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Supplementary appendix

This appendix formed part of the original submission and has been peer reviewed. We post it as supplied by the authors.

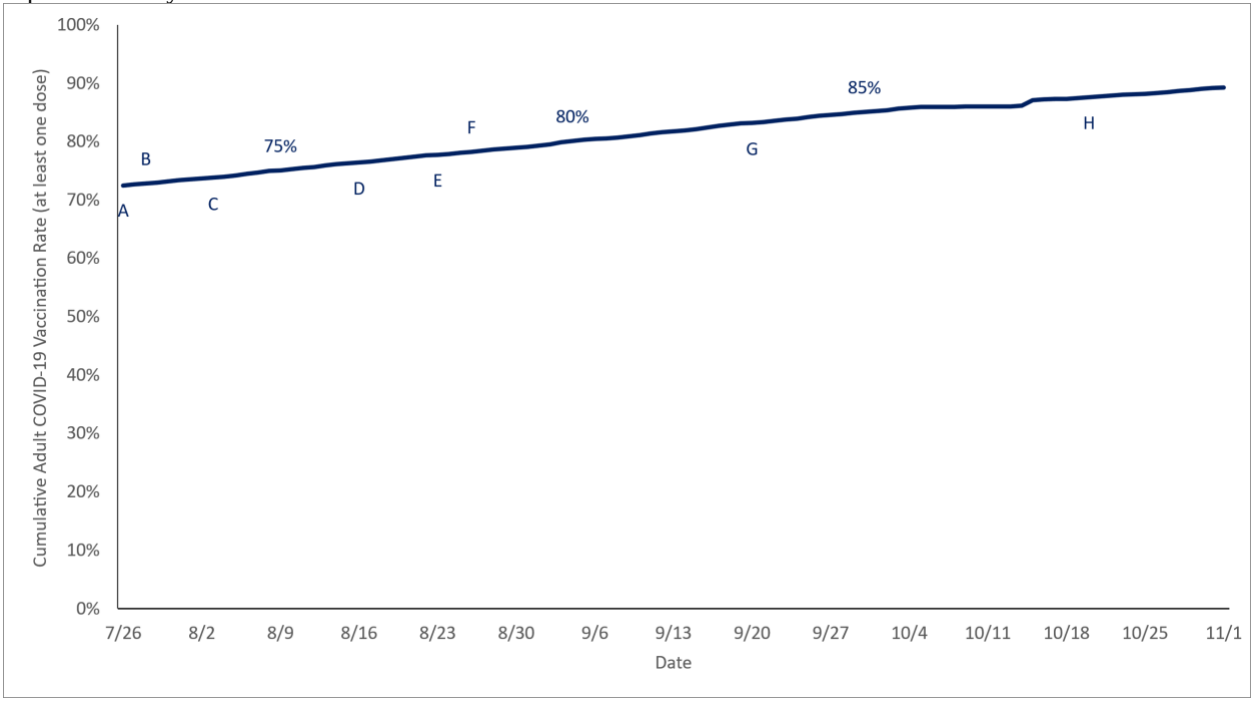
Supplement to: Cohn E, Chimowitz M, Long T, Varma JK, Chokshi DA. The effect of a proof-of-vaccination requirement, incentive payments, and employer-based mandates on COVID-19 vaccination rates in New York City: a synthetic-control analysis. *Lancet Public Health* 2022; **7:** e754–62.

Supplementary Material for "The effect of a proof-of-vaccination requirement, incentive payments, and employer-based mandates on COVID-19 vaccination rates in New York City: a synthetic-control analysis"

Table of Contents

1. NYC COVID-19 Vaccination Campaign Timeline

Figure A1.1: NYC COVID-19 Vaccination Campaign Timeline. Data are from CDC.[1] Policies are indicated by capital letters by announcement date and are summarized in the table below.



Flag in Chart	Announced	Effective	Policy	Population affected	Opt-out	Dose
A	7/26/2021	8/16/2021	Mandate	Certain NYC government employees*	Testing	Full Series
A	7/26/2021	9/13/2021	Mandate	NYC government employees	Testing	Full Series
B	7/28/2021	7/28/2021	$100 incentive	NYC residents	NA	First Dose
C	8/3/2021	8/17/2021†	Proof-of-vaccination	Visitors to covered locations‡	No	First Dose
D	8/16/2021	9/27/2021	Mandate	Healthcare workers	No	First Dose
E	8/23/2021	9/27/2021	Mandate	Department of Education employees	No	First Dose
F	8/26/2021	8/26/2021	Outreach§	Residents of 20 neighborhoods	NA	Full Series
G	9/20/2021	9/20/2021	Counseling§	Medicaid and Medicare Advantage	NA	First Dose
H	10/20/2021	10/20/2021	$500 incentive	NYC government employees	NA	First Dose
H	10/20/2021	10/29/2021	Mandate	NYC government employees	No	Full Series

*The mandate effective August 16, 2021 applied to NYC government employees and contractors in residential and congregate care settings.

†Enforcement of the proof-of-vaccination requirement did not begin until September 13, 2021.

‡The proof-of-vaccination requirement applied to employees and patrons (12 years or older) of indoor portions of entertainment and recreational settings; indoor food services; and indoor gyms and fitness settings.

§The vaccine equity partner engagement program ("outreach") and vaccine outreach and counseling program ("counseling") were not explicitly analyzed as part of the intervention because both consisted of outreach and engagement, while the other policies consisted of incentives or mandates targeted toward individuals. Results are robust to the exclusion of counties known to have implemented policies similar to the vaccine outreach and counseling program (appendix 11). We did not test robustness to the exclusion of counties with programs similar to the vaccine equity partner engagement program out of concern that we would be unable to successfully identify all counties in the donor pool with comparable policies.

2. Data Processing

CDC vaccination data used in the analysis included discontinuities due to reporting adjustments and retroactive reporting. These discontinuities distort the true pace of vaccinations. We made two adjustments to CDC-reported vaccination data to address these discontinuities.

Cumulative vaccination series in the raw CDC data change discontinuously for some states on some dates due to reporting adjustments.[2] We re-scaled pre-adjustment vaccination totals for counties in these states by the ratio of cumulative vaccinations just before and after the adjustment to generate an internally consistent cumulative vaccination series. We calculated daily vaccinations from the adjusted series of cumulative vaccinations.

Some large spikes persisted after these adjustments, perhaps due to retroactive reporting or data updates at the county level. We further adjusted county-level seven-day averages of new vaccinations by discarding and interpolating any seven-day blocks where (1) the seven-day average of vaccinations on the first day of the block was more than twice the seven-day average on the preceding day, and (2) the seven-day average of vaccinations on the first day after the block was less than half the seven-day average on the last day of the block. This adjustment reduced the incidence of large errors in daily vaccination totals at the cost of introducing error into the cumulative sum of daily vaccination totals. We chose to limit errors in daily vaccination totals because large, short-term errors have an outsize impact on the RRMSPE test statistic. We re-ran the analysis omitting this cleaning step as a robustness check. We estimated a cumulative impact of 428,820 persons (95% CI [66,505, 766,564]) or 6·4pp (95% CI [1·0pp,11·6pp]), which is generally consistent with the main analysis.

3. Synthetic Control Group Donor Pool

The synthetic control group donor pool used for the analysis was limited to counties in the core of large metropolitan statistical areas that did not implement vaccination policies before November 1, 2021 similar to those implemented in New York City (NYC) and that had adequate vaccination data. This appendix describes the selection of the synthetic control group donor pool in greater detail.

We selected the synthetic control group from a pool of 119 counties in the core of metropolitan statistical areas (MSAs) with at least 500,000 residents that: (1) contain the entire population of the largest principal city of the MSA, (2) have their entire population contained in the largest principal city of the MSA, (3) contain at least 250,000 residents of any principal city in an MSA with at least 1,000,000 residents, or (4) contain at least 250,000 residents of the largest principal city in an MSA with 500,000-1,000,000 residents. Counties in MSAs with at least 1,000,000 residents that meet conditions (1), (2), or (3) are categorized as "large central metro" counties in the 2013 National Center for Health Statistics Urban-Rural Classification Scheme for Counties.[3]

We excluded from the donor pool any county that implemented at least one policy comparable to those implemented in NYC before November 1, 2021, any county contained in a state that implemented such a policy, or any county whose largest principal city implemented such a policy. We did not exclude counties that implemented weaker versions of policies in NYC as doing so would have eliminated enough counties from the donor pool that it would not have been possible to select a suitable control group. Employer-based mandates were considered disqualifying if failure to comply with the mandate could result in loss of employment, the mandate could not be satisfied by regular testing or prior infection, and the mandate applied to the full sector. Vaccination payments were considered disqualifying if the payments were available to adults of all ages at more than a few sites over more than a few dates, if the number of payments was not capped below 1% of the jurisdiction's population, and if the payments were provided directly to vaccinated persons. Proof-of-vaccination mandates were considered disqualifying if the mandate could not be satisfied with a recent negative test. Vaccine lotteries were not considered disqualifying because NYC did not implement a vaccine lottery (aside from a small number of sites associated with a statewide program); nevertheless, we confirmed that the results of the main analysis were robust to the exclusion of counties with vaccine lotteries (appendix 10). Counties were not eliminated from the donor pool based on messaging, outreach, or vaccine delivery infrastructure alone—and these types of programs were not considered part of the intervention—because New York City undertook analogous programs. 58 counties remained eligible after these exclusions.

