Web Material

Use of an Inverted Synthetic Control Method to Estimate Effects of Recent Drug Overdose Good Samaritan Laws, Overall and by Black/White Race/Ethnicity

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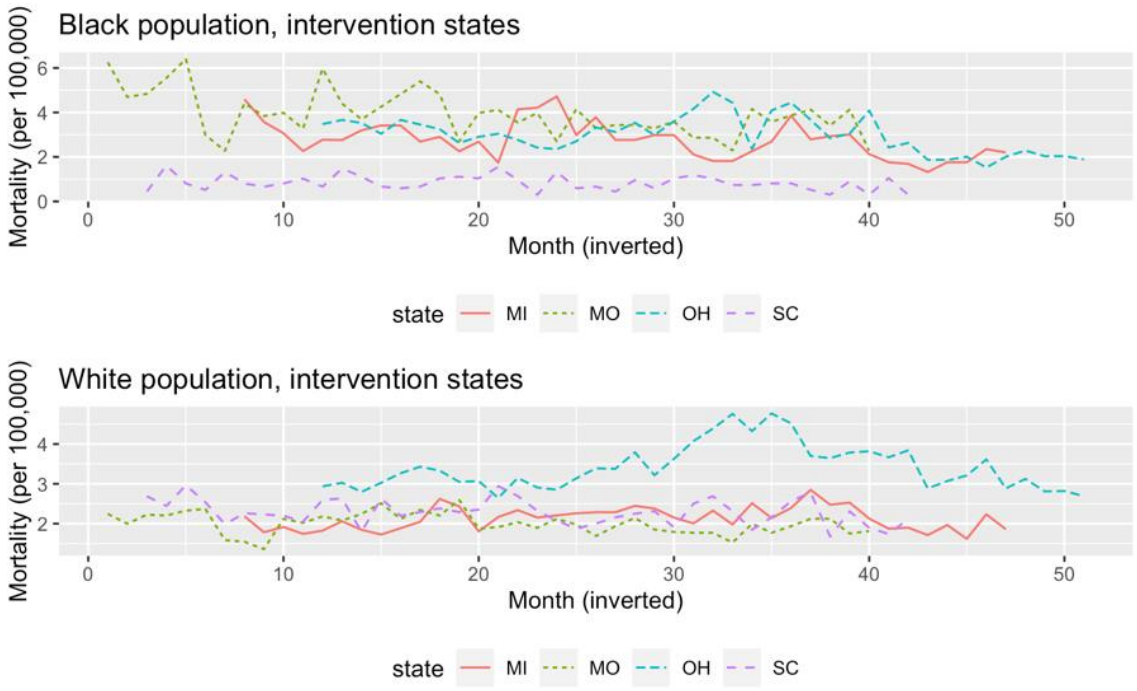
Table of Contents

Web Figure 1. Mortality trends in the intervention states, overall and by Black/White race

A. Overall

B. Stratified by Black/White race



Notes: Overdose mortality on the y-axis. As described in the methods section, intervention state data are truncated to enable examination of the same number of months pre- and post-GSL, respectively. Month 0 is December 2019 and Month 60 is January 2015.

Web Appendix 1. Covariates considered for model inclusion

Datasets

We obtained data on overdose-related laws, including prescription drug monitoring programs (PDMP) (January 2015-December 2018), pain management clinic laws (January 2015-December 2018), and drug-induced homicide laws (January 2017-January 2019) from the Prescription Drug Abuse Policy System (PDAPS; www.pdaps.org); data on Good Samaritan Laws and naloxone access laws (January 2015-June 2019) were obtained from both PDAPS and the Network for Public Health Law (1,2). We acquired state-level sociodemographic data from the 2015-2019 American Community Survey (ACS) one-year estimates.

Sociodemographic covariates

We selected state-level sociodemographic covariates expected to predict overdose-related mortality: percent living under the poverty line; percent unemployed; percent aged 15-17; percent aged 18-34 (by sex); percent aged 35-64 (by sex); percent non-Hispanic White; percent Black; and median household income.

Policy covariates

We selected a set of policy covariates expected to predict overdose-related mortality independent of GSLs, and in which there was sufficient between-state variation during the study period. These included binary indicators of whether any of the following were in effect: any PDMP prescriber access mandate; any pain management clinic law; and any drug-induced homicide law (3).

