Appendix To: Did Ohio's Vaccine Lottery Increase Vaccination Rates? A Pre-Registered, Synthetic Control Study

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A Placebo Analysis Plan

In the pre-registration we also presented a "placebo" test that created a false treatment period of April 5th to May 9th. In this artificial treatment period, we saw little difference between Ohio and synthetic Ohio. Once generated we plotted the difference between synthetic Ohio's vaccination rate and actual Ohio's vaccination rate (Figure 1). This placebo analysis suggested that it generated reasonable out-of-sample fit, with an error of less than a percent in any of the out-of-sample periods.

The exact inference strategy we used to compute statistical significance is a permutation test. We treat each of the donor states in turn as though it was the treated state, and re-estimate a unique synthetic counterfactual. We computed the ratio of the Mean Squared Predictive Error (MSPE) between our pre-treatment and post-treatment data for each state. We then sorted them in descending order based on the ratio of MSPE and used the associated rank for each state as it's associated p-value (See Figure 2). In the case of our placebo analysis, synthetic Ohio had a rank of 41 out of 51 units and an associated p-value of 0.804, indicating that we fail to reject null effects.

For our actual analysis, we repeated these exact same steps using the 17 weeks prior to the lottery announcement as our pre-treatment period and the six weeks following the lottery announcement as our post-treatment period. Failure to reject the null effect hypothesis is not interpreted as proof of null effects.

To describe the net effect of the program, we took the point estimate from the last period's difference between actual Ohio and synthetic Ohio. In the case of Figure 1, our

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TABLE 1: Vaccination Growth Rates by State, Pre Ohio Lottery Announcement

State	Mean	SD	State	Mean	SD
AK	2.141	1.004	MT	2.074	0.844
AL	1.601	0.66	NC	1.966	0.856
AR	1.672	0.737	ND	2.005	0.863
AZ	1.938	0.781	NE	2.259	1.022
CA	2.188	1.129	NH	2.058	1.221
CO	2.337	1.124	NJ	2.552	1.268
CT	2.774	1.492	NM	2.534	0.816
DC	2.176	1.58	NV	1.935	0.833
DE	2.249	1.238	NY	2.455	1.397
FL	2.063	0.849	OH	2.191	1.059
GA	1.702	0.994	OK	1.851	0.85
HI	2.503	1.252	OR	2.237	0.939
IA	2.341	1.203	PA	2.241	1.147
ID	1.772	0.745	RI	2.631	1.48
IL	2.076	1.024	SC	1.824	0.872
IN	1.855	0.672	SD	2.348	0.921
KS	2.102	1.048	TN	1.688	0.661
KY	2.097	0.974	TX	1.848	0.936
LA	1.697	0.778	UT	1.685	0.887
MA	2.678	1.376	VA	2.334	1.129
MD	2.449	1.211	VT	2.671	1.341
ME	2.825	1.517	WA	2.296	0.994
MI	2.219	0.957	WI	2.409	1.111
MN	2.385	1.036	WV	1.858	0.616
MO	1.847	0.818	WY	1.756	0.873
MS	1.5	0.746			

