Online Appendix

Supply-Side Drug Policy in the Presence of Substitutes: Evidence from the Introduction of Abuse-Deterrent Opioids

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Appendix Figure A.1: Geographic Variation in Rate of OxyContin Misuse, 2004-2008

Panel A: States with highest and lowest rates of OxyContin misuse

Top 10 Rates of OxyContin Misuse (%)		Bottom 10 Rates of OxyContin Misuse (%)	
Rhode Island	1.15	Washington D.C.	0.47
West Virginia	1.13	Minnesota	0.47
Utah	1.04	Georgia	0.39
Wisconsin	0.98	Nebraska	0.39
Massachusetts	0.97	Mississippi	0.37
Kentucky	0.97	California	0.30
Montana	0.96	Texas	0.29
Indiana	0.96	Iowa	0.27
Nevada	0.95	South Dakota	0.26
Alaska	0.94	Illinois	0.26

Panel B: State variation in Rate of OxyContin Misuse

0.80-1.15% Rate of OxyContin Misuse
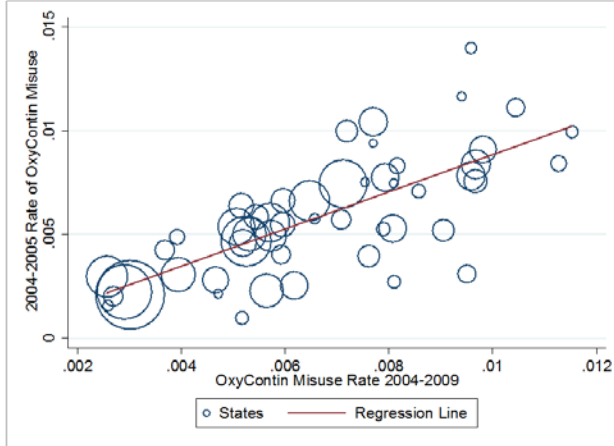0.65-0.79% Rate of OxyContin Misuse
0.50-0.64% Rate of OxyContin Misuse
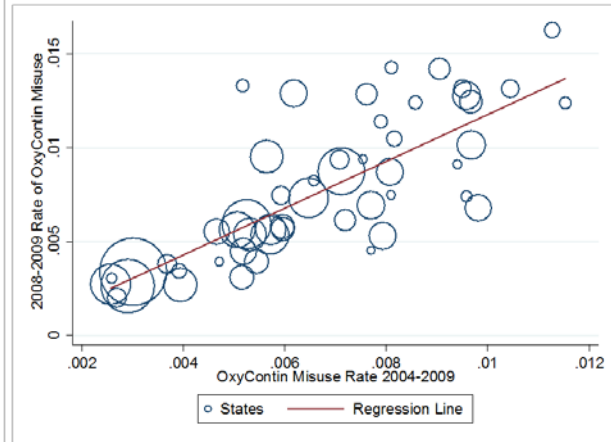0-0.49% Rate of OxyContin Misuse
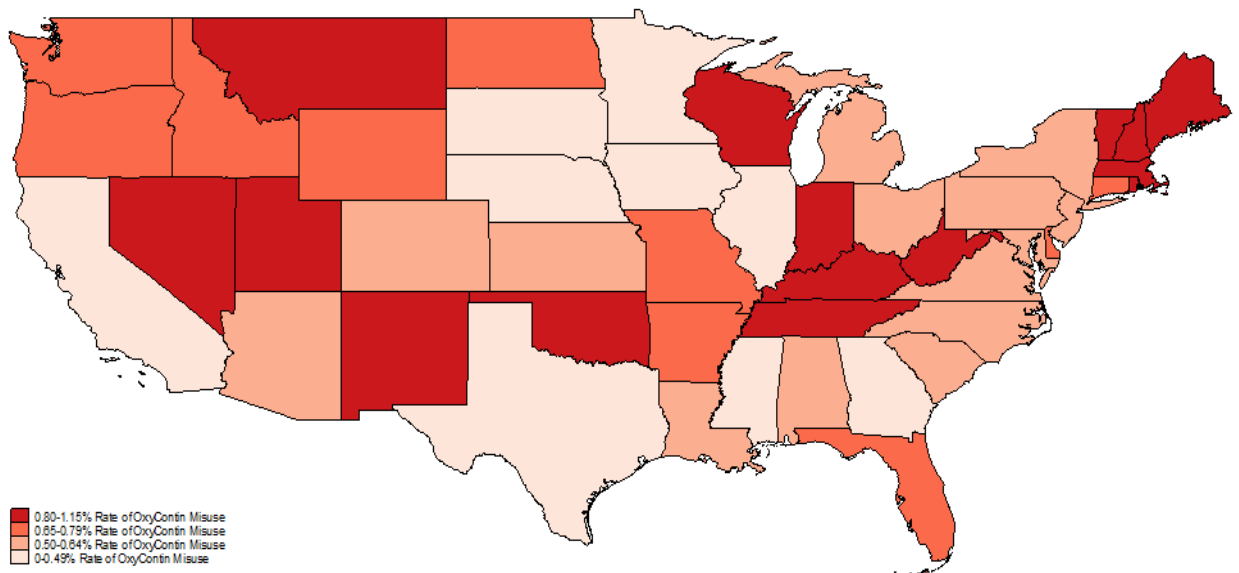
Appendix Figure A.2: Robustness of OxyContin Misuse Rate

Panel A: Relationship between 2004-2009 OxyContin Misuse Measure and 2004 or 2008 OxyContin Misuse Measures (NSDUH)