Finally, we omitted counties if: (1) county of residence was not available for at least 75% of fully vaccinated recipients in the jurisdiction containing the county as of any date during the analysis period, or (2) there was a gap of at least 14 days in the analysis period during which no CDC vaccination data was available for the county. The remaining 44 counties were included in the donor pool. Table A3.1 summarizes the number of counties that remained eligible for the donor pool after each step.

Table A3.1: Selection of counties into the donor pool.

	N
Counties and county-equivalent administrative divisions (excluding U.S. territories)	3,143
+ county is in a metropolitan statistical area with at least 500,000 residents in 2019	623
+ county is included in 2019 ACS 1-year estimates (population 65,000+)	413
+ county is in a core of its metropolitan statistical area	119
+ county did not implement a vaccination policy similar to those implemented in NYC	58
+ county was not excluded due to data limitations	44

We did not find evidence that data missingness introduced bias into the sample (table A3.2). None of the differences between the population eligible for the donor pool and the population included in the donor pool were statistically significant ($p<0{\cdot}05$) using a one-sample, two-tailed t-test.

Table 3.2: Characteristics of counties considered for and included in the donor pool. Educational attainment is reported for adults 25 years and over. Democratic vote share is calculated as the share of all non-third-party votes

earned by the Democratic candidate in the 2020 presidential election. Vaccination outcomes are calculated for adults.

	NYC	Core Counties (N=119)	Eligible for Donor Pool (N=58)	Donor Pool (N=44)
Population (all ages)				
County	8,336,817	1,087,566 (1,212,128)*	959,209 (887,963)	890,916 (750,637)
Metropolitan Statistical Area	19,216,182	3,434,829 (4,881,082)	2,773,220 (3,798,265)	2,377,313 (3,954,769)
Race/Ethnicity, %				
Hispanic	29·1	19·8 (17·1)	19·3 (18·3)	16·6 (13·1)
Non-Hispanic Asian	14·3	6·4 (7·2)	4·9 (6·0)	3·7 (2·5)
Non-Hispanic Black	21·7	17·0 (14·1)	15·7 12·0)	15·4 (11·9)
Age group, %				
16-59	60·5	59·0 (3·7)	58·1 (4·4)	57·3 (4·3)
≥60	21·1	21·4 (4·5)	21·9 (5·8)	23·0 (6·0)
Sex, %				
Male	47·7	48·9 (0·9)	48·9 (0·8)	48·8 (0·7)
Educational attainment, %				
High school graduate or higher	83·2	88·8 (4·6)	89·3 (4·6)	89·7 (2·9)
Bachelor's degree or higher	39·2	36·9 (10·5)	35·4 (9·9)	33·6 (6·2)
Economic attributes				
Median household income ($)	69,407	67,360 (16,761)	64,864 (13,893)	62,148 (8,672)
Poverty rate (%)	16·0	13·3 (4·0)	12·8 (3·6)	12·8 (2·7)
Unemployment rate (%)	5·2	4·8 (1·4)	4·4 (1·0)	4·4 (1·0)
Metropolitan area population, %				
≥ 1 million	100·0	57·1 (49·7)	51·7 (50·4)	47·8 (50·5)
500,000-999,999	0·0	42·9 (49·7)	48·3 (50·4)	52·2 (50·5)
Partisanship, %				
Democratic vote share in 2020	77·0	61·6 (13·3)	55·9 (11·6)	53·6 (10·8)
Vaccination, %†				
At least one dose as of July 25	72·5	65·1 (13·5)	62·0 (9·7)	64·4 (6·9)
Received first dose June 28-July 25	3·4	3·0 (1·4)	2·7 (1·0)	2·8 (1·0)

*Numbers in parentheses show the standard deviation of the population of county-level estimates and do not account for within-county sampling error.

†Vaccination data as of July 25 are available for 110 of 119 core counties and 50 of 58 counties eligible for the donor pool. Texas and Hawaii did not report vaccination data to CDC as of July 25, 2021.

Table A3.3 shows the 44 counties included in the donor pool.

Table A3.3: Donor pool for the synthetic control group. Metropolitan statistical areas are defined by the United States Office of Management and Budget.[4] Population estimates come from the 2019 American Community Survey 1-year estimates.[5]

County	State	Largest City	Metropolitan Statistical Area	Population (County)	Population (MSA)
Jefferson	Alabama	Birmingham	Birmingham-Hoover, AL	658,573	1,090,435
Maricopa	Arizona	Phoenix	Phoenix-Mesa-Chandler, AZ	4,485,414	4,948,203
Pima	Arizona	Tucson	Tucson, AZ	1,047,279	1,047,279
Pulaski	Arkansas	Little Rock	Little Rock-North Little Rock-Conway, AR	391,911	744,483
Brevard	Florida	Palm Bay	Palm Bay-Melbourne-Titusville, FL	601,942	601,942
Duval	Florida	Jacksonville	Jacksonville, FL	957,755	1,559,514
Escambia	Florida	Pensacola	Pensacola-Ferry Pass-Brent, FL	318,316	502,629
Hillsborough	Florida	Tampa	Tampa-St. Petersburg-Clearwater, FL	1,471,968	3,194,831
Lee	Florida	Cape Coral	Cape Coral-Fort Myers, FL	770,577	770,577
Miami-Dade	Florida	Miami	Miami-Fort Lauderdale-Pompano Beach, FL	2,716,940	6,166,488
Orange	Florida	Orlando	Orlando-Kissimmee-Sanford, FL	1,393,452	2,608,147
Pinellas	Florida	St. Petersburg	Tampa-St. Petersburg-Clearwater, FL	974,996	3,194,831

County	State	Largest City	Metropolitan Statistical Area	Population (County)	Population (MSA)
Polk	Florida	Lakeland	Lakeland-Winter Haven, FL	724,777	724,777
Sarasota	Florida	North Port	North Port-Sarasota-Bradenton, FL	433,742	836,995
Volusia	Florida	Deltona	Deltona-Daytona Beach-Ormond Beach, FL	553,284	668,365
Ada	Idaho	Boise	Boise City, ID	481,587	749,057
Marion	Indiana	Indianapolis	Indianapolis-Carmel-Anderson, IN	964,582	2,076,531
Sedgwick	Kansas	Wichita	Wichita, KS	516,042	640,218
Fayette	Kentucky	Lexington	Lexington-Fayette, KY	323,152	517,056
Jefferson	Kentucky	Louisville	Louisville/Jefferson County, KY-IN	766,757	1,266,389
Hampden	Massachusetts	Springfield	Springfield, MA	466,372	697,382
Suffolk	Massachusetts	Boston	Boston-Cambridge-Newton, MA-NH	803,907	4,873,019
Worcester	Massachusetts	Worcester	Worcester, MA-CT	830,622	947,404
Wayne	Michigan	Detroit	Detroit-Warren-Dearborn, MI	1,749,343	4,319,629
Jackson	Missouri	Kansas City	Kansas City, MO-KS	703,011	2,155,068
Clark	Nevada	Las Vegas	Las Vegas-Henderson-Paradise, NV	2,266,715	2,266,715
Hudson	New Jersey	Jersey City	New York-Newark-Jersey City, NY-NJ-PA	672,391	19,216,182
Union	New Jersey	Elizabeth	New York-Newark-Jersey City, NY-NJ-PA	556,341	19,216,182
Franklin	Ohio	Columbus	Columbus, OH	1,316,756	2,122,271
Montgomery	Ohio	Dayton	Dayton-Kettering, OH	531,687	807,611
Oklahoma	Oklahoma	Oklahoma	Oklahoma City, OK	797,434	1,408,950
Tulsa	Oklahoma	Tulsa	Tulsa, OK	651,552	998,655
Allegheny	Pennsylvania	Pittsburgh	Pittsburgh, PA	1,216,045	2,317,600
Dauphin	Pennsylvania	Harrisburg	Harrisburg-Carlisle, PA	278,299	577,941
Lackawanna	Pennsylvania	Scranton	Scranton--Wilkes-Barre, PA	209,674	553,885
Lancaster	Pennsylvania	Lancaster	Lancaster, PA	545,724	545,724
Lehigh	Pennsylvania	Allentown	Allentown-Bethlehem-Easton, PA-NJ	369,318	844,052
Greenville	South Carolina	Greenville	Greenville-Anderson, SC	523,542	920,477
Davidson	Tennessee	Nashville	Nashville-Davidson--Murfreesboro--Franklin, TN	694,144	1,933,860
Knox	Tennessee	Knoxville	Knoxville, TN	470,313	869,525
Shelby	Tennessee	Memphis	Memphis, TN-MS-AR	937,166	1,344,910
Salt Lake	Utah	Salt Lake City	Salt Lake City, UT	1,160,437	1,232,696
Utah	Utah	Provo	Provo-Orem, UT	636,235	649,603
Weber	Utah	Ogden	Ogden-Clearfield, UT	260,213	683,024

103

4. Weights of Attributes Used to Select the Synthetic Control Group

We selected a synthetic control group for each outcome using a two-step process. First, weights were selected for each attribute used in the matching process to capture the relative power of each attribute at predicting vaccination outcomes. Second, the control group was chosen as the weighted average of counties that best matched NYC over the matching period as measured by the weighted set of attributes. Table A4.1 shows the attribute weights used to select the synthetic control group for the main analysis. Race and ethnicity, partisanship, recent vaccinations, age, and median income were most predictive of vaccinations and thus received the most weight in the matching process.