Web Table 1. Policy effective dates and months analyzed

	GSL effective date	GSL date with 1-year lag	NAL effective date	First month analyzed	Last month analyzed
Oregon	1/1/16	1/1/17	6/6/13	Jan-15	Apr-18
Ohio	10/1/16	10/1/17	3/11/14	Oct-15	Jan-19
Michigan	2/1/17	2/1/18	10/14/14	Feb-16	May-19
South Carolina	7/1/17	7/1/18	6/3/15	Jul-16	Oct-19
South Dakota	7/1/17	7/1/18	7/1/16	Jul-16	Oct-19
Missouri	9/1/17	9/1/18	8/28/16	Sep-16	Dec-19
Nebraska	9/1/17	9/1/18	5/28/15	Sep-16	Dec-19

Notes: In the main analyses, dates in the second column were used as implementation dates. Data were truncated to ensure a NAL was present throughout the analytic period, and to allow 15 months of matching period data and 24 months of evaluation period data in all intervention states.

Web Table 2. Matching period fit measured by root mean squared prediction error (RMSPE), by group

State	Overall	Black	White
MI	0.1650	0.7516	0.1921
MO	0.2418	0.8233	0.2642
NE	0.1548	-	-
OH	0.1477	0.2955	0.1888
OR	0.1611	-	-
SC	0.1045	0.3856	0.2151
SD	0.2034	-	-

Notes: Lower RMSPE indicates better matching period fit. Worse fit in the Black population is expected due to smaller sample size.