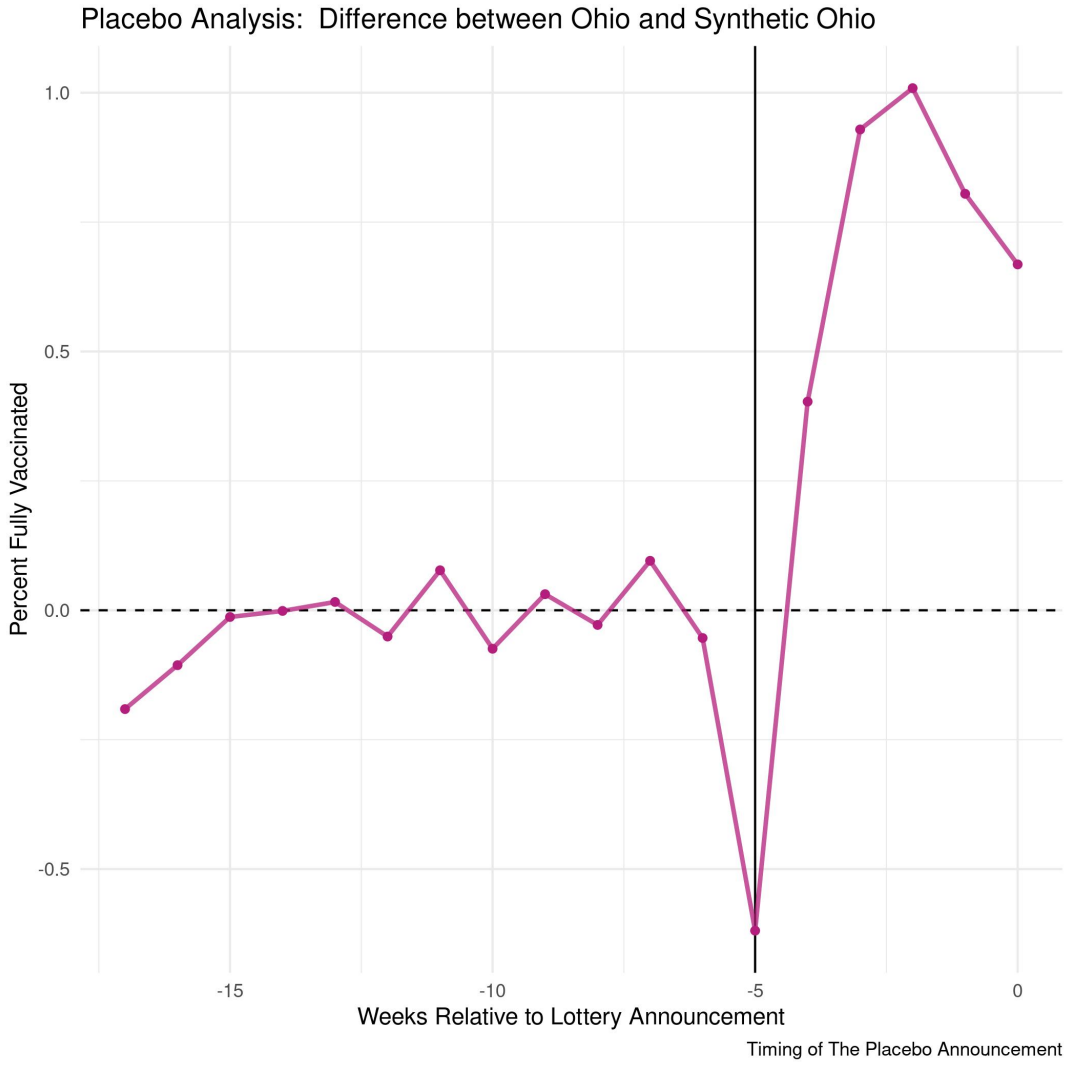

FIGURE 1: Placebo difference in vaccination rates between Ohio and Synthetic Ohio, with a false treatment date set 5 weeks prior to the true treatment date. Positive values show Ohio with a higher percentage of the population fully vaccinated than the synthetic comparison.

