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The Vaccine Boost: Quantifying the Impact of the COVID-19 Vaccine Rollout on Measures of Activity*

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Abstract

This paper investigates the impact of vaccine administration on three main dimensions of activity: spending, mobility, and employment. Our investigation combines two parts. First, we exploit the variation in vaccine administration across states. In panel regressions that include a large set of controls, we find that the rollout has a significant impact on spending, while the results on mobility and employment are mixed. Second, to address concerns of endogeneity, we look at the impact of vaccine lotteries on spending. Using a dynamic event design setting, we find that lotteries have significantly boosted vaccination rates about a week after announcement, with an effect that lasts over the next several days and increases new vaccinations between 3.5 and 5 percent. This boost in vaccination rates, in turn, translates into a significant increase in retail spending, which is larger and somewhat more persistent than what we document in our state-level panel regressions. All told, our findings imply that the vaccine rollout added, on average, 0.5 percentage point to GDP growth in 2021.

Keywords: COVID-19 Vaccine Rollout, Economic Activity

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Several measures of economic activity have shown improvement since the start of the COVID-19 vaccine rollout. However, over the same period, other factors—such as the course of the pandemic and the associated policy interventions—have influenced the response in activity; our analysis isolates the contribution of vaccine administration from other confounders.

With a focus on three main dimensions of activity—spending, mobility, and employment—our investigation combines two parts. First, we exploit the variation in new vaccine administration across states. In panel regressions that include a large set of controls—such as day- and state-quarter fixed effects; new vaccine distribution; the trends in new cases, hospitalizations, and deaths; temperatures; the employment rate; demographic characteristics; and the Oxford Stringency Index, a measure of policy responses to the COVID-19 outbreaks—we find that the rollout is associated with a significant increase in retail spending. The impact on spending, however, takes some time to materialize, roughly consistent with the timing of vaccination to achieve a high degree of effectiveness: In our analysis, the effect of new vaccine administration on retail spending is significant only around 20 days after receiving the shot, with an impact that persists over the following 10 days.[1] The impact on restaurant spending occurs at an even longer lags (around 50 days) from the initial vaccination. In contrast, the results for mobility and employment are mixed.

In a second part of our empirical analysis, we rely on the introduction of vaccine lotteries to instrument for vaccine uptake and, thus, control for all other factors that could have influenced vaccinations or affected economic activity across states. These lotteries were specifically designed to boost vaccination rates and are an ideal instrument for our analysis; in fact, these state-level interventions were unexpected before the official announcement and offer variation across states and over time. Using a dynamic event design setting, we find that lotteries have significantly boosted vaccination rates about a week after announcement, with an effect that lasts over the next several days and increases new vaccinations between 3.5 and 5 percent across lottery adopters compared with states without

[1]While full protection is achieved around 14 days after receiving the second dose, early studies have indicated a high degree of effectiveness of partial immunization (of around 80 percent for both Moderna's and Pfizer's vaccines) 14 days after the first dose but before the second dose. See, for example, Thompson et al. [2021].

lotteries–that is, either never adopters or not-yet adopters. This effect, in turn, translates into a significant boost to retail spending, with an impact that is larger and somewhat more persistent compared with what we find in our state-level analysis. In particular, looking at magnitudes, we find that a one standard deviation increase in vaccinations explains 2.25 standard deviations increase in retail spending about 30 days post-vaccination and over the following two weeks. This effect is consistent with an increase in retail spending at the monthly rate of 0.27 percent.

Finally, to quantify the impact on overall economic activity, we map the effects we documented on retail spending to the effect on GDP. Our estimates imply that vaccine administration, through retail sales, boosted GDP growth, on average, 0.5 percentage point (pp) in 2021. While Robertson et al. [2021a] estimate a lottery cost per marginal vaccination of 55 USD, our estimates of the impact of vaccinations attribute an increase in GDP of about 400 billion USD or 1500 USD per vaccination, suggesting an important contribution of those interventions for the recovery.

Our work contributes to the vast literature on evaluating public policy interventions. Our paper is most closely related to Hansen and Mano [2021], who document the impact of vaccinations on economic activity at the county level through an instrumental variable strategy that relies on local pharmacy density. While what they find is roughly comparable to our state-level estimates of vaccination on economic activity, their empirical strategy is not robust to some endogenous factors—such as demand shocks, which affected the local reallocation of vaccine doses across counties, or urban density, which is significantly correlated with the shape of the recovery. In contrast, lotteries and other monetary incentives are likely to be exogenous to all other sources of state-level variation, with even trends in vaccinations before their introduction not significantly different between states that adopted a lottery and states that did not or those that relied on less significant monetary incentives.

1 Data

Our analysis combines several sources of daily state-level data. To quantify the progress in vaccine administration across states, we draw on the U.S Centers for Disease Control and Prevention's COVID-19 vaccinations by jurisdiction data.

The spending indicators in our investigation are based on sector-level data from Fiserv and SafeGraph. In particular, Fiserv, one of the largest card intermediaries in the country, tracks consumer spending using card transaction data; while each observation in the initial data corresponds to a single card swipe—such as debit, credit, or gift card—data are then aggregated to the state (and national) level, the database we have access to.[2] SafeGraph aggregates data on customers' visits to select businesses using cellphone GPS signals. In addition to state variation, both data sources provide information on spending at the sector-level; in our analysis, we will focus on the retail and restaurant sectors, which commonly characterize retail spending.

To quantify mobility patterns, we rely on two indicators: the Apple driving index and the INRIX index of passenger distance traveled.

