THE OHIO VACCINE LOTTERY AND STARTING VACCINATION RATES

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ABSTRACT

We find that Ohio's "Vax-a-Million" lottery increased first-dose COVID-19 vaccinations by between 50,000 and 100,000, with most of the additional doses occurring during the two weeks between the announcement and the first lottery drawing. We use county-level data and two empirical approaches to provide causal estimates of the lottery in Ohio. First, a difference-in-differences design compares vaccination rates in border counties in Ohio and Indiana before and after the announcement. Second, we use a pooled synthetic control method to construct a counterfactual for each of Ohio's counties using control counties in Indiana, Michigan, and Pennsylvania. The synthetic control analysis reveals larger increases in vaccination rates in more populous counties. Our estimates imply that Ohio paid about $75 per additional starting dose during this period.

KEYWORDS: vaccine lottery, COVID-19 vaccination, Vax-a-Million, event study, synthetic control method
JEL CLASSIFICATION: I12, I18, H75

> *I kept hemming and hawing about it, and I work all the time, and when the Vax-a-Million thing started I immediately went down there and got it. It pushed me over the edge.*
> —Jonathan Carlyle, Vax-a-Million winner, *Cincinnati Enquirer*

I. Introduction

The three primary COVID-19 vaccines in the United States have been shown to be effective at preventing COVID-19 infections, hospitalizations, and deaths. Paid for by the Federal government, the vaccine is free of charge to all people living in the United States. The Centers for Disease Control and Prevention (CDC) currently recommends that everyone 12 years and older receive a vaccination. While the exact herd immunity threshold for COVID-19 is unknown, early studies estimated that at least 70 percent of the population

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All three authors and their eligible immediate family members entered the "Vax-a-Million" lottery and were not selected.

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needs to be immune in order to halt the spread of infection (Randolph and Barreiro 2020; Kwok et al. 2020). With the more transmissible Delta variant, more recent estimates place the threshold at 85 percent (Berg 2021; Mandavilli 2021). Clinical trials demonstrate safety and efficacy, and the vaccine is freely available, yet vaccination coverage remains below this threshold. As of September 25, 2021, 64 percent of the US population has received at least one vaccine dose, and 55 percent is fully vaccinated, with large variation across geography and demographics (CDC 2021a). With herd immunity still out of reach, additional vaccinations are important for reducing transmission, hospitalizations, and deaths.

Ohio introduced its "Vax-a-Million" lottery campaign to nudge unvaccinated residents 12 years and older to receive a COVID-19 vaccine. In the week after the announcement, the Ohio Department of Health reported immediate success from the program, citing that the campaign had caused a 28 percent increase in vaccinations among those 16 and older (Ohio Department of Health 2021). Media reports published much larger increases, with Governor DeWine claiming on CNN that there was a 45 percent increase in all vaccinations and a 94 percent increase in vaccinations among 16- and 17-year-olds by the day of the first drawing.[1] ABC News reported increases in vaccination rates of 43 to 53 percent over the course of the lottery (Lenthang and Periera 2021; Welsh-Huggins 2021). However, these estimates are based on week-to-week changes in vaccination numbers within Ohio, without looking at vaccination trends in comparison states. This caveat is particularly important because other factors could also have influenced vaccinations; around the same time as the lottery announcement, the Pfizer vaccine was approved for individuals aged 12 to 15, and the CDC updated its mask guidance so that vaccinated individuals could stop wearing masks and social distancing in most settings (Rabin, Mandavilli, and Weiland 2021).

We use two empirical approaches to provide a causal estimate of the response of vaccination rates to the Ohio lottery. First, we estimate an event study, comparing daily starting vaccination rates in border counties in Ohio and Indiana before and after the lottery announcement.[2] Second, we use synthetic control analysis to provide causal estimates even when the parallel trends assumption required for difference-in-differences does not hold. We use a pooled synthetic control method to construct a counterfactual for each of the treated Ohio counties (Abadie and Gardeazabal 2003; Abadie, Diamond, and Hainmueller 2010). We then estimate a state-level effect for all of Ohio by summing the county treatment effects and determine statistical significance using placebo tests.

We find that the lottery resulted in between 50,000 and 100,000 additional vaccine doses, mostly during the first two weeks following the announcement. We estimate that

1 For the CNN clip, see https://twitter.com/NewDay/status/1397539038458961920.

2 As shown below, the parallel trends assumption fails using control groups of border counties in Michigan and Pennsylvania. We do not use data from West Virginia and Kentucky for two reasons. First, West Virginia and Kentucky both announced lotteries at the start of June. These programs mean that our "control" counties would also be treated. West Virginia also announced a guaranteed savings bond program in April. Second, neither West Virginia nor Kentucky provides sufficient county-level vaccination data by administration date.

Ohio paid $75 per additional starting dose. In this short-run analysis, it is unclear to what extent the increase in vaccinations is along the intensive (pulled forward) or extensive (newly induced vaccinations) margins. Nevertheless, even if all the additional vaccinations are pulled forward in time, there would still be a reduction in transmission due to achieving a higher vaccination rate earlier. Compared with estimates of the value of statistical life of $9.8 million, the $5.6 million initiative need only save one life to be worth the cost (Robinson 2007). Back-of-the-envelope calculations suggest that vaccinating an additional 75,000 individuals will save between six and several hundred lives, assuming that they are additional vaccinations and not merely pulled forward in time.

Citing the success of Ohio's lottery, at least 15 other states have initiated similar programs, designed as a lottery among vaccinated residents or as offers of free lottery tickets to those who get a vaccine. Previous studies show that financial incentives do increase vaccination rates, though these findings are in the context of randomized trials with modest awards (Jacob et al. 2016; Mantzari, Vogt, and Marteau 2015; Greengold et al. 2009). To our knowledge, Ohio's "Vax-a-Million" public health initiative was the first of its kind intending to increase vaccination rates among the broader population.

This paper adds to existing research on financial incentives and vaccination decisions by documenting responses among the broader population, rather than in a randomized trial, and at a lower cost per vaccination compared with other estimates of the effect of financial incentives (Jacob et al. 2016). The estimated short-run response to the lottery is relevant in the context of evidence that booster doses increase vaccine-induced protection and the recent authorization of boosters for some members of the population (US Food and Drug Administration 2021a). Our results suggest that vaccine lotteries may play a role in inducing the marginal patient to get vaccinated, and may do so at a reasonable cost per marginal vaccination. However, they also highlight the limited potential of lotteries. While an additional 100,000 vaccines in a state of over 11 million is likely to save lives, it is unlikely to push Ohio to the point of herd immunity.

II. Background and Incentives

The US Food and Drug Administration issued emergency-use authorizations for the Pfizer-BioNTech COVID-19 vaccine (for individuals 16 and older) and the Moderna COVID-19 vaccine (for individuals 18 and older) in December 2020. Emergency-use authorization for the Pfizer vaccine was expanded to include adolescents 12 through 15 years old on May 10, 2021. The Janssen (Johnson & Johnson) COVID-19 vaccine received emergency-use authorization in February 2021 (US Food and Drug Administration, 2021b, 2021c, 2021d).