Web Table 3. State-specific effect estimates, evaluation period

A. Overall overdose mortality

	Michigan		*Missouri*		*Nebraska*		*Ohio*		*Oregon*		*South Carolina*		*South Dakota*	
Time	Est.	95% CI	Est.	95% CI	Est.	95% CI	Est.	95% CI	Est.	95% CI	Est.	95% CI	Est.	95% CI
0	0.53	(-0.7, 1.57)	0.26	(-0.46, 0.91)	-0.49	(-1.33, 0.31)	0.85	(-0.16, 0.64)	0.15	(-0.24, 0.44)	0.19	(-0.21, 0.55)	0.34	(-0.37, 0.96)
1	0.05	(-0.22, 0.3)	0.09	(-0.23, 0.41)	-0.20	(-0.62, 0.25)	0.24	(-0.62, 1.17)	0.07	(-0.48, 0.24)	-0.12	(-0.44, 0.24)	-0.15	(-0.61, 0.38)
2	0.40	(-0.55, 1.26)	0.21	(-0.26, 0.6)	-0.34	(-0.85, 0.19)	0.38	(-1.19, 2.69)	-0.11	(-0.29, 0.35)	0.51	(-0.78, 1.55)	-0.50	(-1.47, 0.42)
3	0.24	(-0.52, 0.85)	-0.40	(-1.17, 0.42)	-0.30	(-0.78, 0.23)	0.97	(-1.43, 4.19)	0.05	(-0.3, 0.27)	0.13	(-0.21, 0.43)	0.00	(-0.41, 0.4)
4	0.31	(-0.47, 1.05)	0.00	(-0.31, 0.38)	-0.30	(-0.87, 0.43)	1.53	(-2.01, 4.3)	-0.04	(-0.68, 0.2)	-0.11	(-0.33, 0.09)	-0.50	(-1.56, 0.74)
5	0.40	(-0.49, 1.25)	-0.20	(-0.56, 0.2)	0.02	(-0.5, 0.49)	1.49	(-0.77, 2.68)	-0.26	(-0.32, 0.62)	-0.20	(-0.6, 0.25)	0.10	(-0.41, 0.51)
6	-0.03	(-0.17, 0.14)	-0.04	(-0.28, 0.21)	-0.12	(-0.94, 0.73)	0.98	(-2.15, 4.75)	0.19	(-0.37, 0.71)	-0.52	(-1.45, 0.66)	-0.34	(-1.03, 0.43)
7	-0.06	(-0.39, 0.35)	-0.02	(-0.11, 0.07)	-0.35	(-0.9, 0.19)	1.64	(-1.57, 3.49)	0.23	(-0.37, 0.71)	-0.47	(-1.19, 0.25)	0.28	(-0.33, 0.91)
8	0.14	(-0.2, 0.48)	-0.26	(-0.68, 0.21)	-0.29	(-0.78, 0.29)	1.23	(-0.8, 1.49)	-0.17	(-0.46, 0.12)	-0.16	(-0.44, 0.13)	0.11	(-0.55, 0.63)
9	-0.17	(-0.81, 0.61)	-0.40	(-1.18, 0.42)	0.35	(-0.8, 1.34)	0.45	(-0.49, 1.17)	-0.15	(-0.62, 0.41)	-0.15	(-0.5, 0.3)	-0.09	(-0.55, 0.41)
10	0.20	(-0.08, 0.48)	0.10	(-0.3, 0.42)	0.33	(-0.81, 1.3)	0.41	(-1.16, 2.43)	-0.07	(-0.36, 0.25)	-0.09	(-0.29, 0.11)	0.32	(-0.3, 0.92)
11	0.14	(-0.29, 0.56)	0.07	(-0.11, 0.25)	0.07	(-0.27, 0.34)	0.77	(-1.32, 2.76)	0.06	(-0.91, 0.97)	-0.30	(-0.93, 0.46)	0.11	(-0.39, 0.67)
12	0.35	(-0.28, 0.96)	-0.18	(-0.63, 0.4)	-0.06	(-0.68, 0.61)	0.93	(-0.71, 1.43)	0.17	(-0.81, 0.98)	0.17	(-0.28, 0.59)	0.03	(-0.2, 0.24)
13	0.65	(-0.6, 1.83)	-0.26	(-0.91, 0.57)	-0.18	(-0.79, 0.28)	0.43	(-0.83, 1.9)	0.23	(-0.76, 1.04)	0.39	(-0.37, 1.07)	0.06	(-0.82, 0.95)
14	0.41	(-0.33, 1.09)	-0.24	(-0.92, 0.68)	-0.30	(-0.4, 0.61)	0.69	(-0.88, 0.36)	0.11	(-0.81, 0.93)	-0.21	(-0.67, 0.24)	-0.23	(-0.79, 0.38)
15	0.64	(-0.65, 1.88)	-0.23	(-0.92, 0.69)	0.16	(-0.85, 0.21)	-0.26	(-0.3, 0.46)	0.20	(-0.88, 1.09)	-0.38	(-1.4, 0.95)	-0.74	(-2.23, 0.8)
16	0.25	(-0.33, 0.74)	-0.66	(-1.96, 1.1)	-0.32	(-1.74, 0.67)	0.06	(-0.24, 0.36)	0.69	(-1.41, 2.43)	-0.07	(-0.24, 0.06)	-0.04	(-0.23, 0.13)
17	-0.15	(-0.73, 0.53)	-0.33	(-0.9, 0.35)	-0.60	(-0.71, 0.86)	0.07	(-0.6, 1.61)	0.33	(-0.77, 1.22)	-0.09	(-0.34, 0.21)	0.28	(-0.51, 1.01)
18	-0.14	(-0.51, 0.31)	-0.24	(-0.78, 0.31)	0.07	(-0.9, 0.18)	0.56	(-0.56, 0.29)	0.57	(-1.13, 1.96)	-0.04	(-0.29, 0.16)	-0.22	(-0.68, 0.27)
19	-0.48	(-1.41, 0.63)	-0.13	(-0.71, 0.67)	-0.33	(-0.33, 0.31)	-0.05	(-0.86, 1.45)	0.23	(-0.74, 1.02)	-0.50	(-1.68, 0.99)	-0.34	(-1.16, 0.68)
20	-0.14	(-0.57, 0.34)	0.10	(-0.39, 0.58)	-0.03	(-0.24, 0.48)	0.38	(-0.72, 0.9)	-0.05	(-0.9, 0.76)	0.14	(-0.27, 0.51)	0.07	(-0.13, 0.31)
21	-0.38	(-1.12, 0.52)	0.28	(-0.34, 0.91)	0.10	(-1.26, 0.35)	0.15	(-0.64, 0.78)	0.13	(-0.53, 0.68)	-0.24	(-0.64, 0.23)	0.49	(-0.67, 1.48)
22	-0.04	(-0.68, 0.55)	-0.13	(-0.51, 0.27)	-0.46	(-0.35, 0.33)	0.13	(-0.83, 1.03)	0.32	(-0.56, 1.08)	-0.32	(-1, 0.35)	0.29	(-0.27, 0.82)
23	-0.17	(-0.56, 0.2)	0.08	(-0.52, 0.67)	-0.05	(-0.79, 2.35)	0.18	(-0.1, 0.4)	0.50	(-0.92, 1.65)	-0.17	(-0.55, 0.29)	0.15	(-0.14, 0.43)