Measures of employment conditions come from Homebase, a provider of clock-in/clock-out tracking software focused on small businesses.[3]

Finally, we complement our main indicators with additional information from the New York Times COVID-19 cases and deaths database, the Health and Human Services' data on hospitalization, the Oxford stringency index, the National Oceanic and Atmospheric Administration's National Climatic Data, and employment and demographics data from the Bureau of Labor Statistics' Current Population Survey (CPS).

Because of data availability, our sample covers the period between February 10, 2021 and March 19, 2022.

[2]For more details, see Aladangady et al. [2019].
[3]For more details on Homebase, see Crane et al. [2020].

2 Empirical Analysis

2.1 State-Level Analysis

In the first part of our exploration, we leverage the state-level variation in the vaccine rollout to evaluate its effects on various economic outcomes. In particular, our baseline specification relates the number of new people in state s that received the first dose of the vaccine at day $t-j$, New Adm.$_{s,t-j}$, with current indicators of activity,

$$y_{st} = \beta_0 + \beta_{1,j}\text{New Adm.}_{s,t-j} + \gamma X_{st} + d_{sq} + d_s + d_t + \varepsilon_{st},\ j = 0, ..., 60 \tag{1}$$

where y_{st} denotes measures of spending, mobility, or employment. With a specification that investigates the impact of vaccinations over different lags from receiving the first dose of a COVID vaccine—and lags ranging from the contemporaneous impact up to 60 days after—we aim to describe the high-frequency behavioral response of individuals after vaccinations, an objective akin to constructing empirical impulse response functions. The evolution of individual behavior along various economic measures is, then, captured by $\beta_{1,j}\ j = 0, ..., 60$, the coefficients of interest. The time horizon of our evaluation—a window of about two months after the first dose—tends to largely capture the full high-frequency impact of vaccinations on various indicators.[4]

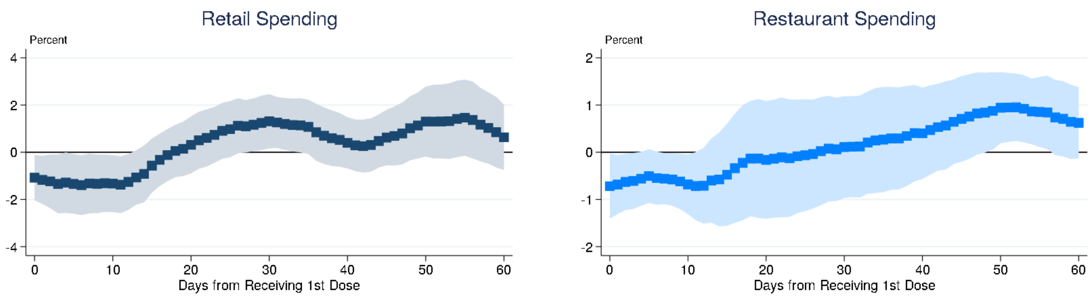
To separately identify the interaction between vaccinations and economic indicators from other confounders, our specification controls for several factors. First, we rely on new vaccine distribution to capture supply shocks in vaccine availability. Second, we include new cases, new hospitalizations, and new deaths to account for the effect of the pandemic on vaccine administration and economic activity. Third, we add the Oxford stringency index, a composite measure of non-pharmaceutical interventions that records policy responses to the course of the disease. Fourth, we control for heating and cooling degree days because of the interactions among health, behavioral outcomes, and weather variables. Fifth, we draw on CPS data to include labor market—the employment rate—and demographics—share of male population, share of white non-hispanic population, share

[4] Extending the windows for longer time horizons does not bring forth novel results, and it is more likely to capture also the impact of other factors.

of population with high school degree or less, share of young (aged 24 or less) and prime-age (25-64) population—characteristics, which, according to Robertson et al. [2021b], have been important correlates of vaccine hesitance; we also rely on state-quarter dummies, d_{sq}, to capture other relevant state-level features varying across states and quarters. Finally, we include day- and state-fixed effects to absorb, respectively, common shocks across states and time-invariant state-level characteristics—such as different attitudes towards vaccinations, geographic characteristics, and similar factors.

Results

Figures 1-3 illustrate the impact of new vaccinations on our main indicators of economic activities over the following 60 days after receiving the first dose. In those figures, each marker denotes the coefficient from model (1) for a specific lag j, while the shaded areas represent the 95 percent confidence interval. For example, looking at the left panel of figure 1, the impact of new vaccinations on retail spending is negative and significant until around 15 days after receiving the first dose of any vaccine. Afterward, the coefficient estimate gradually increases, peaking around 30 days post-vaccination—or before individuals achieve full immunization. The magnitude of the coefficient at 30 days implies that, everything else equal, a 1 percent increase in the dependent variable is associated with a $1\frac{1}{2}$ percent increase in retail spending around 30 days after receiving the first dose. The impact of vaccination on retail spending remains significant for around 10 days and, then, becomes insignificant through the end of the period in our analysis.



Source: CDC and Fiserv, Inc.
Notes: Point estimates of the effect of vaccination on retail spending, controlling for new cases, hospitalizations, and deaths; Oxford stringency index; heating and cooling degree days; employment rate; demographics; state-quarter dummies; and state- and day-fixed effects. Blue-shaded area denotes 95 percent confidence interval.

Source: CDC and Fiserv, Inc.
Notes: Point estimates of the effect of vaccination on restaurant spending, controlling for new cases, hospitalizations, and deaths; Oxford stringency index; heating and cooling degree days; employment rate; demographics; state-quarter dummies; and state- and day-fixed effects. Blue-shaded area denotes 95 percent confidence interval.

