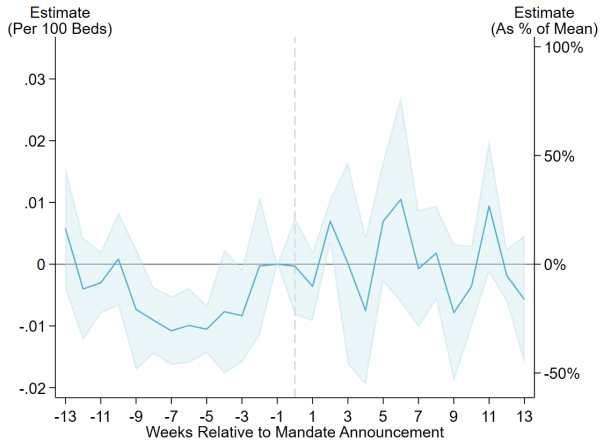



*Notes.* These figures plot event study regressions which compare treated facilities that implemented a vaccination mandate relative to control facilities that did not implement a vaccination mandate. Regressions include week and facility fixed effects. Standard errors are clustered at the chain level. The y-axis on the left-hand side shows the change for each outcome relative to to the week when vaccination mandates were announced in panels (a) and (c) and relative to four weeks prior to the week when vaccination mandates were enforced in panels (b) and (d). Four weeks prior to the mandate enforced week is used as the reference period because of potential anticipation effects. The y-axis on the right-hand side of panels (a) and (c) represents the estimate as percent change relative to the week prior to the mandate announcement week. The y-axis on the right-hand side of panels (b) and (d) represents the estimate as percent change relative to the four weeks prior to the mandate enforcement week. The x-axis illustrates the event-time relative to the week in which the chain's vaccination mandate was enforced.

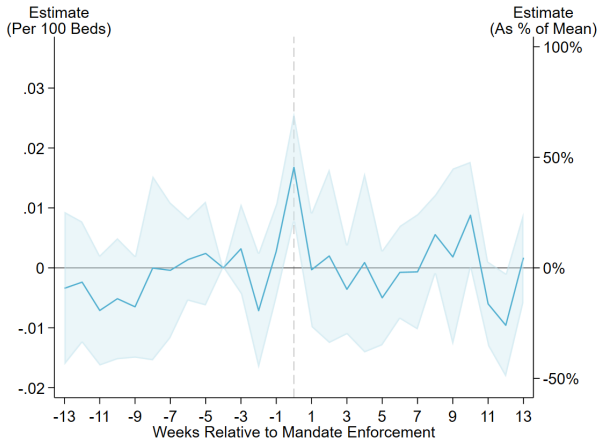
Figure S13: Estimated Effect of Mandates on RN Staffing Changes