Table A4.1: Weights of attributes used in the matching process

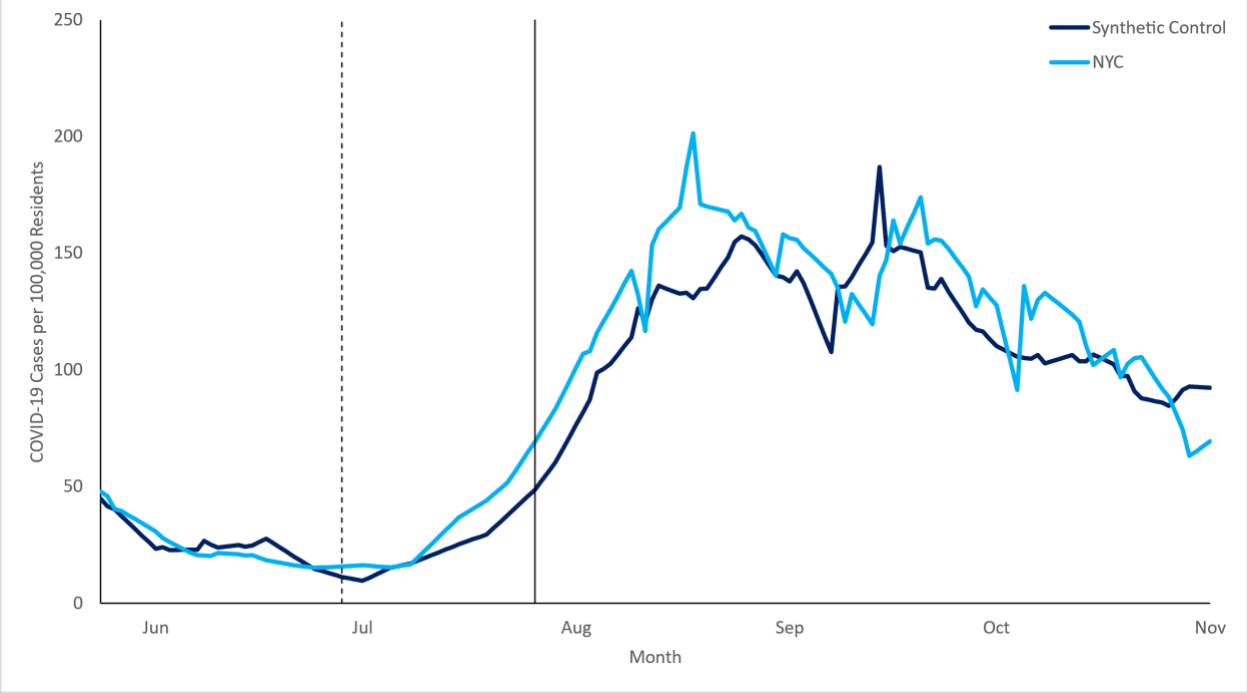
Attribute	Weight
Race/Ethnicity, all categories (%)	**21%**
Hispanic (%)	8%
Non-Hispanic Asian (%)	4%
Non-Hispanic Black (%)	9%
Democratic vote share in 2020 (%)	18%
Received first dose in prior four weeks (%)	14%
Age, all categories (%)	**13%**
Age, 16-59 (%)	8%
Age, ≥ 60 (%)	5%
Median Income ($)	10%
Educational attainment, all categories (%)	**8%**
High school graduate or higher (%)	5%
Bachelor's degree or higher (%)	3%
At least one dose to date (%)	9%
Poverty rate (%)	4%
Male (%)	1%
Metropolitan area population (% ≥ 1 million)	1%
Unemployment rate (%)	1%

5. COVID-19 Transmission in NYC and the Synthetic Control Group

The synthetic control group used in the main analysis was constructed by matching on pre-intervention vaccination outcomes and several constant-in-time demographic and socioeconomic attributes associated with variation in vaccination rates. In addition to those factors used in the matching process, variation in vaccination rates may also reflect variation in perceived risk of COVID-19 transmission, which we proxied using case rates reported by CDC.[6,7] We did not use historical COVID-19 transmission data to construct the synthetic control group because the timing of historical transmission and widespread vaccine availability in the United States would not have allowed for the assignment of an appropriate attribute weight to COVID-19 transmission: vaccination rates were supply-constrained at the start of training period (breaking any link between transmission and vaccination), and case levels were low throughout the country later in the training period (leaving little meaningful variation in transmission to drive variation in vaccination rates). Instead, we first selected a synthetic control group using other attributes and then compared NYC's reported case rate against that of the synthetic control group to assess the likelihood that differences in COVID-19 transmission (or the perceived risk of transmission) could explain differences in vaccination. NYC's reported rate of COVID-19 transmission tracked the trend and approximate magnitude of COVID-19 transmission in the control group during the pre-intervention and intervention periods (figure A5.1). This provides suggestive evidence that the difference in vaccination outcomes during the intervention period was not primarily driven by a discontinuous shift in relative transmission rates between the pre-intervention and intervention periods.

Figure A5.1: Daily new COVID-19 cases in NYC and the synthetic control group

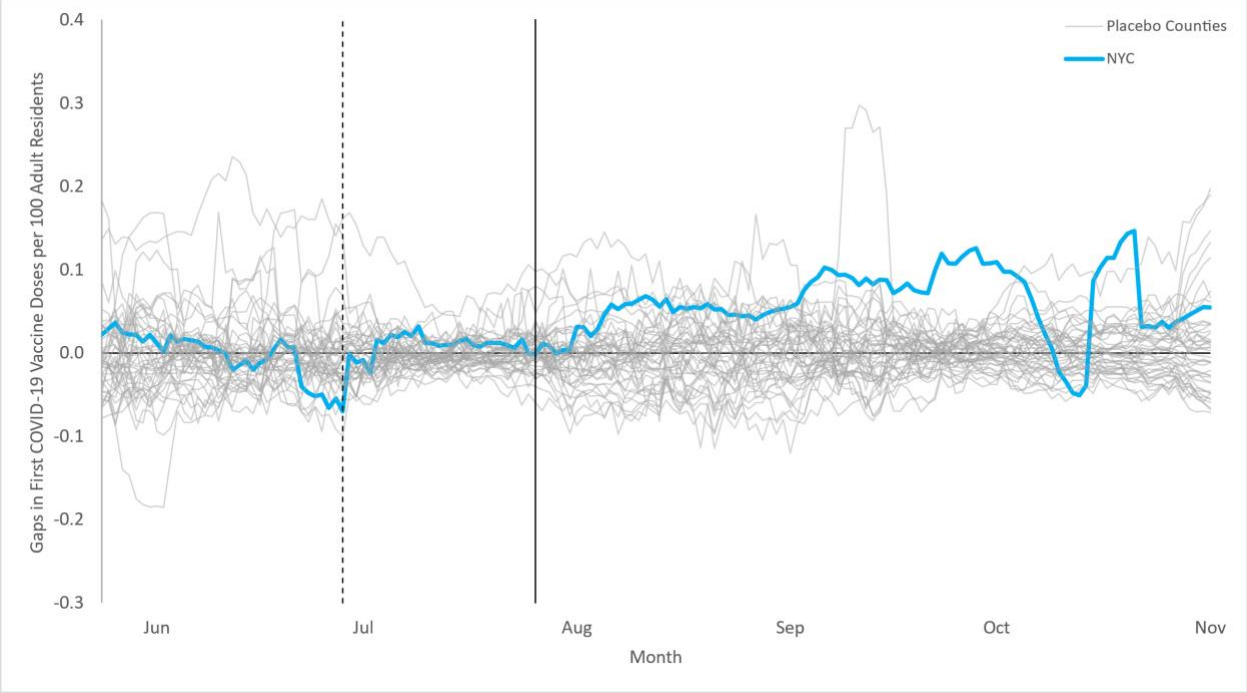
Data are from CDC Community Profile Reports and were interpolated for days on which no report was published.[8] The validation period starts at the Y-axis. The vertical dashed line indicates the start of the matching period. The vertical solid line indicates the start of the intervention period.



6. Placebo Studies

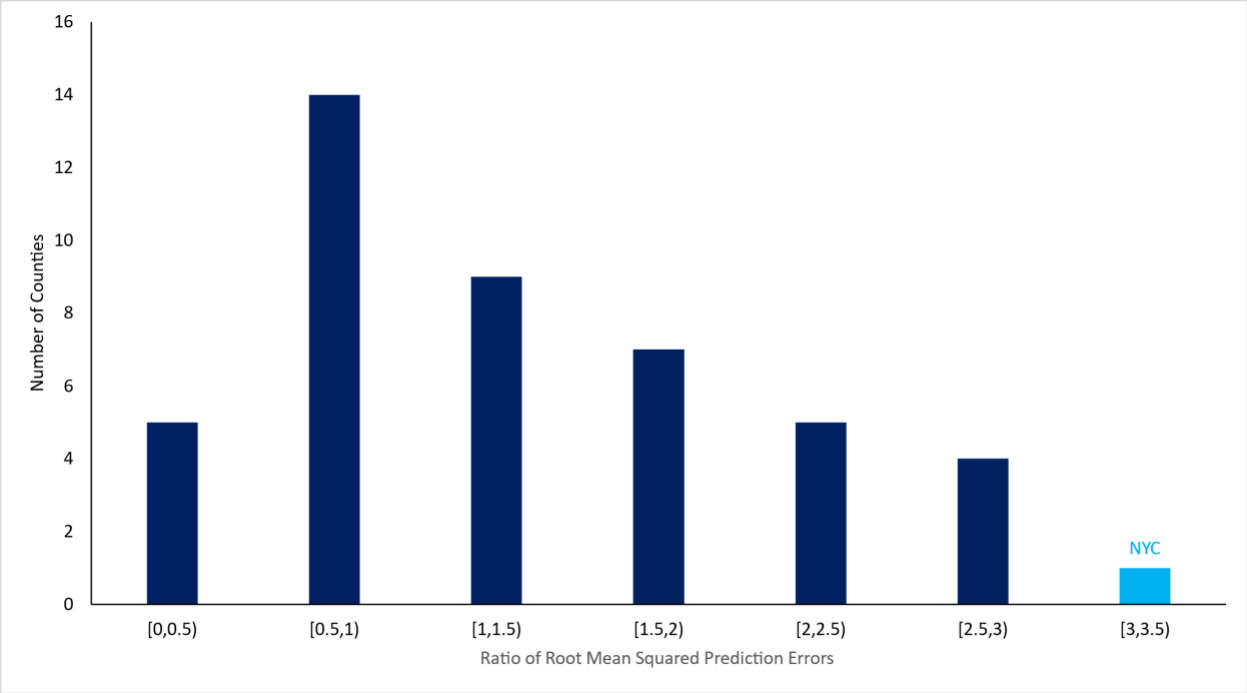
We assessed the significance of our impact estimate using placebo tests.[9] A separate control group was selected for each member of the donor pool. We would not expect to observe differences in vaccination outcomes between each donor pool county and its corresponding control group during the intervention period because no intervention occurred. We compared the intervention-period gap in vaccination outcomes for NYC against the distribution of gaps for placebo counties to determine whether NYC's gap was sufficiently large that it would have been unlikely to have occurred by chance. In fact, the City's intervention period gap in vaccination outcomes was large relative to the distribution of gaps among donor pool counties (figure A6.1). We might also expect to observe a comparatively large intervention period gap in vaccination outcomes for NYC even in the absence of an impact if NYC's control group fit poorly compared to the control groups selected for donor pool counties. In fact, pre-intervention gaps for most placebo counties were comparable in magnitude to NYC's (figure A6.1). This suggests that NYC's comparatively large intervention period gap in vaccination outcomes cannot be attributed to a poorly fitting control group.

