Supplementary Appendix

Supplement to: "Comparing the Impact of Cigarette Excise Taxes of Varying Size on Cigarette Sales and Prices in Pennsylvania and Ohio"

Acronyms and Abbreviations

SDID	Synthetic Difference-in-Differences
SCM	Synthetic Control Methods
ATT	Average Treatment Effect on the Treated

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Table A1. Donor pool for SDID analysis, 2008-2019

States Without a Tax Change	AK, AZ, CO, GA, ID, IN, IA, ME, MD, MI, MO, MT, NE, ND, SD, TN, TX, VA, WY (19)
States With a Tax Change	AL, AR, CA, CT, DE, DC, FL, HI, IL, KS, KY, LA, MA, MN, MS, NV, NH, NJ, NM, NY, NC, OK, OR, RI, SC, UT, VT, WA, WV, WI (30)

Table A2. Donor pool for SDID analysis, 2011-2019

States Without a Tax Change	AK, AZ, AR, CO, FL, GA, ID, IN, IA, ME, MD, MI, MS, MO, MT, NE, NJ, NM, NY, NC, ND, SC, SD, TN, TX, UT, VA, WA, WI, WY (30)
States With a Tax Change	AL, CA, CT, DE, DC, HI, IL, KS, KY, LA, MA, MN, NV, NH, OK, OR, RI, VT, WV (19)

Table A3. Donor pool for SDID analysis, 2008-2024

States Without a Tax Change	AK, AZ, GA, ID, IN, IA, ME, MI, MO, MT, NE, ND, SD, TN, TX, WY (16)
States With a Tax Change	AL, AR, CA, CO, CT, DE, DC, FL, HI, IL, KS, KY, LA, MA, MN, MD, MS, NV, NH, NJ, NM, NY, NC, OK, OR, RI, SC, UT, VA, VT, WA, WV, WI (33)

Table A4. SDID unit and time weights for Pennsylvania, 2008-2019

	Per-capita cigarette sales	Price per pack of cigarettes	ln(per-capita cigarette sales)	ln(price per pack of cigarettes)
Donor pool state		**Unit weights**		
AK	8.01	11.80	9.71	6.14
AZ	6.35	6.70	4.54	5.54
CO	5.62	3.15	4.74	3.85
GA	6.65	6.13	6.53	7.04
ID	4.45	5.98	3.01	7.31
IN	4.10	10.82	4.54	10.21
IA	4.58	0.12	4.47	0.46
ME	5.46	0.12	5.82	0.40
MD	6.57	0.12	4.99	0.24
MI	4.01	5.46	4.08	5.04
MO	5.58	6.56	6.43	8.32
MT	6.36	1.41	5.69	1.54
NE	8.80	9.35	6.48	8.45
ND	1.31	7.42	3.22	8.46
SD	4.48	10.92	5.06	8.63
TN	5.40	0.28	7.73	2.00
TX	4.42	4.93	5.09	4.83
VA	4.75	4.31	5.09	5.61
WY	3.10	4.44	2.79	5.91
Year		**Time weights**		
2008	0.0	3.3	0.0	0.0
2009	0.0	11.3	0.0	13.3
2010	36.5	5.6	24.5	0.0
2011	0.0	0.0	0.0	0.0
2012	0.0	0.0	0.0	0.0
2013	0.0	0.0	0.0	0.0
2014	63.5	39.3	74.5	44.2
2015	0.0	36.9	0.0	42.5

Table A5. SDID unit and time weights for Ohio, 2008-2019

	Per-capita cigarette sales	Price per pack of cigarettes	ln(per-capita cigarette sales)	ln(price per pack of cigarettes)
Donor pool state		**Unit weights**		
AK	4.96	3.17	4.36	3.51
AZ	3.28	5.13	2.33	4.95
CO	4.97	5.22	5.19	5.21
GA	7.41	5.87	5.69	5.97
ID	6.73	4.70	6.16	4.90
IN	8.55	5.00	6.80	5.09
IA	7.46	5.90	6.53	5.68
ME	7.07	6.08	7.00	5.91
MD	5.39	5.54	4.91	5.58
MI	6.19	5.32	6.40	5.43
MO	4.52	4.08	4.31	4.37
MT	4.37	5.54	5.46	5.39
NE	5.99	5.22	4.82	4.95
ND	2.46	4.33	5.36	4.76
SD	8.30	6.13	8.93	5.83
TN	1.99	5.81	4.57	5.79
TX	4.66	6.54	4.23	6.16
VA	1.71	5.16	3.74	5.18
WY	4.00	5.27	3.21	5.33
Year		**Time weights**		
2008	0.0	0.0	0.0	0.0
2009	0.0	11.9	0.0	13.6
2010	26.3	14.6	19.7	12.2
2011	3.8	0.0	0.0	0.0
2012	0.0	0.0	0.0	0.0
2013	0.0	0.0	0.0	0.0
2014	69.9	73.5	80.3	74.2

Table A6. Unadjusted effects of cigarette tax increases on per-capita cigarette sales and price per pack in Pennsylvania and Ohio, 2008-2019

	ATT (95% CI)	
Outcome measure	**Pennsylvania**	**Ohio**
Per-capita cigarette sales	-6.64* (-11.92, -1.35)	-1.22 (-5.36, 2.92)
Price per pack ($)	1.30*** (1.10, 1.49)	0.32*** (0.15, 0.48)
Logged per-capita cigarette sales (% change)	-12.8*** (-19.2, -5.9)	-1.3 (-7.3, 5.2)
Logged price per pack (% change)	17.5*** (14.2, 20.8)	5.0*** (2.2, 7.9)

Note: None of the SDID models controlled for any pre-tax covariates. Monetary values were inflation-adjusted to 2019 dollars. Log-transformed outcomes (and their 95% CIs) were transformed into percent changes using the following formula: $\%\Delta = [\exp(ATT)-1] \times 100$.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

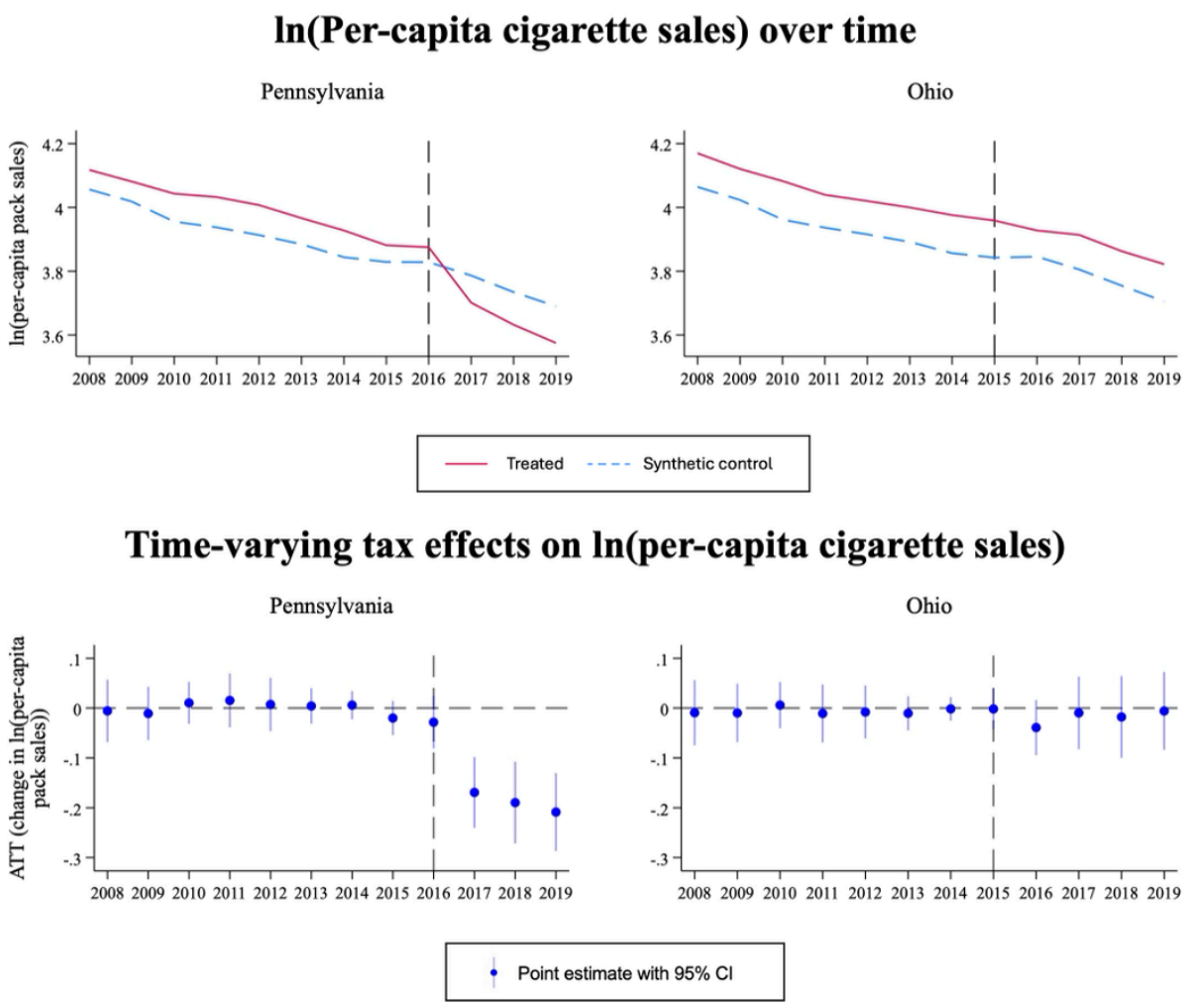

Figure A1. SDID results comparing ln(per-capita cigarette pack sales) in Pennsylvania and Ohio to their synthetic counterparts, 2008-2019

Note: The top plots show the change in logged per-capita cigarette pack sales, derived from SDID estimation that include the full set of covariates. The bottom plots show the change over time in the effects of the taxes on logged per-capita cigarette pack sales, in which each plotted point represents a covariate-adjusted SDID coefficient estimate (ATT) with its corresponding 95% CI.