B. Black overdose mortality

	Michigan		*Missouri*		*Ohio*		*South Carolina*	
Time	Est.	95% CI	Est.	95% CI	Est.	95% CI	Est.	95% CI
0	2.27	(-3.80, 7.63)	1.29	(-1.18, 4.48)	1.02	(-1.28, 3.64)	0.27	(-0.98, 1.38)
1	-0.57	(-1.96, 0.62)	0.82	(-0.87, 2.81)	0.08	(-0.3, 0.57)	0.64	(-0.72, 2.22)
2	1.48	(-1.89, 4.59)	-1.24	(-4.83, 2.15)	0.89	(-1.25, 3.1)	1.19	(-1.38, 4.21)
3	0.70	(-0.71, 2.39)	0.46	(-0.87, 1.64)	0.59	(-1.59, 2.62)	0.07	(-0.19, 0.4)
4	0.90	(-0.99, 3.07)	0.92	(-1.26, 3.18)	1.73	(-2.72, 6.05)	-0.15	(-0.79, 0.49)
5	0.30	(-0.43, 1.12)	-0.74	(-2.87, 1.34)	1.85	(-2.35, 6.38)	0.64	(-1.72, 2.74)
6	0.00	(-0.51, 0.64)	0.32	(-0.61, 1.28)	-0.79	(-3.04, 1.41)	0.34	(-0.81, 1.41)
7	-1.04	(-3.57, 2.10)	-1.52	(-5.42, 1.67)	0.32	(-1.64, 2.18)	0.07	(-0.71, 0.86)
8	-0.98	(-3.91, 2.71)	0.04	(-0.13, 0.21)	1.38	(-2.21, 5.01)	0.23	(-0.72, 1.16)
9	-0.56	(-3.02, 2.44)	-1.29	(-4.6, 1.36)	1.15	(-1.12, 3.86)	0.41	(-1.35, 1.99)
10	-0.54	(-2.24, 1.61)	-0.27	(-0.95, 0.28)	-0.11	(-1.08, 0.91)	0.00	(-0.74, 0.77)
11	-0.43	(-1.70, 1.00)	-1.00	(-3.76, 1.35)	0.23	(-1.29, 1.68)	0.89	(-0.9, 2.95)
12	1.12	(-1.58, 3.58)	0.08	(-1.33, 1.5)	1.23	(-2.94, 5.03)	0.69	(-0.71, 2.21)
13	-0.18	(-0.92, 0.55)	0.46	(-1.65, 2.27)	-0.36	(-1.28, 0.58)	0.59	(-0.69, 2.03)
14	0.16	(-0.4, 0.84)	-0.26	(-3.35, 2.9)	-0.66	(-2.11, 0.56)	0.30	(-0.28, 1.01)
15	0.98	(-1.35, 3.14)	-0.18	(-3.55, 3.16)	-1.12	(-3.77, 1.33)	0.49	(-0.68, 1.81)
16	-0.16	(-1.27, 0.63)	-1.29	(-5.31, 3.21)	-1.26	(-4.28, 1.52)	0.57	(-0.74, 2.02)
17	-0.31	(-1.73, 1.18)	0.80	(-1.34, 3)	-1.35	(-4.5, 1.53)	0.36	(-0.38, 1.19)
18	-0.91	(-3.34, 1.94)	-0.63	(-2.39, 1.02)	-1.07	(-4.1, 1.72)	0.43	(-0.39, 1.33)
19	-1.54	(-5.08, 2.45)	-0.06	(-0.62, 0.52)	-0.24	(-0.87, 0.31)	0.44	(-1.15, 1.97)
20	-1.20	(-3.77, 1.69)	0.33	(-0.31, 1)	-0.48	(-2.31, 1.34)	0.68	(-1.75, 2.88)
21	-1.20	(-3.91, 1.89)	0.33	(-2.18, 2.75)	-0.69	(-2.17, 0.63)	0.37	(-0.75, 1.48)
22	-0.15	(-0.73, 0.50)	1.56	(-1.61, 5.57)	-0.88	(-3.35, 1.32)	1.34	(-1.64, 4.6)
23	0.30	(-0.47, 1.13)	-0.63	(-3.1, 2.05)	-0.79	(-2.61, 0.72)	-0.09	(-0.65, 0.50)