Figure 1: Vaccinations: Impact on Spending

Table 1 summarizes the cumulative impact on retail spending, aggregating across different lags. In particular, we estimate the effect of vaccinations on spending using a specification that includes all lags

$$y_{st} = \beta_0 + \sum_{j=0}^{60} \beta_{1,j} \text{New Adm.}_{s,t-j} + \gamma X_{st} + d_{sq} + d_s + d_t + \varepsilon_{st} \qquad (2)$$

and we report point estimates associated with linear combinations of coefficients over specified periods. Column (1) refers to retail spending, and we continue to report the elasticity of spending to changes in vaccinations—that is, the coefficient in column (1) implies that an increase of new vaccine administration of 1 percent is associated with 4 percent higher spending for about 10 days (from the 21st through the 30th day post-vaccination).[5] Quantifying the impact of vaccinations in terms of standard deviations of the explanatory variable—for comparability across various measures—implies that a one standard deviation increase in vaccinations is associated with a 39 percent of a standard deviation higher spending at retail businesses 21 days post-vaccination and over the next 10 days.

Columns (2)-(4) focus on spending at retail establishments that were classified as nonessential during the more acute phase of the pandemic—and thus, more likely to be subject to mandated closures during that time. While the direct indicators of spending at clothing and at sports and hobby stores—based on the Fiserv data and shown in columns (2) and (3)—appear to have not been significantly affected by the vaccine rollout, we find a significant impact on visits at those types of establishments (column (4)). The effect that we report in column (4), however, is based on a linear combination of the coefficients between 15 and 25 days post-vaccination; the point estimate would gradually become insignificant if we were to extend the window of the analysis much further. The pattern of little changes in spending and a significantly increase in visits suggests that a substitution in the *type* of spending; this interpretation is confirmed by the results in table A1, where the indicator for visits at nonessential establishments becomes insignificant after controlling for change in total spending at non-store retailers.

[5]The coefficient estimate is robust to the choice of similar windows around the 30th day post-vaccination.

Table 1: Effects of the Vaccine Rollout on Retail Spending

	(1)	(2)	(3)	(4)	(5)	(6)
	Retail		Nonessential		Restaurants	
VARIABLES	Spending	Clothing	Sports & Hobby	Visits	Spending	Visits
New Adm.	4.394***	-0.181	0.006	6.361***	0.017**	5.260***
	(1.516)	(3.550)	(0.033)	(3.002)	(0.008)	(2.204)
Other Controls[1]	y	y	y	y	y	y
State-Quarter FE	y	y	y	y	y	y
Day FE	y	y	y	y	y	y
State FE	y	y	y	y	y	y
Obs.	2,676	2,510	1,701	1,119	2,676	1,119
R-squared	0.553	0.487	0.681	0.765	0.793	0.680
Number of States	51	49	36	51	51	51

Source: Fiserv, Inc., SafeGraph, CDC, CPS, and NOAA.

[1] Other controls include new vaccine distribution; new cases, hospitalizations, and deaths; heating and cooling degree days; the employment rate; demographics characteristics; and the Oxford stringency index.

Retail Sales: Percentage change in retail sales spending relative to 2019.

Grocery, Spending: Percentage change in grocery spending (NAICS 445) relative to 2019.

Clothing: Percentage change in spending at apparel stores (NAICS 448) relative to 2019.

Sports & Hobby: Percentage change in spending at sporting goods, hobby, book, and music stores (NAICS 451) relative to 2019.

Nonessential, Visits: Percentage change in visits to nonessential retail stores relative to 2019.

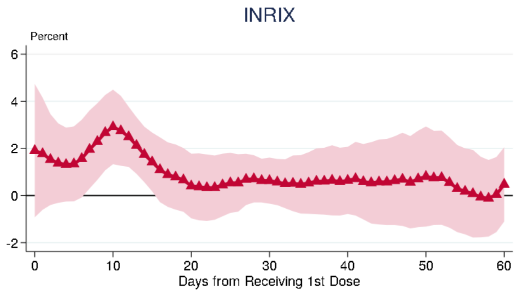
Restaurants, Spending: Percentage change in restaurant spending (NAICS 722) relative to 2019.

Restaurants, Visits: Percentage change in visits to restaurants relative to 2019.

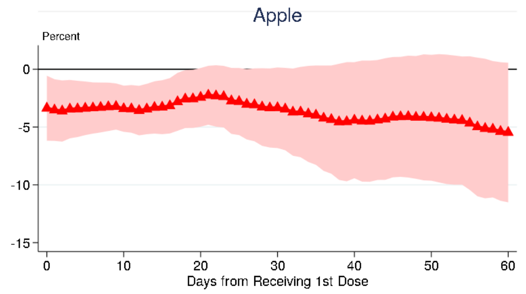
New Adm.: Log-number of 7-day moving average of new daily vaccine administration, cumulated effect after vaccination.

Legend: *** significant at 1%, ** at 5%, * at 10%.

Notes: State FE regressions. Point estimates for the main explanatory variable are based on linear combinations of coefficients: in columns (1)-(3), we report the linear combination from the 21st-day through the 30th-day lag; in column (5), we report the linear combination from the 51st-day through the 60th day; in columns (4) and (6), we report the linear combination from the 15th-day through the 25th-day lag. Robust standard errors, clustered at the state level, are reported in parenthesis.



Source: CDC and INRIX.
Notes: Point estimates of the effect of vaccination on passenger distance traveled, controlling for new cases, hospitalizations, and deaths; Oxford stringency index; heating and cooling degree days; employment rate; demographics; state-quarter dummies; and state- and day-fixed effects. Red-shaded area denotes 95 percent confidence interval.



Source: CDC and Apple, Inc.
Notes: Point estimates of the effect of vaccination on apple mobility index, controlling for new cases, hospitalizations, and deaths; Oxford stringency index; heating and cooling degree days; employment rate; demographics; state-quarter dummies; and state- and day-fixed effects. Orange-shaded area denotes 95 percent confidence interval.