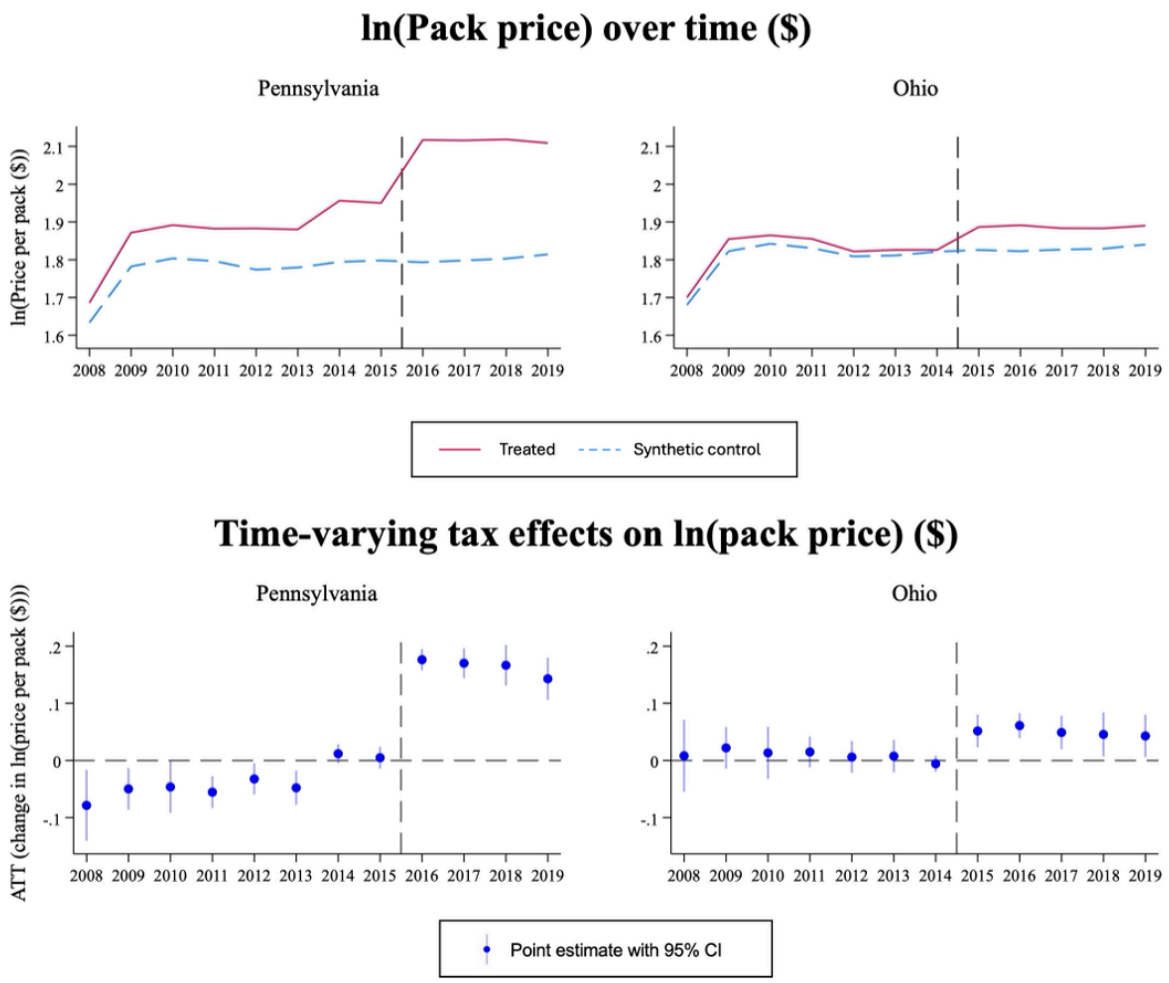

Figure A2. SDID results comparing the ln(price per pack of cigarettes) between Pennsylvania and Ohio to their synthetic counterparts, 2008-2019

Note: The top plots show the change in average logged retail price per pack, in inflation-adjusted 2019 dollars, derived from SDID estimation that include the full set of covariates. The bottom plots show the change over time in the effects of the taxes on logged retail prices per pack, in which each plotted point represents a covariate-adjusted SDID coefficient estimate (ATT, in logged USD) with its corresponding 95% CI.

Table A7. Effects of cigarette tax increases on per-capita cigarette sales and price per pack in Pennsylvania and Ohio, 2011-2019

	ATT (95% CI)	
Outcome measure	**Pennsylvania**	**Ohio**
Per-capita cigarette sales	-6.51** (-11.38, -1.65)	-1.64 (-5.36, 2.09)
Price per pack ($)	1.37*** (1.14, 1.60)	0.37** (0.12, 0.63)
Logged per-capita cigarette sales (% change)	-13.2*** (-19.8, -5.9)	-1.4 (-7.6, 5.1)
Logged price per pack (% change)	17.2*** (13.6, 20.9)	5.6** (2.0, 9.4)

Note: All SDID models controlled for the following pre-tax covariates: natural log of per-capita income, the percentage of state residents aged 15-24, male, non-Hispanic white, and who consume alcohol, and indoor smoking restrictions (ISR) coverage. Monetary values were inflation-adjusted to 2019 dollars. Log-transformed outcomes (and their 95% CIs) were transformed into percent changes using the following formula: $\%\Delta = [\exp(ATT)-1] \times 100$.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table A8. Unadjusted effects of cigarette tax increases on per-capita cigarette sales and price per pack in Pennsylvania and Ohio, 2011-2019

	ATT (95% CI)	
Outcome measure	**Pennsylvania**	**Ohio**
Per-capita cigarette sales	-6.02** (-10.43, -1.62)	-1.07 (-4.27, 2.12)
Price per pack ($)	1.29*** (1.05, 1.54)	$0.36** (0.10, 0.61)
Logged per-capita cigarette sales (% change)	-12.1*** (-18.3, -5.4)	-1.2 (-6.8, 4.8)
Logged price per pack (% change)	17.1*** (13.5, 20.9)	5.4** (1.7, 9.2)

Note: None of the SDID models controlled for any pre-tax covariates. Monetary values were inflation-adjusted to 2019 dollars. Log-transformed outcomes (and their 95% CIs) were transformed into percent changes using the following formula: $\%\Delta = [\exp(ATT)-1] \times 100$.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

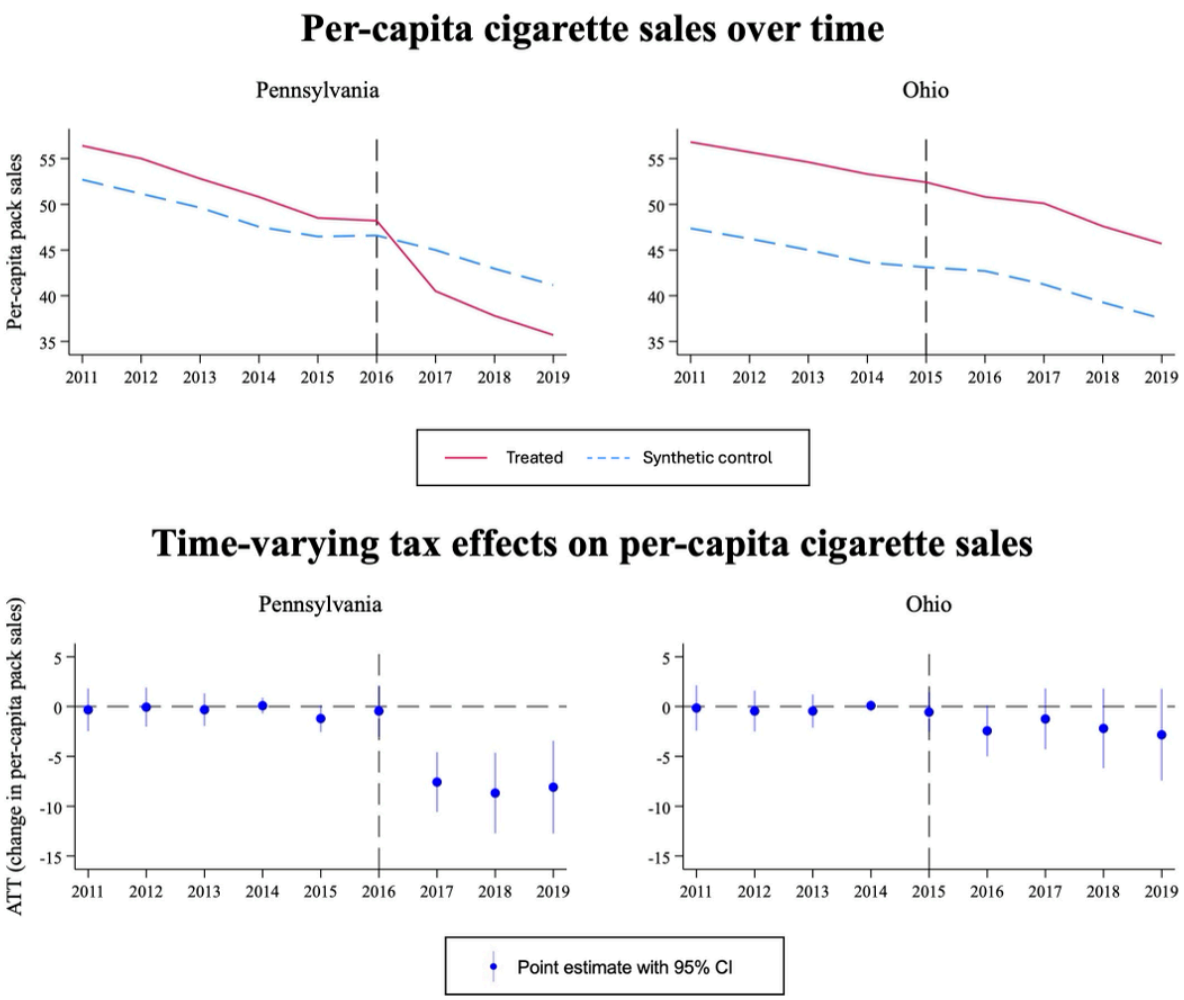

Figure A3. SDID results comparing per-capita cigarette pack sales in Pennsylvania and Ohio to their synthetic counterparts, 2011-2019

Note: The top plots show the change in per-capita cigarette pack sales, derived from SDID estimation that include the full set of covariates. The bottom plots show the change over time in the effects of the taxes on per-capita cigarette pack sales, in which each plotted point represents a covariate-adjusted SDID coefficient estimate (ATT) with its corresponding 95% CI.