2004 Misuse: Correlation= 0.811   2008 Misuse: Correlation= 0.835
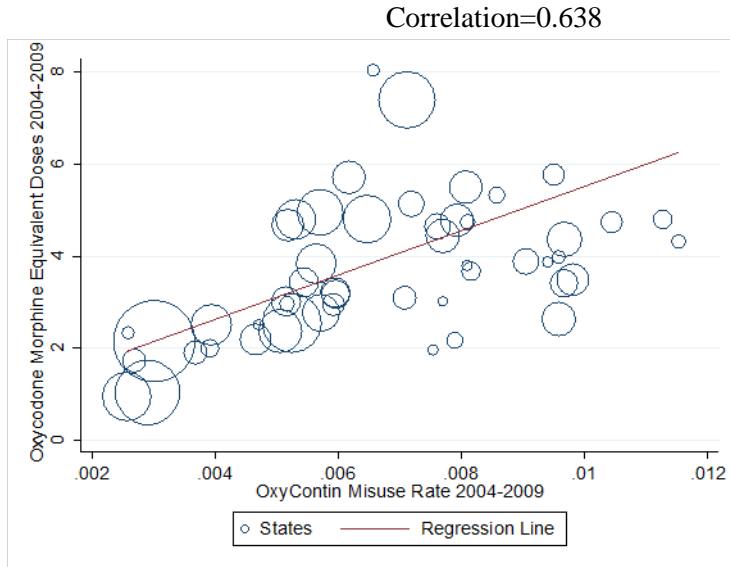

Panel B: Year-to-Year Correlations in OxyContin Misuse (NSDUH)

| NSDUH	2004	2006	2008
2004	1		
2006	0.4445	1	
2008	0.4631	0.6144	1

Note: Each year represents a 2-year wave (e.g. "2004" is 2004-2005)

Appendix Figure A.3: Alternative Measures of OxyContin Misuse Rate

Panel A: Relationship between 2004-2009 OxyContin Misuse (NSDUH) and 2004-2009 Oxycodone Doses (ARCOS)

Correlation=0.638

Panel B: Relationship between 2004-2009 OxyContin Misuse (NSDUH) and 2004-2009 Proportion with OxyContin/Oxycodone Prescription (MEPS)

Correlation= 0.466
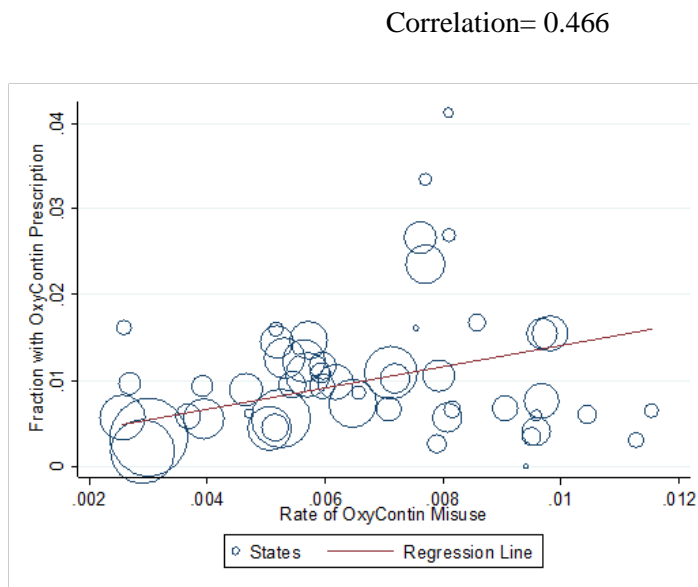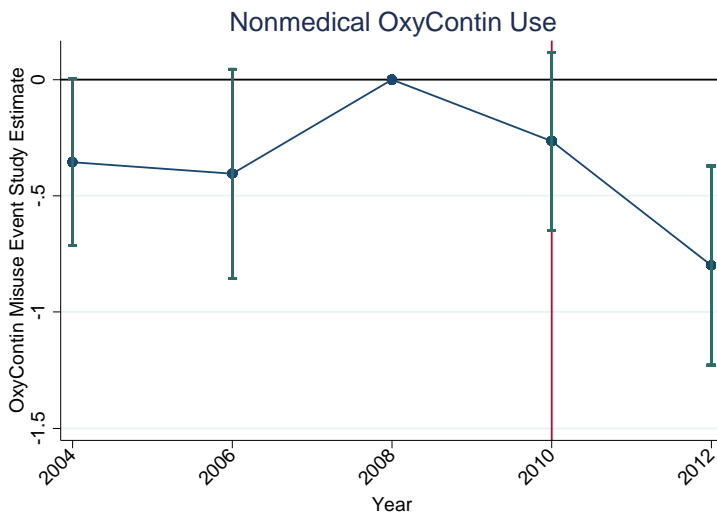
Panel C: Relationship between 2004-2009 OxyContin Misuse (NSDUH) and 2004-2009 Pain Reliever Misuse (NSDUH)
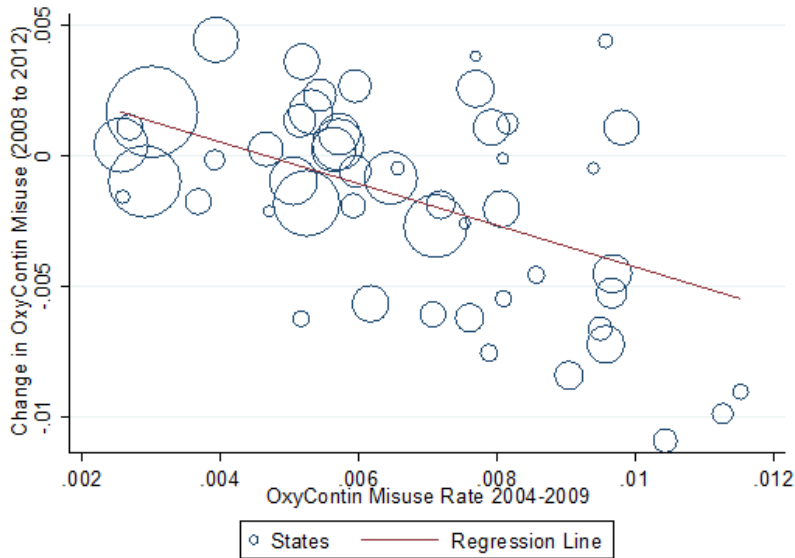
Correlation=0.457
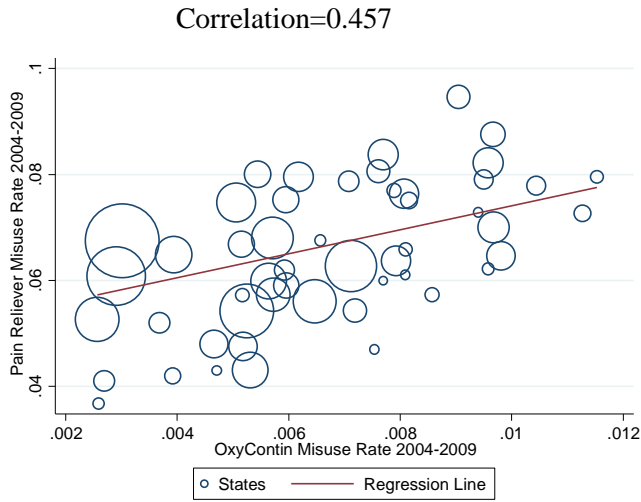
Notes: Size of marker reflects population size.

