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Do State and Local Policies Surrounding Fentanyl Test Strips Impact Overdose Deaths?

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Abstract

We examine the effects of legalizing fentanyl test strips (FTS), which identify the presence of fentanyl in recreational drugs, on overdose deaths. Using difference-in-differences methods, we find that purely increasing *de jure* access to fentanyl test strips (FTS), which can reduce information asymmetries regarding drug contents, had little effect on overdose mortality. We then examine the effects of multi-dimensional community-based interventions aimed at increasing *de facto* access to FTS and other harm reduction resources. These hands-on approaches were more effective in reducing overdose deaths. Together, these findings suggest that FTS are used at sub-optimal levels, and more active efforts to distribute them could reduce overdoses.

Keywords: Opioids, Fentanyl, Overdoses, Harm Reduction, Difference-in-Differences, Synthetic Control

JEL codes: I12, I18, D62, H41, H75

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1 Introduction

In 2022 there were over 100,000 drug overdose deaths, a 160% increase in the 10 years since 2012. Synthetic opioids, predominantly fentanyl, have been the primary driver of overdose deaths in the U.S. (National Institute on Drug Abuse, ND). Many of these overdoses come from using other substances laced with fentanyl rather than fentanyl alone. Starting in the mid-2000s, fentanyl has increasingly been found as an adulterant in the illicit drug supply, including in heroin, cocaine, and methamphetamine, as well as illicit opioid and benzodiazepine pills (Armenian et al., 2018; Ciccarone, 2019). Fentanyl is so lethally potent that it has crowded out overdose deaths from other illicit substances. In 2013, there were roughly 46,500 overdose deaths across the U.S., and around 3,100 or 6.7% were from synthetic opioids. However, by 2019, more than half of all overdose deaths involved synthetic opioids (Mattson, 2021; Xu et al., 2016).

To combat this rise in overdoses, a number of harm reduction tools have been made available to people who use drugs, including medications for opioid use disorder (MOUD), Narcan (naloxone), and fentanyl test strips (FTS). FTS are low cost and are used to detect the presence of fentanyl in other drugs. The optimal bundle of harm reduction measures depends on the economic primitives behind the recent increase in overdose deaths. If drug users are fentanyl averse, and unaware that fentanyl is in their drugs, tools like FTS that alleviate asymmetric information about adulterants are a crucial component. However, if as some evidence suggests, some drug users prefer drugs that contain fentanyl because of its low cost and high potency (Stein et al., 2019; Park et al., 2021; LaForge et al., 2022), other measures such as MOUD and Narcan may have greater impacts on overdose death rates.

In this paper, we examine the effects of increased access to FTS on overdose deaths through two types of policy interventions. Clinical evidence has shown that the use of FTS can reduce risky drug usage and the likelihood of a drug overdose (Karamouzian et al., 2018; Goldman et al., 2019; Park et al., 2021). However, War-on-Drugs era legislation from the 1970's and 1980's that outlawed drug paraphernalia made drug checking equipment like FTS illegal in several states (Legislative Analysis and Public Policy Association, 2022). Starting in 2018, states began legalizing possession and usage of FTS. Using both event studies and staggered difference-in-differences approach, we first examine whether removing the legal constraint, and increasing *de jure* access to FTS, has any impact on overdose death rates. We compile a novel dataset consisting of restricted-access multiple cause of mortality (MCOM) data from Centers for Disease Control (CDC), merged with publicly available CDC data on county-level opioid prescriptions, and legislative data on enacted dates of FTS legalization. The results indicate that legalizing FTS did not, in and of itself, have a statistically significant effect on overdose deaths.[1] While the applied economics literature has conditioned readers to expect that any increases in access will improve outcomes, several things need to be true for greater *de jure* access to FTS to reduce overdose deaths. First, overdoses would need to be at least partially attributable to asymmetric information about drug purity, rather than some rational addiction process (Akerlof, 1970; Becker and Murphy, 1988). Second, users of illicit substances would need to prefer drugs without fentanyl.[2] Third, drug paraphernalia laws must have substantially constrained access to FTS. However, drug paraphernalia laws were not consistently enforced, at least with respect to drug checking equipment (Davis et al., 2022). These null results indicate that some of these conditions do not hold. Importantly however, these results should not be used cast doubt on FTS as an effective harm reduction tool, nor should they be used to discourage efforts to increase access to FTS. FTS usage is associated with risk-reducing behaviors among drug users, such as using less of the substance or asking someone to check on them (Goldman et al., 2019; Park et al., 2021). Furthermore, legalizing FTS is an important step in clearing up any confusion surrounding the legality of drug checking equipment. Legalization signals to residents that FTS are available in their state, and empowers public health agencies and non-governmental organizations to proactively distribute FTS. However, our findings indicate that increasing *de jure* access by itself is insufficient and more comprehensive interventions may be required to increase *de facto* access and utilization of FTS.