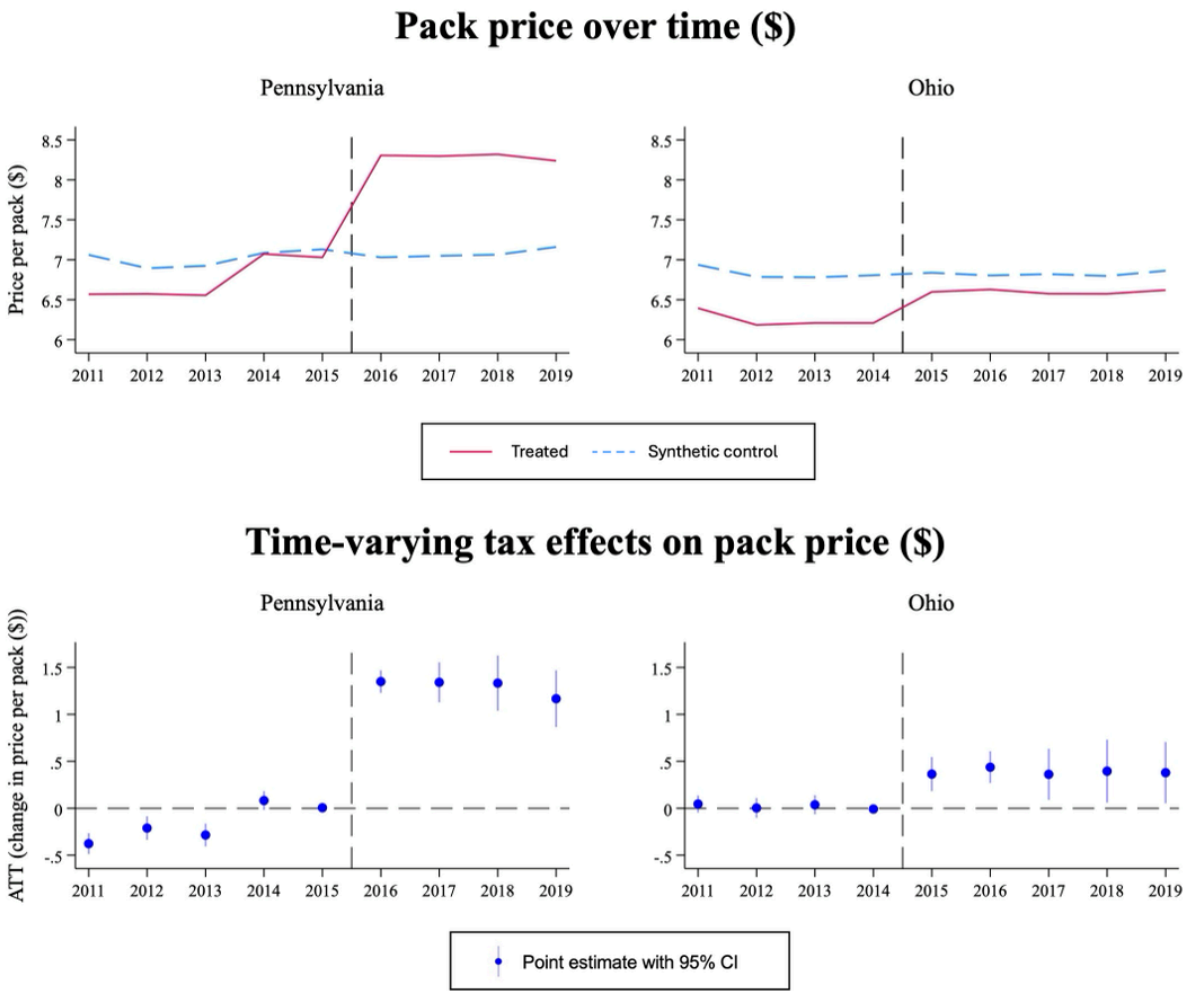

Figure A4. SDID results comparing the price per pack of cigarettes between Pennsylvania and Ohio and their synthetic counterparts, 2011-2019

Note: The top plots show the change in average retail price per pack, in inflation-adjusted 2019 dollars, derived from SDID estimation that include the full set of covariates. The bottom plots show the change over time in the effects of the taxes on retail prices per pack, in which each plotted point represents a covariate-adjusted SDID coefficient estimate (ATT, in USD) with its corresponding 95% CI.

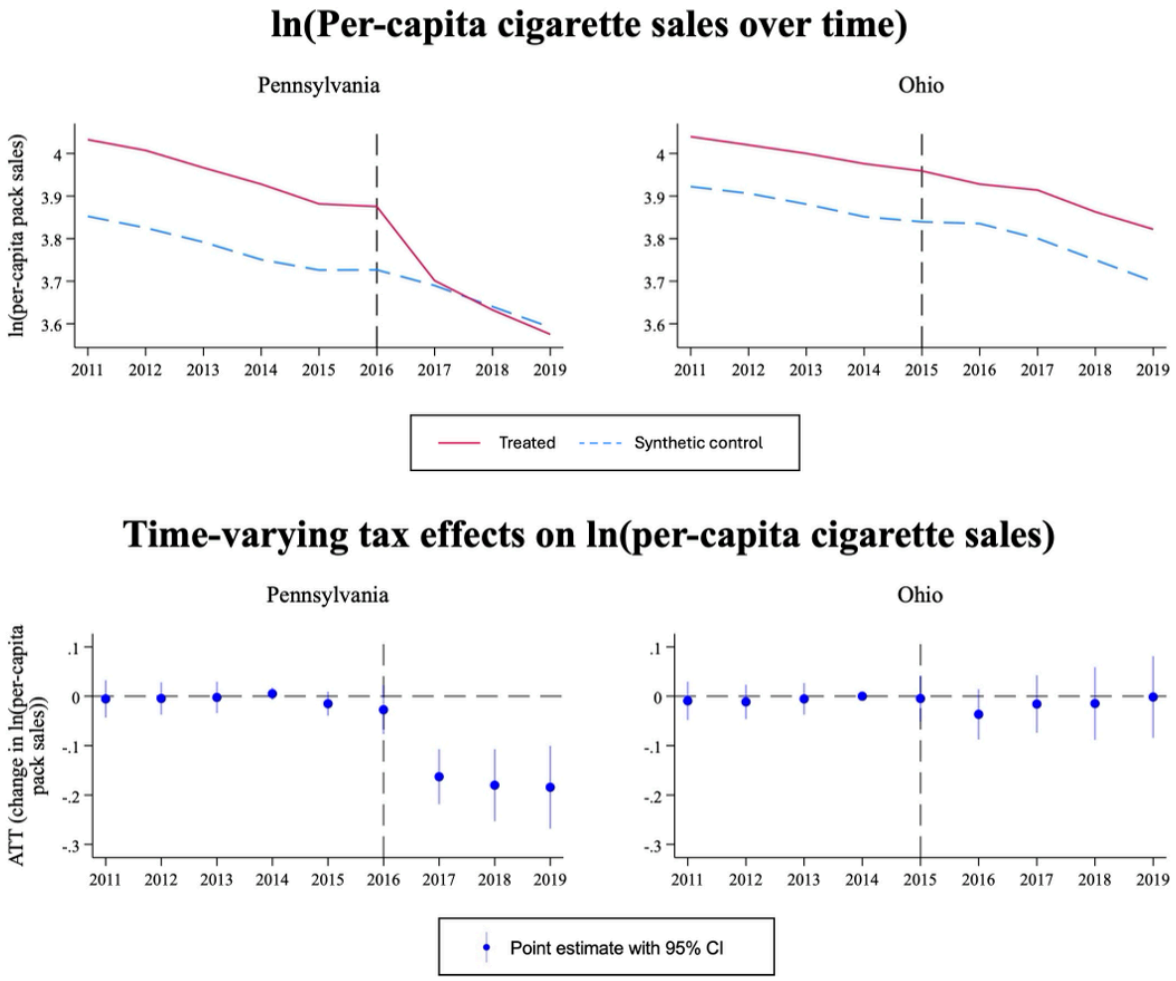

Figure A5. SDID results comparing ln(per-capita cigarette pack sales) in Pennsylvania and Ohio to their synthetic counterparts, 2011-2019

Note: The top plots show the change in logged per-capita cigarette pack sales, derived from SDID estimation that include the full set of covariates. The bottom plots show the change over time in the effects of the taxes on logged per-capita cigarette pack sales, in which each plotted point represents a covariate-adjusted SDID coefficient estimate (ATT) with its corresponding 95% CI.