Figure 2: Vaccinations: Impact on Mobility

The right panel of figure 1 focuses on spending in the restaurant sector (NAICS 722), which has been more sensitive to the evolution of the pandemic given its high-contact-intensity nature. After being significantly negative in the first few days post-vaccination, the coefficient estimates in the figure show a slight upward trend and become significant only around 50 days post-vaccination and through the end of our evaluation window. Relatedly, the cumulative impact on restaurant spending shown in column (5) of table (1) is positive over the period between the 51st and 60th-day post-vaccination, but it is rather small, implying an increase of 0.1 percent of a standard deviation per standard deviation increase in new vaccine administration. Looking at the SafeGraph measure for the sector, we continue to document a significant impact on visits at restaurant establishments over 10 days after the 15th day post-vaccination; this effect, however, continues to be related to some substitution patterns from online spending, and, in fact, it is not robust to the inclusion of the change in spending at non-store retailers (column (2), table A1).

Turning to mobility, our results look more mixed. While the left panel of figure 2 suggests a boost in mobility according to the INRIX index of passenger distance traveled, even upon receiving the first dose of a COVID vaccine, the point estimates for the Apple mobility index are, at first, negative and significant, but become insignificant around 20 days post-vaccination. A similar dichotomy appears in the cumulative effects, reported in columns (1) and (2) of table 2.

Finally, employment indicators appear largely unaffected by the vaccine rollout. Interestingly, the point estimates for either hours worked (left panel, figure 3) or the number

Table 2: Effects of the Vaccine Rollout on Mobility and Employment

	(1)	(2)	(3)	(4)
	Mobility		Employment	
Variable	INRIX	Apple	Hours Worked	Business Open
New Adm.	3.057***	-15.706***	1.445	0.119
	(1.330)	(6.746)	(1.203)	(0.612)
Other Controls[1]	y	y	y	y
State-Quarter FE	y	y	y	y
Day FE	y	y	y	y
State FE	y	y	y	y
Observations	942	2,676	2,676	2,676
R-squared	0.552	0.879	0.800	0.837
Number of States	51	51	51	51

Source: INRIX, Apple, Household Pulse Survey, Homebase, CDC, and NOAA.

[1] Other controls include new vaccine distribution; new cases, hospitalizations, and deaths; heating and cooling degree days; the employment rate; demographics characteristics; and the Oxford stringency index.

INRIX: Percentage change in the 7-day moving average of passenger distance traveled.

Apple: Percentage change in the 7-day moving average of the driving index.

Hours worked: Percentage change in the number of total hours worked relative to 2019 in small business establishments.

Business Open: Percentage change in the number of open businesses relative to 2019 in small business establishments.

New Adm.: Log-number of the 7-day moving average of new daily vaccine administration, cumulated effect.

Legend: *** significant at 1%, ** at 5%, * at 10%.

Notes: State FE regressions. Point estimates for the main explanatory variable are based on linear combinations of coefficients: in column (1), we report the linear combination from the 1st-day through the 14th day; in column (2), we report the linear combination through the 60th day; in columns (3)-(4), we report the linear combination from the 5th-day through the 14th day. All specifications include state and day fixed effects, new vaccine distribution; new cases, hospitalizations, and deaths; heating and cooling degree days; and the Oxford stringency index. Robust standard errors, clustered at the state level, are reported in parenthesis.

Figure 3: Vaccinations: Impact on Employment

of open businesses (right panel) are negative, although largely insignificant—with the exception of a few days for the number of open businesses towards the end of our window. The negative relationship between the vaccine rollout and measures of employment in the first few days after vaccination is suggestive of the use of sick leave due to possible side effects after receiving the vaccine, but the fact that the negative sign of the coefficient persists throughout our evaluation window is somewhat puzzling. Looking over a window between the 5th and the 14th day post-vaccination, the cumulative effects of vaccination on hours worked or the number of businesses open—shown in columns (4) and (5), respectively—are actually insignificant, and they show a more intuitive positive sign.

2.2 Instrumenting Vaccine Uptake: The Impact of Lotteries

While our main specification includes a fairly exhaustive set of controls, it is not fully robust to concerns of further omitted variables or endogeneity. In this section, we explore an instrumental variable strategy that addresses those concerns. In particular, we rely on the implementation of vaccine lotteries. Between May 10 and July 1, 2021, 19 states announced lotteries to boost vaccination rates. Participation to the lotteries required having received or receiving one shot of the vaccine; while, in some instances, individuals were not required to take any additional steps, most states set up web portals for the submission of the vaccination record. Table A2 summarizes announcements and last extraction dates by state.

Evidence on the impact of lotteries or other monetary incentives on vaccine uptake is mixed. In particular, the closest papers to this part of our analysis, Dave et al. [2021] and Robertson et al. [2021a], document contrasting results.[6] Looking across various state lotteries, Dave et al. [2021] argue that lotteries had no impact on vaccine administration, while Robertson et al. [2021a] suggest that 10 of the 12 statewide lotteries they studied generated a positive and statistically significant impact on vaccine uptake. Those papers differ in terms of the level of the analysis (state-level for Dave et al. [2021] vs county-level for Robertson et al. [2021a]) and what controls are used in the study, but both rely on data through early July. While we perform our analysis at the state-level, we extend the lottery data to encompass all extractions; we also adopt a more exhaustive specification.[7]