C. White overdose mortality

	Michigan		*Missouri*		*Ohio*		*South Carolina*	
Time	Est.	95% CI	Est.	95% CI	Est.	95% CI	Est.	95% CI
0	0.25	(-0.27, 0.87)	-0.21	(-1.13, 0.78)	0.76	(-1, 2.59)	0.09	(-0.45, 0.69)
1	-0.12	(-0.63, 0.4)	-0.02	(-0.33, 0.31)	0.19	(-0.24, 0.68)	-0.13	(-0.55, 0.33)
2	-0.03	(-0.69, 0.6)	0.26	(-0.74, 1.20)	0.59	(-0.74, 2.04)	0.73	(-0.83, 2.49)
3	-0.23	(-1.33, 0.9)	-0.44	(-1.48, 0.66)	1.20	(-1.59, 4.20)	0.24	(-0.28, 0.85)
4	0.44	(-0.44, 1.56)	-0.12	(-0.45, 0.24)	1.35	(-1.98, 4.78)	-0.09	(-0.58, 0.39)
5	0.23	(-0.33, 0.85)	-0.18	(-0.82, 0.35)	1.56	(-2.63, 5.63)	-0.27	(-1.08, 0.44)
6	0.07	(-0.09, 0.25)	0.12	(-0.4, 0.59)	1.16	(-1.93, 4.24)	-0.60	(-2.16, 0.9)
7	-0.35	(-1.15, 0.32)	0.05	(-0.43, 0.56)	1.89	(-3.12, 7.02)	-0.48	(-1.69, 0.6)
8	0.15	(-0.25, 0.6)	-0.44	(-1.34, 0.4)	1.21	(-1.8, 4.35)	-0.13	(-0.8, 0.41)
9	-0.48	(-1.64, 0.44)	-0.15	(-1.02, 0.74)	0.68	(-1, 2.42)	-0.14	(-0.63, 0.38)
10	0.07	(-0.59, 0.77)	0.28	(-0.66, 1.16)	0.55	(-1.17, 2.16)	-0.24	(-0.8, 0.22)
11	-0.03	(-0.98, 0.91)	-0.21	(-0.71, 0.24)	1.03	(-1.52, 3.65)	-0.37	(-1.52, 0.86)
12	-0.07	(-0.31, 0.18)	-0.64	(-1.92, 0.61)	1.12	(-1.62, 3.91)	0.05	(-0.37, 0.50)
13	0.59	(-1.1, 2.32)	-0.21	(-1.03, 0.61)	0.67	(-1.22, 2.53)	0.27	(-0.38, 1.00)
14	0.00	(-1.07, 1.07)	-0.65	(-1.99, 0.64)	0.72	(-1.28, 2.80)	-0.43	(-1.43, 0.4)
15	0.42	(-1.10, 1.98)	-0.42	(-1.50, 0.65)	-0.21	(-0.76, 0.29)	-0.67	(-2.48, 1.11)
16	0.19	(-0.65, 0.97)	-0.65	(-2.37, 1.06)	-0.14	(-0.54, 0.25)	0.28	(-0.25, 0.92)
17	-0.13	(-0.44, 0.12)	-0.43	(-1.33, 0.52)	0.15	(-0.63, 1.01)	-0.06	(-0.37, 0.29)
18	-0.08	(-0.33, 0.16)	-0.02	(-0.57, 0.49)	0.71	(-1.35, 2.62)	0.31	(-0.46, 1.13)
19	-0.48	(-1.67, 0.44)	-0.47	(-1.68, 0.77)	0.09	(-0.3, 0.44)	-0.58	(-2.18, 1.05)
20	0.01	(-0.14, 0.14)	0.13	(-0.25, 0.53)	0.25	(-1.1, 1.63)	-0.09	(-0.5, 0.29)
21	-0.51	(-1.59, 0.49)	0.48	(-0.44, 1.52)	0.08	(-0.81, 0.92)	-0.14	(-0.88, 0.46)
22	0.03	(-0.80, 0.85)	-0.13	(-0.52, 0.3)	0.17	(-0.78, 1.22)	-0.51	(-2.09, 0.79)
23	-0.01	(-0.15, 0.11)	0.54	(-0.73, 1.89)	-0.03	(-0.89, 0.75)	-0.04	(-0.46, 0.44)

Notes: Time = matching period month. Est. = estimated effect of the GSL in a given state on overdose mortality. The estimated effect is measured as a difference (observed minus counterfactual) in mortality per 100,000 population (all, Black, and White). Time 0 is the month before the intervention date, where intervention date is defined as one year after the GSL effective date to allow for lagged