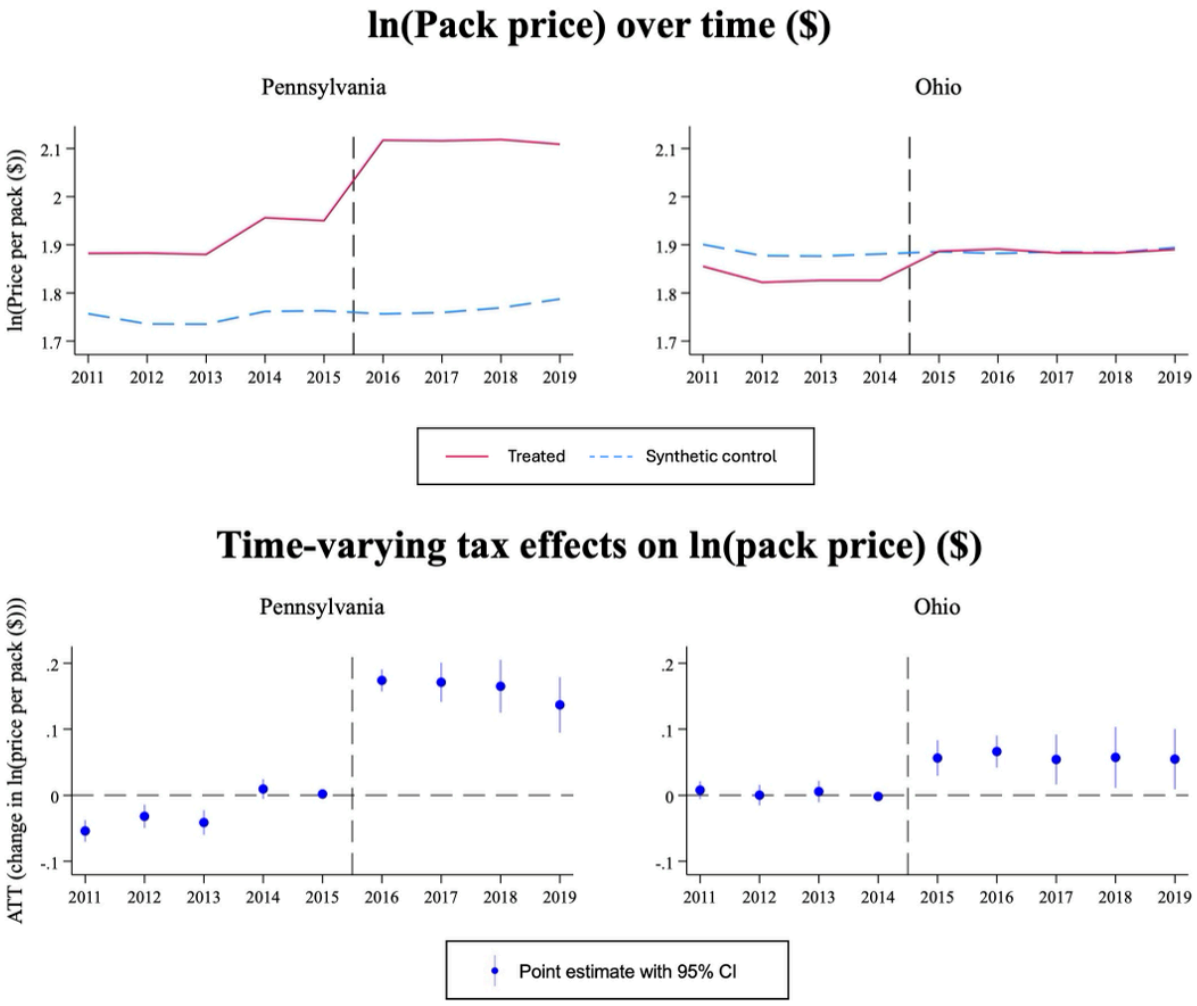

Figure A6. SDID results comparing the ln(price per pack of cigarettes) between Pennsylvania and Ohio to their synthetic counterparts, 2011-2019

Note: The top plots show the change in average logged retail price per pack, inflation-adjusted to 2019 dollars, derived from SDID estimation that include the full set of covariates. The bottom plots show the change over time in the effects of the taxes on logged retail prices per pack, in which each plotted point represents a covariate-adjusted SDID coefficient estimate (ATT, in logged USD) with its corresponding 95% CI.

Table A9. Price elasticity calculation for Pennsylvania and Ohio based on SDID estimates, 2011-2019

	Pennsylvania	**Ohio**
Δ ln(Sales) (ATT)	-0.141***	-0.015
Δ ln(Price) (ATT)	0.158***	0.055**
Implied price elasticity	-0.89	-0.27
95% CI	[-1.28, -0.50]	[-1.13, 0.60]

Note: Implied price elasticities were calculated using ATT estimates of logged per-capita cigarette sales and price per pack of cigarettes from 2011-2019 SDID analyses. 95% CIs were calculated by creating joint placebo estimates for all states in the donor pool (**Table A2**), estimating the joint covariance of the two reduced-form effects, and using the delta method to generate standard errors. To improve the accuracy of the calculated 95% CIs, an RMSPE cutoff of 3 was used to eliminate outlier donor pool states from the calculation.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table A10. Effects of cigarette tax increases on per-capita cigarette sales and price per pack in Pennsylvania and Ohio, 2008-2024

	ATT (95% CI)	
Outcome measure	**Pennsylvania**	**Ohio**
Per-capita cigarette sales	-8.18* (-15.73, -0.64)	-2.81 (-9.61, 4.00)
Price per pack ($)	1.40*** (0.95, 1.86)	0.39 (-0.04, 0.81)
Logged per-capita cigarette sales (% change)	-18.2*** (-26.8, -8.5)	-2.1 (-11.7, 8.7)
Logged price per pack (% change)	13.9*** (7.8, 20.3)	5.1* (0.0, 10.5)

Note: All SDID models controlled for the following pre-tax covariates: natural log of per-capita income, the percentage of state residents aged 15-24, male, non-Hispanic white, and who consume alcohol, and indoor smoking restrictions (ISR) coverage. Monetary values were inflation-adjusted to 2024 dollars. Log-transformed outcomes (and their 95% CIs) were transformed into percent changes using the following formula: $\%\Delta = [\exp(ATT)-1] \times 100$.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table A11. Unadjusted effects of cigarette tax increases on per-capita cigarette sales and price per pack in Pennsylvania and Ohio, 2008-2024

	ATT (95% CI)	
Outcome measure	**Pennsylvania**	**Ohio**
Per-capita cigarette sales	-7.77 (-16.70, 1.15)	-1.19 (-9.12, 6.74)
Price per pack ($)	1.49*** (1.09, 1.90)	0.32 (-0.04, 0.68)
Logged per-capita cigarette sales (% change)	-17.5** (-27.2, -6.6)	-0.8 (-10.9, 10.5)
Logged price per pack (% change)	14.4*** (8.3, 20.9)	4.1 (-1.0, 9.3)

Note: None of the SDID models controlled for any pre-tax covariates. Monetary values were inflation-adjusted to 2019 dollars. Log-transformed outcomes (and their 95% CIs) were transformed into percent changes using the following formula: $\%\Delta = [\exp(ATT)-1] \times 100$.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