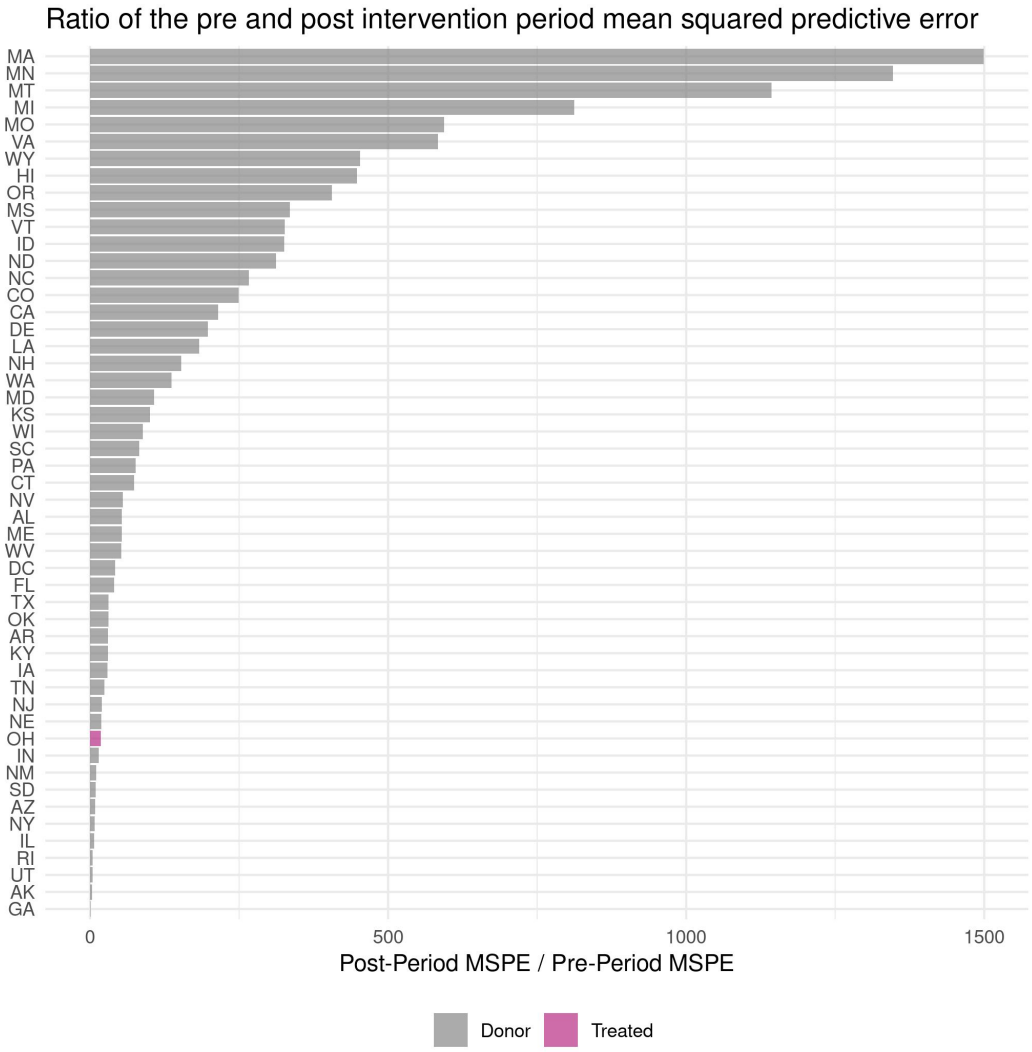

FIGURE 2: Placebo Test

point estimate would suggest the lottery program increased participation by 0.6% . We also computed the average difference between synthetic and actual Ohio across the treatment period. This information can be quite descriptive if, for instance, a program had no effect in the long run but encouraged some individuals to get vaccinated several weeks earlier.

B Power Analysis

We conducted power analyses with different potential effect sizes. We generated subsequent outcomes assuming that states would continue to grow at their weekly rate as sampled from historical mean and standard deviation (See Table 1). We truncate these distributions such that vaccination rates cannot decrease from week to week. We then assumed that the effect of the lottery would have an increase between zero and two percentage points per week.

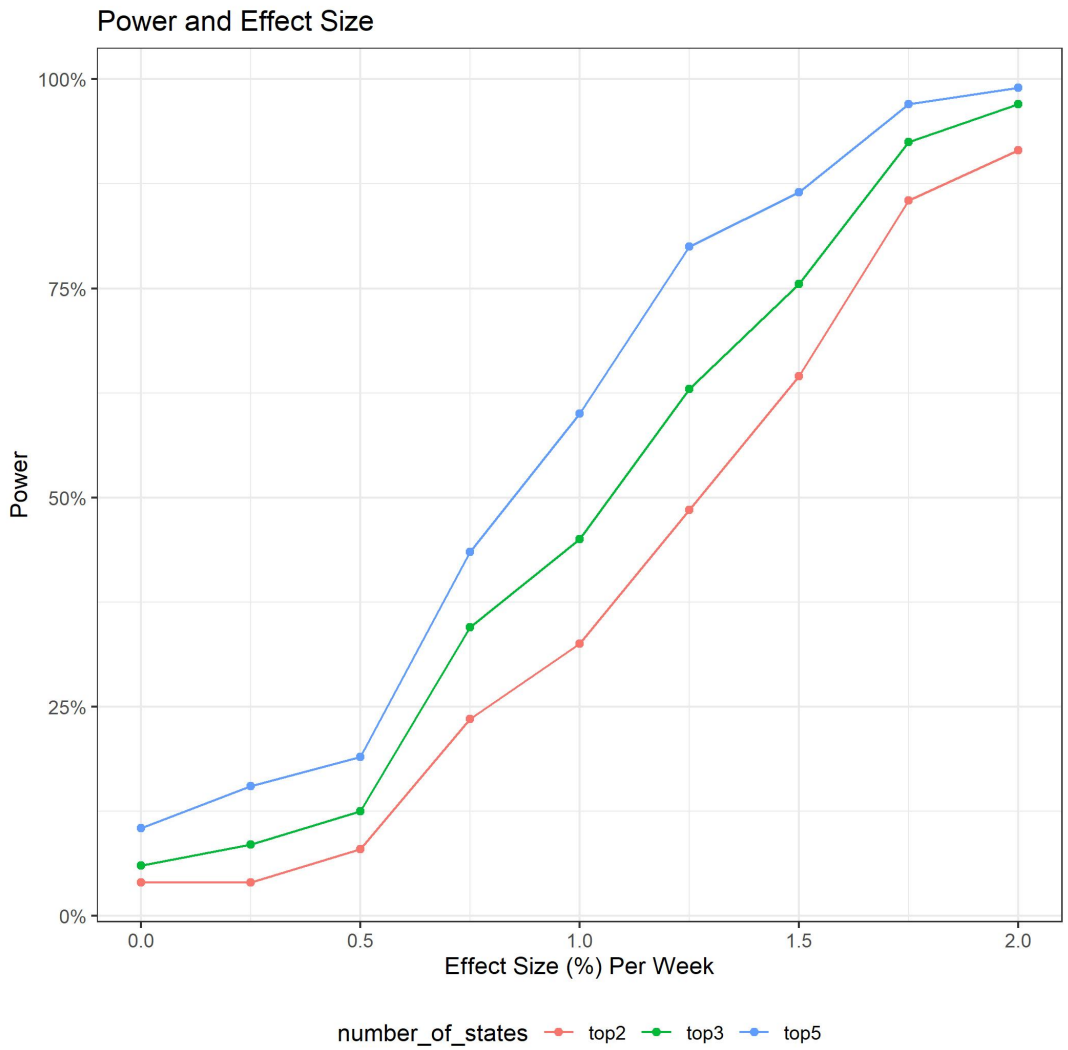

FIGURE 3: Effect Size and Power

We computed 200 bootstrap simulations and conducted our permutation tests. Based on Figure 3, we were reasonably powered to detect effect sizes on the order of 1.75% percentage points or larger using a p-value cutoff of 0.10, this correspond to the top 5 states. The associated power with this cutoff is 0.97. This effect is roughly on the order of the absolute effect associated with compensating individuals to receive the HPV vaccine, which saw between a 9.8% to 13.2% percentage point increase in first-time vaccination rates (Mantzari et al., 2015). To put this in context of statewide vaccination rates at the time of the lottery announcement, Ohio has a fully vaccinated rate of 37%. Such an effect would make it the second-most vaccinated state in the country just behind Maine at 48%.