Separations

(a) Mandate Announcement

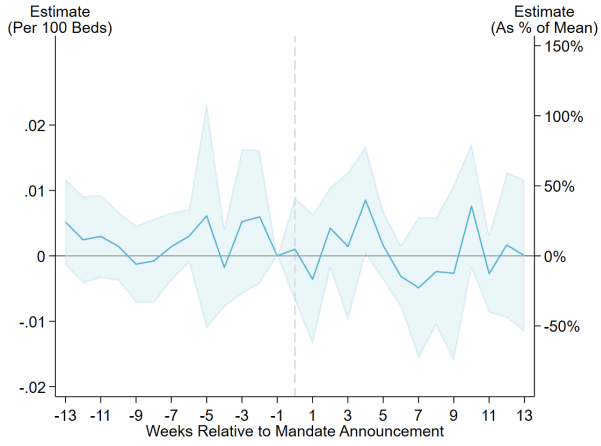



(b) Mandate Enforcement

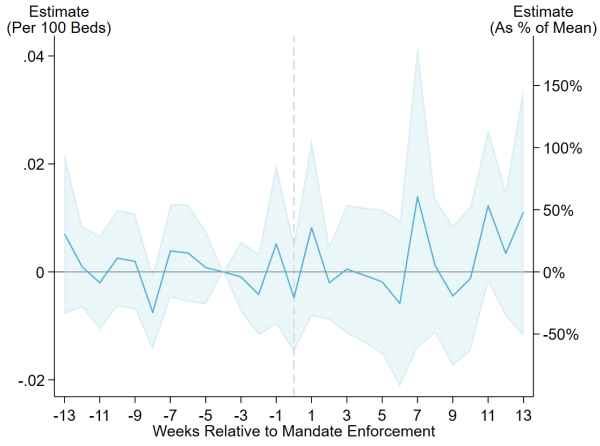



Hires

(c) Mandate Announcement




(d) Mandate Enforcement

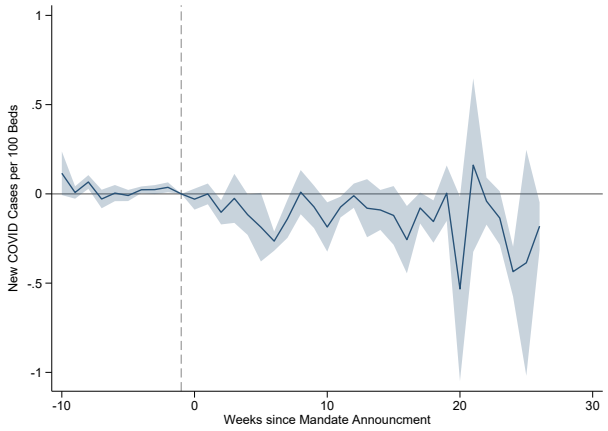



*Notes.* These figures plot event study regressions which compare treated facilities that implemented a vaccination mandate relative to control facilities that did not implement a vaccination mandate. Regressions include week and facility fixed effects. Standard errors are clustered at the chain level. The y-axis on the left-hand side shows the change for each outcome relative to to the week when vaccination mandates were announced in panels (a) and (c) and relative to four weeks prior to the week when vaccination mandates were enforced in panels (b) and (d). Four weeks prior to the mandate enforcement week is used as the reference period because of potential anticipation effects. The y-axis on the right-hand side of panels (a) and (c) represents the estimate as percent change relative to the week prior to the mandate announcement week. The y-axis on the right-hand side of panels (b) and (d) represents the estimate as percent change relative to the four weeks prior to the mandate effective week. The x-axis illustrates the event-time relative to the week in which the chain's vaccination mandate was enforced.

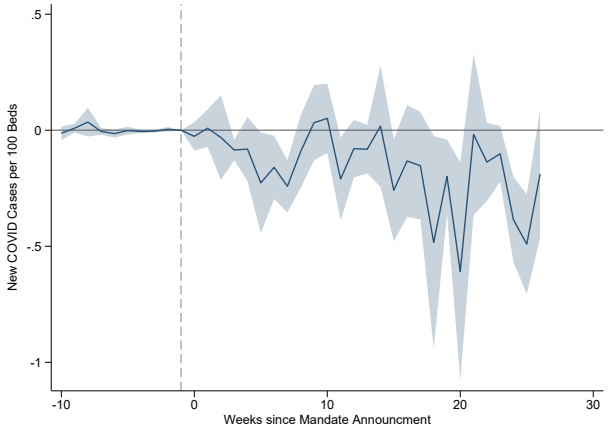
## 3.5 Results for COVID Cases and Deaths

Figure S14: Event Study for COVID Cases and Deaths (Matched Sample)