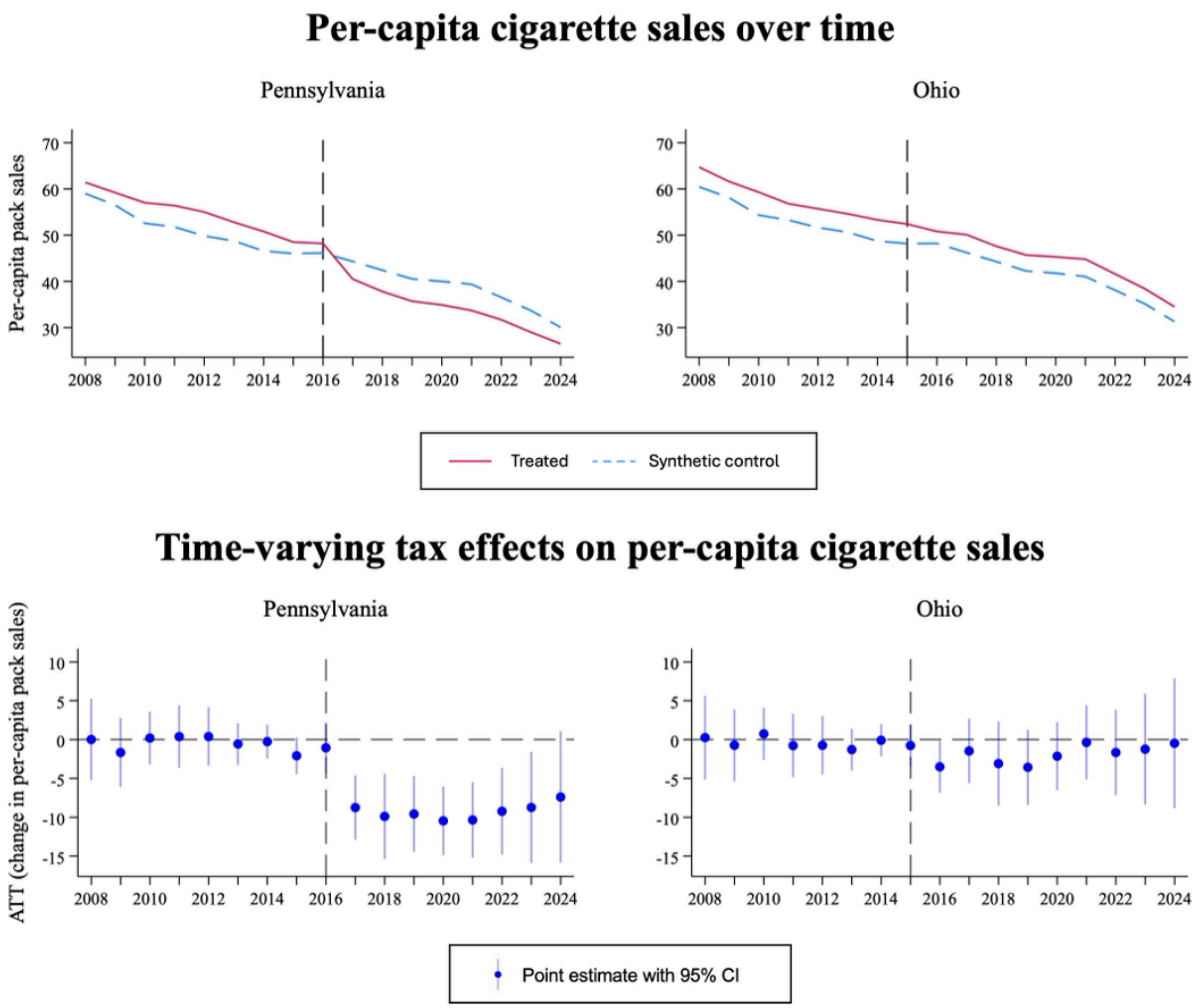

Figure A7. SDID results comparing per-capita cigarette pack sales in Pennsylvania and Ohio to their synthetic counterparts, 2008-2024

Note: The top plots show the change in per-capita cigarette pack sales, derived from SDID estimation that include the full set of covariates. The bottom plots show the change over time in the effects of the taxes on per-capita cigarette pack sales, in which each plotted point represents a covariate-adjusted SDID coefficient estimate (ATT) with its corresponding 95% CI.

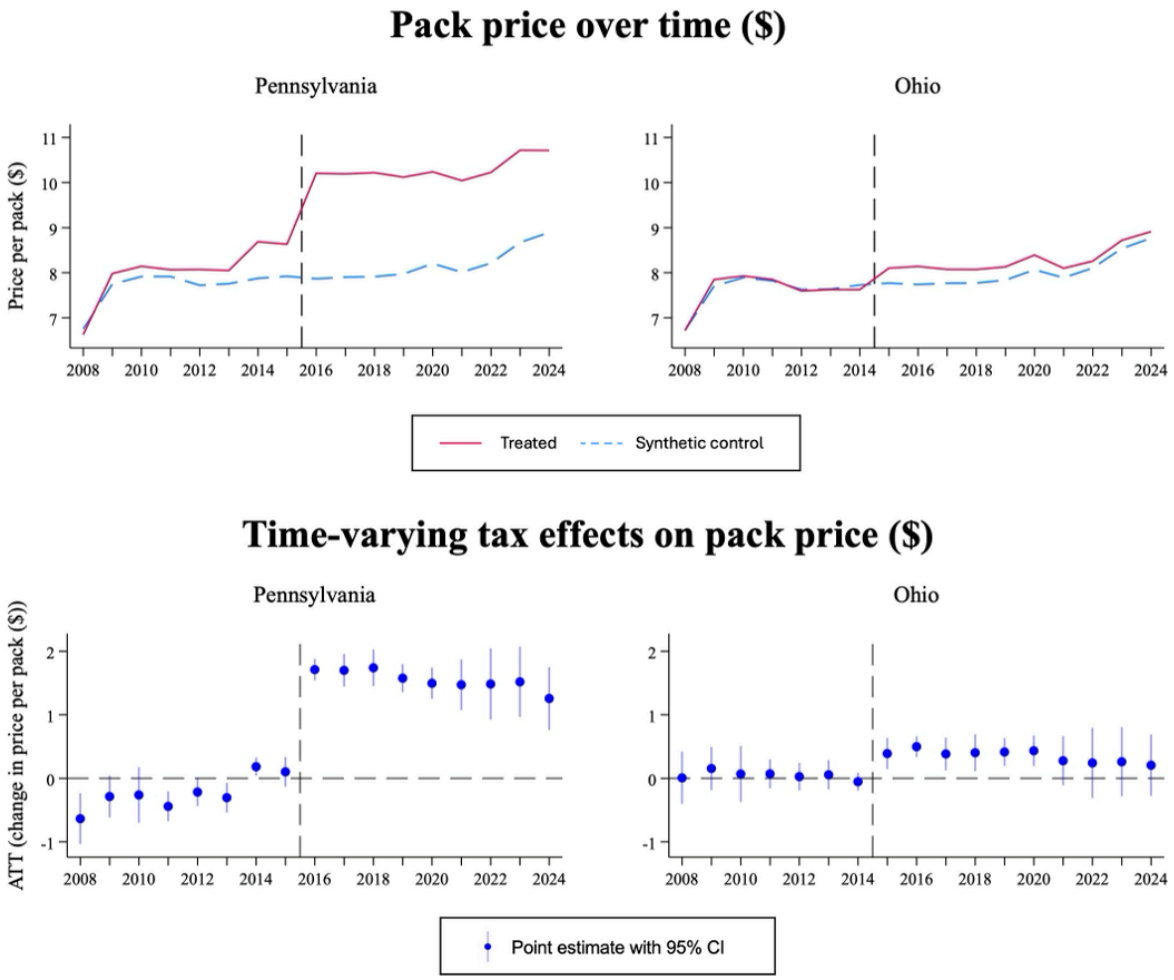

Figure A8. SDID results comparing the price per pack of cigarettes between Pennsylvania and Ohio and their synthetic counterparts, 2008-2024

Note: The top plots show the change in average retail price per pack, in inflation-adjusted 2024 dollars, derived from SDID estimation that include the full set of covariates. The bottom plots show the change over time in the effects of the taxes on retail prices per pack, in which each plotted point represents a covariate-adjusted SDID coefficient estimate (ATT, in USD) with its corresponding 95% CI.

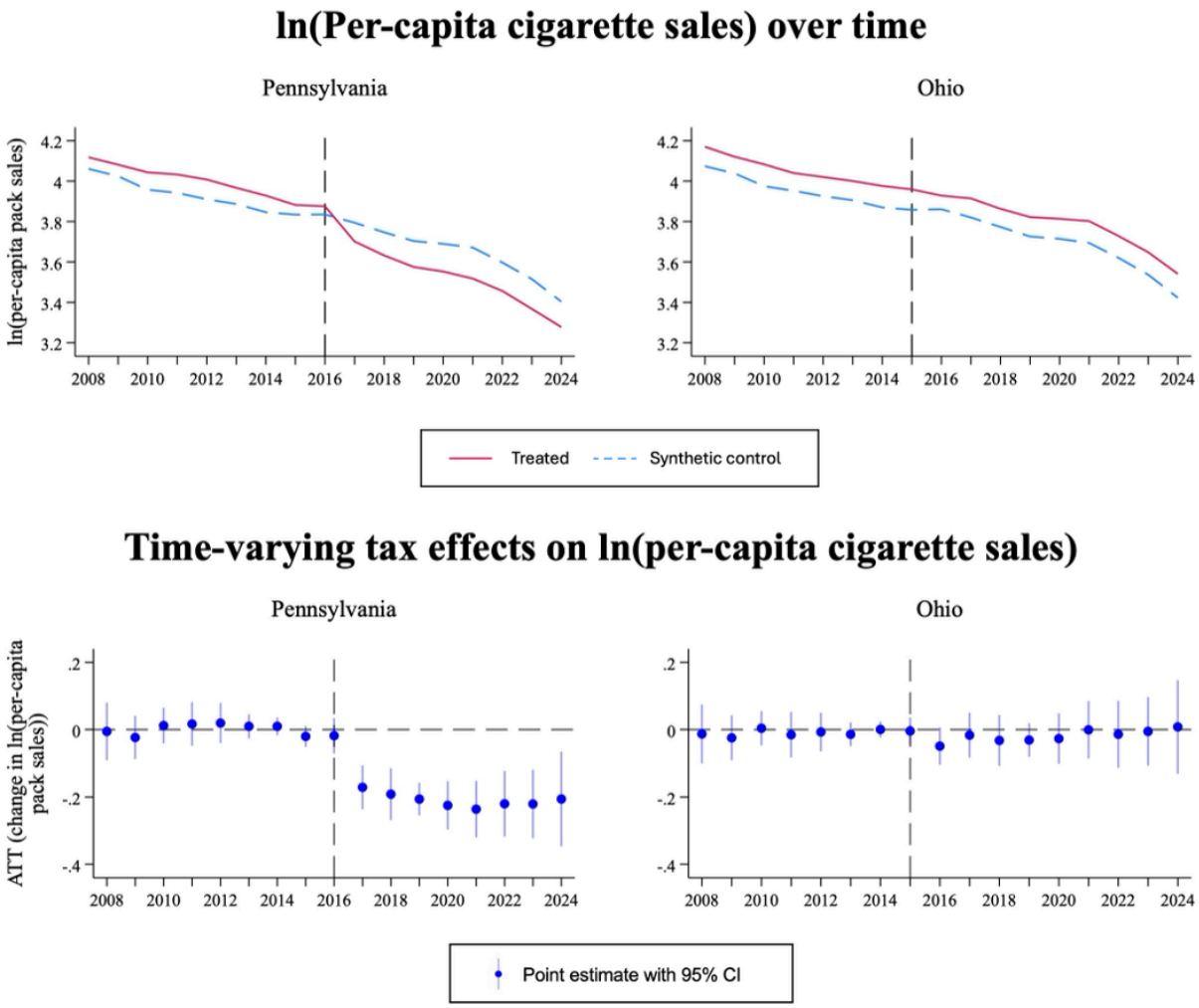

Figure A9. SDID results comparing ln(per-capita cigarette pack sales) in Pennsylvania and Ohio to their synthetic counterparts, 2008-2024

Note: The top plots show the change in logged per-capita cigarette pack sales, derived from SDID estimation that include the full set of covariates. The bottom plots show the change over time in the effects of the taxes on logged per-capita cigarette pack sales, in which each plotted point represents a covariate-adjusted SDID coefficient estimate (ATT) with its corresponding 95% CI.