TABLE 2: State Lottery Announcement Dates as of July 2nd, 2021

State	Lottery Announcement Date
OH	5/13/21
MD	5/20/21
NY	5/20/21
OR	5/21/21
AR	5/25/21
CO	5/25/21
DE	5/25/21
CA	5/28/21
NM	6/1/21
WV	6/1/21
WA	6/3/21
KY	6/4/21
NC	6/10/21
MA	6/15/21
ME	6/16/21
NV	6/16/21
IL	6/17/21
LA	6/17/21
MI	6/30/21

C Fifty State Specification

In our original pre-registration we did not anticipate that other states would so quickly follow Ohio's lead in adopting lottery sweepstake prizes. See Table 2 for a list of state vaccine lottery announcements. We modified our OSF pre-registration on June 15, 2020 to note that we would exclude states that adopted lotteries from the synthetic comparison. This was before the final two lottery drawings in Ohio occurred. In the interest of full transparency, we present here results using our original pre-registration that includes all 50 states in the synthetic comparison. The pre-registered weights for the composition of the synthetic control can be seen in Table 3 and are presented alongside the weights used in the primary analysis. The most notable change is that Delaware was originally part of the synthetic control for Ohio, but due to their lottery adoption ended up being excluded. This shifted weights on other states, causing Alaska to be removed as well and adding Pennsylvania.

The quality of the match between Actual Ohio and this version of Synthetic Ohio exhibits marginally better fit in the pre-treatment period. In total the error in this period is at most 0.6% in any given week (see Table 4).

We present differences between Actual and Synthetic Ohio in Figure 4. Through the entire treatment period, vaccination rates for Ohio are below our synthetic counterfactual. At the end of the period, this difference was approximately -0.9%. The associated confidence

TABLE 3: Synthetic Ohio weights, including states that also adopted lotteries from the donor pool. For comparative purposes we include here the weights used in the main analysis, excluding other lottery adopting states.

Unit	Including Lottery State Weights	Excluding Lottery State Weights
AK	0.009	0.000
CT	0.060	0.029
DE	0.128	Excluded
GA	0.160	0.168
HI	0.035	0.061
IA	0.039	0.066
KS	0.319	0.256
PA	0.000	0.056
VA	0.080	0.173
WI	0.170	0.192

TABLE 4: Balance Table (Alternative Specification)

Pretreatment Outcome	Ohio	Synthetic Ohio	Difference	Donor Pool
lagged_vaccinations_week17	0.120	0.398	−0.278	0.556
lagged_vaccinations_week16	0.610	0.839	−0.229	1.083
lagged_vaccinations_week15	1.400	1.472	−0.072	1.871
lagged_vaccinations_week14	2.440	2.451	−0.011	2.961
lagged_vaccinations_week13	3.830	3.745	0.085	4.346
lagged_vaccinations_week12	5.560	5.673	−0.113	6.157
lagged_vaccinations_week11	7.670	7.651	0.019	7.972
lagged_vaccinations_week10	9.440	9.538	−0.098	9.809
lagged_vaccinations_week09	11.870	11.777	0.093	12.057
lagged_vaccinations_week08	13.860	13.823	0.037	14.081
lagged_vaccinations_week07	16.130	16.042	0.088	16.373
lagged_vaccinations_week06	18.780	18.748	0.032	19.368
lagged_vaccinations_week05	21.610	22.181	−0.571	22.757
lagged_vaccinations_week04	26.320	26.101	0.219	26.153
lagged_vaccinations_week03	30.110	29.802	0.308	29.197
lagged_vaccinations_week02	33.230	33.076	0.154	32.036
lagged_vaccinations_week01	35.620	35.822	−0.202	34.709

interval associated with this point estimate is between -2.4% and 0.6%.

We present the same set of outcome measures as in our main analysis in Table 5 below. The associated p-value for our pre-registered metric is created from an MSPE ratio rank of 29/51 which is approximately 0.57. Related measures such as the average difference or end of period differences are also negative but not statistically significant. These results are not substantively different from those we present in the main body of the paper.