Appendix Figure A.4: Relationship Between Initial OxyContin Misuse and Changes in OxyContin Misuse – Event Study Specification


Notes: Each year on the x-axis refers to that year and the following year since each NSDUH wave includes two years. Consequently, we should expect a partial effect in 2010 (which includes post-reformulation year 2011) and a full year effect for 2012 (and 2013). The graph reports point estimates and 95% confidence intervals (which are adjusted for within-state clustering) from the event study in Equation 1 using OxyContin misuse as the outcome variable. We can reject that the 2012-2013 estimate is equal to the 2004-2005 estimate at the 5% level, the 2006-2007 estimate at the 10% level, the (normalized to 0) 2008-2009 estimate at the 1% level, and the (partially-treated) 2010-2011 estimate at the 1% level. A joint test that the 2012-2013 estimate is equal to each of the pre-reformulation estimates (2004-2005, 2006-2007, and 2008-2009) rejects at the 1% level.

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Appendix Figure A.5: Relationship Between Initial OxyContin Misuse and Changes in OxyContin Misuse – Scatterplot

Notes: Size of marker reflects population size.

Appendix Figure A.6: Relationship Between Initial Rate of OxyContin Misuse and Heroin Deaths Before the OxyContin Reformulation
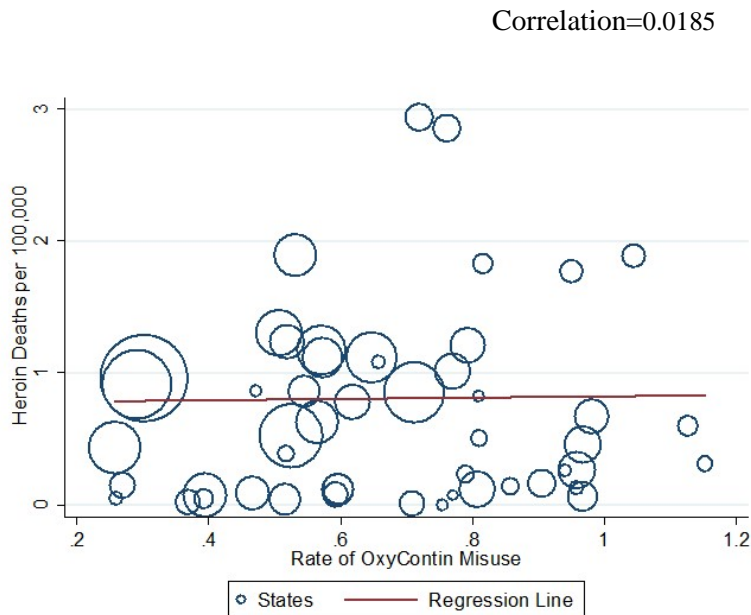
Correlation=0.0185

Notes: This figure shows the correlation between the heroin death rate from 1999-2009 with the initial rate of OxyContin misuse in each state. The size of the marker corresponds to the state population and the regression line is population-weighted.

Appendix Figure A.7: Poisson Event Study Specification
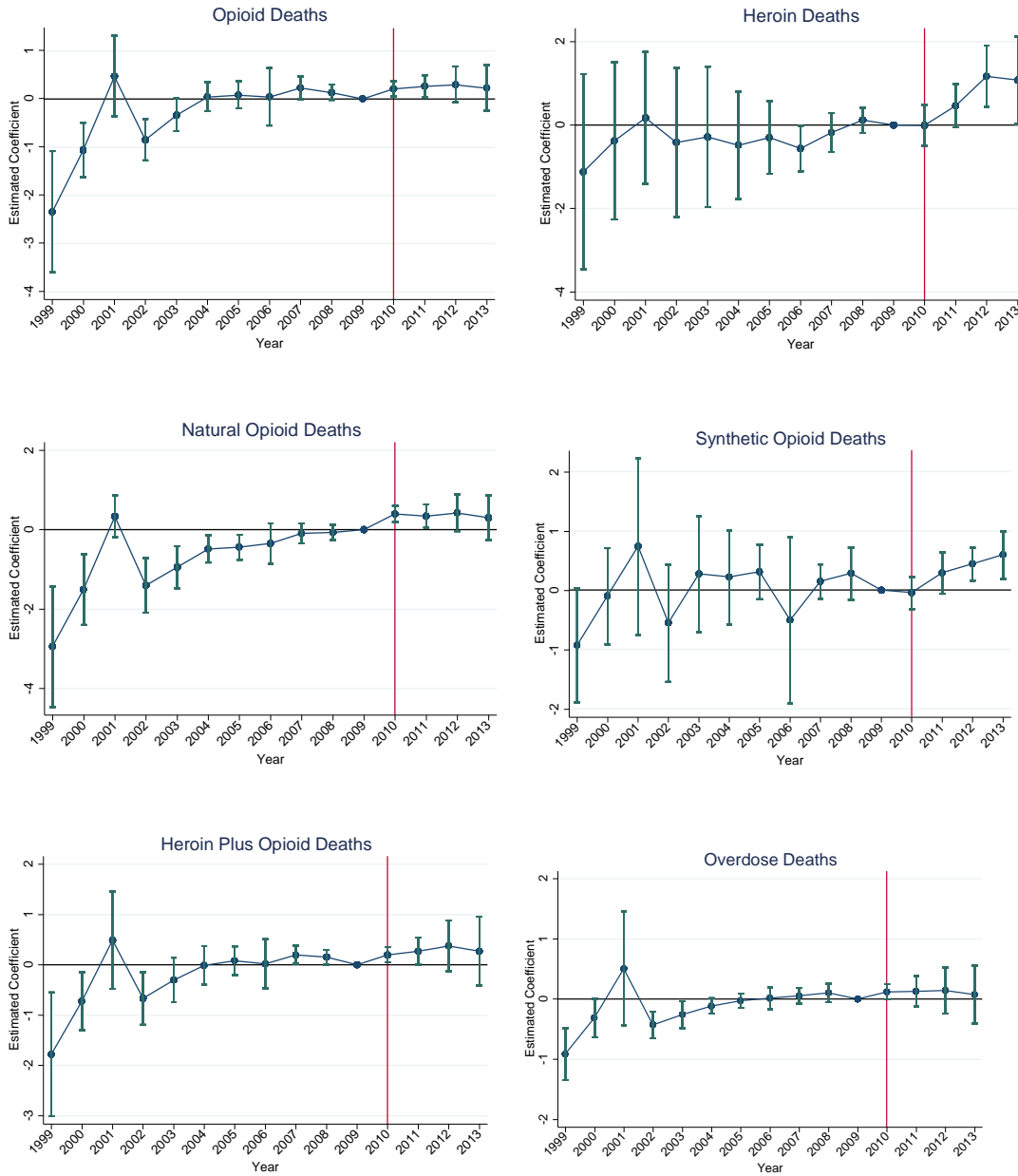
Notes: Each graph includes point estimates from event study (normalized to 0 in 2009) and 95% confidence intervals which are adjusted for within-state clustering.