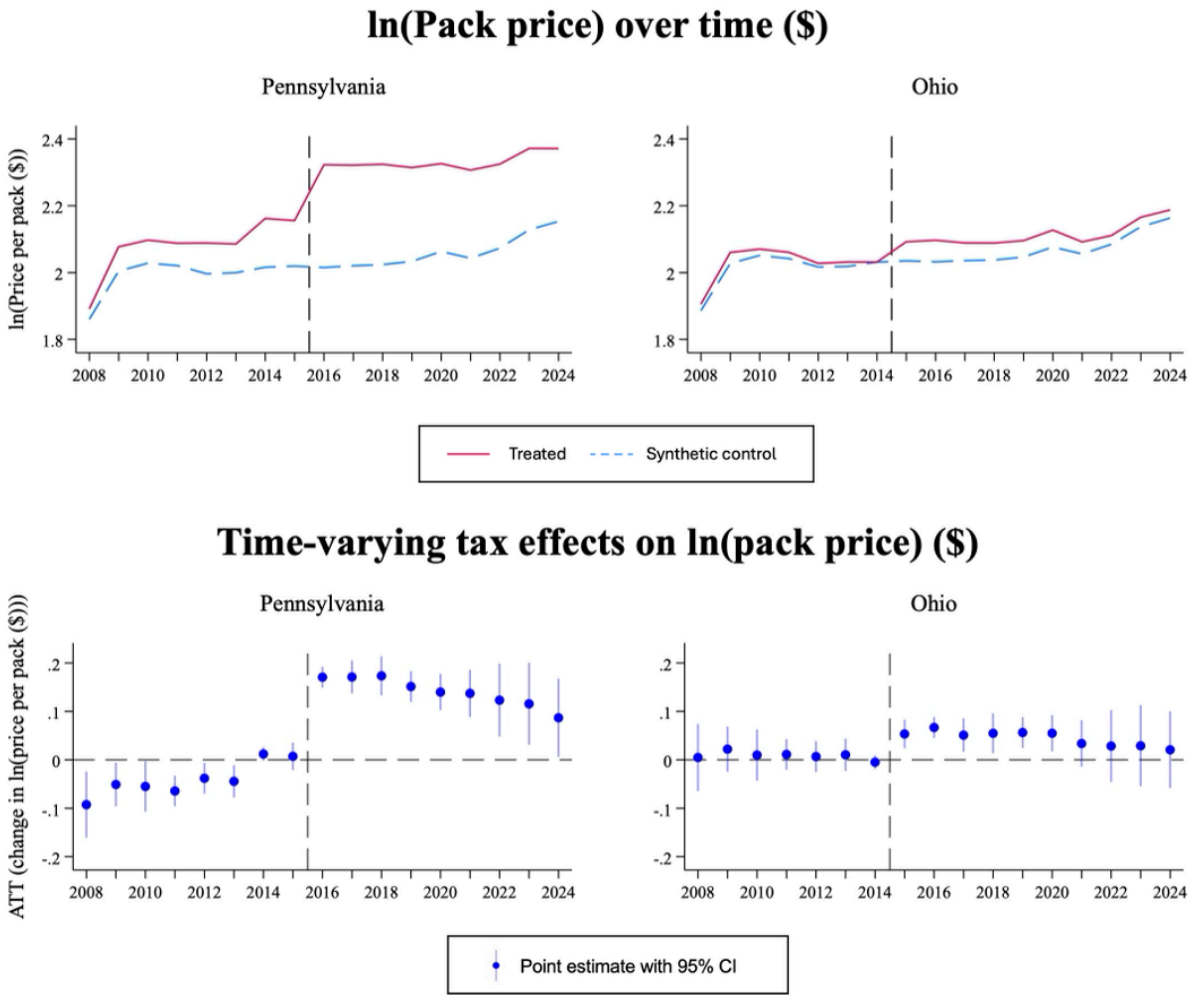

Figure A10. SDID results comparing the ln(price per pack of cigarettes) between Pennsylvania and Ohio to their synthetic counterparts, 2008-2024

Note: The top plots show the change in average logged retail price per pack, inflation-adjusted to 2024 dollars, derived from SDID estimation that include the full set of covariates. The bottom plots show the change over time in the effects of the taxes on logged retail prices per pack, in which each plotted point represents a covariate-adjusted SDID coefficient estimate (ATT, in logged USD) with its corresponding 95% CI.

Table A12. Price elasticity calculation for Pennsylvania and Ohio based on SDID estimates, 2008-2024

	Pennsylvania	**Ohio**
Δ ln(Sales) (ATT)	-0.200***	-0.021
Δ ln(Price) (ATT)	0.131***	0.050*
Implied price elasticity	-1.54	-0.42
95% CI	[-2.68, -0.40]	[-2.23, 1.40]

Note: Implied price elasticities were calculated using ATT estimates of logged per-capita cigarette sales and price per pack of cigarettes from 2008-2024 SDID analyses. 95% CIs were calculated by creating joint placebo estimates for all states in the donor pool (**Table A3**), estimating the joint covariance of the two reduced-form effects, and using the delta method to generate standard errors. To improve the accuracy of the calculated 95% CIs, an RMSPE cutoff of 3 was used to eliminate outlier donor pool states from the calculation.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table A13. Placebo estimates of per-capita cigarette pack sales for states bordering Pennsylvania and Ohio based on 2008-2019 SDID model

Pennsylvania			Ohio		
State	**2016 tax rate**	**Δ per-capita cigarette sales (ATT) (95% CI)**	**State**	**2015 tax rate**	**Δ per-capita cigarette sales (ATT) (95% CI)**
NY	$4.35	0.70 (-4.74, 6.14)	MI	$2.00	2.15 (-1.88, 6.19)
NJ	$2.70	0.76 (-4.58, 6.11)	IN	$1.00	1.03 (-3.24, 5.31)
DE	$1.60	-3.10 (-8.44, 2.24)	KY	$0.62	-10.70*** (-14.90, -6.49)
MD	$2.00	0.59 (-4.88, 6.07)	WV	$0.55	-10.89*** (-15.13, -6.66)
WV	$0.55	-13.54*** (-18.76, -8.33)			

Note: Placebo treatment years were assigned as 2016 for Pennsylvania border states and 2015 for Ohio border states. Highlighted states had lower tax rates than the corresponding treated state. West Virginia increased its state excise tax rate by $0.65 (from $0.55 to $1.20) in 2016, coinciding with the observed decline in cigarette sales and occurring concurrently with Pennsylvania's tax change and shortly after Ohio's. While Kentucky increased its state excise tax rate $0.50 (from $0.60 to $1.10) in 2018, it had the highest per-capita cigarette sales at the start of the study period (141.9 in 2008) and experienced significant declines even before the respective tax changes went into effect. Correspondingly, SDID event-study analyses indicated significant violations of the parallel trends assumption.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