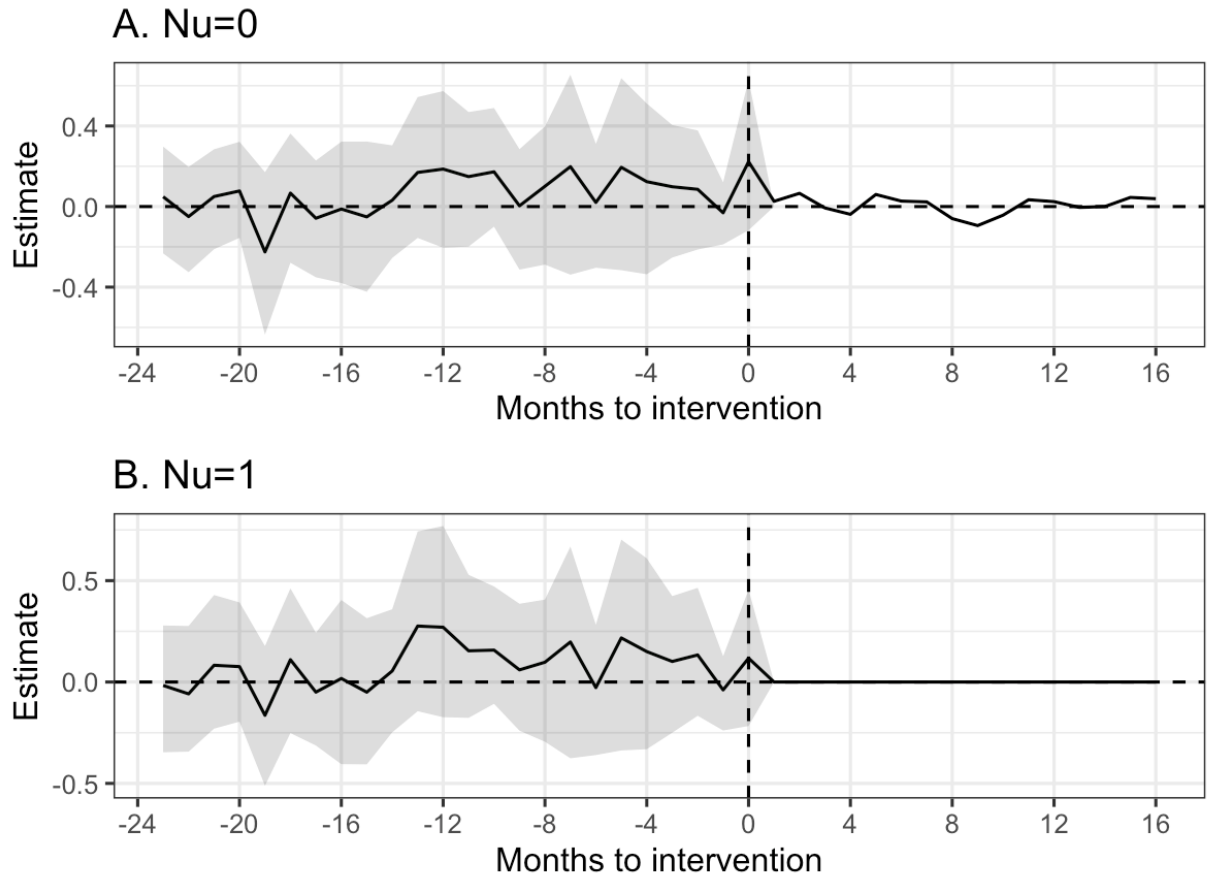
effects. 95% confidence intervals were generated via the wild bootstrap. Note that the overall results cannot be directly compared to the race-stratified results, as they are produced by a distinct set of intervention states, donor states, and weights.

Web Table 4. Weights applied to donor states for each intervention state to create the synthetic control, Black and White mortality

	Black overdose mortality				White overdose mortality			
	MI	MO	OH	SC	MI	MO	OH	SC
CA	0	0	0	0.61	0	0	0	0
CO	0	0	0.10	0	0.12	0.05	0.01	0.41
CT	0.41	0	0	0	0.06	0	0	0
DC	0	0	0	0	0	0	0.10	0.19
DE	0	0	0	0	0	0	0.11	0
GA	0	0	0	0	0.72	0	0.28	0
IL	0	0.90	0	0	0.08	0	0	0.12
MA	0.14	0	0.07	0.24	0	0	0	0.03
MD	0.28	0	0.10	0	0	0	0	0
MI	0	0	0	0	0	0	0	0
MN	0	0	0.41	0	0.02	0.03	0.11	0
MO	0	0	0	0	0	0	0	0
NC	0	0	0	0	0	0.45	0	0
NJ	0.03	0	0	0.11	0	0.47	0	0.24
NY	0	0	0	0	0	0	0	0
OH	0	0	0	0	0	0	0	0
PA	0	0	0	0	0	0	0	0
SC	0	0	0	0	0	0	0	0
WA	0.14	0.10	0.23	0.04	0	0	0.39	0
WI	0	0	0.09	0	0	0	0.01	0.02