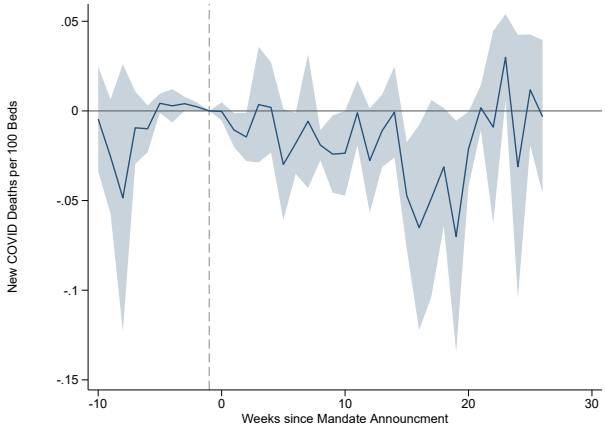
(a) Staff Cases




(b) Resident Cases



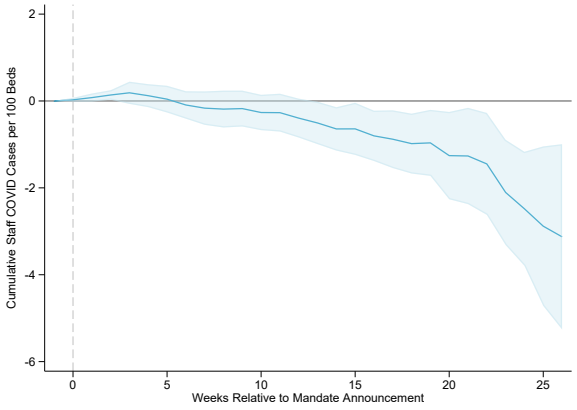

(c) Resident Deaths



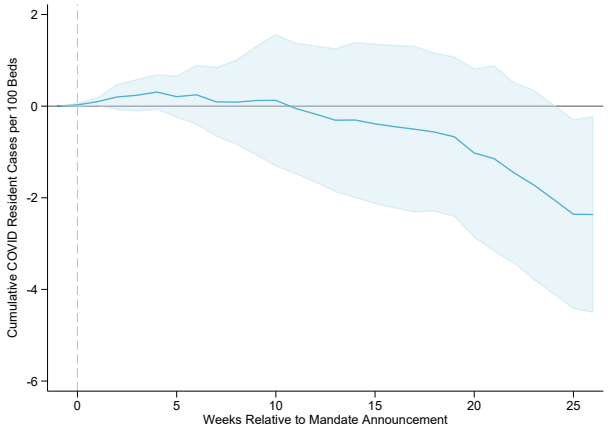

*Notes.* These figures plot matched event study estimates which compare matched treated facilities that implemented a vaccination mandate relative to matched control facilities that did not implement a vaccination mandate. Regressions include week and facility fixed effects. Standard errors are clustered at the chain level. The y-axis represents weekly staff COVID cases (a), resident COVID cases (b), and resident COVID deaths (c) per 100 beds. Estimates for weeks ¿=0 are summed to calculate the cumulative effect estimates presented in Figure 4 in the manuscript.

Figure S15: Event Study for COVID Cases and Deaths (CSDID)

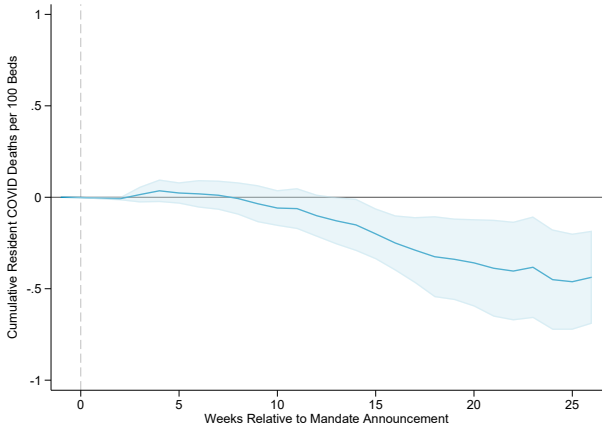
(a) Staff Cases




(b) Resident Cases




(c) Resident Deaths




*Notes.* These figures plot matched event study estimates which compare matched treated facilities that implemented a vaccination mandate relative to matched control facilities that did not implement a vaccination mandate. Regressions include week and facility fixed effects. Standard errors are clustered at the chain level. The y-axis represents weekly cumulative staff COVID cases (a), resident COVID cases (b), and resident COVID deaths (c) per 100 beds. Estimates were obtained using the Callaway-Sant'Anna difference-in-differences estimation packed to account for potential negative weighting bias.

# References


1. CMS . Biden-Harris Administration Takes Additional Action to Protect America's Nursing Home Residents from COVID-19. 2021.

2. CMS . Biden-Harris Administration to Expand Vaccination Requirements for Health Care Settings. 2021.

3. CMS . Design for Care Compare Nursing Home Five-Star Quality Rating System: Technical Users' Guide. 2023.

4. Goodman-Bacon A. Difference-in-differences with variation in treatment timing. *Journal of Econometrics.* 2021;225(2):254–277.

5. Callaway B, Sant'Anna PHC. Difference-in-Differences with multiple time periods. *Journal of Econometrics.* 2021;225(2):200–230.