On May 12, 2021, Ohio Governor DeWine announced the "Vax-a-Million" drawing to incentivize people to receive at least one dose of a COVID-19 vaccine. The lottery consisted of five drawings over five weeks, with each drawing providing a $1 million prize for an Ohio resident 18 years and older and a full-ride scholarship to an Ohio four-year university for residents between 12 and 17 years old. Governor DeWine explained in a *New York Times* guest essay that the five-drawing design was intended to generate additional enthusiasm and vaccinations each time a winner is announced (DeWine 2021).

All Ohio residents who had received at least one dose of the vaccine by the Sunday before the weekly Wednesday drawing were eligible. Residents only needed to register one time by filling out a brief questionnaire on ohiovaxamillion.com or calling the Ohio Department of Health hotline. The first drawing was Wednesday, May 26. The Ohio Department of Health funded the initiative using federal Coronavirus Relief Funds. The stated purpose of the initiative was to raise awareness of the availability and effectiveness of the COVID-19 vaccines.

The COVID-19 vaccines are free, regardless of health insurance status or immigration status. Appointments were plentiful at the time of the announcement and residents could directly schedule with local pharmacies or use gettheshot.coronavirus.ohio.gov to make an appointment. Although all residents 16 and older were eligible to receive the vaccine (and all residents 12 and older as of May 10), only about 36 percent of Ohio's population was fully vaccinated just prior to the lottery announcement (Vigdor and Paybarah 2021). While vaccines are free and highly effective, vaccine hesitancy remains prevalent. Across several nationwide surveys conducted in 2020, 31 to 54 percent of respondents said they would not want to get vaccinated even if the vaccine was freely available (Khubchandani et al. 2021). One reason for vaccine hesitancy is lack of confidence in the approval process for the COVID-19 vaccines; 62 percent of respondents in a September 2020 poll believed that political factors would result in a rush to approve vaccines without proper attention to safety and effectiveness (Kaiser Family Foundation 2020).

With a large share of the population holding unfavorable beliefs about the COVID-19 vaccines, incentive programs are an appealing strategy because they are not designed to change beliefs, but to alter the cost-benefit calculation about whether to receive the vaccine (Brewer et al. 2017). The Ohio lottery increased the marginal benefit of receiving a vaccine. If meaningful, we expect to see a short-run increase in vaccinations, reflecting either vaccinations among those who were planning to get vaccinated eventually pulled forward in time, or new vaccinations among those not originally intending to be vaccinated. The odds of winning the first $1 million lottery were placed at about 1 in 2.7 million (Mervosh 2021). While small, these are better than the 1 in 12 million odds of winning the equivalent amount in the Ohio Mega Millions state lottery (Ohio Lottery 2021).

Contemporaneous studies of the lottery in Ohio come to differing conclusions on its effectiveness. Two state-level analyses have found no effect of the lottery. Outside the economics literature, Walkey, Law, and Bosch (2021) use an interrupted time series method to compare starting vaccination rates in Ohio with those in the rest of the United States. A limitation of this comparison is that Ohio and the rest of the country have different pre-trends. We instead use neighboring states to construct counterfactual vaccination trajectories for Ohio rather than for the United States as a whole, emphasizing similar pre-trends in our empirical analysis. We also use county-level data from individual state health departments, rather than from the CDC. Lang, Esbenshade, and Willer (2021) use synthetic controls to compare Ohio with a synthetic Ohio built from the remaining states and also finds no effect on *full* vaccination rates through the day of the last lottery. One possibility for this conclusion is that measuring changes in full vaccination rates may lead to muted estimates. First, individuals who received their first dose of a two-dose vaccine prior to the lottery announcement already qualified for the lottery; for these individuals, the second dose is not a response to the lottery. Second, those who do receive a first dose in response to the lottery are not fully vaccinated for at least an additional three weeks. It is also possible that vaccine-hesitant individuals respond to the lottery by receiving only the first dose, because of the perceived risk of the second dose and small marginal benefit. Early estimates suggest as many as 10 percent of vaccine recipients did not receive their second dose (Kriss et al. 2021). A measure of full vaccination rates over a short time frame could miss an increase in first doses followed by no, or even a several-weeks-delayed, second dose. Finally, two other studies that both use a state-level synthetic control method find the lottery increased the starting dose vaccination rate, and the estimated magnitudes—one finds an estimated additional 82,000 first vaccinations and the other estimates an additional 115,000 first vaccinations—are similar to ours (Barber and West 2021; Sehgal 2021).

There is prior empirical evidence that vaccination decisions respond to financial incentives. Many studies estimating the effect of financial incentives are designed as randomized trials, with small samples of participants and modest awards. Most relevant for the lottery studied here, Yokley and Glenwick (1984) find that sending parents tickets for a cash lottery increases vaccination rates among their preschool-aged children. Mantzari, Vogt, and Marteau (2015) show that vouchers increase uptake of HPV vaccinations, and Greengold et al. (2009) find that monetary incentives motivate homeless individuals to return for additional doses of hepatitis B vaccinations. Bronchetti, Huffman, and Magenheim (2015) show that financial incentives increase flu vaccinations among those who did not receive a flu shot the previous year.

It is possible that the lottery may lead to a short-run increase in vaccinations but lower uptake in the long run because the lottery could signal that the vaccination is risky (Cryder et al. 2010). Recent surveys by the UCLA COVID-19 Health and Politics Project show that some people report they are less likely to receive the vaccine with incentive payments (Vavrek 2021).

At least 15 states and three Canadian provinces have joined Ohio in creating a vaccine lottery program as an incentive for vaccination.[3] The number of drawings and size of prizes vary. For example, Maryland's lottery doled out $2 million over 40 daily drawings of $40,000 each and a $400,000 grand prize the last day. New Mexico's lottery offered the largest grand prize of $5 million to a single winner. Some states automatically enrolled all eligible residents, while others were opt-in programs like Ohio's. In addition to these large lottery programs, states are offering smaller incentives to those who receive a vaccination. For example, New Jersey and Connecticut offered residents 21 and older a free beer after their first dose. West Virginia announced at the end of April 2021 a program giving $100 savings bonds to 16- to 35-year-olds who get the vaccine, including those who received the vaccine prior to the announcement (West Virginia Office of the Governor 2021).

3 The National Governors Association published a July 30 memo outlining all state COVID-19 vaccine incentives, available at https://www.nga.org/center/publications/covid-19-vaccine-incentives/ (accessed September 28, 2021).