Figure A6.1: Daily gaps in adult COVID-19 vaccinations (first dose) between NYC and its synthetic control group and between each placebo county and the corresponding synthetic control group. Data are from CDC.[1] The validation period starts at the Y-axis. The vertical dashed line indicates the start of the matching period. The vertical solid line indicates the start of the intervention period. The large, week-long gap in a placebo county in early September occurs in Jefferson County, Kentucky, and results from retroactive reporting.



To assess statistical significance more precisely, we normalized intervention period gaps in vaccination outcomes (which were summarized as the RMSPE during the intervention period) by the preintervention fit of each control group (which was measured by validation period RMSPE). If each county had the same probability of receiving the intervention, the impact on NYC could be interpreted as statistically significant if the intervention-period-to-pre-intervention-period ratio of RMSPEs was larger than the ratio of RMSPE calculated for at least 95% of units in the donor pool, including NYC. In fact, NYC's intervention-period-to-pre-intervention-period ratio of RMSPEs was larger than the ratio of all 44 donor pool counties (figure A6.2).

Figure A6.2: Ratio of intervention-period to pre-intervention root mean squared prediction errors for NYC and each donor pool county. Data are from CDC.[1]


16
14
12
10
8
6
4
2
0
Number of Counties
[0,0.5)
[0.5,1)
[1,1.5)
[1.5,2)
[2,2.5)
[2.5,3)
[3,3.5)
NYC
Ratio of Root Mean Squared Prediction Errors

164

7. Adjustment for the Pre-Intervention Difference in Vaccinations

The impact estimate presented in the main analysis implicitly assumed no difference in pre-intervention vaccination outcomes between NYC and the synthetic control group. In fact, the validation-period sum of the seven-day average of the share of adult NYC residents receiving a first dose of an authorized COVID-19 vaccine on each day was 1·2% or 0·1pp higher than the comparable figure for the control group (11·1pp vs. 10·9pp). The estimated impact on vaccinations may be partially explained this pre-intervention difference in vaccination outcomes. We re-ran the analysis, adjusting control group vaccination outcomes upward by 1·2%, as a robustness check. The policies' estimated cumulative impact shrank slightly from 6·2pp (410,201 persons) to 6·1pp (401,741 persons) and remained statistically significant (p=0·022).

8. Robustness to the Beginning of the Pre-Intervention Period

The main analysis excluded vaccination data from before April 26, 2021 out of concern that earlier vaccination data might reflect supply or administration capacity constraints rather than demand. The choice to exclude data from before April 26, 2021 followed from an analysis of county-level vaccination data. We used the peak seven-day average of new vaccinations in each county as a proxy for the earliest possible date on which vaccine administration could be considered demand-constrained. All but one county in the analysis sample (Hampden County, Massachusetts) peaked on or before April 17, 2021. We discarded an additional eight days of data, from April 18, 2021 to April 25, 2021, to provide additional certainty that vaccine administration was demand-constrained. The exact choice of April 26, 2021 was somewhat arbitrary. Table A8.1 shows impact estimates and confidence intervals using alternate start points. The results are consistent with the main analysis.

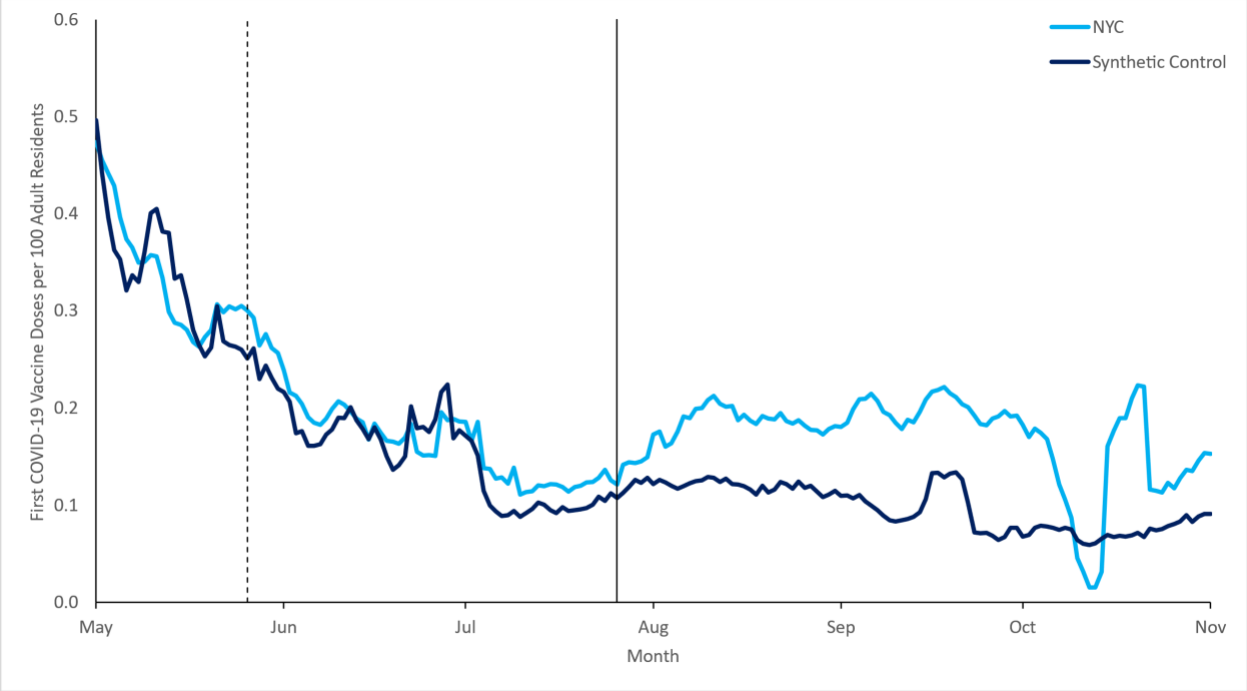
Table A8.1: Estimated impact of NYC's policies on COVID-19 vaccinations (first dose) for alternate choices for the start of the training period. The main analysis appears in the second row.

Training Period		Validation Period			
Start	**End**	**Start**	**End**	**Impact**	**95% CI**
4/19/2021	5/16/2021	5/17/2021	7/25/2021	+6·1pp	[+1·6pp, +10·4pp]
4/26/2021	5/23/2021	5/24/2021	7/25/2021	+6·2pp	[+1·4pp, +10·7pp]
5/3/2021	5/30/2021	5/31/2021	7/25/2021	+6·2pp	[+0·3pp, +11·9pp]
5/10/2021	6/6/2021	6/7/2021	7/25/2021	+6·4pp	[-1·6pp, +14·1pp]
5/17/2021	6/13/2021	6/14/2021	7/25/2021	+6·8pp	[-4·2pp, +17·5pp]
5/24/2021	6/20/2021	6/21/2021	7/25/2021	+6·3pp	[-6·2pp, + 18·6pp]

9. Placebo-in-time and Leave-one-out Robustness Checks

We conducted two robustness checks. First, we conducted an in-time placebo test, in which we constructed a synthetic control group using data through May 23, 2021 and compared vaccination outcomes through July 25, 2021.[10] No intervention occurred during this period, so vaccination rates should match through July 25, 2021 and diverge thereafter. Figure A9.1 shows the results of the in-time placebo analysis. As expected, vaccination rates in New York City closely tracked those of the in-time placebo synthetic control group through July 25 and deviated thereafter.

Figure A9.1: Daily COVID-19 vaccinations (first dose) for adults 18 or older in NYC and the placebo-in-time synthetic control group. Data are from CDC.[1] The vertical dashed line indicates the placebo intervention date; the synthetic control group was constructed using vaccination data from before this date. The vertical solid line indicates the start of the actual intervention period.