TABLE 5: Outcome Table (Alternative Specification)

Measure	MSPE-Ratio	Average Difference	Last Period Difference
Value	15.7	−0.81	−0.90
Rank	27	32	30
p-value	0.53	0.63	0.59

D Existing Point Estimates

One benefit of the synthetic control method is that only the primary outcome variable and associated weights are necessary to replicate and extend estimates from other model specifications. Here we have replicated the first dose effect estimates reported in two other synthetic control papers (Barber and West, 2021; Sehgal, 2021) and extended the estimates through August 22nd, 2021 using the weights available in those papers. We also present estimates for a first dose model that we estimate that is identical to the model we present in the main body of this paper except for the choice of outcome variable. While there may be some minor differences between these estimates and their original authors' work due to different data pre-processing decisions, these results are broadly comparable.

The results are presented in Figure 5. We note that Sehgel (2021) trained their weights on only 30 days of data before the lottery announcement and thus it is expected that their pre-fit quality would degrade for earlier dates. All three models show positive point estimates during the lottery period. However, all models show that the cumulative effect rapidly turned negative after the lottery ended. This suggests that the lottery may have shifted some individuals to get vaccinated earlier than they would have otherwise, but in the long term vaccination rates in Ohio fell below the synthetic control group [1]. These findings highlight the importance of researchers aligning the effect studied with the policy relevant outcomes that are most important to change, and checking for the persistence of effects over the long term. We note here that long term is denoted by extending the study period by a matter of weeks.

[1]We note that Kansas had data revision on July 23rd `https://www.kansasvaccine.gov/158/Data` . Exclusion of Kansas from the synthetic control does not change the sign of our estimates. Seghal's estimates do not attribute any weight to Kansas and finds a similar estimate.

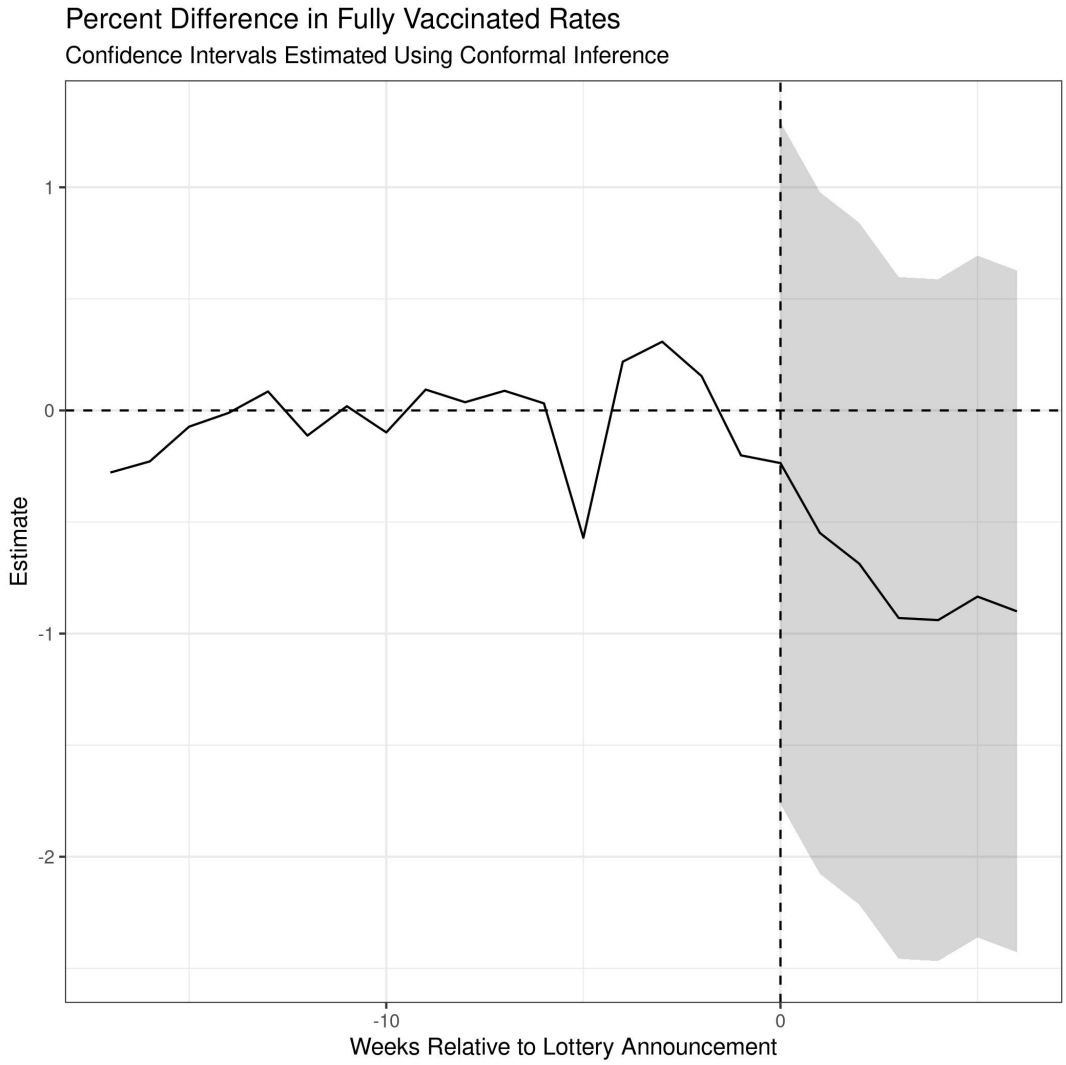

FIGURE 4: Alternate specification difference in Vaccination rates between Ohio and Synthetic Ohio, all states that adopted lotteries after Ohio have been included. Negative values show that Ohio has a lower total vaccination rate than the synthetic comparison