III. Data and Methodology

A. DATA

We use daily data on the number of first-dose COVID-19 vaccinations by county of residence from the health departments of Ohio, Indiana, Michigan, and Pennsylvania.[4,5] We do not use data from West Virginia and Kentucky, the other two states bordering Ohio, because both states announced lotteries at the start of June.[6] West Virginia also announced a savings bond program at the end of April. Additionally, vaccination data from West Virginia's and Kentucky's health departments are insufficient for our analysis. The Indiana, Michigan, and Ohio data provide the number of vaccinations started by date, with separate counts of the number of first doses of the Pfizer and Moderna vaccines and the number of single-shot J&J vaccines. The Pennsylvania data report the number of partially vaccinated doses (first dose of Pfizer or Moderna) and fully vaccinated (second dose of Pfizer or Moderna or the single-shot J&J). We cannot separate the number of J&J doses, which should be included in the count of starting doses, from second doses of Pfizer and Moderna. To generate a measure of the approximate number of first doses in Pennsylvania counties, we assume that 6 percent of final doses are first and final doses of the J&J vaccine.[7] We use first doses to calculate the daily starting vaccination rate per 10,000 residents in each county. Using the number of starting doses rather than the total number of doses allows us to better identify short-run responses to the lottery due to the three- to four-week span between first and second doses.

In addition to the daily vaccination data, we obtain data on race/ethnicity, age, and county-level population estimates as of July 1st, 2019, from the US census.[8] We also use

4 We drop Philadelphia, which only reports a subset of vaccinations at the daily level, and counties that are missing data. We use data reported by the individual state health departments rather than the CDC's COVID-19 Vaccine Tracker. Inspection of the data suggests that state health departments report the date vaccines were administered, while the CDC data are lagged. Online Appendix A.1 shows that J&J administration patterns in the state data better align with the CDC's recommended pause in the J&J vaccine. The date in the CDC data may reflect when data are received by the CDC, rather than the date of vaccine administration. This makes it impossible to have a clean break point after the announcement of the lottery using the CDC data.

5 Approximately 2–3 percent of doses, depending on the state, have "out of state" listed as the county of residence.

6 Michigan's lottery was announced on July 1, 2021, after the conclusion of Ohio's lottery.

7 The J&J shot was paused during the first weeks of our sample; we only apply this correction after April 23rd when the vaccine resumed use. We choose 6 percent because that is the average percentage of final doses in Michigan and Indiana that are Johnson & Johnson. Assuming 1 percent or 15 percent instead of 6 percent changes our main result by less than 3 percent.

8 As of the time of this writing, the county-level 2020 census files have not been published. It is possible that county-level demographics have changed in response to the pandemic. In addition to migration across states, there may have also been cross-county migration. For example, the population of urban counties may have declined as much office work has become remote. Our intuition is that this is unlikely to affect the results of our study so long as counties that had similar demographics in 2019 were similarly affected by the pandemic, and thus would have still been reasonable counterfactual counties in 2020. However, if Ohio counties were differentially affected by the pandemic than counties with similar demographics in the donor

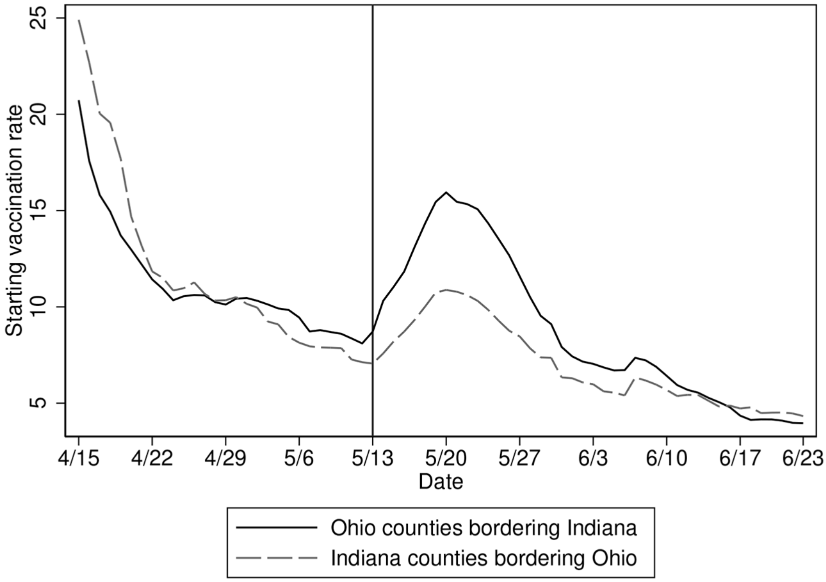

FIGURE 1. The starting vaccination rates in bordering counties. Starting vaccination rates are a seven-day moving average of doses per 10,000 residents and do not include second doses of either Pfizer or Moderna. The "Vax-a-Million" lottery was announced on the evening of May 12, 2021.

data on median household incomes, urbanicity, unemployment rates, poverty rates, and college education levels that are prepared by the US Department of Agriculture and drawn from the American Community Survey. Finally, we include data on the percentage of votes in the 2020 presidential election that were for Donald Trump.[9]

B. DIFFERENCE-IN-DIFFERENCES

We first compare starting vaccination rates in contiguous Ohio and Indiana border counties before and after the lottery announcement.[10] Figure 1 plots the daily seven-day moving average of the number of starting doses per 10,000 residents separately in Ohio and Indiana border counties. Border counties in Indiana are a good control group for estimating the lottery effect in Ohio if the populations are similar except for eligibility for the Ohio lottery. The solid line is the average starting dose vaccination rate for Ohio counties that border Indiana, and the dashed line is the average starting dose vaccination rate in Indiana counties that border Ohio.

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pool, using 2019 data for constructing the synthetic controls may be a source of bias. As migration patterns both within and across states from 2019 to 2020 remain to be seen, it is unclear in which direction this would bias our results.

9 Election results reported by Fox News, the *New York Times*, and Politico. Data are available on GitHub.

10 For examples of studies applying difference-in-differences to bordering counties, see Dube, Lester, and Reich (2010) and Lyu and Wehby (2020).

In the weeks before the lottery announcement, vaccination rates were trending downward for both groups. A reversal of this trend appears for Ohio counties starting on May 13, 2021, the day after Governor DeWine's evening Tweet announcing the lottery. Over the next week, the vaccination rate increased from approximately 10 doses per 10,000 to approximately 16 doses per 10,000. This trend accounts for the media reports in which it was claimed that vaccination rates were up nearly 60 percent since the announcement of the lottery (Lenthang and Periera 2021). Around the same time, vaccination rates in neighboring border counties also increased, suggesting that some of the increase would have happened in Ohio in the absence of the lottery. The most likely explanation for this is the approval of the Pfizer vaccine for individuals ages 12 to 15 on May 10. On May 13, the CDC announced it would lift its mask recommendation for vaccinated individuals, which may have also increased vaccinations (Cohen 2021).

One could be concerned about whether the border Ohio counties are representative of the entire state, or whether the nine counties on the Ohio side of the border are demographically similar to the 10 counties on the Indiana side. Table 1 displays summary statistics of demographic, economic, and political variables for all Ohio counties (column 1), Ohio counties that border Indiana (column 2), and Indiana counties that border Ohio (column 3). The remaining columns test whether there are statistically significant differences between all of the Ohio and the nine border counties or between counties on either side of the Indiana/Ohio border. When comparing the Ohio border counties with all of Ohio, three variables are statistically different: Ohio border counties have more individuals who are under 14 years old (0.8 percentage points), fewer people in poverty (2 percentage points), and a lower unemployment rate (1 percentage point). There are no meaningful differences in the total population, a seven-day moving average of starting vaccination rates before the lottery announcement, the distribution of sex or race, educational attainment, urbanicity, median household income, or Trump vote share. When comparing counties on both sides of the Indiana/Ohio border, none of the differences are statistically significant, except that counties on the Indiana side have slightly lower unemployment rates. Additionally, some of the differences are economically meaningful. Most notably, total population is larger on the Ohio side of the border, because Hamilton County contains Cincinnati, Ohio, whereas the largest city on the Indiana side is Fort Wayne.