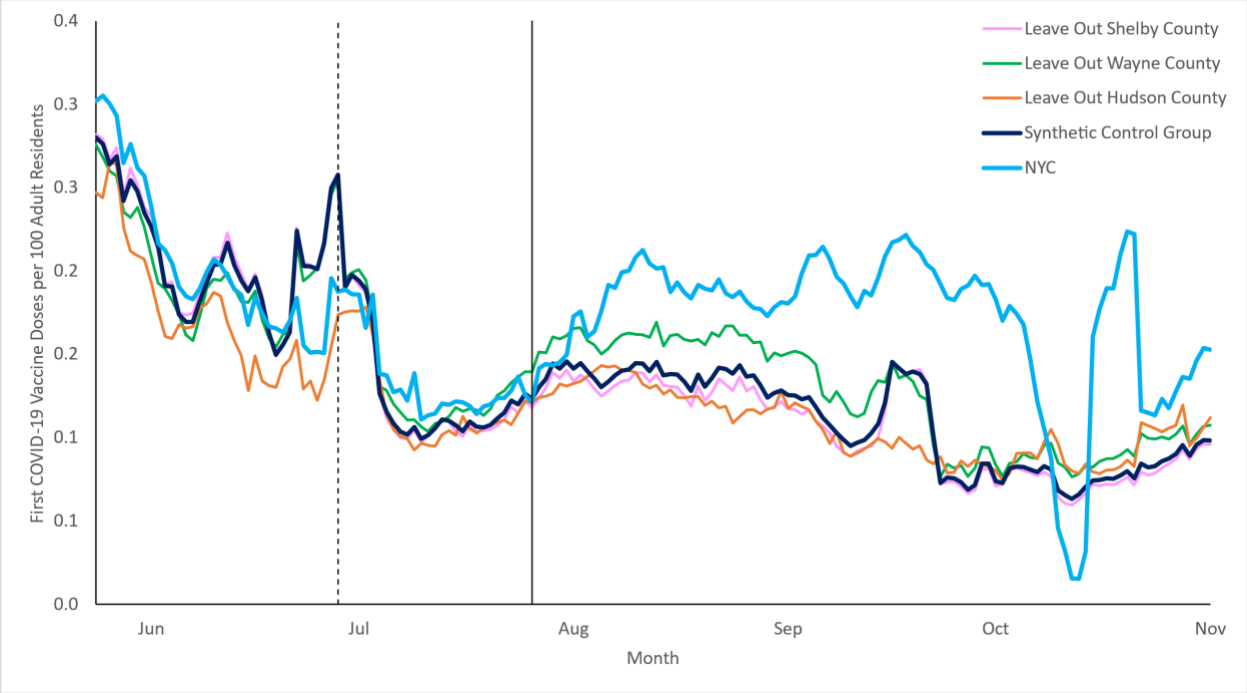
Second, we conducted a leave-one-out test, in which we iterated over the synthetic control group and reselected an alternate synthetic control group corresponding to each control county from a constrained donor pool that omitted that county.[10] Any inconsistencies between the main analysis and the leave-one-out tests could indicate that the impact from the main analysis was driven by an idiosyncratic vaccination trend one of the control counties. Table A9.1 shows the original synthetic control group alongside the three alternate control groups. Figure A9.2 shows the results of the leave-one-out test. Results were broadly consistent for each of the three alternate synthetic control groups.

Table A9.1: Composition of the synthetic control groups selected for the leave-one-out test. Weights may not add to 100% due to rounding.

			Weight in Synthetic Control Group			
County	**State**	**Largest City**	**Full Donor Pool**	**Omit Hudson (NJ)**	**Omit Wayne (MI)**	**Omit Shelby (TN)**
Hudson	New Jersey	Jersey City	68·7%	N/A	63·5%	68·4%
Wayne	Michigan	Detroit	23·9%	0·0%	N/A	31·2%
Shelby	Tennessee	Memphis	7·4%	0·0%	28·2%	N/A
Suffolk	Massachusetts	Boston	0·0%	60·8%	8·3%	0·0%
Miami-Dade	Florida	Miami	0·0%	9·1%	0·0%	0·4%

Clark	Nevada	Las Vegas	0·0%	30·1%	0·0%	0·0%

Figure A9.2: Daily COVID-19 vaccinations (first dose) for adults 18 or older in NYC and the leave-one-out test synthetic control groups. Data are from CDC.[1] The validation period starts at the Y-axis. The vertical dashed line indicates the start of the matching period. The vertical solid line indicates the start of the intervention period.



10. Robustness to Exclusion of Counties with Vaccination Incentive Lotteries

The donor pool for a synthetic control analysis typically excludes any units that have implemented policies similar to those implemented in the treated unit(s). The analysis presented in the main text included 12 counties whose residents were eligible for vaccination incentive lotteries (table A10.1). These lotteries could be considered sufficiently comparable to NYC's $100 vaccination incentive to justify the exclusion of the 12 counties from the control pool. NYC residents were likewise eligible for a state-run lottery, but there were only four participating sites in the entire City. We retained the 12 lottery counties in the donor pool for the main analysis to preserve power for statistical inference. Here, we test the robustness of the main analysis to the exclusion of these 12 counties from the donor pool.

Table A10.1 Donor pool counties with COVID-19 vaccination lotteries.

County	State	Largest City	Metropolitan Statistical Area	Implemented By	Announced	Last Eligibility Date
Pima[12]	Arizona	Tucson	Tucson, AZ	County	6/4/2021	6/30/2021
Pulaski[12]	Arkansas	Little Rock	Little Rock-North Little Rock-Conway, AR	State	5/25/2021	Unknown or N/A
Fayette[13]	Kentucky	Lexington	Lexington-Fayette, KY	State	6/4/2021	8/25/2021
Jefferson[13]	Kentucky	Louisville	Louisville/Jefferson County, KY-IN	State	6/4/2021	8/25/2021
Hampden[14]	Massachusetts	Springfield	Springfield, MA	State	6/15/2021	8/19/2021
Suffolk[14]	Massachusetts	Boston	Boston-Cambridge-Newton, MA-NH	State	6/15/2021	8/19/2021
Worcester[14]	Massachusetts	Worcester	Worcester, MA-CT	State	6/15/2021	8/19/2021
Wayne[15]	Michigan	Detroit	Detroit-Warren-Dearborn, MI	State	7/1/2021	8/3/2021
Jackson[16]	Missouri	Kansas City	Kansas City, MO-KS	State	7/21/2021	10/6/2021
Clark[17]	Nevada	Las Vegas	Las Vegas-Henderson-Paradise, NV	State	6/17/2021	8/26/2021
Franklin[18]	Ohio	Columbus	Columbus, OH	State	5/13/2021	6/23/2021
Montgomery[18]	Ohio	Dayton	Dayton-Kettering, OH	State	5/12/2021	6/23/2021

The synthetic control group for this analysis consisted of Hudson County, New Jersey (66·3%), Shelby County, Tennessee (31·6%), and Sarasota County, Florida (2·0%) (table A10.2). Hudson County and Shelby County were also included in the synthetic control group for the main analysis. Wayne County—the third county from that synthetic control group—was not eligible for inclusion here since Michigan implemented a vaccination incentive lottery.

Table A10.2: Composition of the synthetic control group.

County	State	Largest City	Metropolitan Statistical Area	Weight
Hudson	New Jersey	Jersey City	New York-Newark-Jersey City, NY-NJ-PA	66·3%
Shelby	Tennessee	Memphis	Memphis, TN-MS-AR	31·6%
Sarasota	Florida	North Port	North Port, Sarasota, Bradenton, FL	2·0%

NYC generally resembled this synthetic control group across characteristics used in the matching process (table A10.3). NYC was slightly less Hispanic and non-Hispanic Black more non-Hispanic Asian, more Democratic, older, and lower income than the control group used here, but the differences were small. Additionally, NYC had a slightly lower recent vaccination rate as of July 25, 2021.

Table A10.3: Characteristics of NYC and the synthetic control group. Educational attainment is reported for adults 25 years and over. Democratic vote share is calculated as the share of all non-third-party votes earned by the Democratic candidate in the 2020 presidential election. Vaccination outcomes are calculated for adults.

	NYC (SE)*	Synthetic Control (SE)
Race/Ethnicity, %		
Hispanic	29·1 (NA)†	30·6 (NA)
Non-Hispanic Asian	14·3 (0·1)	11·1 (0·1)

	NYC (SE)*	Synthetic Control (SE)
Non-Hispanic Black	21·7 (0·1)	23·9 (0·1)
Age group, %		
16-59	60·5 (0·1)	61·6 (0·2)
≥60	21·1 (0·1)	18·8 (0·2)
Sex, %		
Male	47·7 (0·0)	49·0 (0·1)
Educational attainment, %		
High school graduate or higher	83·2 (0·2)	86·6 (0·4)
Bachelor's degree or higher	39·2 (0·2)	40·7 (0·6)
Economic attributes		
Median household income ($)‡	69,407 (681)	70,203 (1,321)
Poverty rate (%)	16·0 (0·2)	14·7 (0·6)
Unemployment rate (%)	5·2 (0·1)	4·1 (0·3)
Metropolitan area population, %		
≥ 1 million	100·0 (NA)§	98·0 (NA)
500,000-999,999	0·0 (NA)	2·0 (NA)
Partisanship, %		
Democratic vote share in 2020	77·0 (NA)	70·3 (NA)
Vaccination, %		
At least one dose as of Jul 25	72·5 (NA)	72·6 (NA)
Received first dose June 28-July 25	3·4 (NA)	3·5 (NA)

*NYC's standard errors for most outcomes are calculated from the margins of error (90% confidence interval) reported by the Census Bureau. Standard errors for the synthetic control group and donor pool are estimated from means and margins of error reported for each county and do not account for covariance across counties. Standard errors for the share of residents between 16 and 59 are estimated from the point estimates and standard errors for the share of the population 16 or older and 60 or older.