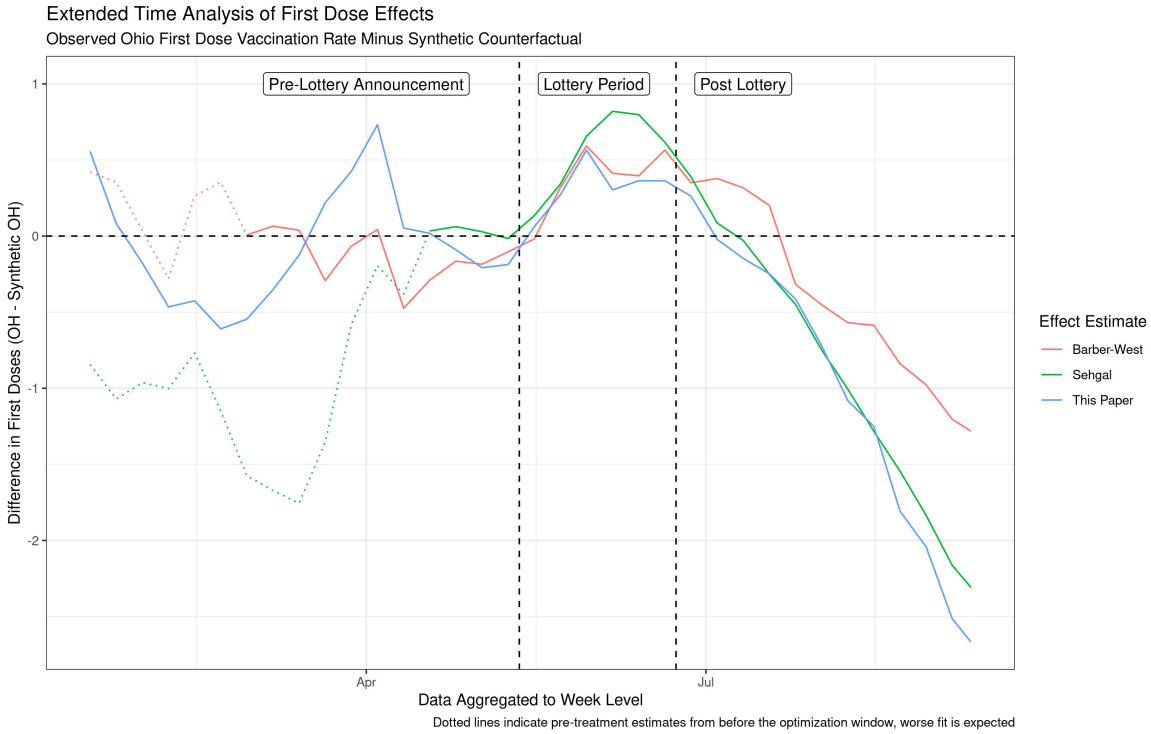

FIGURE 5: Comparison of estimates of effects of lottery on first doses(Barber and West, 2021; Sehgal, 2021)

E Exploratory analysis of multiple lottery announcements

After the initial positive news coverage of the Ohio lottery and with encouragement from the White House (White House Press Briefing, 2021), seventeen states have so far followed Ohio's lead by announcing lotteries of their own (see Table 2). We estimate a synthetic control model that explicitly allow for multiple treated units with differential treatment timing. This analysis was not included in our pre-registration plan and is therefore included here as exploratory. We present the descriptive trends of total vaccination rates across states in Figure 6. In this figure we see that states with high vaccination rates, like Massachusetts and Maine, and states with low vaccination rates, like Louisiana and Arkansas, have adopted lottery incentives. Descriptively, we see that most states appear to maintain a roughly constant relative ranking after adopting the lottery incentive, which suggests that lotteries did not have large effects on vaccination rates.

We use the augmented synthetic control method to estimate the average treatment effect across states that adopt lotteries (Ben-Michael et al., 2021a, 2021b). This method is a natural extension of our pre-registered plan. We preserve the same outcome - the percent of the population fully vaccinated - for this analysis. We examine the change in vaccination rates up to 12 weeks after a state's initial lottery announcement. This allows us to detect whether the lottery had any lasting impact on vaccination rates.