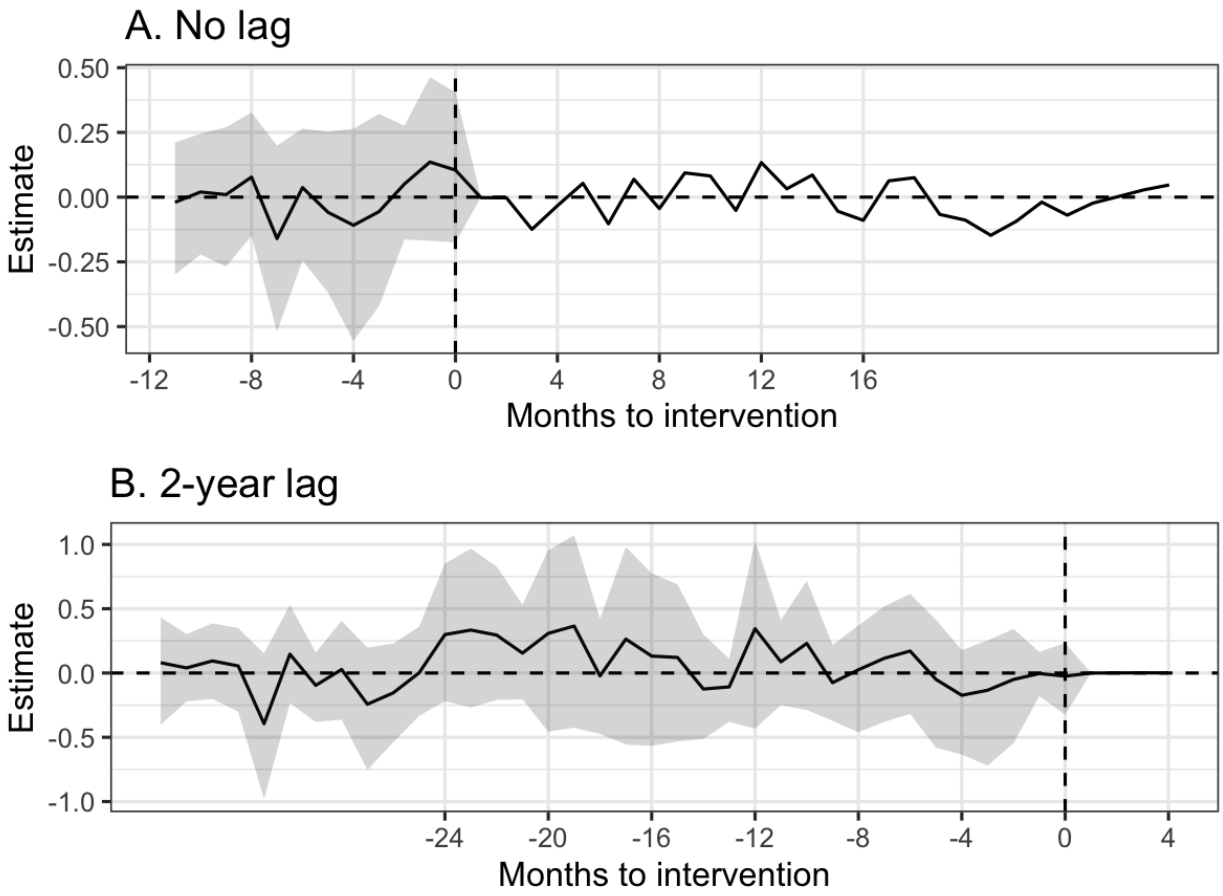
Notes: First column contains donor states; first row contains intervention states. “0” indicates a weight with absolute value <0.0001. Weights sum to 1.