Appendix Figure A.8: Event Study Specification for Heroin-Only Deaths

Heroin-Only Deaths
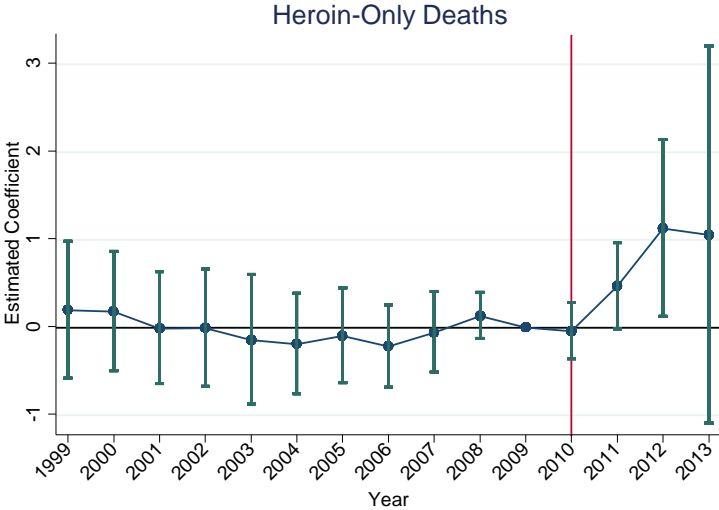
Notes: We exclude deaths also involving other opioids (T40.2-T40.4). Graph includes point estimates from event study (normalized to 0 in 2009) and 95% confidence intervals which are adjusted for within-state clustering.

Appendix Figure A.9: Baseline Event Study Specification for Different Types of Opioid Deaths
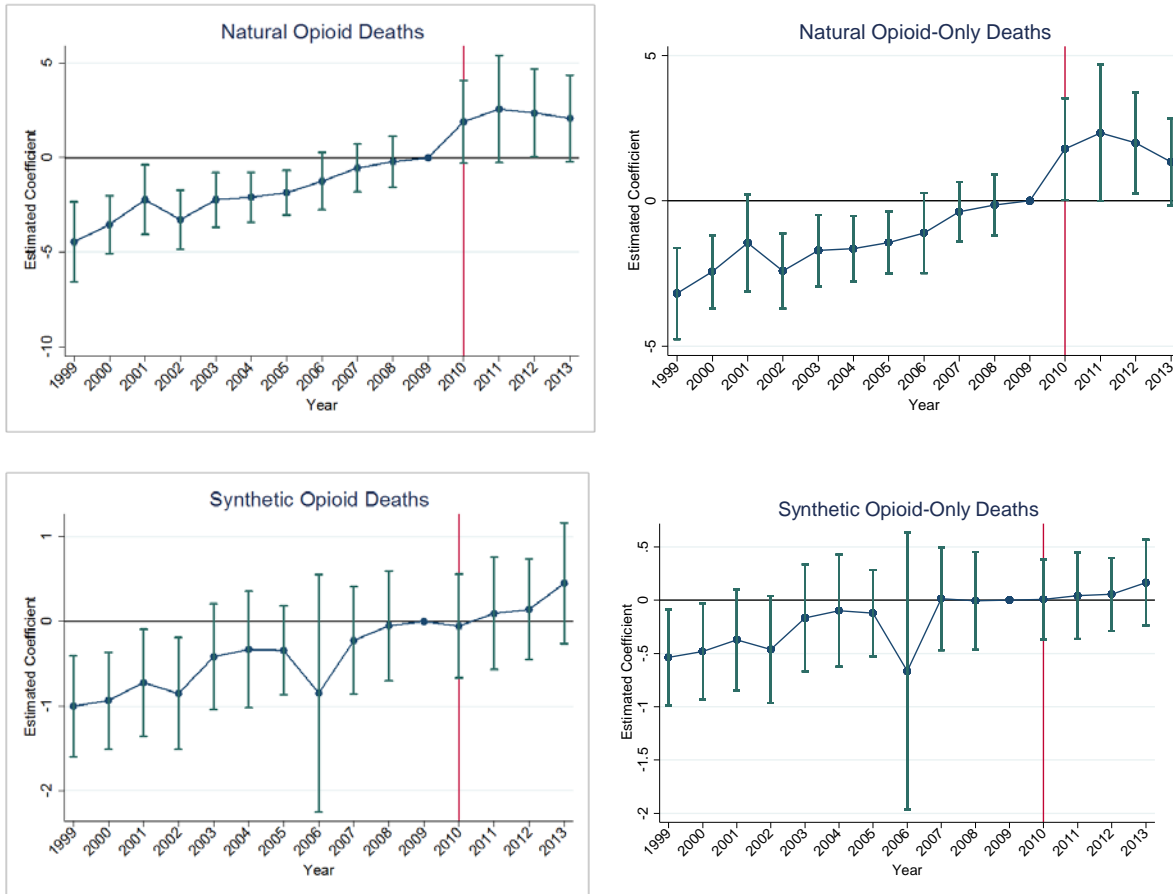
Notes: In the top figures, the left figure includes all drug overdoses involving T40.2 and the right figure uses the same outcome but excludes overdoses that also involve T40.1, T40.3, or T40.4. In the bottom figures, the left figure includes all drug overdoses involving T40.4 and the right figure uses the same outcome but excludes T40.1, T40.2, or T40.3.