†No standard errors are provided for the percent of the population that is Hispanic because the share is controlled to the official population estimate.

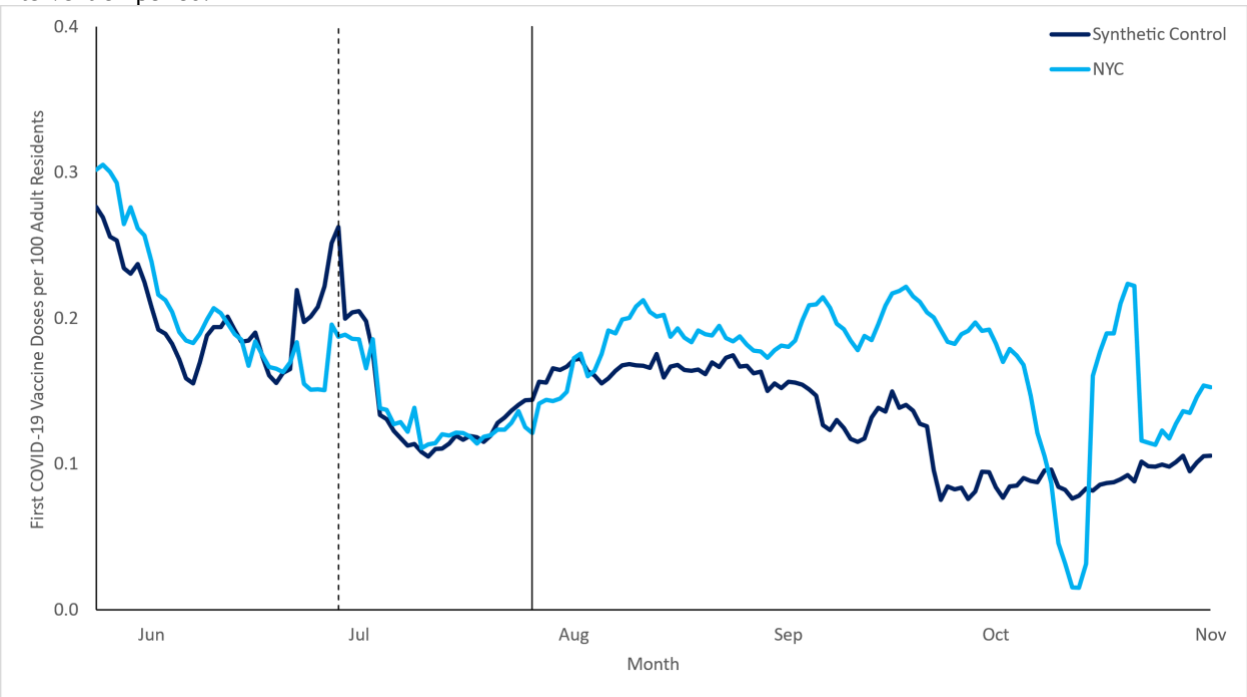
‡Estimates for median household income are reported with a standard error rather than an IQR because the American Community Survey 1-year estimate data tables do not include the 25th and 75th percentile of household income for counties.

§Metropolitan area population, 2020 Democratic vote share, and vaccination outcomes are observed without sampling error. NA indicates that standard errors are not applicable for these attributes.

Figure A10.1 shows the seven-day average of the share of residents 18 or older who received a first dose of an authorized COVID-19 vaccine on each day in NYC and in the synthetic control group. Vaccination rates were broadly similar between May 24 and July 25. Vaccination rates in New York exceed those in the synthetic control group throughout most of the intervention period, as in the main analysis. The cumulative gap in the share of adult residents receiving at least one dose of an authorized COVID-19 vaccine is 289,627 persons or 4·4pp through November 1, 2021 (95% CI [-3·6pp, +12·2pp]). Though not statistically significant, the impact estimate is consistent in direction and comparable in magnitude to the impact estimate from the main analysis.

Figure A10.1: Daily COVID-19 vaccination (first dose) for adults in NYC and a synthetic control group that excludes counties with vaccine lotteries. Data are from CDC.[1] The validation period starts at the Y-axis. The vertical dashed line indicates the start of the matching period. The vertical solid line indicates the start of the

intervention period.



11. Robustness to Exclusion of Counties with Reimbursement for Vaccine Counseling

The donor pool for a synthetic control analysis typically excludes any units that have implemented policies similar to those implemented in the treated unit(s). The analysis presented in the main text included three counties in Massachusetts, which provided reimbursement to doctors for vaccine counseling conversations with participants in Medicaid.[19] Massachusetts' program could be considered comparable to NYC's vaccine counseling reimbursement program for primary care physicians for participants in some Medicaid and Medicare Advantage programs. We retained the three vaccine counseling reimbursement counties in the donor pool for the main analysis out of concern that vaccine counseling reimbursement programs might be less well publicized than the other programs analyzed and thus we might not successfully identify all programs implemented in other counties. Here, we test the robustness of the main analysis to the exclusion of these three counties from the donor pool.

The synthetic control group for this analysis consisted of Hudson County, New Jersey (67·5%), Wayne County, Michigan (25·7%), Shelby County, Tennessee (6·7%), and Miami-Dade County, Florida (0·1%) (table A11.1). Hudson, Wayne, and Shelby Counties were also included in the synthetic control group for the main analysis, with similar weights.

Table A11.1: Composition of the synthetic control group.

County	State	Largest City	Metropolitan Statistical Area	Weight
Hudson	New Jersey	Jersey City	New York-Newark-Jersey City, NY-NJ-PA	67·5%
Wayne	Michigan	Detroit	Detroit-Warren-Dearborn, MI	25·7%
Shelby	Tennessee	Memphis	Memphis, TN-MS-AR	6·7%
Miami-Dade	Florida	Miami	Miami-Fort Lauderdale-Pompano Beach, FL	0·1%

NYC generally resembled this synthetic control group across characteristics used in the matching process (table A11.2). NYC was slightly less Hispanic, more non-Hispanic Asian and non-Hispanic Black, more Democratic, and older than the control group used here, but the differences were small. Additionally, NYC had a slightly higher recent vaccination rate but a slightly lower cumulative vaccination rate as of July 25, 2021.

Table A11.2: Characteristics of NYC and the synthetic control group. Educational attainment is reported for adults 25 years and over. Democratic vote share is calculated as the share of all non-third-party votes earned by the Democratic candidate in the 2020 presidential election. Vaccination outcomes are calculated for adults.

	NYC (SE)*	Synthetic Control (SE)
Race/Ethnicity, %		
Hispanic	29·1 (NA)†	30·9 (NA)
Non-Hispanic Asian	14·3 (0·1)	11·4 (0·1)
Non-Hispanic Black	21·7 (0·1)	20·4 (0·1)
Age group, %		
16-59	60·5 (0·1)	61·8 (0·2)
≥60	21·1 (0·1)	18·9 (0·2)
Sex, %		
Male	47·7 (0·0)	49·2 (0·1)
Educational attainment, %		
High school graduate or higher	83·2 (0·2)	86·4 (0·4)
Bachelor's degree or higher	39·2 (0·2)	39·1 (0·5)
Economic attributes		
Median household income ($)‡	69,407 (681)	69,819 (1,263)
Poverty rate (%)	16·0 (0·2)	15·6 (0·5)
Unemployment rate (%)	5·2 (0·1)	4·2 (0·2)

	NYC (SE)*	Synthetic Control (SE)
Metropolitan area population, %		
≥ 1 million	100·0 (NA)§	100·0 (NA)
500,000-999,999	0·0 (NA)	0·0 (NA)
Partisanship, %		
Democratic vote share in 2020	77·0 (NA)	71·8 (NA)
Vaccination, %		
At least one dose as of July 25	72·5 (NA)	73·0 (NA)
Received first dose June 28-July 25	3·4 (NA)	3·2 (NA)

*NYC's standard errors for most outcomes are calculated from the margins of error (90% confidence interval) reported by the Census Bureau. Standard errors for the synthetic control group and donor pool are estimated from means and margins of error reported for each county and do not account for covariance across counties. Standard errors for the share of residents between 16 and 59 are estimated from the point estimates and standard errors for the share of the population 16 or older and 60 or older.