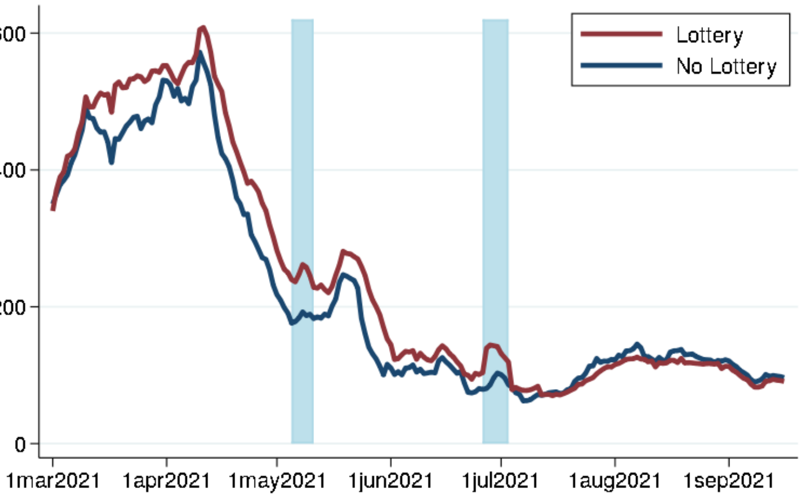
Before describing our strategy for the identification of lottery effects, figure 4 compares the trends in vaccination rates between states that have announced a lottery at any time in our sample and states that never did. Interestingly, future adopters of vaccine lotteries display higher levels of vaccine uptake since mid-March 2021. While generally the trends in vaccination are not too dissimilar, the figure highlights a couple of instances where deviations in the trends between the two groups of states are more visible (shaded blue areas); those deviations occur in early May, around the time of the earliest lottery announcements, and around July 1st, when several extractions for various lotteries occurred. This quick comparison, however, is very rudimentary and does not take into account the different timing of the announcements or differences in other state-level factors.

To precisely identify the impact of lotteries on vaccinations, we rely on a dynamic difference-in-difference estimation that contrasts the variation in vaccination rates in states that have implemented the lottery with that of states that have not—but may at some point in the future—implemented it. In particular, our baseline specification is the following

$$\text{New Adm.}_{st} = \delta_0 + \sum_{j=-15}^{60} \delta_{1,j} \text{Post Announc.}_{s,t-j} + \xi X_{st} + d_{sm} + d_s + d_t + \epsilon_{st} \tag{3}$$

[6]Several other papers have looked at the impact of lotteries or other monetary incentives on vaccinations. In particular, Brehm et al. [2021] and Mallow et al. [2021] document a positive impact on vaccinations for the Ohio lottery, in contrast with the findings of Lang et al. [2021]. Other evidence points to a positive impact of guaranteed monetary incentives in Sweden (Campos-Mercade et al. [2021]) and in the U.S. (Dai et al. [2021]), but not for the vaccine hesitant population (Chang et al. [2021]).

[7]Our sample covers data through March 2022, well after the last extraction on August 26 in the Kentucky lottery.



Source: CDC.
Notes: Average daily vaccine administration per capita across groups of states that announced a vaccine lottery and those that offered no or other types of incentives. Shaded areas denotes deviations from trends.

Figure 4: Comparison of Vaccine Administration Trends between States with and without Vaccine Lotteries

where Post Announc.$_{s,t-j}$ collects the leads and lags relative to the lottery announcement.[8] $\delta_{1,j}$, $j \in \{-15, ..., 60\}$ are our coefficient of interests and identify the dynamic treatment effects under the assumption of conditional parallel trends of lottery adopters relative to the not-yet adopters and the never adopters groups; thus, under those parallel trend assumptions, the coefficients could be interpreted as a weighed average of the average treatment effect on the treated. Importantly, in our setting, treatment effects are heterogeneous in time since lotteries are adopted in different time periods across different states. As noted by Goodman-Bacon [2021], this setting may lead to estimates that are biased away from a weighed average of the average treatment effect on the treated. This problem, however, is addressed in our panel event study design with a dynamic specification that includes two-way fixed effects.

While parallel trend assumptions might be less likely to hold for part of the comparison groups, our specification includes a rather exhaustive set of controls. In particular, we continue to control for the same explanatory variables as in equation (1); in addition, equation

[8] All periods beyond some specified values are accumulated into final lag and lead points to avoid unbalanced leads and lags.

(3) includes a regressor that captures the time to extraction and a dummy for the presence of other types of incentives.[9] Furthermore, we adopt a more stringent fixed effect specification relative to model (1), with state-month fixed effects, d_{sm}, to capture differences in the monthly timing of lottery adoption across states as well as cross-state variation in economic conditions or other monthly factors that might have influenced the decision to announce a lottery.

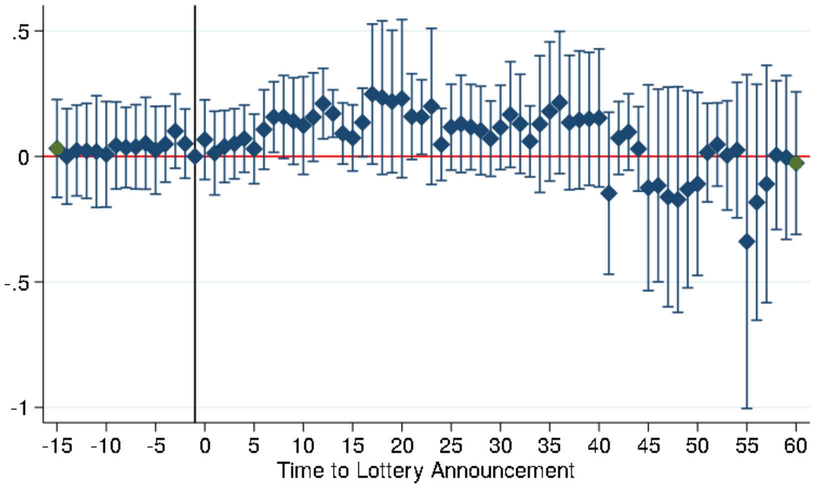
While equation 3 represents the first stage of our instrumental variable strategy, we will then use the estimates from that model to predict new vaccine administration and use this prediction in our baseline models (1) and (2).