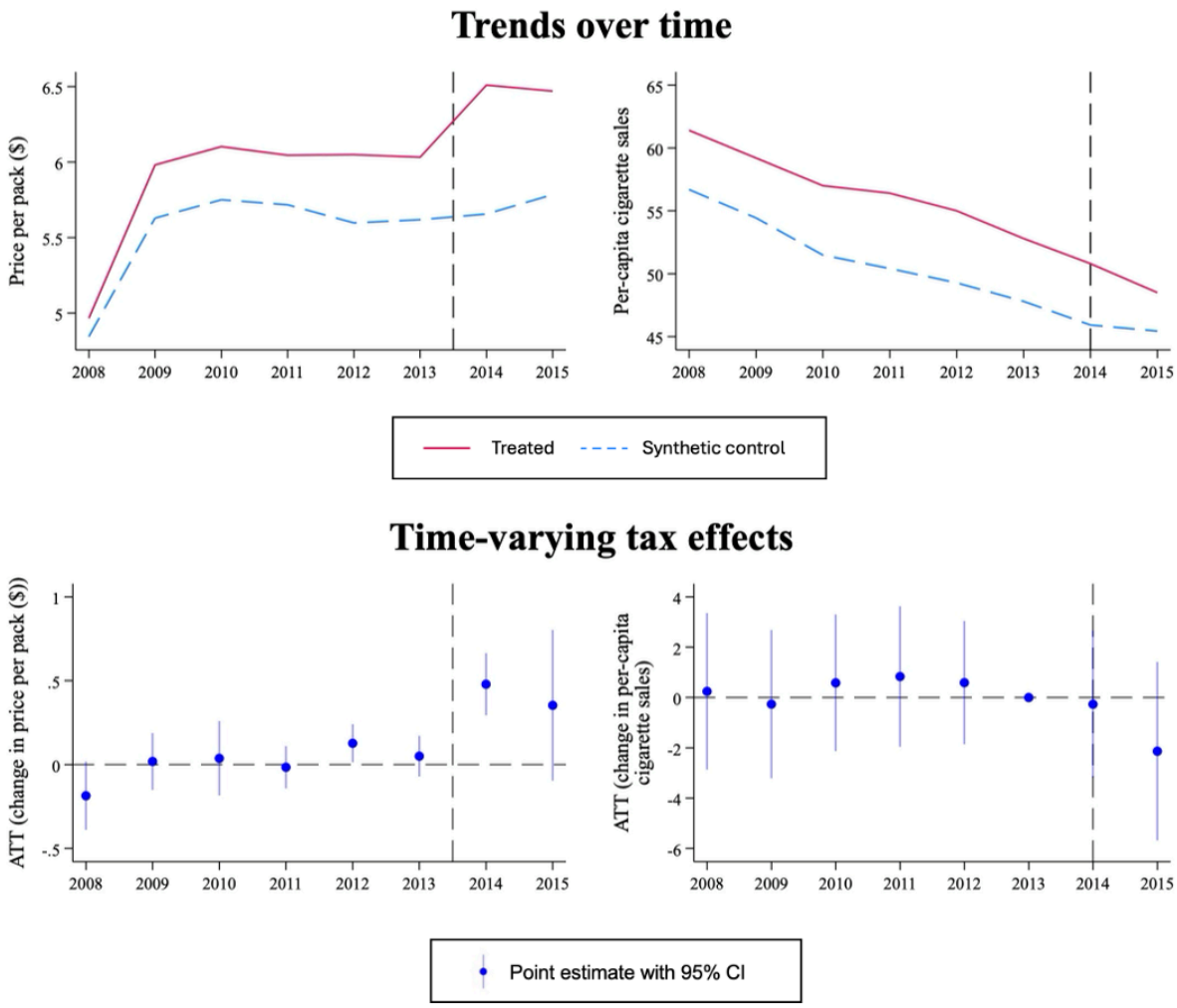

Figure A11. 2014 in-time placebo SDID analysis comparing the price per pack of cigarettes in Pennsylvania to its synthetic counterpart, 2008-2015

Note: An in-time placebo analysis was conducted to assess the impact of a 2014 local excise tax increase of $2.00 in Philadelphia on cigarette prices and per-capita sales across Pennsylvania. An abridged study period (2008-2015) was used to avoid measuring the impacts of the 2016 statewide tax increase. The donor pool was accordingly adjusted to include only states that did not modify their cigarette excise tax rates from 2008-2015. All monetary values were inflation-adjusted to 2015 dollars. The top plots show the change in average retail price per pack and per-capita cigarette pack sales, derived from SDID estimation that includes the full set of covariates.

The bottom plots show the change over time in the effects of the tax on average retail price per pack and per-capita cigarette pack sales, in which each plotted point represents a covariate-adjusted SDID coefficient estimate (ATT, in USD) with its corresponding 95% CI. Philadelphia's price increase was associated with a $0.36 (95% CI: 0.06 to 0.65; $p = 0.017$) increase to Pennsylvania statewide cigarette prices (inflation-adjusted to 2015 dollars) and no statistically significant impact on cigarette sales (ATT = -1.19; 95% CI: -4.89 to 2.51; $p = 0.53$).

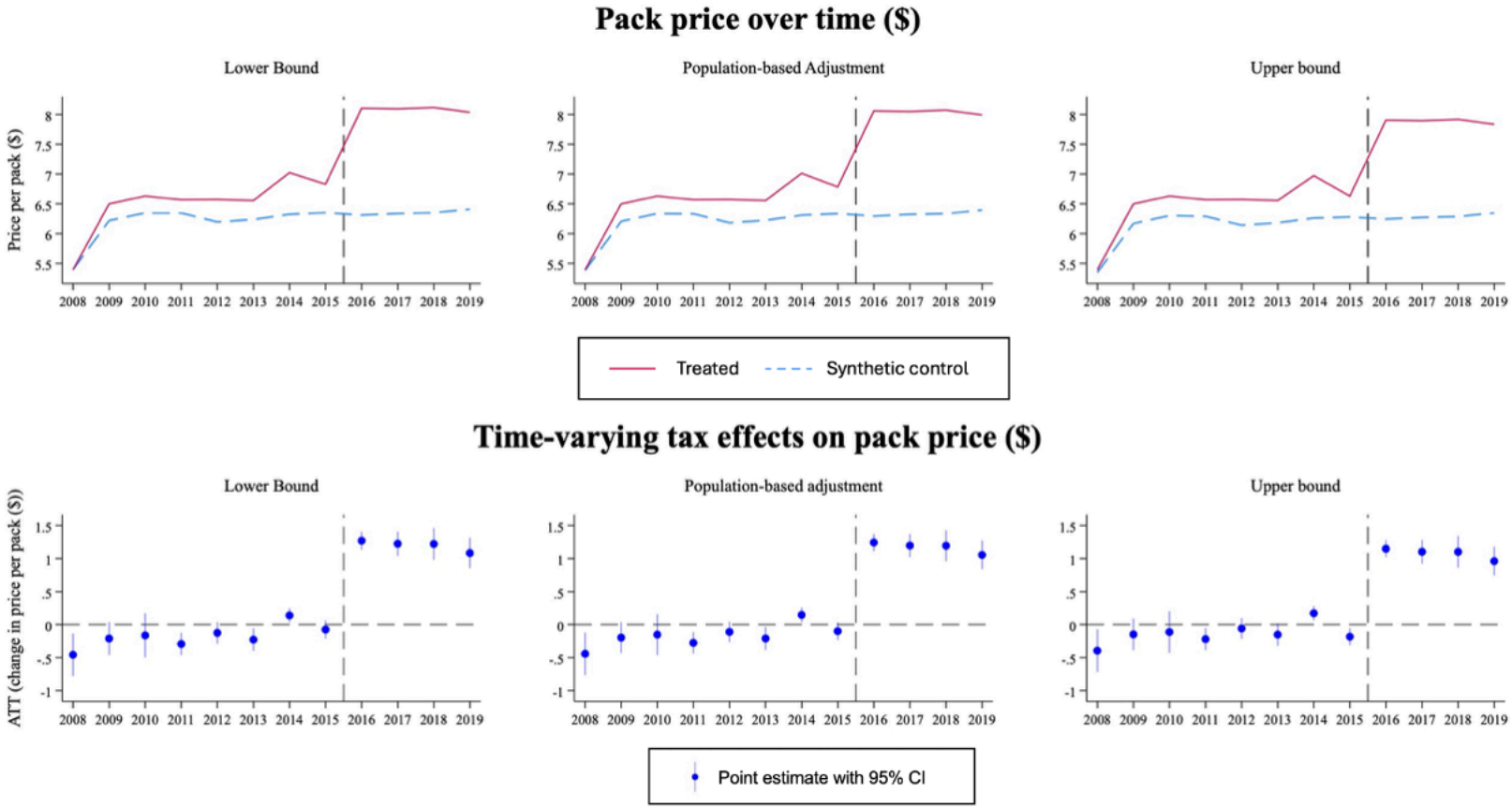

Figure A12. Bounded SDID estimates comparing the price per pack of cigarettes in Pennsylvania, net of the 2014 Philadelphia local tax increase, to its synthetic counterpart, 2008-2019

Note: The top plots show the change in average retail price per pack, in inflation-adjusted 2019 dollars, derived from SDID estimation that include the full set of covariates. The bottom plots show the change over time in the effects of Pennsylvania's tax increase on retail prices per pack, in which each plotted point represents a covariate-adjusted SDID coefficient estimate (ATT, in USD) with its

corresponding 95% CI. In 2014, Philadelphia implemented a local excise tax of $2.00 per pack of cigarettes. To estimate the impact of Pennsylvania's 2016 statewide tax increase while accounting for Philadelphia's local excise tax, Pennsylvania's prices were adjusted, starting in October 2014 (multiplied the price adjustment by 0.25 for 2014), by subtracting from Pennsylvania's price a degree of plausible population-weighted price estimates. Our lower and upper bound estimates were 10% and 20% of $2.00, respectively. To calculate the population-based estimate, the average proportion of Pennsylvania residents living in Philadelphia County across the study period was used as the adjustment. This corresponded to adjustments of $0.20, $0.25, and $0.40 for the lower-, middle-, and upper-bound estimates, respectively. Across the three sensitivities, we observed statistically significant price increases of $1.16, $1.14, and $1.06, respectively, all of which would still be at or above 100% pass-through rate for Pennsylvania's statewide tax increase.

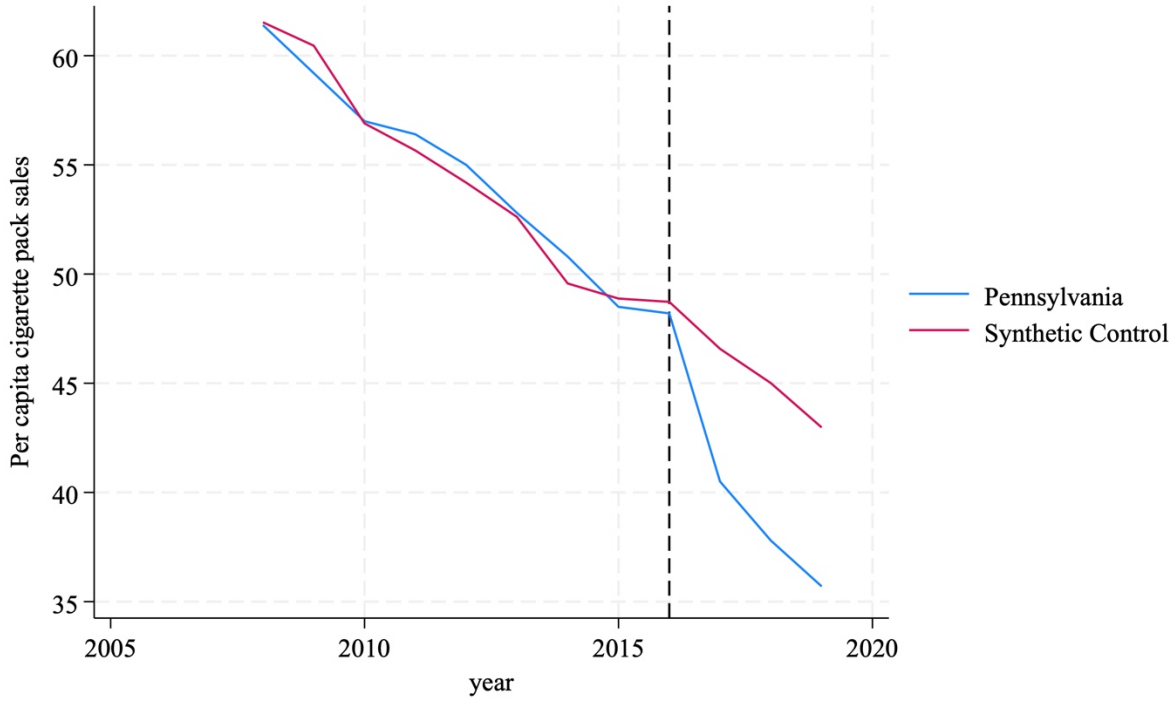

Figure A13. SCM results comparing per-capita cigarette sales in Pennsylvania and its synthetic control, 2008-2019

Note: The donor pool matched that of the 2008-2019 SDID analysis and was limited to states that did not undergo a tax change between 2008 and 2019.