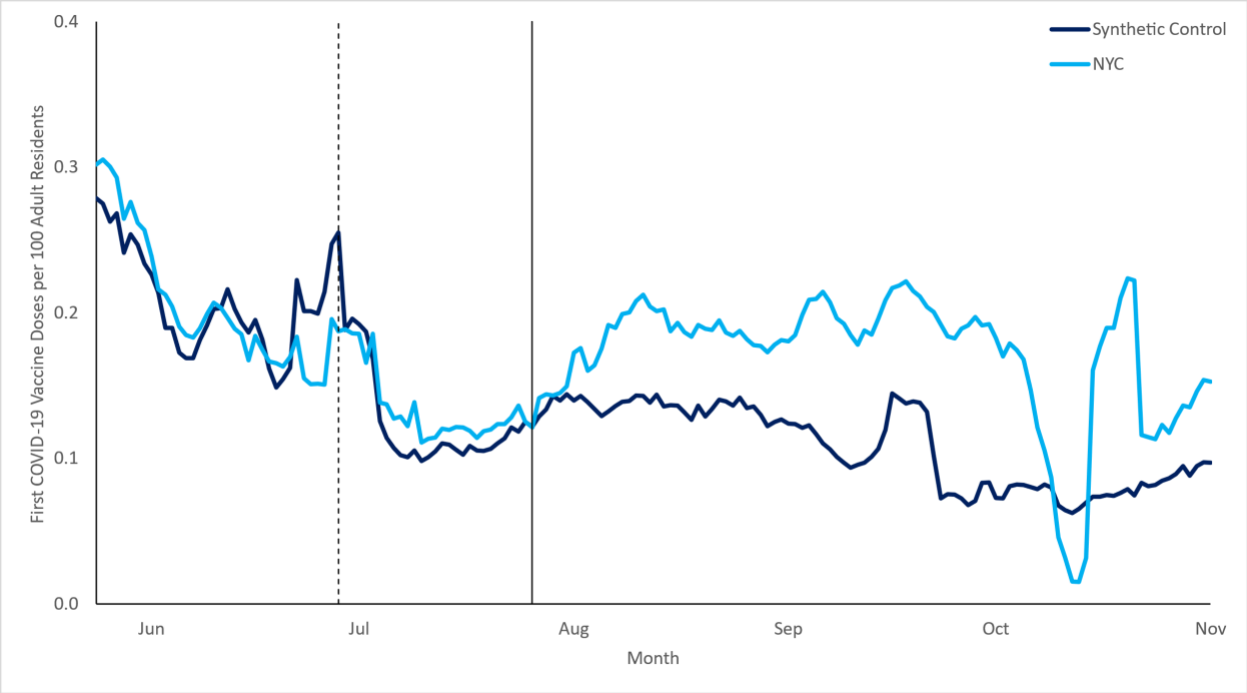
†No standard errors are provided for the percent of the population that is Hispanic because the share is controlled to the official population estimate.

‡Estimates for median household income are reported with a standard error rather than an IQR because the American Community Survey 1-year estimate data tables do not include the 25th and 75th percentile of household income for counties.

§Metropolitan area population, 2020 Democratic vote share, and vaccination outcomes are observed without sampling error. NA indicates that standard errors are not applicable for these attributes.

Figure A11.1 shows the seven-day average of the share of residents 18 or older who received a first dose of an authorized COVID-19 vaccine on each day in NYC and in the synthetic control group. Vaccination rates are broadly similar between May 24 and July 25. Vaccination rates in New York exceed those in the synthetic control group throughout most of the intervention period, as in the main analysis. The cumulative gap in the share of adult residents receiving at least one dose of an authorized COVID-19 vaccine is 418,648 persons or 6·3pp through November 1, 2021 (95% CI [+1·3pp, +11·0pp]). The impact estimate is consistent in direction and comparable in magnitude to the impact estimate from the main analysis.

Figure A11.1: Daily COVID-19 vaccination (first dose) for adults in NYC and a synthetic control group that excludes counties with reimbursement for vaccine counseling. Data are from CDC.[1] The validation period starts at the Y-axis. The vertical dashed line indicates the start of the matching period. The vertical solid line indicates the start of the intervention period.


Synthetic Control
NYC
First COVID-19 Vaccine Doses per 100 Adult Residents
0.4
0.3
0.2
0.1
0.0
Jun
Jul
Aug
Sep
Oct
Nov
Month

305

12. Impact on Receipt of First Doses for Residents 65 or Older

Results presented in the main text show that the policies implemented in NYC had little or no impact on the receipt of first doses by residents 65 or older. We present that analysis here in greater detail.

We selected a separate synthetic control group for this analysis using a similar specification to the main analysis. We matched on age-specific covariates where available and population-wide covariates otherwise.

The synthetic control group used for this analysis consisted of Hudson County, New Jersey (62·2%), Shelby County, Tennessee (17·4%), Suffolk County, Massachusetts (13·8%), and Union County, New Jersey (6·6%) (table A12.1). Hudson County and Shelby County were also part of the main analysis synthetic control group.

Table A12.1: Composition of the synthetic control group.

County	State	Largest City	Metropolitan Statistical Area	Weight
Hudson	New Jersey	Jersey City	New York-Newark-Jersey City, NY-NJ-PA	62·2%
Shelby	Tennessee	Memphis	Memphis, TN-MS-AR	17·4%
Suffolk	Massachusetts	Boston	Boston-Cambridge-Newton, MA	13·8%
Union	New Jersey	Elizabeth	New York-Newark-Jersey City, NY-NJ-PA	6·6%

New York City generally resembled the synthetic control group for this analysis across characteristics used in the matching process (table A12.2). NYC was slightly less Hispanic, more non-Hispanic Asian and non-Hispanic Black, more Democratic, and higher income than the control group used here, but the differences were small. Additionally, NYC had a slightly higher recent vaccination rate but a slightly lower cumulative vaccination rate as of July 25, 2021.

Table A12.2: Characteristics of NYC and the synthetic control group. Sex, educational attainment, economic attributes, and vaccination rates are reported for adults 65 years and over. Race/ethnicity, metropolitan area population, and partisanship are calculated for all ages. Democratic vote share is calculated as the share of all non-third-party votes earned by the Democratic candidate in the 2020 presidential election.

	NYC (SE)*	Synthetic Control (SE)
Race/Ethnicity, %		
Hispanic	29·1 (NA)†	33·1 (NA)
Non-Hispanic Asian	14·3 (0·1)	11·6 (0·1)
Non-Hispanic Black	21·7 (0·1)	19·8 (0·1)
Sex, %		
Male	41·3 (0·4)	41·9 (1·0)
Educational attainment, %		
High school graduate or higher	72·3 (0·4)	72·1 (1·0)
Bachelor's degree or higher	28·6 (0·4)	24·7 (0·9)
Economic attributes		
Median household income ($)‡	41,054 (781)	37,919 (1,222)
Poverty rate (%)	18·4 (0·4)	18·1 (1·2)
Unemployment rate (%)	3·4 (0·4)	2·1 (0·7)
Metropolitan area population, %		
≥ 1 million	100·0 (NA)§	100·0 (NA)
500,000-999,999	0·0 (NA)	0·0 (NA)
Partisanship, %		
Democratic vote share in 2020	77·0 (NA)	72·9 (NA)
Vaccination, %		

	NYC (SE)*	Synthetic Control (SE)
At least one dose as of July 25	79·0 (NA)	81·9 (NA)
Received first dose June 28-July 25	2·1 (NA)	1·9 (NA)

*NYC's standard errors for most outcomes are calculated from the margins of error (90% confidence interval) reported by the Census Bureau. Standard errors for the synthetic control group and donor pool are estimated from means and margins of error reported for each county and do not account for covariance across counties. Standard errors for sex and unemployment rate are estimated from the point estimates and standard errors from other reported outcomes.

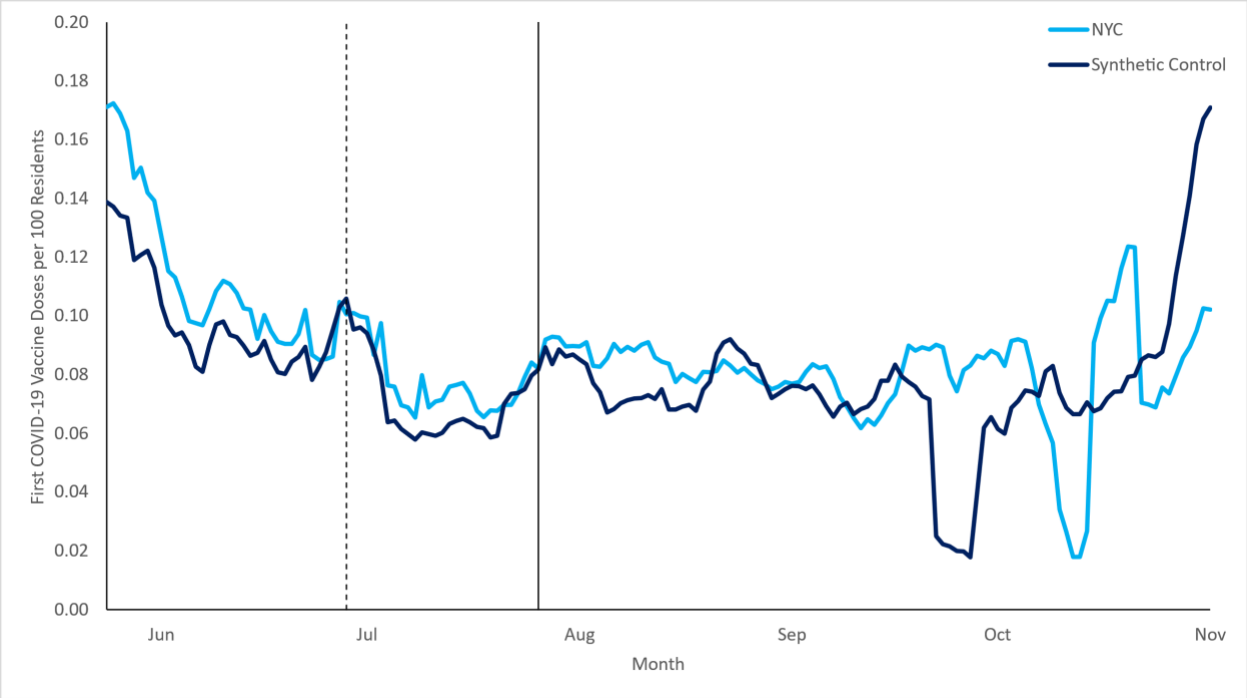
†No standard errors are provided for the percent of the population that is Hispanic because the share is controlled to the official population estimate.