Appendix Figure A.10: Relationship Between Initial Rate of OxyContin Misuse and Heroin Substance Abuse Treatment Admissions

Heroin Substance Abuse Treatment Admissions
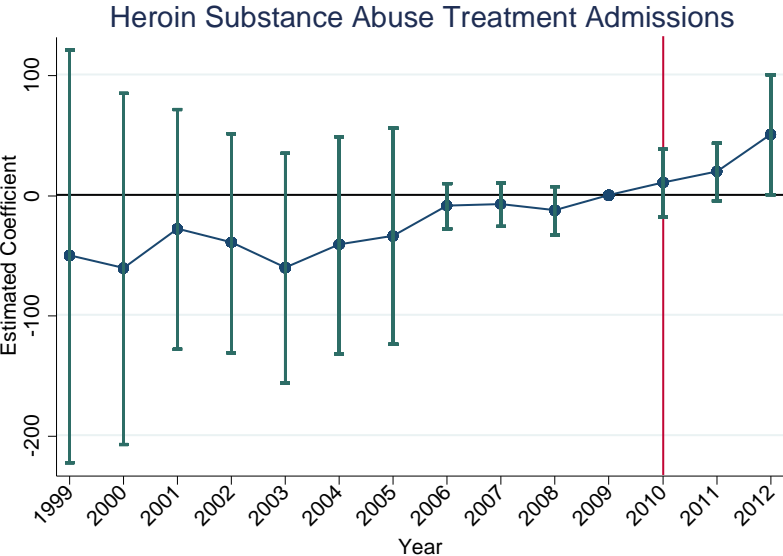
Notes: Outcome variable is number of treatment admissions in the TEDS involving heroin per 100,000. 95% confidence intervals adjusted for clustering at state-level.

Appendix Figure A.11 – Instrumental Variables Event Study Specification for Heroin Deaths

Panel A: Effects of Initial (2008) OxyContin Misuse
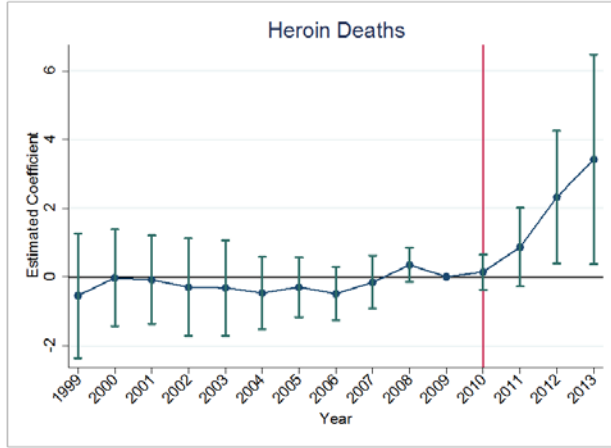
Panel B: Jointly Estimating Effects of Initial OxyContin and Pain Reliever Misuse
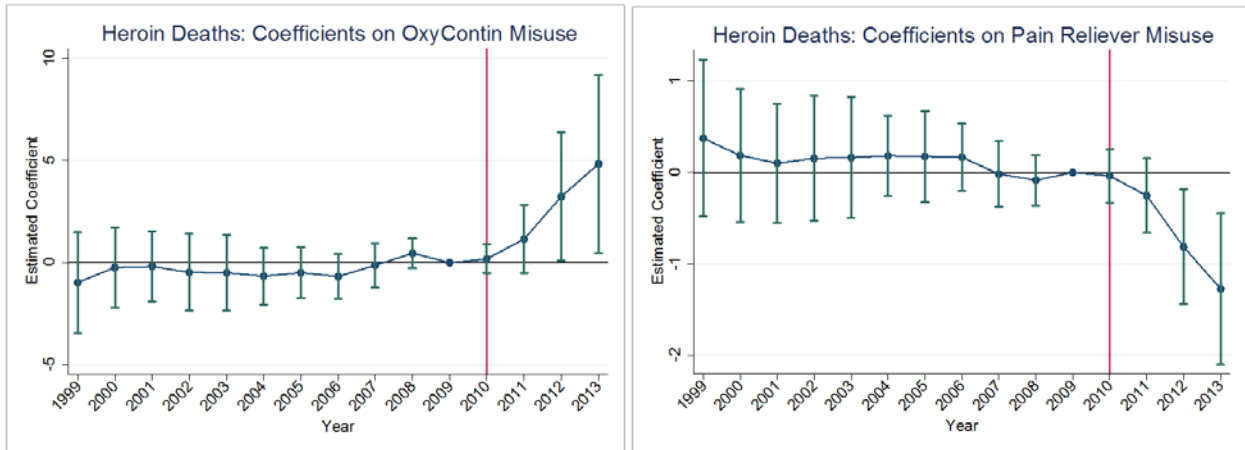
Notes: The graph on the left shows the estimates and 95% confidence intervals for the 2008 nonmedical OxyContin misuse variable for each sample. The graph on the right shows the estimates and 95% confidence intervals for the 2008 nonmedical pain reliever misuse variable for each sample. The estimates in both figures are jointly estimated. The specification uses the 2004 nonmedical OxyContin misuse rates and 2004 nonmedical pain reliever misuse rates interacted with year indicators as instruments.