This approach does have several key distinctions from the traditional synthetic control

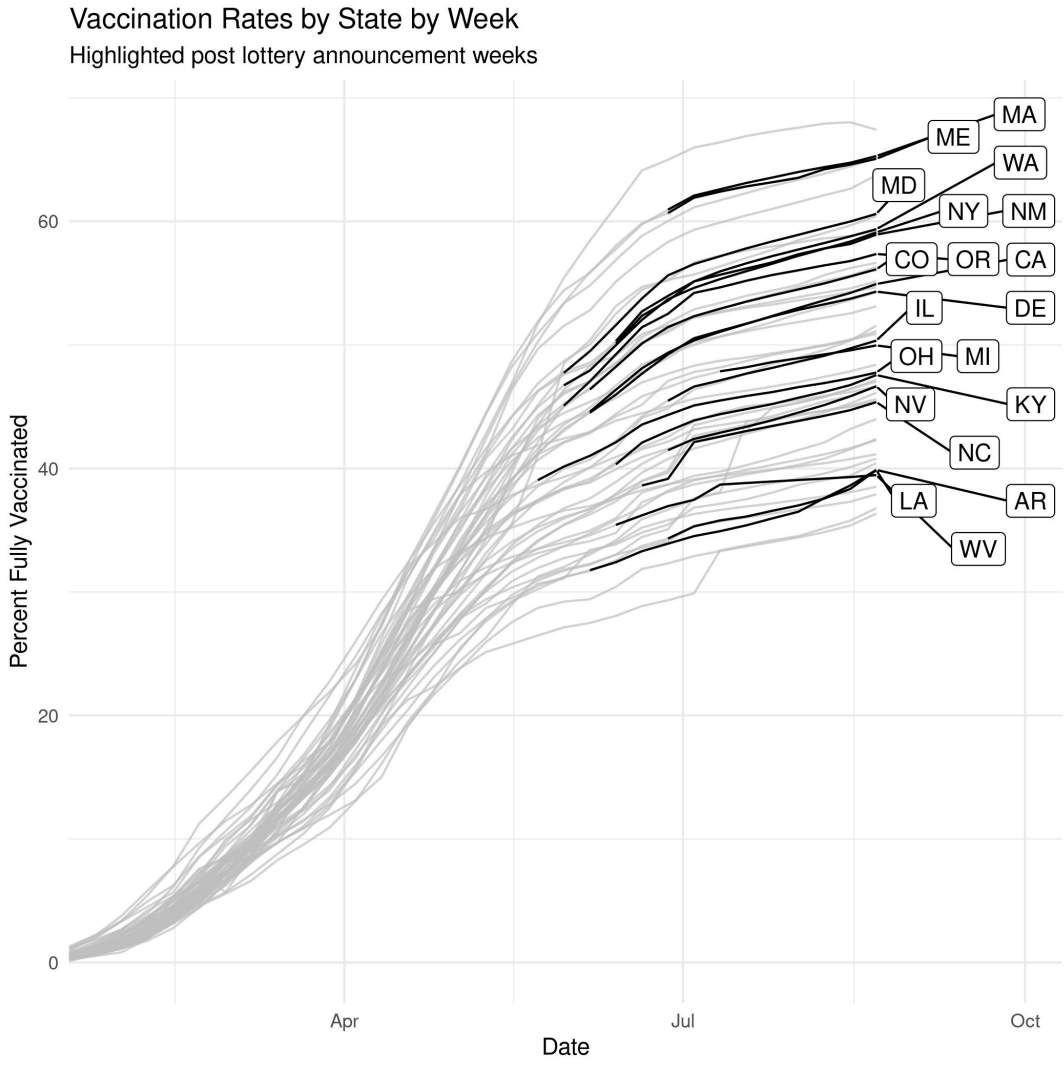

FIGURE 6: Vaccination Rates by State with Lottery Adoption Highlighted

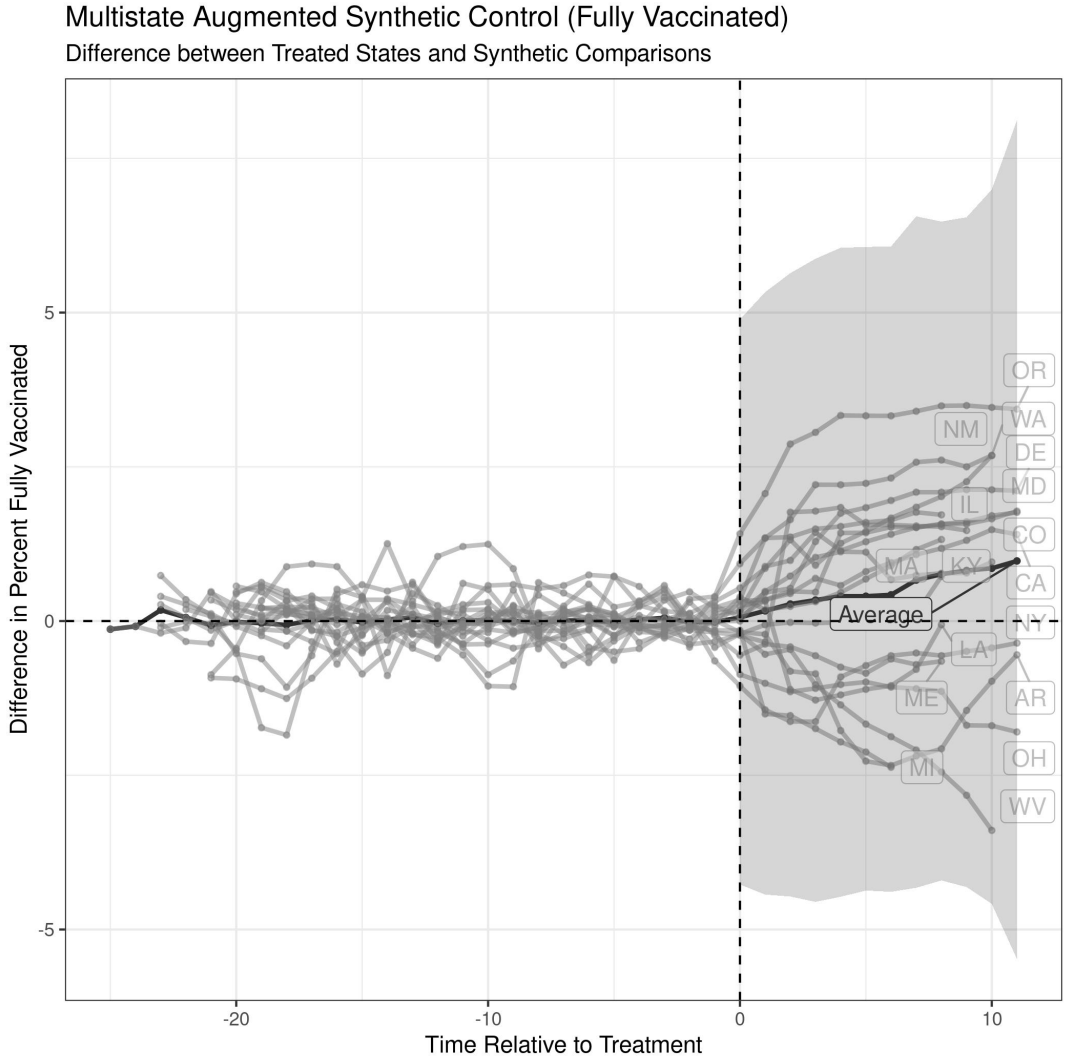

FIGURE 7: Augmented Synthetic Comparison with Multiple Adopting States

approach for the single-state case. First, it provides more flexibility in terms of the possible search space for generating the synthetic control, allowing weights to be negative and a unit-intercept term. Second, it adds regularization to the construction of the match, both to adjust for over-fitting and to help ensure unique solutions to the optimization. Third, it allows flexibility to balance the quality of match for an individual treated state and the composite average of all treated states.

The results of this analysis are presented in Figure 7. We now observe a small, statistically insignificant, average increase of 1.0 percentage points per week in the fully vaccinated rate of states that adopt lotteries relative to the synthetic counterfactual. This effect is consistent with another recent working paper that analyzed twelve state lotteries and also found small positive effects in ten of the lotteries they studied (Robertson et al., 2021).

F Recommended Reporting Standards

This was a synthetic control analysis, not a randomized controlled trial. Our research design used synthetic control methods to estimate the effect of Ohio's COVID-19 lottery on vaccination.

F.1 Hypotheses

Our pre-registered hypothesis was that Ohio would see higher full vaccination rates relative to it's counterfactual at the end of the Ohio lottery period.

F.2 Subjects and Context

This is a quasi-experimental analysis of public data, we had no role in recruitment of participants or the design of the lottery intervention. We used state level aggregate vaccination rate data.

F.3 Allocation Method