Results

Figure 5 summarizes the first-stage result. The coefficient estimates of the leads and lags around the lottery announcements are relative to the period before announcement, coded as -1 and identified by the black vertical bar. The chart highlights no significant effects on new vaccinations in the 15 days before announcements, consistent with the parallel trend assumptions required for our estimation. However, we also find that there is no immediate increase in vaccinations after announcement; this finding is consistent with the fact that eligibility in several lotteries required registering through an online portal before scheduled extraction dates. On the 8th day post-announcement, the coefficient estimate is significant as well as in a few other instances over the following two weeks.

Table 3 summarizes the cumulative impact on new vaccine administration in the pre- and post-announcement period. Column (1) reports that the cumulative effect in the pre-period is effectively zero, confirming that the conditional parallel trend assumption is satisfied in the 15 days before announcement. After excluding the first 7 days post-announcement, we find a significant effect of lotteries on new vaccinations through the 45th day post-announcement (columns (2) and (3)). When extending the window through day 60 (column (4)), we find a similar point estimate, although less tightly estimated. Looking at magnitudes and using the coefficient from column (2), the effect implies that states that announced lotteries experienced a 3.5 percent increase in vaccinations a week after an-

[9]Information on incentives is collected from a publication of the National Governors Association available here.



Note: Point estimates of lottery announcement on new vaccine administration, controlling for new cases, hospitalizations, and deaths; Oxford stringency index; heating and cooling degree days; state-month dummies; and day-fixed effects. Vertical bars denote 95 percent confidence interval.

Figure 5: Lottery Announcements and Impact on New Vaccinations

nouncement and over the next 20 days relative to those that did not introduce or had not yet made an announcement. As an alternative quantification, the effect of lotteries translates into an increase in vaccinations of almost 2.5 standard deviations in lottery adopters when comparing to never or not-yet adopters.

Figures A1-A3 summarize the second-stage impact of vaccinations on our measures of activity using our impulse response framework. The results are generally consistent with what we have documented in the previous section. Importantly, our estimate of the impact on retail spending continues to be significant, although the effect is shifted by a week, likely reflecting the slight delay in the impact of lotteries on vaccination after announcement. In our second stage analysis, three other main differences emerge. First, we do not find a positive and significant impact of vaccinations on restaurant spending. Second, mobility indicators display a more similar behavior, with both INRIX and Apple indexes showing, at first, no significant effects and, later on, pointing to a negative impact. Third, the significance of the negative point estimates for measures of employment has largely disappeared.

Table 4 looks at the cumulative impact of vaccinations on our main measures of eco-

Table 3: Cumulative Impact of Lotteries on New Vaccinations around Announcement

	(1)	(2)	(3)	(4)
Variable	New Vaccine Adm.			
	Before	After		
	2 - 15 days	8-30 days	8-45 days	8-60 days
Cum Impact	0.501	3.565**	5.121**	3.545
	(1.123)	(1.624)	(2.326)	(2.686)
Other Controls[1]	y	y	y	y
State-Month FE	y	y	y	y
Day FE	y	y	y	y
State FE	y	y	y	y
Obs.	14,026	14,026	14,026	14,026
R-squared	0.580	0.580	0.580	0.580
Number of States	51	51	51	51

Source: CDC and NOAA.

[1] Other controls include new vaccine distribution; new cases, hospitalizations, and deaths; heating and cooling degree days; the employment rate; demographics characteristics; the Oxford stringency index; the time to extraction; and a dummy for the presence of other incentives.

New Vaccine Adm.: Log-number of the 7-day moving average of new daily vaccine administration.

Legend: *** significant at 1%, ** at 5%, * at 10%.

Notes: Dynamic difference-in-difference regressions, cumulated effects before (column (1)) and after (columns (2)-(4)) lottery announcment. In the post-announcement period, we exclude the first 7 days to account for learning about eligibility conditions Robust standard errors, clustered at the state level, are reported in parenthesis.

nomic activity in our instrumental variable setting. The cumulative estimates are evaluated over the 15 days after day 30—or, between day 31 and day 45 post-vaccination—a window that we chose based on the impulse response function results.[10] As already highlighted by figures A1-A3, our results are robust only for retail spending. In particular, our estimates imply that an increase in vaccinations raises retail spending by 23.8 percent—or 2.25 standard deviations per standard deviation—after 30 days from receiving the first dose of the vaccine and over the following two weeks. In other words, our effect suggest a daily boost to retail sales of about 1.6 percent per day for 15 days per percentage increase in vaccinations–which translates into a monthly rate of 0.27 percent.

3 Implications for GDP growth

Our analysis suggests that retail spending has received a significant boost from the progress in the vaccine rollout. But what do those effects ultimately tell us about aggregate economic activity? We have drawn a direct inference—summarized in table 5—based on two features: (1) the relation between our main spending indicator and the retail sales component of personal consumption expenditures (PCE) and (2) its contribution to GDP. First, we estimate the growth rate of Census' retail sales, the official source of GDP data released by the Bureau of Economic Analysis (BEA), using our Fiserv indicator. Our Fiserv spending measure is highly correlated with the Census's data on retail sales, and our estimate suggests an average growth of 0.87 percent per month in 2021. As a result, our estimates predict that retail sales grew at almost 10 percent at an annual rate in 2021 (line 1, table 5)—vs. 10½ percent using the BEA GDP Data. Second, we calculate the contribution of our vaccine effects to retail sales and to GDP. Based on the average growth of new vaccine administration since the beginning of the year, we estimate that the vaccine uptake explains about 15 percent of the average increase in retail sales and, as a result, accounts for about 0.5 percentage point of GDP growth over the same time horizon (line 3). The impact of vaccinations on GDP we calculated, however, is likely a lower bound as it focuses on a

[10]The version of model (2) used for this analysis includes only those lags beyond all other controls, as the inclusion of additional lags significantly restricts the sample for estimation. Results are, however, robust to the use of a model with up to 30 lags around the same window.