Appendix Figure A.12 – Alternative Explanations: Event Study Results for Economic Conditions

Panel A: Unemployment Rate

log(Unemployment Rate)
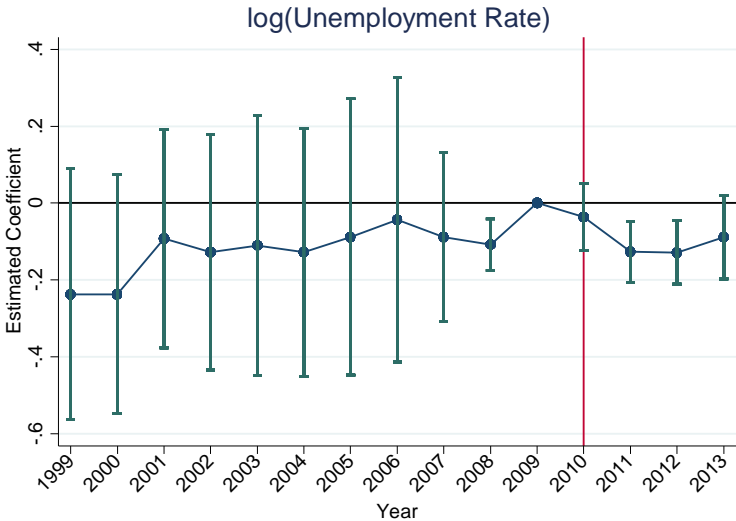
Notes: 2011-2013 estimates are not statistically different from any pre-reformulation estimate except for the (excluded) 2009 estimate (smallest p-value=0.3492).

Panel B: Housing Price Index

Log of HPI
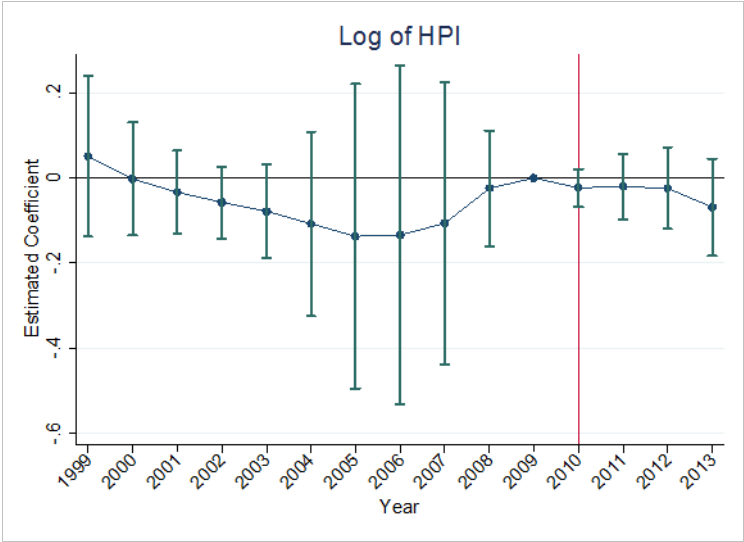
Source: Federal Housing Finance Agency

Appendix Figure A.13: Placebo Tests – Effect of Reformulation on Other Types of Drug Overdoses

Panel A: Cocaine Overdoses

Cocaine Deaths
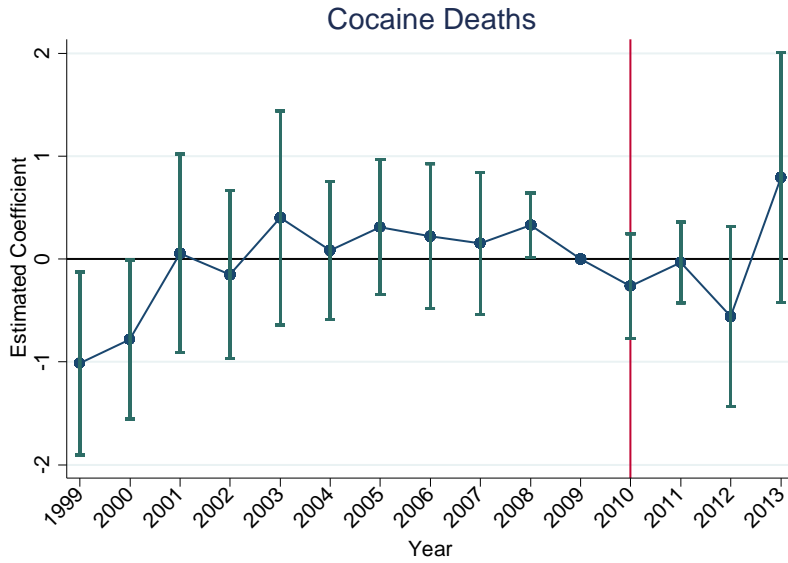
Panel B: All Drug Overdoses, Excluding Heroin and Opioids

Overdose Deaths (Excluding Heroin and Opioids)
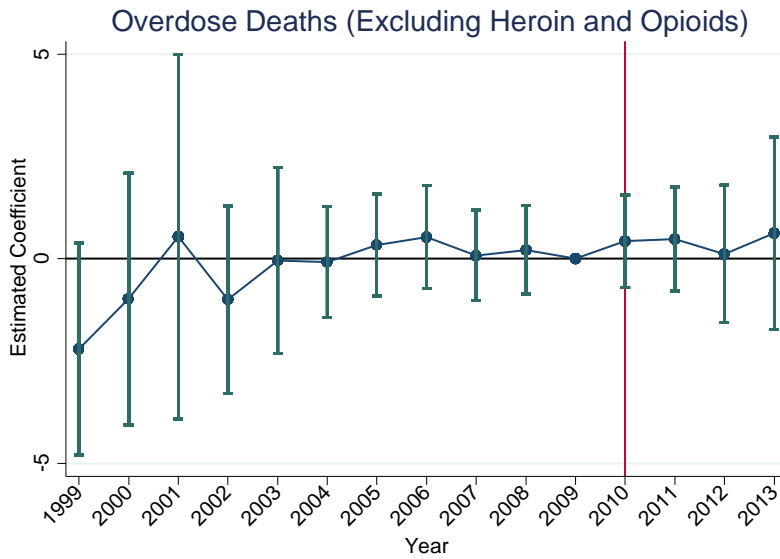
Appendix Table A1: Relationship between Legal Opioid Supply (ARCOS) and Pain Reliever Misuse Rates (NSDUH)