The key identification assumption of difference-in-differences is that in the absence of the vaccine lottery, the trends in the vaccination rates would have been the same in the treatment and control counties. We test whether this assumption held during the pre-lottery period using an event study framework. We are also able to estimate whether there is an initial lottery effect in response to the lottery announcement or a sustained effect over the course of the five drawings. We include nine interaction terms composed of an indicator for whether the county is in Ohio and indicators for each of the three weeks before and six weeks after the lottery announcement. The week before the announcement is the omitted group, yielding the following equation:

$$v_{ct} = \alpha_c + \gamma_t + Ohio_c \times \left[\sum_{k=-4}^{-2} \pi_k 1(Week_t = k) + \sum_{k=0}^{5} \rho_k 1(Week_t = k)\right] + \varepsilon_{ct} \qquad (1),$$

TABLE 1. Demographic differences between Ohio and Indiana border counties

	All Ohio	OH border	IN border	(1) − (2) diff.	p	(2) − (3) diff.	p
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Total population	132,830.7	161,722.2	68,340.0	−32,183.0	0.7	−93,382.2	0.4
Starting vaccination rate on May 12	8.8	8.1	7.1	0.7	0.4	−1.0	0.4
Male	0.497	0.495	0.496	0.003	0.335	0.001	0.845
White share	0.921	0.919	0.948	0.002	0.954	0.029	0.456
Proportion age 0–14	0.183	0.190	0.194	−0.008[b]	0.048	0.003	0.692
Proportion age 15–49	0.424	0.421	0.417	0.003	0.776	−0.004	0.685
Proportion age 50 plus	0.394	0.387	0.388	0.008	0.392	0.001	0.918
Trump vote share	0.675	0.706	0.721	−0.035	0.449	0.015	0.772
Poverty rate	12.265	10.044	11.030	2.473[b]	0.017	0.986	0.363
Percentage with a college degree	20.559	20.442	19.020	0.131	0.964	−1.422	0.652
Rural-urban continuum	3.716	4.778	4.400	−1.183	0.169	−0.378	0.722
Median household income	58,037.8	60,389.7	56,988.8	−2,619.9	0.2	−3,400.9	0.3
Unemployment rate	4.482	3.589	3.190	0.995[a]	0.000	−0.399[c]	0.059
N	88	9	10				

Note: Ohio border counties include all Ohio counties that border Indiana, and Indiana border counties include all Indiana counties that border Ohio. The starting vaccination rate is the 7-day moving average of starting doses per 10,000 residents as of 5/12, the day before the lottery announcement. The Trump vote share is from the 2020 election. Demographics are census estimates from 2019. [a]$p < 0.01$, [b]$p < 0.05$, [c]$p < 0.10$.

where v_{ct} is the starting vaccination rate of county c on day t. The variable α_c represents county-level fixed effects and accounts for county-level characteristics that do not vary over time (such as demographics or political, religious, or cultural attitudes). Similarly, γ_t represents day-level fixed effects that account for time-specific shocks that affect all counties similarly, such as day of the week or news (e.g., access to the vaccine for 12- to 15-year-olds, or the release of new studies about vaccine efficacy and/or side effects). The coefficients π_k and ρ_k provide the estimated change in starting vaccination rates relative to the week prior to the lottery announcement ($k = -1$). Estimates close to zero on the interaction terms π_k

in the pre-announcement weeks provide evidence against concerning pre-trends. The coefficients on the interaction terms ρ_k in the post-announcement weeks allow for a dynamic response over the duration of the lottery through the week of the last drawing on June 23. To account for serial correlation, we present wild bootstrapped standard errors clustered at the county level (MacKinnon and Webb 2019). Online Appendix B.1 displays alternative methods for calculating standard errors.[11]

Online Appendix B.2 shows that vaccination rates in Michigan and Pennsylvania border counties do not trend parallel to those in their Ohio border county counterparts prior to the lottery announcement. One possible explanation for the lack of common trends is that both Michigan and Pennsylvania have Democratic governors, whereas both Indiana and Ohio both have Republican governors. Importantly, state health departments, a part of the executive branch, are in charge of distributing vaccines at the state level. Additionally, the COVID-19 vaccines have become highly politicized, and residents may have responded differently to health departments run by an opposing party. Although we focus on estimates using the sample of Ohio/Indiana border counties, we also present separate estimates using Michigan or Pennsylvania border counties in Online Appendix Figure B2.

C. SYNTHETIC CONTROL METHOD

To estimate a causal effect for the entire state of Ohio, we turn to a pooled synthetic control method. This approach also has the advantage of not relying on the parallel trends assumption required for the difference-in-differences approach above (Abadie and Gardeazabal 2003; Abadie, Diamond, and Hainmueller 2010). The synthetic control method was originally designed for one treated unit, comparing outcomes of the treated unit with that of a counterfactual weighted average of untreated units, with weights chosen so that the "synthetic control" closely resembles the treated unit in the pre-treatment period. The method provides causal estimates when the parallel trends assumption required for difference-in-differences estimation fails. We estimate treatment effects separately for each of Ohio's 88 counties, with synthetic controls formed from Indiana, Michigan, and Pennsylvania counties. We aggregate to estimate a state-level effect (Abadie 2021). Previous work has applied the synthetic control method when multiple units are treated at the same time (Kreif et al. 2016; Robbins, Saunders, and Kilmer 2017; Lépine, Lagarde, and Le Nestour 2018). Like the event study method, the synthetic control method allows for estimating treatment effects over time, relevant for determining the timing of any response, with respect to either the announcement or one or more of the five drawings.

The synthetic control for each county is built using observable characteristics in the period before the lottery announcement. To construct the counterfactual trajectory of vaccination rates in each treated Ohio county in the absence of the lottery, we use four pre-lottery announcement average vaccination rates and the following county-level covariates: population, percentage of population with a college degree, median household income, unemployment rate, poverty rate, urbanicity as measured by the urban-rural continuum,

11 The lottery is a state-level policy, and our preferred approach would be to cluster at the state level. We do not do this, however, because standard asymptotics require more than two clusters.

percentage white, percentage male, percentage aged 0–14, percentage aged 15–49, percentage aged 50 and over, and percentage of votes in the 2020 presidential election for Donald Trump. Because of state differences in day-of-week vaccination patterns, using seven-day average vaccination rates improves matching between treated counties and their synthetic controls. The dependent variable is the daily starting vaccination rate, as used in the difference-in-differences specification above.[12] Online Appendix C.1 provides additional information about donor pool counties used in our synthetic control analysis and compares Ohio counties with the donor pool.