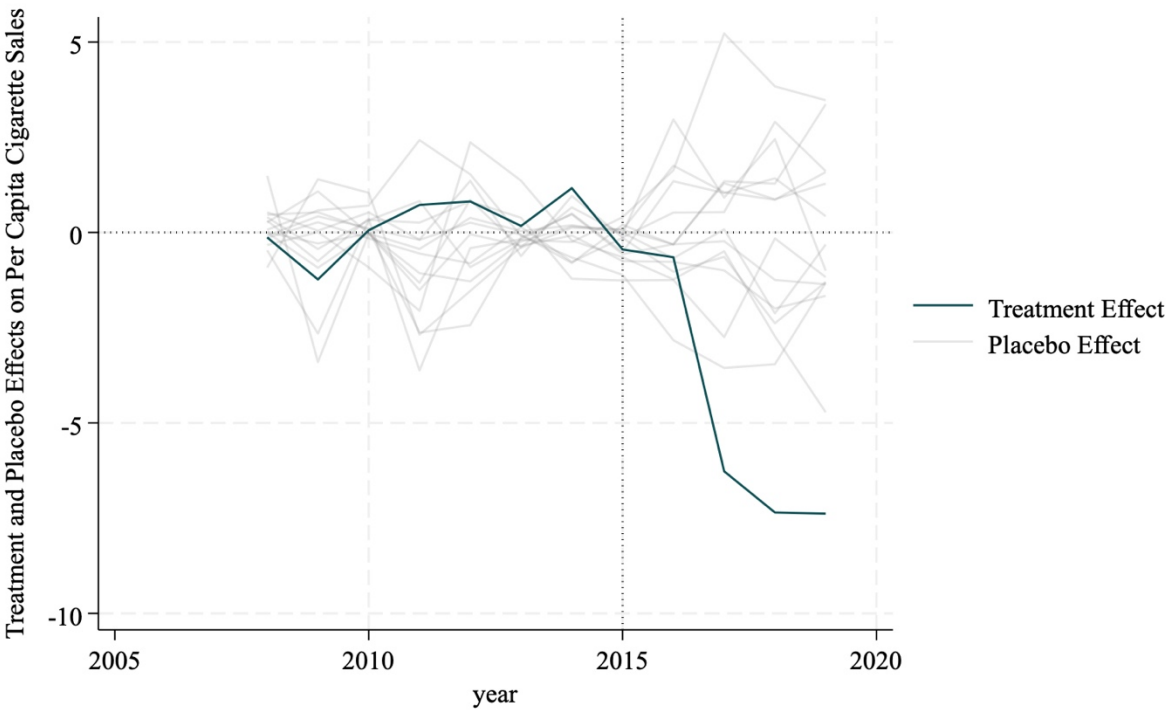

Figure A14. In-space placebo test of Pennsylvania's tax increase on cigarette sales using SCM, 2008-2019

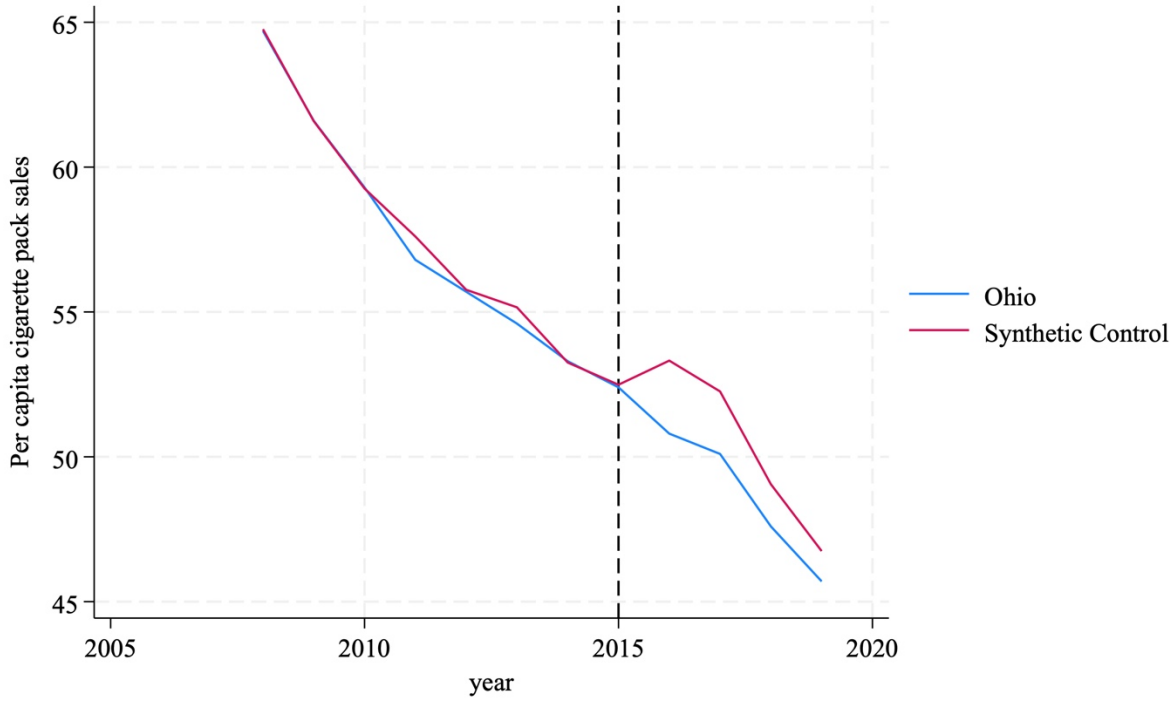

Figure A15. SCM results comparing per-capita cigarette sales in Ohio and its synthetic control, 2008-2019

Note: The donor pool matched that of the 2008-2019 SDID analysis and was limited to states that did not undergo a tax change between 2008 and 2019.

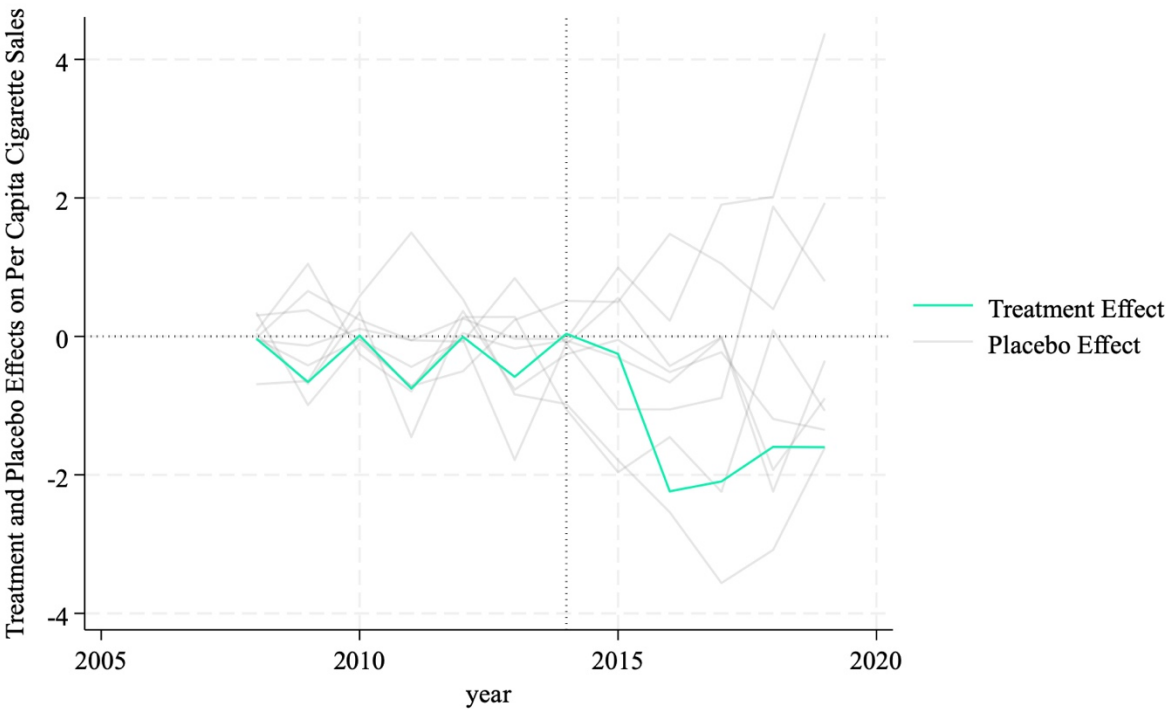

Figure A16. In-space placebo test of Ohio's tax increase on cigarette sales using SCM, 2008-2019