	OxyContin misuse	Other Pain Reliever misuse
Per Capita oxycodone MED	0.085***	0.035
	(0.022)	(0.083)
Per Capita hydrocodone MED	0.041	0.656***
	(0.028)	(0.160)
N	51	51

Notes: *10% Significance, **5% Significance, ***1% Significance. Heteroskedastic-robust standard errors shown in parentheses. MED = morphine equivalent doses. Results are from cross-sectional regressions. All variables are constructed by averaging over 2004-2009 data.

Appendix Table A2: Relationship Between OxyContin Misuse and Changes in Heroin Death Rates –Coefficient Estimates

Outcome:	Heroin Deaths per 100,000					
	(1)	(2)	(3)	(4)	(5)	(6)
Coefficient from Equation (2):						
delta1	0.839**	0.964***	1.218***	1.366***	1.015***	1.089***
	(0.323)	(0.335)	(0.365)	(0.372)	(0.230)	(0.208)
delta2	-0.049	-0.301	-0.224	-0.335	-0.339**	-0.439***
	(0.122)	(0.273)	(0.244)	(0.261)	(0.163)	(0.154)
delta3	0.687	0.920*	0.653	1.107**	0.202	0.251
	(0.528)	(0.538)	(0.497)	(0.498)	(0.274)	(0.269)
Implied 1 year effect (delta1)	0.839**	0.964***	1.218***	1.366***	1.015***	1.089***
	(0.323)	(0.335)	(0.365)	(0.372)	(0.230)	(0.208)
Implied 2 year effect (delta1 + 1*delta3)	1.526***	1.884***	1.870***	2.473***	1.217***	1.340***
	(0.537)	(0.555)	(0.622)	(0.631)	(0.376)	(0.367)
Implied 3 year effect (delta1 + 2*delta3)	2.212**	2.804***	2.523**	3.581***	1.420**	1.591***
	(1.016)	(1.041)	(1.065)	(1.074)	(0.616)	(0.608)
State and Time-Varying Covariates	No	Yes	Yes	Yes	Yes	Yes
Policy Variables	No	No	Yes	Yes	Yes	Yes
Control for Initial Pain Reliever	No	No	No	Yes	No	Yes
Estimator	OLS	OLS	OLS	OLS	Poisson	Poisson

Notes: *10% Significance, **5% Significance, ***1% Significance. Standard errors in parentheses adjusted for clustering at the state-level. This table replicates Table 2, reporting the underlying "delta" coefficients used to compute the 3-year effect. Coefficients for initial pain reliever use variables (not shown) are constructed similarly.

Appendix Table A3: Relationship Between OxyContin Misuse and Changes in Heroin Death Rates -- Block-Bootstrapped Confidence Intervals

Outcome:	Heroin Deaths per 100,000			
	(1)	(2)	(3)	(4)
A. Total Heroin Deaths per 100,000				
Initial OxyContin (3 Year Effect)	2.212**	2.804***	2.523**	3.581***
	[0.419, 4.005]	[1.026, 4.582]	[0.483, 4.563]	[1.791, 5.371]
Initial Pain Reliever (3 Year Effect)				-0.495**
				[-0.909, -0.080]
Mean of Dep. Variable (2008-09):	1.060			
State and Time-Varying Covariates	No	Yes	Yes	Yes
Policy Variables	No	No	Yes	Yes
Estimator	OLS	OLS	OLS	OLS

Notes: *10% Significance, **5% Significance, ***1% Significance. This table replicates Table 2 using a block-bootstrapped procedure for inference. 95% confidence intervals are shown in brackets adjusted for block-bootstrapping at the state-level, using a percentile-*t* bootstrap and creating symmetric confidence intervals. State fixed effects and year fixed effects included in all specifications. Each model also includes a linear trend interacted with initial nonmedical OxyContin misuse as well as a post-2011 indicator interacted with initial nonmedical OxyContin misuse. Finally, a separate post-2011 linear trend interacted with initial nonmedical OxyContin misuse is also included. We report the 3 year post-2011 effect of the initial OxyContin variable. Regressions are weighted by population. Years 2008-2013 are used.

Appendix Table A4: Heroin Effects Using Alternative Measures of Exposure to the Reformulation

Outcome:	Heroin Deaths per 100,000			
	Main Result	OxyContin Misuse/ Pain Reliever Misuse	Oxycodone/ (Oxycodone+Hydrocodone)	Oxycodone/ Hydrocodone
Exposure Measure:	2.523**	22.804***	4.079**	0.360***
	(1.065)	(7.594)	(1.666)	(0.132)
Effect of One Std Dev Increase:	0.568	0.709	0.668	0.702

Notes: *10% Significance, **5% Significance, ***1% Significance. Standard errors in parentheses adjusted for clustering at the state-level. State fixed effects, year fixed effects, and additional covariates are included in all specifications. Each model also includes a linear trend interacted with the exposure measure (e.g. initial nonmedical OxyContin misuse) as well as a post-2011 indicator interacted with the exposure measure. Finally, a separate post-2011 linear trend interacted with the exposure measure is also included. We report the 3 year post-2011 effect of the exposure variable. Regressions are weighted by population. Since units are different for each exposure measure, the effect of a one standard deviation increase in exposure to the reformulation is shown in the bottom row.