‡Estimates for median household income are reported with a standard error rather than an IQR because the American Community Survey 1-year estimate data tables do not include the 25th and 75th percentile of household income for counties.

§Metropolitan area population, 2020 Democratic vote share, and vaccination outcomes are observed without sampling error. NA indicates that standard errors are not applicable for these attributes.

Figure A12.1 (included in the main text as figure 7) shows the seven-day average of the share of residents 65 or older who received a first dose of an authorized COVID-19 vaccine on each date in NYC and in the synthetic control group. Vaccination rates were slightly higher in NYC than in the synthetic control group between May 24 and July 25, indicating a good but imperfect fit. Vaccination rates in New York tracked those in the synthetic control group closely after July 25, 2021, indicating no impact. The apparent divergences in late September and early-to-mid October reflect reporting issues and do not indicate true differences in vaccination rates between the two groups. The cumulative gap in vaccinations between NYC and the synthetic control group through November 1, 2021 is 0·3 percentage points (95% CI [-11·4pp, +12·3pp]), or 3,967 additional persons vaccinated.

Figure A12.1: Daily COVID-19 vaccinations (first dose) for adults 65 or older in NYC and the synthetic control group. Data are from CDC.[1] The validation period starts at the Y-axis. The vertical dashed line indicates the start of the matching period. The vertical solid line indicates the start of the intervention period.



13. Impact on Completion of Vaccination Series for Residents 18 or Older

Results presented in the main text show that the policies implemented in NYC increased completion of vaccination series after a lag. We present that analysis here in greater detail.

We selected a separate synthetic control group for this analysis using a similar specification to the main analysis, matching on completion of COVID-19 vaccination series rather than on receipt of the first dose of an authorized COVID-19 vaccine.

The synthetic control group used for this analysis consisted of Suffolk County, Massachusetts (34.1%), Hudson County, New Jersey (26·1%), Miami-Dade County, Florida (19·3%), Wayne County, Michigan (13·3%), and Shelby County, Tennessee (7·2%) (table A13.1). All three counties included in the synthetic control group for the main analysis were included here as well.

Table A13.1: Composition of the synthetic control group.

County	State	Largest City	Metropolitan Statistical Area	Weight
Suffolk	Massachusetts	Boston	Boston-Cambridge-Newton, MA	34·1%
Hudson	New Jersey	Jersey City	New York-Newark-Jersey City, NY-NJ-PA	26·1%
Miami-Dade	Florida	Miami	Miami-Fort Lauderdale-Pompano Beach, FL	19·3%
Wayne	Michigan	Detroit	Detroit, Warren, Dearborn, MI	13·3%
Shelby	Tennessee	Memphis	Memphis, TN-MS-AR	7·2%

NYC generally resembled this synthetic control group across characteristics used in the matching process (table A13.2). NYC was slightly less Hispanic, substantially more non-Hispanic Asian, more Democratic, and lower income than the control group used here, but most differences were small. Additionally, NYC had a slightly higher recent vaccination rate but a slightly lower cumulative vaccination rate as of July 25, 2021.

Table A13.2: Characteristics of NYC and the synthetic control group. Educational attainment is reported for adults 25 years and over. Democratic vote share is calculated as the share of all non-third-party votes earned by the Democratic candidate in the 2020 presidential election. Vaccination outcomes are calculated for adults.

	NYC (SE)*	Synthetic Control (SE)
Race/Ethnicity, %		
Hispanic	29·1 (NA)†	33·8 (NA)
Non-Hispanic Asian	14·3 (0·1)	8·0 (0·1)
Non-Hispanic Black	21·7 (0·1)	21·3 (0·1)
Age group, %		
16-59	60·5 (0·1)	63·2 (0·1)
≥60	21·1 (0·1)	19·2 (0·1)
Sex, %		
Male	47·7 (0·0)	48·6 (0·1)
Educational attainment, %		
High school graduate or higher	83·2 (0·2)	85·9 (0·3)
Bachelor's degree or higher	39·2 (0·2)	39·7 (0·3)
Economic attributes		
Median household income ($)‡	69,407 (681)	68,203 (974)
Poverty rate (%)	16·0 (0·2)	16·2 (0·3)
Unemployment rate (%)	5·2 (0·1)	4·3 (0·2)
Metropolitan area population, %		
≥ 1 million	100·0 (NA)§	100·0 (NA)

	NYC (SE)*	Synthetic Control (SE)
500,000-999,999	0·0 (NA)	0·0 (NA)
Partisanship, %		
Democratic vote share in 2020	77·0 (NA)	71·5 (NA)
Vaccination, %		
Fully vaccinated as of July 25	65·0 (NA)	65·2 (NA)
Became fully vaccinated June 28-July 25	3·6 (NA)	3·4 (NA)

*NYC's standard errors for most outcomes are calculated from the margins of error (90% confidence interval) reported by the Census Bureau. Standard errors for the synthetic control group and donor pool are estimated from means and margins of error reported for each county and do not account for covariance across counties. Standard errors for the share of residents between 16 and 59 are estimated from the point estimates and standard errors for the share of the population 16 or older and 60 or older.

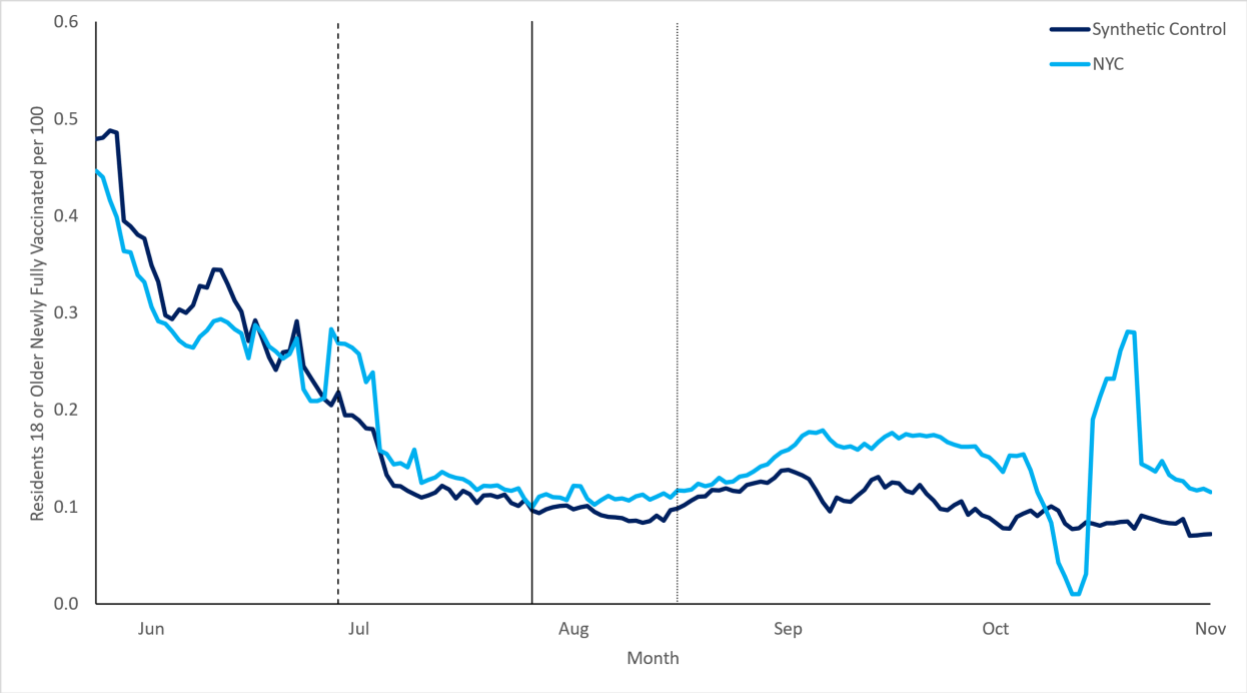
†No standard errors are provided for the percent of the population that is Hispanic because the share is controlled to the official population estimate.

‡Estimates for median household income are reported with a standard error rather than an IQR because the American Community Survey 1-year estimate data tables do not include the 25th and 75th percentile of household income for counties.

§Metropolitan area population, 2020 Democratic vote share, and vaccination outcomes are observed without sampling error. NA indicates that standard errors are not applicable for these attributes.

Figure A13.1 (included in the main text as figure 8) shows the seven-day average of the share of residents 18 or older becoming fully vaccinated on each date in NYC and in the synthetic control group. Vaccination rates are broadly similar between May 24 and July 25. Vaccination rates in New York exceed those in the synthetic control group slightly in the first five weeks after July 26, 2021 and more so thereafter. A lagged impact of three-to-four weeks was expected since the earliest policies implemented on or after July 26, 2021 targeted receipt of first doses only. The cumulative gap in vaccination series completions between NYC and the synthetic control group through November 1, 2021 is 270,401 persons or 4·1pp (95% CI [-2·9 pp, +10·8pp]), compared to an impact of 6·2pp in the main analysis. A smaller impact was expected because of attrition between the first and second dose and because no impact was expected during the first three-to-four weeks.

Figure A13.1: Daily COVID-19 vaccination series completions for adults in NYC and the synthetic control group. Data are from CDC.[1] The validation period starts at the Y-axis. The vertical dashed line indicates the start of the matching period. The vertical solid line indicates the start of the intervention period. The vertical dotted line indicates the first date on which someone who received the first dose of a two-dose series at the start of the intervention period could have become eligible for a second dose.


Synthetic Control
NYC
Residents 18 or Older Newly Fully Vaccinated per 100
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Jun
Jul
Aug
Sep
Oct
Nov
Month

390

391

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