Table 4: Second Stage Effects of the Vaccine Rollout on Activity

	(1)	(2)	(3)	(4)	(5)	(6)
	Spending		Mobility		Employment	
VARIABLES	Retail	Restaurant	INRIX	Apple	Hours	Open Businesses
New Adm.	23.770***	3.535	-41.412	-6.213	-1.822	-0.950
	(5.661)	(6.077)	(88.460)	(7.070)	(3.065)	(1.745)
Other Controls[1]	y	y	y	y	y	y
State-Month FE	y	y	y	y	y	y
Day FE	y	y	y	y	y	y
State FE	y	y	y	y	y	y
Obs.	1,127	1,127	94	1,127	1,127	1,127
R-squared	0.810	0.805	0.949	0.976	0.979	0.986
Number of States	50	50	20	50	50	50

Source: Fiserv, Inc., INRIX, Apple, Homebase, CDC, CPS, and NOAA.

[1] Other controls include new vaccine distribution; new cases, hospitalizations, and deaths; heating and cooling degree days; the employment rate; demographics characteristics; the Oxford stringency index; the time to extraction; and a dummy for the presence of other incentives.

Retail Spending: Percentage change in retail sales spending relative to 2019.

Restaurants Spending: Percentage change in restaurant spending (NAICS 722) relative to 2019.

INRIX: Percentage change in the 7-day moving average of passenger distance traveled.

Apple: Percentage change in the 7-day moving average of the driving index.

Hours worked: Percentage change in the number of total hours worked relative to 2019 in small business establishments.

Business Open: Percentage change in the number of open businesses relative to 2019 in small business establishments.

New Adm.: Log-number of 7-day moving average of new daily vaccine administration, cumulated effect after vaccination.

Legend: *** significant at 1%, ** at 5%, * at 10%.

Notes: Second-stage FE regressions. Point estimates for the main explanatory variable are based on linear combinations of coefficients: in columns (1)-(3), we report the linear combination from the 21st-day through the 30th-day lag; in column (5), we report the linear combination from the 51st-day through the 60th day; in columns (4) and (6), we report the linear combination from the 15th-day through the 25th-day lag. Robust standard errors, clustered at the state level, are reported in parenthesis.

single channel—although the most important, according to our estimates.

Table 5: Vaccinations: Impact on GDP Growth

	2021 Average
1. Retail Sales Growth[1]	9.98%
2. Retail Sales Contribution to GDP	3.38%
3. Vaccinations Impact	0.54%

Source: BEA, Census, and Fiserv, Inc.

[1] Retail sales growth prediction based on Fiserv data.

Notes: Estimates of vaccine rollout effects on GDP growth.

Finally, we propose a cost-benefit analysis, comparing our GDP implications with cost estimates for the lotteries implemented. Our calculation suggest that the vaccine rollout added 400 billion to GDP in 2021—or about 1500 USD per vaccination. Robertson et al. [2021a] estimate that the cost of lotteries per marginal vaccination was 55 USD. Even accounting for the fact that the implementation of lotteries largely occurred between the middle of the second quarter and the third quarter, the benefit per quarter—or around 375 USD—remains much higher than the cost of lotteries, pointing to the importance of the vaccine rollout and of the state-level lotteries for economic activity.

4 Conclusions

In this paper, we analyzed the impact of vaccine administration on three main dimensions of activity: spending, mobility, and employment. We complement an investigation using panel state-level data with an instrumental variable strategy that relies on the implementation of vaccine lotteries. Our results highlight the effect of new vaccinations on retail spending. In particular, relying on the results from our IV strategy, we find that lotteries have significantly boosted vaccination rates about a week after announcement, with an effect that lasted over the next several days and, overall, increased new vaccinations by at least 3.5 percent across lottery adopters compared to states without a lottery (either never adopters or not-yet adopters). This boost in vaccination rates, in turn, translates into a significant increase in retail spending, with a 1 percent increase in new vaccinations associated with a monthly growth of 0.27 percent in retail spending. All told, our findings imply that the vaccine rollout added, on average, about 0.5 percentage point to GDP growth in 2021 and that the cost of lotteries was well below the boost to retail sales.

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A Additional Figures and Tables