Appendix Table A5: Heterogeneity in Opioid Effects

Outcome:	Opioid Deaths per 100,000								
By Subgroup:	Age Group			Gender		Race		Education	
								HS degree or less	More than HS
	Ages 0-24	Ages 25-64	Ages 65+	Female	Male	White	Non-White		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Initial OxyContin (3 Year Effect)	-0.774	-0.510	0.798	0.837	-1.764	0.049	1.860	-0.334	0.990
	(0.706)	(2.872)	(1.081)	(1.169)	(2.545)	(2.155)	(1.438)	(4.000)	(2.093)
Mean of Dep. Variable (2008-09):	1.601	8.453	1.310	4.008	6.417	6.899	1.992	10.254	4.655

Notes: *10% Significance, **5% Significance, ***1% Significance. Standard errors in parentheses adjusted for clustering at the state-level. State fixed effects and year fixed effects and the full set of covariates are included in all specifications. Each model also includes a linear trend interacted with initial nonmedical OxyContin misuse as well as a post-2011 indicator interacted with initial nonmedical OxyContin misuse. Finally, a separate post-2011 linear trend interacted with initial nonmedical OxyContin misuse is also included. We report the 3 year post-2011 effect of the initial OxyContin variable. Regressions are weighted by population. Years 2008-2013 are used. Columns 8 and 9 include only individuals ages 25+ to exclude those without completed education.

Appendix Table A6: Robustness Tests for Baseline Estimates for Opioid and Heroin Deaths

Panel A: Heroin Deaths

Outcome:	Heroin Deaths per 100,000							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Initial OxyContin (3 Year Effect)	2.523**	3.725**	3.759***	2.523**	2.035*	2.700***	1.256*	2.637**
	(1.065)	(1.801)	(1.229)	(1.008)	(1.018)	(0.804)	(0.731)	(1.100)
State Linear Trends	No	No	No	Yes	No	No	No	No
Weighted	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Years	2008-2013	No 2010	2008-2013	2008-2013	1999-2013	2008-2013	2008-2013	2008-2013
Initial Abuse Measure	2004-2008	2004-2008	2004-2008	2004-2008	2004-2008	2004	2008	2004-2008
Age-Adjusted	No	No	No	No	No	No	No	Yes

Panel B: Opioid Deaths

Outcome:	Opioid Deaths per 100,000							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Initial OxyContin (3 Year Effect)	-0.420	4.250	1.391	-0.261	-2.813***	1.402	-1.229	-0.463
	(1.698)	(5.883)	(1.960)	(1.892)	(0.917)	(1.525)	(1.258)	(1.809)
State Linear Trends	No	No	No	Yes	No	No	No	No
Weighted	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Years	2008-2013	No 2010	2008-2013	2008-2013	1999-2013	2008-2013	2008-2013	2008-2013
Initial Abuse Measure	2004-2008	2004-2008	2004-2008	2004-2008	2004-2008	2004	2008	2004-2008
Age-Adjusted	No	No	No	No	No	No	No	Yes

Notes: *10% Significance, **5% Significance, ***1% Significance. Standard errors in parentheses adjusted for clustering at the state-level. State fixed effects, year fixed effects, and the full set of covariates are included in all specifications. Each model also includes a linear trend interacted with initial nonmedical OxyContin misuse as well as a post-2011 indicator interacted with initial nonmedical OxyContin misuse. Finally, a separate post-2011 linear trend interacted with initial nonmedical OxyContin misuse is also included. We report the 3 year post-2011 effect of the initial OxyContin variable. Regressions are weighted by population unless noted otherwise. "Age Adjusted" uses an age-adjusted version of the outcome variable by weighting age-specific mortality rates, holding the weights constant across states and time.

Appendix Table A7: IV Estimates using Alternative Measures of OxyContin Misuse

	Heroin		Opioids	
Initial OxyContin (3 Year Effect)	5.218**	6.447**	2.272	4.172
	(2.156)	(3.012)	(2.942)	(4.276)
Initial Pain Reliever (3 Year Effect)		-1.814*		-1.568
		(0.884)		(1.131)
Years	2008-2013	2008-2013	2008-2013	2008-2013
Initial Abuse Measure	2008	2008	2008	2008
Estimator	IV	IV	IV	IV

Notes: *10% Significance, **5% Significance, ***1% Significance. Standard errors in parentheses adjusted for clustering at the state-level. State fixed effects, year fixed effects, and additional covariates are included in all specifications. Each model also includes a linear trend interacted with initial (2008) nonmedical OxyContin misuse as well as a post-2011 indicator interacted with initial (2008) nonmedical OxyContin misuse. Finally, a separate post-2011 linear trend interacted with initial (2008) nonmedical OxyContin misuse is also included. We report the 3 year post-2011 effect of the initial OxyContin variable. Regressions are weighted by population. IV estimation is used in which the instruments are the same variables using the 2004 measures of initial nonmedical use.

Appendix Table A8: Alternative Explanations: Opioid Deaths

Outcome:	Opioid Deaths per 100,000							
	Main Result	Add PDMP	Must Access	Add MMLs	Add Pill Mill Laws	No FL	No Pill Mill States	West Only
Initial OxyContin (3 Year Effect)	-0.266	-0.231	-0.211	-0.360	-0.420	0.349	1.475	-1.445
	(1.765)	(1.751)	(1.717)	(1.728)	(1.698)	(1.742)	(1.549)	(4.498)
Mean of Dep. Variable (2008-09)	5.192	5.192	5.192	5.192	5.192	5.012	4.895	6.262
Number of Observations	306	306	306	306	306	300	288	78

Notes: *10% Significance, **5% Significance, ***1% Significance. Standard errors in parentheses adjusted for clustering at the state-level. State fixed effects, year fixed effects, and the full set of state and time-varying covariates (excluding policy variables) are included in all specifications. Each model also includes a linear trend interacted with initial nonmedical OxyContin misuse as well as a post-2011 indicator interacted with initial nonmedical OxyContin misuse. Finally, a separate post-2011 linear trend interacted with initial nonmedical OxyContin misuse is also included. We report the 3 year post-2011 effect of the initial OxyContin variable. Regressions are weighted by population. "No Pill Mill States" means that Florida, Kentucky, and West Virginia are excluded. "West Only" means that only states in the West Census Region are included in the sample.