This research studied a policy that was adopted by the governor of Ohio. We compared outcomes in Ohio to outcomes in other states that did not adopt lotteries. There was no randomization of individuals. The researchers had no contact or communication with any representatives of Ohio government and no influence on the lottery program in Ohio.

F.4 Treatment

The treatment group is the state of Ohio, which adopted a million dollar lottery sweepstakes for individuals living in Ohio who were 18 years of age or older and received at least one dose of a Covid vaccine. The control group is a synthetic counterfactual of other states that did not adopt vaccination lotteries. Questions regarding protocol are not applicable as this was not a true experiment.

F.5 Results

Our primary, pre-registered outcome metric was the full vaccination rate, defined as the percentage of the total state population that was fully vaccinated against the COVID-19 virus. Secondary outcomes that were explored in our multiverse analysis include first-dose rates, the percentage of the total state population that had received at least one dose of a COVID-19 vaccine, and total vaccine doses administered.

We did not analyze any subgroup outcomes or test for heterogenous treatment effects.

F.6 Consort Diagram

This is not applicable as this was not an experimental design with a recruitment procedure.

F.7 Statistical Analysis

The pre-registered inference strategy was a permutation test. This methodology is described in the main body of the text and in our placebo analysis appendix.

F.8 Other Information

This study waas sent to an IRB officer from our institution. It was deemed not human subject research. Pre-registration and replication information can be found at `https://osf.io/cypbr/` and at `https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/QYXN9L`.

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