This approach relies on the assumption that there are no spillover effects to untreated counties and that there is no anticipation of treatment. The former assumption is plausible in our setting because the Ohio lottery was open to only Ohio residents and our data are measured at the county of residence, not at the county of administration.[13] The latter assumption is plausible because Ohio was the first state to announce such a lottery for receiving the COVID-19 vaccines; it is unlikely that there were forward-looking individuals who received a vaccine in anticipation of the lottery announcement.

The synthetic control estimates provide an estimate of the effect of the lottery on the vaccination rate per 10,000 residents for each of Ohio's 88 counties. To aggregate the estimates to the state level, we take a population-weighted average of the individual county-specific effects. We then determine statistical significance of the estimated effects by running placebo tests (Abadie, Diamond, and Hainmueller 2010, 2015).[14] In the placebo tests, we drop Ohio from the sample and apply the synthetic control method to each of the counties in Indiana, Pennsylvania, and Michigan. We estimate effects using the remaining counties to construct a synthetic control for each. This results in a distribution of placebo treatment effects where we expect no treatment effect.[15]

Without including any controls, Online Appendix Figure A1 shows that Ohio's increase in the starting vaccination rate was steeper and proportionately larger than all of its neighbors following the announcement.

12 We use the synth package for Stata and the regression-based technique to calculate weights. Because of computational constraints, results cannot be calculated for all counties using the "nested" option to generate weights, but when possible, results are similar. We also note that McClelland and Gault (2017, 37) find that the "nested" option can result in different estimates if a predictor's units are rescaled and that "[this] may merit future adjustments."

13 Two to three percent of doses are listed as "out of state." If the lottery resulted in a disproportionately large share of Ohio residents traveling across state lines, this undercount of first doses in Ohio counties would bias our results downwards (or vice versa if this were instead true of non-Ohio residents). We also note that we cannot rule out that vaccination rates in control states may have increased because individuals in these states anticipated the possibility that their state would implement a similar financial incentive program as Ohio's in the future. To the extent that this occurred, our analysis would be biased against finding results, suggesting that the true effect is larger.

14 There are no conventional standard error estimates with the synthetic control method.

15 This inference approach with multiple treatment units is similar to Dube and Zipperer (2015) and Lépine, Lagarde, and Le Nestour (2018). This is an extension of the standard placebo approach in Abadie, Diamond, and Hainmueller (2010, 2015), developed for a single treatment unit. Placebo estimates are constructed during the same time frame in which the treatment occurred.

IV. Results

A. DIFFERENCE-IN-DIFFERENCES RESULTS

Panels A and B of Figure 2 display weighted and unweighted estimates from the event study regression in equation 1 using Ohio and Indiana border counties.[16] The estimated effects are relative to the week before the lottery announcement and suggest that the lottery increased daily starting vaccination rates. The weighted estimates imply that the daily vaccination rate increased by 6.3 doses per 10,000 residents during the first week after the announcement and 3.5 doses per 10,000 residents during the second week after the announcement; the unweighted estimates are 3.7 and 2.9, respectively. The dashed lines present 95 percent confidence intervals. In both regressions, the point estimates in the first and second week are statistically significant at conventional levels. By the third week, vaccination rates return to baseline, and remain small in magnitude and statistically insignificant through the duration of the lottery. None of the pre-treatment weeks are statistically significant, providing empirical support for the necessary identification assumption of parallel trends. The lack of a statistically significant drop in vaccinations suggests that if the additional doses are being pulled forward in time, they are being re-timed by more than four weeks, beyond the duration of the lottery. However, we cannot rule out that some of the induced first doses are re-timed.

We use these event study results to generate an estimate of the approximate number of additional doses induced by the lottery. Using the weighted estimates of an increase in daily vaccination rates of 6.3 doses per 10,000 residents in the first week, 3.5 per 10,000 in the second week, and no change thereafter, we find that vaccinations over the full period increased by about 69 doses per 10,000$((6.3 \times 7 + 3.5 \times 7)/10{,}000)$. Scaling this number by Ohio's population of 11.7 million implies an increase of about 80,000 doses attributable to the lottery. Using the estimates from the unweighted regression implies the lottery induced an additional 46 doses per 10,000$((3.7 \times 7 + 2.9 \times 7)/10{,}000)$, or by about 54,000 doses when scaled to the population of Ohio.

It is possible that these estimates are biased because Indiana border counties are a poor control group for Ohio border counties and/or the parallel trends assumption does not hold. Roth (2021) shows that it is possible that conditioning on only the samples in which the parallel trends assumption holds has the potential to introduce bias. To address these concerns, we next implement our synthetic control approach, which does not rely on the parallel trends assumption, and provide estimates of a lottery effect for the entire state of Ohio using counties from multiple neighboring states as a comparison group.

B. SYNTHETIC CONTROL RESULTS

Results from our synthetic control approach are consistent with the findings from the event study analysis and imply that the lottery induced roughly 65 additional vaccinations

16 Event study results using separate control groups of Michigan and Pennsylvania border counties are in Online Appendix Figure B2. While in both cases there is an upward trend in the pre-treatment estimates, several of which are statistically different from zero, most of the post-announcement point estimates are similar in magnitude to those using Indiana border counties as a control group.