Web Figure 2. Robustness check: Set ν to 0 and 1



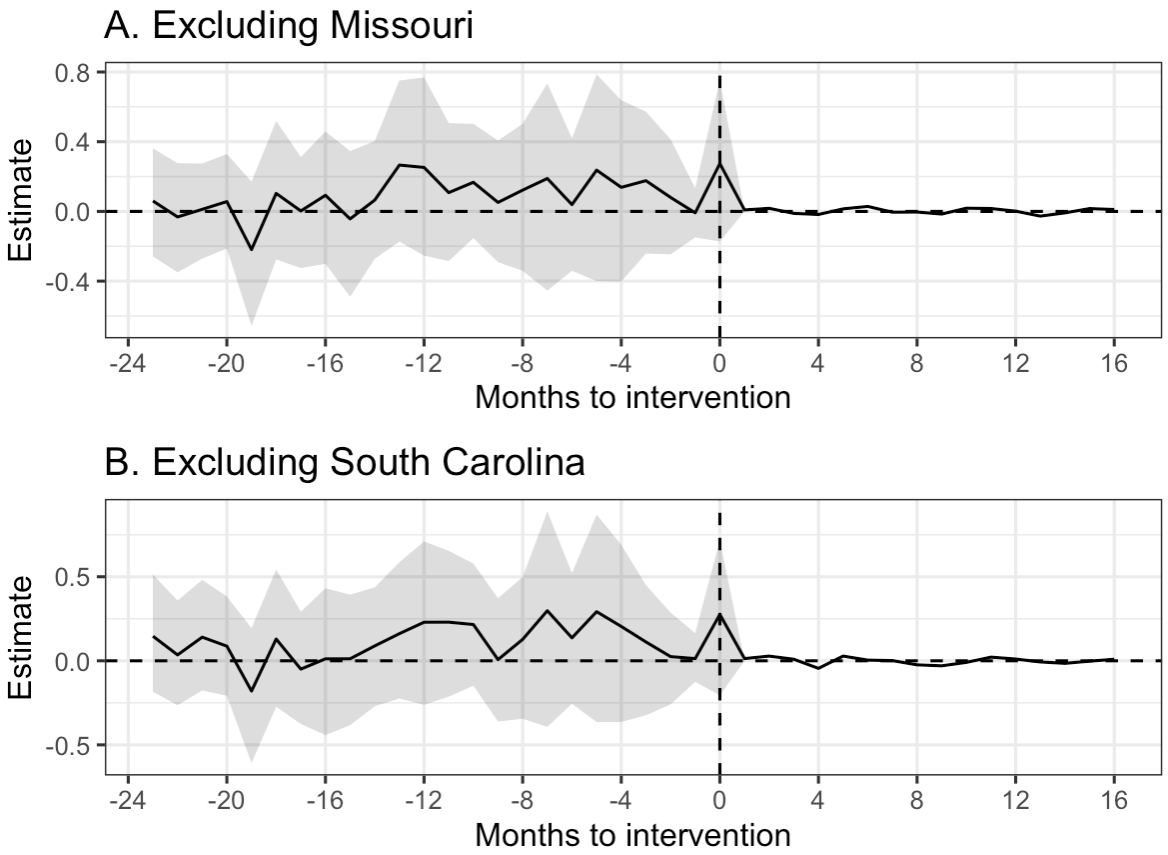
Notes: Setting $\nu = 0$ corresponds to conducting separate SCM for each intervention state and taking the average of the effects; setting $\nu = 1$ corresponds to pooling all intervention states and estimating the average effect. Vertical line indicates intervention date, defined as one year after the GSL effective date. Months to the right of this line indicate the matching period, during which the synthetic control is generated (post-intervention); months to the left indicate the evaluation period (pre-intervention), during which the observed and counterfactual estimates are compared. An estimated effect closer to 0 during the matching period indicates a better fitting synthetic control. Intervention states are Ohio, Oregon, Michigan, Missouri, Nebraska, South Carolina, South Dakota.

Web Figure 3. Robustness check: assume no versus two-year lagged effects



Notes: A. Define the intervention month using the date the GSL in each state became effective, i.e., as if effects are not lagged. B. Define the intervention month assuming a two-year lag. Vertical line indicates intervention date; months to the right of this line indicate the matching period, during which the synthetic control is generated (post-intervention); months to the left indicate the evaluation period (pre-intervention), during which the observed and counterfactual estimates are compared. An estimated effect closer to 0 during the matching period indicates a better fitting synthetic control. Intervention states are Ohio, Oregon, Michigan, Missouri, Nebraska, South Carolina, South Dakota.

Web Figure 4. Robustness check: Exclude Missouri (worst fit) and South Carolina (no protection from arrest), respectively



Notes: A. Exclude the state with the worst pre-intervention fit (i.e., largest root mean squared prediction error), Missouri. B. Exclude the only state that does not protect from arrest, South Carolina. Vertical line indicates intervention date; months to the right of this line indicate the matching period, during which the synthetic control is generated (post-intervention); months to the left indicate the evaluation period (pre-intervention), during which the observed and counterfactual estimates are compared. An estimated effect closer to 0 during the matching period indicates a better fitting synthetic control. Other intervention states are Ohio, Oregon, Michigan, Nebraska, South Dakota.

REFERENCES

1. The Network for Public Health Law. *Legal interventions to reduce overdose mortality: Naloxone access and overdose Good Samaritan Laws*. Edina, MN: The Network for Public Health Law; 2018.

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