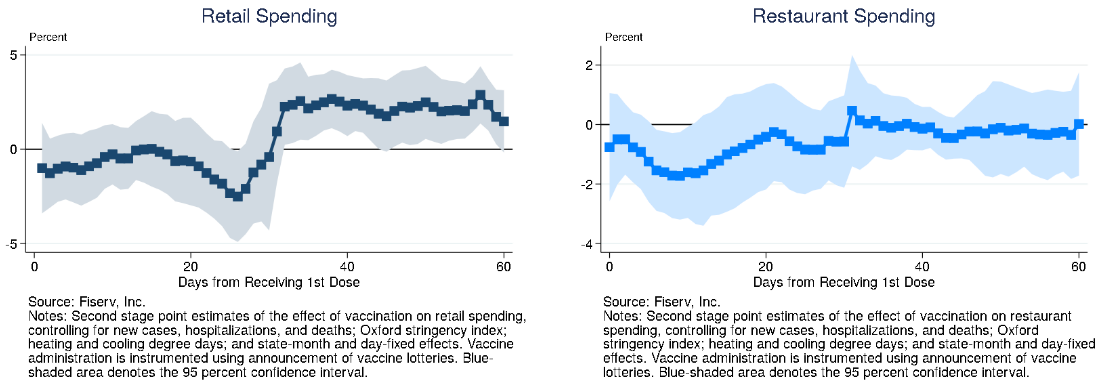

Figure A1: Second Stage Effect of Vaccinations: Impact on Spending

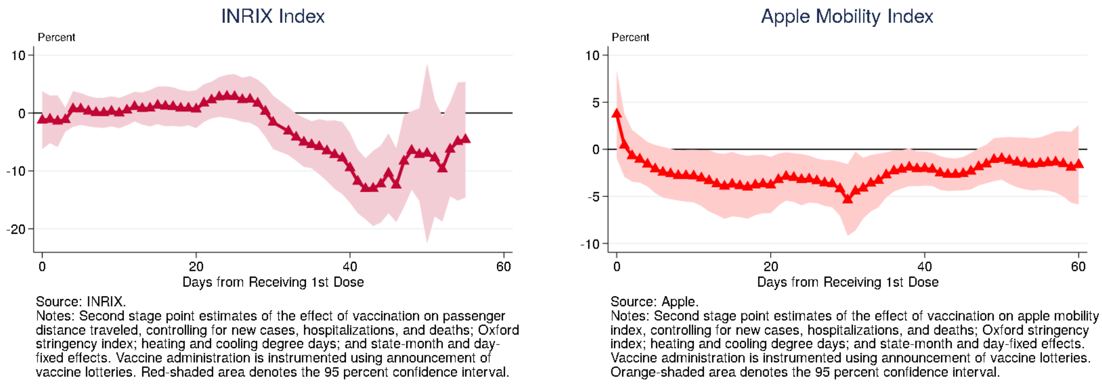

Figure A2: Second Stage Effect of Vaccinations: Impact on Mobility

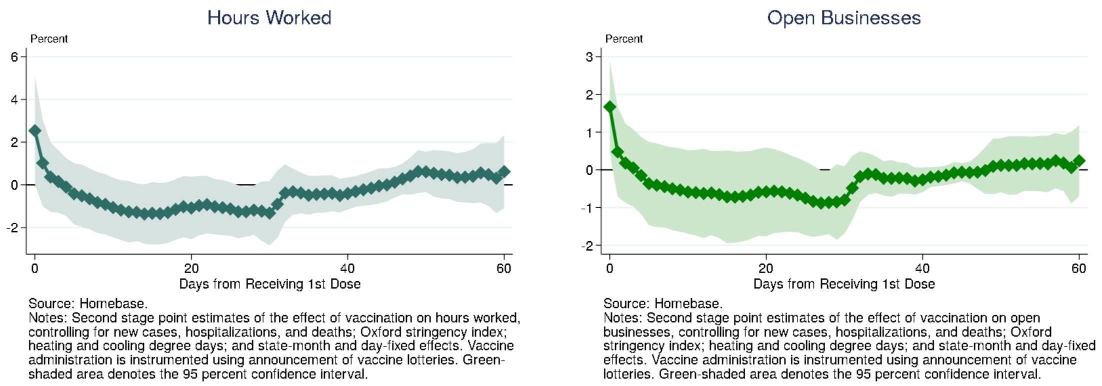

Figure A3: Second Stage Effect of Vaccinations: Impact on Employment

Table A1: The Vaccine Rollout and Visits: Controlling for Non-Store Spending

Variables	(1) Nonessential Visits	(2) Restaurant Visits
New Adm.	3.156	4.223
	(4.492)	(3.985)
Non-Store Spending[1]	y	y
Other Controls[2]	y	y
State-Quarter FE	y	y
Day FE	y	y
State FE	y	y
Obs.	2,595	2,595
R-squared	0.218	0.209
Number of States	51	51

Source: SafeGraph, CDC, CPS, and NOAA.

[1] Change in spending at non-store retailers (NAICS 454) relative to 2019.

[2] Other controls include new vaccine distribution; new cases, hospitalizations, and deaths; heating and cooling degree days; the employment rate; demographics characteristics; and the Oxford stringency index.

Nonessential, Visits: Percentage change in visits to nonessential retail stores relative to 2019.

Restaurants, Visits: Percentage change in visits to restaurants relative to 2019.

New Adm.: Log-number of 7-day moving average of new daily vaccine administration, cumulated effect.

Legend: *** significant at 1%, ** at 5%, * at 10%.

Notes: State FE regressions. Point estimates for the main explanatory variable are based on linear combinations of coefficients from the 15th-day through the 25th-day lag. Robust standard errors, clustered at the state level, are reported in parenthesis.

Table A2: State Lottery Summary

State	Announcement Date	Extraction Date (Last)
Arkansas	May 25	-
California	May 27	July 1
Colorado	May 25	July 6
Delaware	May 25	June 29
Illinois	June 17	August 16
Kentucky[1]	June 4	August 26
Louisiana	June 17	July 31
Maine	June 16	June 30
Maryland	May 20	July 3
Massachusetts	June 15	August 19
Michigan	July 1	August 3
Nevada	June 17	August 26
New Mexico	June 1	August 6
New York	May 20	June 11
North Carolina	June 10	August 1
Ohio	May 12	June 20
Oregon	May 21	June 27
Washington	June 3	July 13
West Virginia	June 1	August 1

[1] On May 10, Kentucky offered a coupon for a free lottery ticket ($225,000 maximum cash award to winner) to those ages 18+ who received a COVID-19 vaccine only at 180 Kroger and WalMart locations statewide.

Notes: Announcement dates and last extraction dates across states that instituted lotteries.