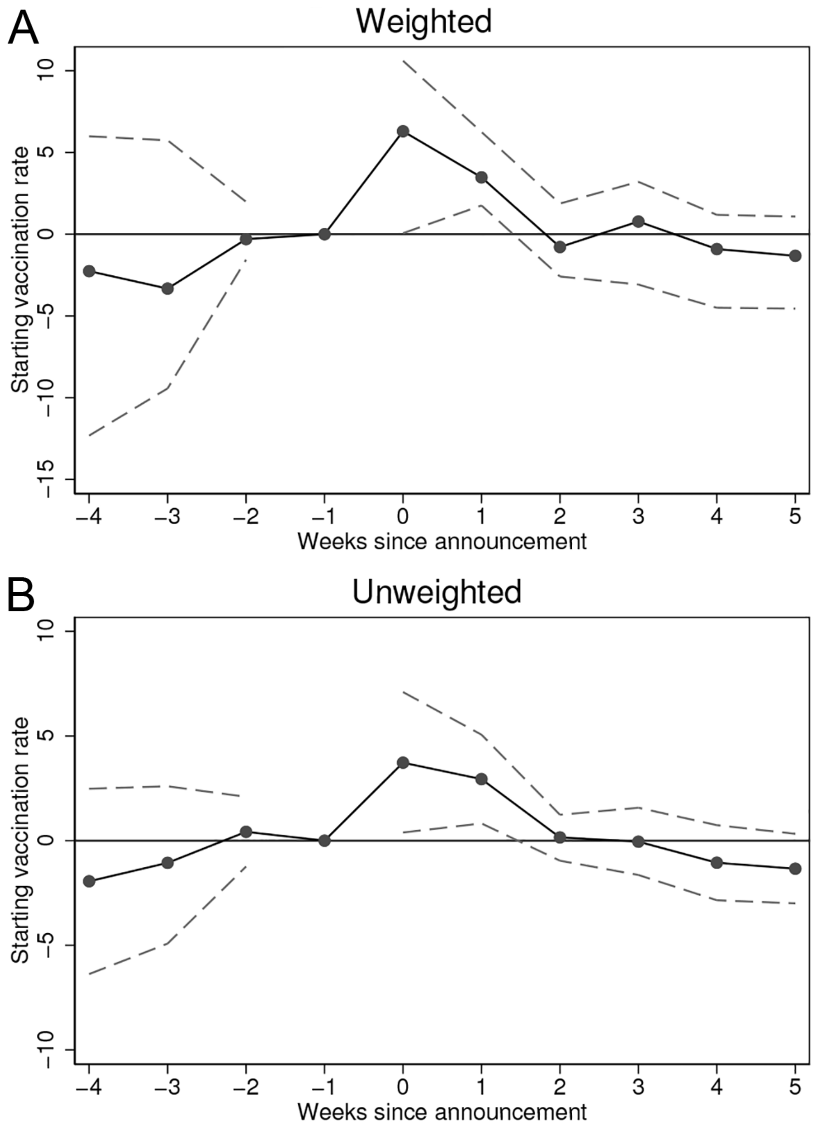

FIGURE 2. Event study estimates of the lottery effect on starting vaccination rates. Starting vaccination rates are doses per 10,000 residents. The omitted group is the week before the lottery announcement (May 6 to May 12, 2021). The weighted regression weights each observation by the county's population. The dashed lines display 95 percent confidence intervals, calculated using a wild bootstrap clustered at the county level (MacKinnon and Webb 2019).

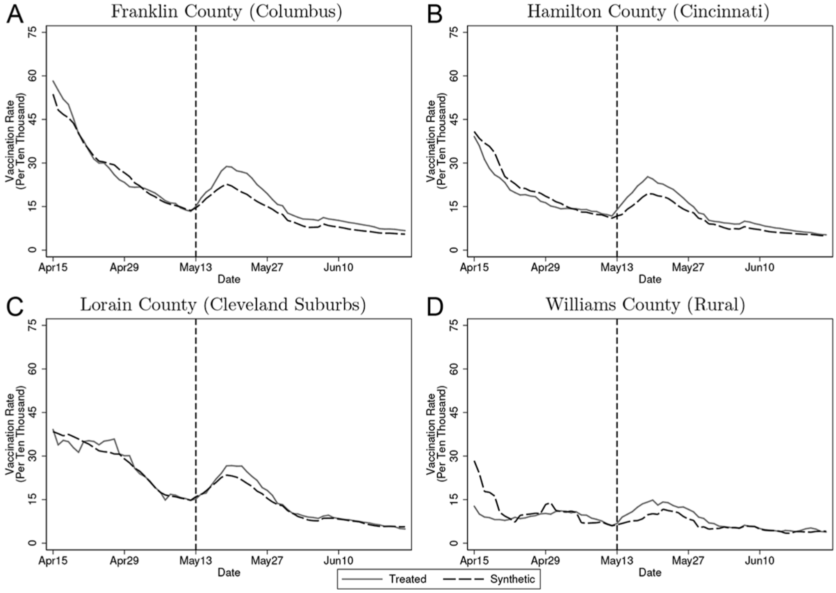

FIGURE 3. Synthetic control results: Sample counties. These figures provide sample results from two of Ohio's most populous counties (Franklin and Hamilton), a Cleveland suburban county (Lorain, where Oberlin College is located), and a rural county (Williams, in the northwest corner of Ohio).

for every 10,000 residents, totaling to about 76,000 additional vaccinations, with most of the effect over the first two weeks following Governor DeWine's announcement and prior to the first lottery drawing. Figure 3 presents sample results from Franklin (home of Columbus), Hamilton (home of Cincinnati), Lorain (suburban Cleveland, home of Oberlin College), and Williams (rural, northwest Ohio) counties. The figures plot a seven-day moving average of doses per 10,000 residents in the treated county compared with its synthetic control.[17] Generally, vaccination rates in the treated counties and their synthetic controls appear similar prior to the announcement. In the first two weeks following the announcement, vaccinations in the treated counties outpace those in their synthetic controls. Afterwards, any differences are smaller and the treated counties are similar to their synthetic controls.[18]

Figure 4 compares the distribution of the estimates of the increase in vaccination rates in each of the Ohio counties with that of the placebo estimates from applying the synthetic

17 While the figures use data beginning April 8 to construct the moving averages, the synthetic control estimates are based on data beginning April 15.

18 Online Appendix C.2 provides a synthetic control analysis using a national set of donor pool counties, excluding states that had active lotteries or announcements during the sample period. Results are similar to those presented here.

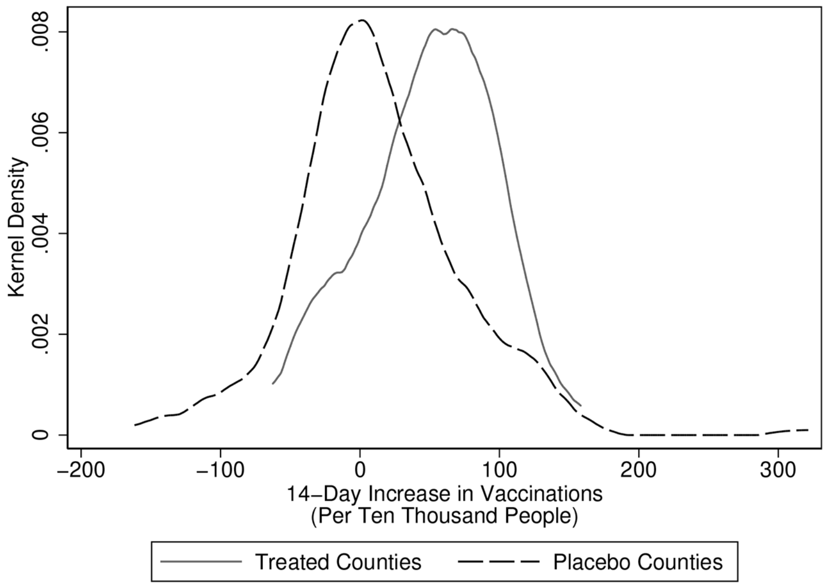

FIGURE 4. Synthetic control method results compared with placebo results. The "treated counties" distribution gives the estimated probability density function of the estimated increase in the vaccination rate in the first two weeks after the lottery announcement from the synthetic control analysis across all Ohio counties. The "placebo counties" distribution does so across all counties in Pennsylvania, Michigan, and Indiana.

control method to each of the counties in the donor pool from Pennsylvania, Michigan, and Indiana. This allows us to see whether the effects estimated in the Ohio counties are sufficiently large relative to the effects in counties where we expect no treatment effect. The distribution of Ohio estimates has an average of 49 additional vaccinations per 10,000 inhabitants; it lies to the right of the placebo distribution, which has an average of 13 additional vaccinations per 10,000 inhabitants.[19] A Kolmogorov–Smirnov test that the distributions are different from each other yields a p-value less than 0.001, while a t-test that the distributions' means are different yields a p-value less than 0.0001. These tests imply that our results are very unlikely to be due to chance.

We estimate a statewide effect by aggregating the estimated treatment effects across Ohio's 88 counties, weighted by county population. This results in an estimated aggregate increase of about 95,000 vaccinations. However, we prefer a more conservative estimate of the effect of the lottery that takes into account the placebo estimates. If we aggregate the estimated placebo treatment effects and then scale to Ohio's population, we find an

19 These values are *not* weighted by county size.

estimate of 19,000 additional vaccinations when we expect no effect.[20,21] Subtracting this implied bias from our headline estimate of 95,000 vaccinations, we find that the lottery resulted in about 76,000 additional vaccinations, representing about 65 additional vaccinations for every 10,000 residents, and covering about 0.65 percent of the population.[22,23] This bias correction approach is similar in spirit to Cummins et al. (2019).

Finally, the synthetic control analysis allows for estimating heterogeneous effects. We estimate larger effects in more populous counties. After taking into account bias implied by the placebo estimates, we find that counties with over 250,000 people average 61 additional vaccinations for every 10,000 residents. Counties with populations under 250,000 see 35 additional vaccinations for every 10,000 residents. However, we interpret this heterogeneity with some caution. Online Appendix C.2 estimates the effects using a national donor pool. While the headline result is similar, we no longer see strong heterogeneity by county size.

V. Discussion

Using two different empirical methods, we estimate that Ohio's lottery led to between 50,000 and 100,000 additional vaccinations, with most of the additional vaccinations occurring in the first two weeks after the announcement and prior to the first lottery drawing. With a total lottery payout of $5,600,000, this would imply that Ohio paid about $75 per additional starting dose (DeWine 2021).[24] This is below the range of previous cost estimates per additional vaccinated person from studies on interventions providing financial incentives to increase vaccination rates ($290–$2,860 in 2021 USD) (Jacob et al. 2016). The program would also pass a cost-benefit analysis if one additional life is saved, with a mean estimate of the value of a statistical life of about $9.8 million (Robinson 2007).

In our short-run analysis, it is unclear how much of the increase in vaccinations reflects responses on the intensive (pulled forward) or the extensive (newly induced vaccinations) margin. It is possible there are vaccinations pulled forward in time beyond the lottery

20 The sum of the estimated placebo treatment effects across the 212 non-Ohio counties, with a total population of 27.5 million, is about 45,000. To scale down to Ohio's population of 11.7 million, we calculate 45,000 × 11.7/27.5.

21 This bias can result because some counties are oversampled when running the synthetic control analysis. It appears that our oversampled counties have lower-than-average post–May 13th vaccination rates.

22 If we exclude data from Michigan, our estimate drops from roughly 95,000 to 73,000. Dropping Pennsylvania instead increases the estimate to 102,000. Finally, dropping only Indiana causes the estimate to decline to 66,000. After correcting for the bias implied by the placebo, these estimates range between 54,000 extra shots and 86,000 extra shots.

23 If we instead assume that 1 percent of final doses in Pennsylvania were J&J, we find that 97,000 additional shots were induced by the lottery, with a potential placebo bias of 20,000 (for a total of 77,000 additional vaccinations). If we instead assume that 15 percent of final doses in Pennsylvania were J&J, we find that 92,000 additional shots were induced by the lottery, with a potential placebo bias of 14,000 (for a total of 78,000 additional vaccinations).

24 Calculated as $5.6 million/75,000. The true payout per dose will be higher if there were also marketing expenditures associated with the campaign.

window, with substantial re-timing of vaccinations in order to participate in the lottery. Either type of response achieves a higher vaccination rate earlier, providing public health benefits. Our results suggest that the five-drawing design did not result in renewed enthusiasm each week as winners were announced; most additional vaccinations occurred in the first two weeks after the announcement prior to the first drawing, with no immediate increases in vaccinations after any of the five drawings. It is also unclear whether the financial incentive acted as a signal of risk and discouraged some individuals from receiving the vaccine at all, leading to lower uptake in the long run.

Determining how many lives will likely be saved by the lottery depends on several parameters that are currently unknown, such as what percentage of unvaccinated individuals will eventually contract COVID-19 and what their case-fatality rate will be. These latter two parameters could take on a wide range of values, depending on factors like which variant of the virus becomes dominant and how individuals and policy makers endogenously respond to the emergence of these variants. We present a wide range of possible values in Table 2. Each row assumes that either 10 percent, 40 percent, or 70 percent of unvaccinated individuals will contract the disease. The columns assume that the case-fatality rate will be either 0.1 percent, 0.5 percent, or 1 percent. We also assume the lottery induced 75,000 individuals to become vaccinated and that vaccination would have prevented 90 percent of deaths.[25] Our estimates of the number of lives saved ranges from 6.75 to 472.5, with a median scenario of 67.5. These estimates also assume that the 75,000 additional vaccinations are newly induced vaccinations, rather than pulled forward in time. If all the additional vaccinations were pulled forward by six weeks, the number of lives saved decreases to around one.[26] However, we believe it is unlikely that *all* the additional vaccinations were re-timed, and that if they were re-timed, vaccinations were accelerated by more than six weeks. Overall, these estimates suggest that the lottery likely passes a cost-benefit analysis even before considering factors like prevented hospitalizations, reductions in transmission from newly vaccinated individuals, and the value of reduced morbidity.

The synthetic control analysis allows for some estimates of heterogeneous effects; we find larger effects in more populous counties. This finding is consistent with the larger point estimates from the population-weighted event study regression compared with unweighted regressions. There are several explanations for this finding. There may be more access to vaccination appointments or locations, greater knowledge of the lottery, stronger peer effects, or lower vaccine hesitancy among more urban populations. We are unable to estimate differential responses by age because of lack of data on vaccination starts by age.

Our results are likely to generalize to other lotteries like Oregon's or Maryland's. However, it is possible that Ohio benefited from being the first to announce a lottery and that

25 The assumption that 90 percent of deaths are prevented by the vaccine is conservatively consistent with recent observational data from Virginia (see https://www.vdh.virginia.gov/coronavirus/covid-19-data-insights/covid-19-cases-by-vaccination-status/). Roughly half the state is fully vaccinated and only 10 out of 150 deaths between May 13th and July 18th occurred among the vaccinated population.

26 This estimate is based on a comparison of death rates among the vaccinated and unvaccinated populations in Virginia over a six-week period. Virginia had similar caseloads to Ohio around this time and provides data by vaccination status.

TABLE 2. Lives saved from the lottery under various assumptions

		Case-fatality rate		
		0.1%	0.5%	1%
	10%	6.75	33.75	67.50
Infection rate	40%	27.00	135.00	270.00
	70%	47.25	236.25	472.50

Note: Each cell presents the number of lives saved for various assumptions on the infection rate (10%, 40%, and 70%) among unvaccinated individuals. Each column assumes a different case-fatality rate (0.1%, 0.5%, and 1%). We additionally assume that the lottery induced 75,000 people to become vaccinated and that vaccination prevents 90% of deaths. For example, the upper right cell is calculated as $75{,}000 \times 0.1 \times 0.01 \times 0.9 = 67.5$.

the novelty improved Ohio's outcomes; subsequent state lotteries may have seen smaller returns as the novelty wore off. Additionally, Governor DeWine explicitly chose the lottery instead of a smaller but certain payment with Bill Veeck's words in mind: "To give one can of beer to a thousand people is not nearly as much fun as to give 1,000 cans of beer to one guy" (DeWine 2021). While the quote's claim may not be true, we find it reasonable that West Virginia's free savings bonds or New Jersey's free beer could have different effects. Ohio's program may be less expensive per marginal shot when compared with West Virginia's savings bond program. We estimate that Ohio paid $75 per marginal recipient, while West Virginia's program provides a $100 savings bond to all recipients (ages 16 to 35) of the vaccine, rather than only to those who were induced by the program. It is unclear whether those programs induce more or fewer additional vaccinations. Recent experimental evidence suggests that a lottery is more cost-effective than a lump-sum transfer payment (Kim 2021).

It is possible that other approaches, particularly those involving "sticks" instead of "carrots," may be more cost-effective than those providing financial incentives directly to individuals. Insurers could be allowed to impose a health coverage surcharge for the unvaccinated, with a precedent in the Affordable Care Act (ACA) allowing insurers to impose up to a 50 percent surcharge on tobacco users' premiums. It is estimated that companies charge between $20 and $50 monthly surcharges for employees who smoke (Japsen 2021). In the COVID-19 context, Delta Air Lines implemented this strategy, announcing in August 2021 a monthly $200 surcharge for unvaccinated employees (Bastian 2021). Existing research on the tobacco surcharges does not find that the penalty is effective; instead, higher surcharges lead to reduced health-care coverage among smokers with no decrease in tobacco use (Friedman, Schpero, and Busch 2016). Nevertheless, choosing to cease smoking is a different health decision than vaccination, and it is an empirical question whether surcharges for the unvaccinated will increase vaccination coverage.

Vaccine and testing requirements are other policy tools for increasing vaccination rates. With regard to vaccination for other diseases, all US states require evidence of vaccination for at least some diseases for public school entry, as do many US universities, and some employers. Existing research on vaccine requirements generally finds that they are effective in increasing coverage (see Brewer et al. [2017] for a review). In the case of the influenza vaccine, where the target is a 90 percent vaccination coverage rate, there is evidence that mandates increase the vaccination rate from about 70 percent to 90 to 95 percent (US Department of Health and Human Services 2021; Nowalk et al. 2013; Babcock et al. 2010).

The main costs to vaccine requirements are neither explicit nor easy to measure. With previous divisions over lockdowns and mask mandates, it is possible that vaccine requirements could further damage relations among Americans with different beliefs. Those who think that a mandate infringes on their freedom or safety may feel coerced, reject the requirement, and become even more likely to hold unfavorable beliefs about vaccines (Brewer et al. 2017). Regular testing for COVID-19, likely less objectionable than a mandate, is financially expensive. With an estimated median cost of one diagnostic test at $148, the total cost of regular testing adds up quickly (Kurani et al. 2021). Although regular testing may not lead to a higher vaccination rate, it may reduce spread of infection.

In September 2021, President Biden announced that all employers with 100 or more employees must require that their workers either be vaccinated or be tested weekly. Practically, it is unclear whether the federal vaccine and testing mandates are constitutional. State and local governments may instead have the authority to issue vaccine mandates. While 22 states have implemented mandates for state and health-care workers, as of September 2021, 20 other states have laws that ban vaccine mandates, by either employers or schools, or laws that prohibit vaccine passports or require that individuals present proof of vaccination in order to receive services or travel (National Academy for State Health Policy 2021). In this latter set of states, opt-in incentive programs, such as a lottery, may be particularly useful.

VI. Conclusion

Ohio's "Vax-a-Million" lottery was the first of the now many statewide lotteries intended to increase COVID-19 vaccinations. With five adult winners of $1 million and five youth (age 12–17) winners of a four-year full-ride college scholarship for receiving at least one dose of the vaccines, the Ohio lottery provided a unique opportunity to study the response of vaccination decisions to financial incentives among the broader population and with a sizable reward, rather than in a randomized trial. Additionally, as the first announced lottery, there was no anticipation among the public of the program, allowing for clean estimation of the response.

Using two analytical approaches, we find that Ohio's lottery increased vaccinations in Ohio by between 50,000 and 100,000 doses in the first two weeks after the lottery announcement. While the additional doses due to the lottery cover only about 0.66 percent of Ohio's population, the cost per dose falls below the range from prior studies of the effects of financial incentives on vaccination rates. It is also likely the total program costs are small relative to the damage caused by COVID-19. Only one death needs to be prevented in order for the program to pass a cost-benefit analysis; if all the estimated additional vaccinations are new rather than pulled forward in time, our lower-bound estimate is that the lottery will save at least six lives, with the potential for many more.

Our findings are consistent with work using a state-level synthetic control method (Barber and West, 2021), though different from two other state-level analyses finding no effect of the lottery in Ohio (Walkey, Law, and Bosch 2021; Lang, Esbenshade, and Willer 2021). We use neighboring states to construct a counterfactual vaccination trajectory for Ohio, rather than comparing Ohio to the United States as a whole. Additionally, we estimate the effect of the lottery on starting vaccination rates, as opposed to full vaccination rates.

There is still room for states to design incentive programs to encourage COVID-19 vaccinations. Using incentives to encourage vaccinations will likely continue to be relevant in light of evidence that booster doses may be recommended annually (US Food and Drug Administration 2021a; CDC 2021b). Tinkering with the lottery design by changing the number or size of prizes could change the cost-effectiveness or the total vaccination yield. An alternative would be to capitalize on loss aversion by drawing a winner from the entire vaccine-*eligible* population, but require the winner to give up the earnings if they were not already vaccinated (Levitt and Severts 2021). This "regret lottery" approach has been implemented in Philadelphia's lottery, announced June 7, 2021, and consisted of three drawings over a six-week period (Center for Health Incentives and Behavioral Economics 2017; Gandhi et al. 2021).[27] It is also possible that smaller but guaranteed payouts will be more successful, signaling less risk and perhaps leading to greater vaccine uptake in the long run. Indeed, this may be Ohio's strategy going forward: the day after the last lottery drawing in Ohio, Governor DeWine announced on Twitter a new incentive, offering $25 gift cards to those vaccinated at select locations over the following week.[28]

It is worth noting that while this vaccine lottery passed a cost-benefit analysis, and was thus worth doing, lotteries are unlikely to be a panacea. The lottery's effects were short lived (in this case about two weeks) and some of the additional vaccinations may be pulled forward in time. Vaccinating roughly an additional 0.67 percent of the population will likely save lives, but is unlikely to be pivotal in moving Ohio towards herd immunity.

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27 Prizes in the drawings ranged from $1,000 to $50,000. Recent analysis of the regret lotteries in Philadelphia does not find evidence of statistically significant increases in vaccination rates (Gandhi et al. 2021), though it is important to note that these prizes are considerably smaller than the ones in Ohio's lottery.

28 See https://twitter.com/GovMikeDeWine/status/1408065778583179277?s = 20.

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