It is also possible that the null effects found in the full sample analysis could mask heterogeneous effects among different subpopulations or different subsets of counties. For example, risk aversion

[1]These results contrast those from Bhai et al. (2025), who find that FTS legalization is linked to decreased mortality. However, while Bhai et al. (2025) examine the relationship between FTS and *total* overdose deaths at the state-month level, we examine county-year level mortality specific to opioids and synthetic opioids, which FTS is designed to detect.

[2]As noted earlier some drug users actually prefer drugs containing fentanyl.

and receptivity to information treatments may vary with age (Dohmen et al., 2011; Albert and Duffy, 2012). Therefore, we examine whether FTS legalization affected overdose death rates across different age groups. We find modest effects for users aged 15-24, 25-34, and 35-44, but only after at least three years following legalization. Second, we examine whether legalizing FTS reduced the number of accidental overdose deaths, and find no effect. Finally, FTS may have more beneficial effects when legalized in places with higher susceptibility to illicit drug use and overdose deaths. To avoid introducing simultaneity bias, we follow an approach similar to Alpert et al. (2018) and estimate heterogeneous treatment effects across counties with lower (higher) opioid prescription rates prior to the 2010 reformulation of OxyContin.[3] These results are largely consistent with our main findings, legalizing FTS did not have a meaningful impact on overdose death rates in counties with higher or lower pre-reformulation exposure to prescription opioids. Taken together, all of these results indicate that legalizing FTS, on its own, does not reduce information asymmetries enough to prevent overdose death rates.

In the second part of our analysis, we examine case studies from four community-based harm reduction initiatives in which FTS distribution was a key feature. Recognizing the need for multi-faceted interventions to reduce overdoses, a number of community-based agencies have developed comprehensive harm reduction programs in an effort to increase engagement among illicit drug users. The harm reduction services offered are heterogeneous, and range with respect to the harm reduction tools offered (e.g. FTS, Narcan, sterile syringes, etc.), their communication strategies, and their distribution methods (e.g. providing kits that can be picked up at a community center vs. delivering to individuals). For this reason, we investigate the effects of each community harm reduction strategy individually. We examine four county-level case studies: New Castle, DE; Essex, MA; Baltimore, MD; and Frederick, MD.[4] We use synthetic control methods to determine whether the harm reduction efforts reduced overdose deaths in any of these counties relative to their untreated counterfactual counterparts. Results indicate that the interventions in Baltimore, MD; Frederick, MD; and Essex, MA reduced overdose deaths, while the intervention in New Castle,

[3] Alpert et al. (2018) found that areas with higher exposure to OxyContin prior to the the 2010 reformulation experienced worse outcomes after the reformulation.

[4] We examine these four counties because FTS distribution began during our sample period, and based on the availability of information regarding key features of their respective programs.

DE had more moderate effects. These results suggest that *de facto* access to harm reduction tools, including FTS, is more effective in reducing overdose death rates.

This paper contributes to the economic literature in a number of respects. First, we provide insight on the determinants of rising overdose death rates. It is true that information asymmetries with respect to drug purity likely impact overdose mortality. However, we find that legalizing FTS, which can alleviate these asymmetries, has no impact on overdose death rates. This suggests that FTS are used at suboptimal levels, and increased access does not always increase utilization. The underlying implication is that suboptimal usage of FTS is most likely driven by demand side considerations. Second, we examine the impact of community harm reduction strategies, which lower the cost of obtaining FTS, be it monetary costs, search costs, or travel costs, and find that these interventions are more effective in reducing overdose death rates. Finally, we contribute to the literature on the relationship between the policy environment and the substance use disorder (SUD) epidemic. While policy changes can (and often do) affect outcomes in and of themselves, these results illustrate the importance of grass roots activity to affect that change.

The rest of the paper proceeds as follows. Section 2 provides more context on FTS as a harm reduction measure, and what differentiates FTS from other SUD-related measures studied in the economics literature. Section 3 details the primary data sources and the construction of our outcome measures. Section 4 describes the empirical methodology used to analyze both the changes in FTS legalization and the effects of grass roots community interventions. Section 5 contains results and Section 6 concludes.

2 Policies Aimed at Curbing Substance Use Disorder

Over the last two decades, a number of policies and interventions have been implemented in an effort to address the elevated rates of SUD and overdose deaths in the U.S. Important examples include supply-side restrictions aimed at preventing initiation into substance misuse and the escalation thereof, or identifying drug-seeking patients. These measures include the 2010 reformulation of OxyContin to make it more difficult to abuse, and the implementation of must-access prescription drug monitoring programs (PDMPs).[5] However, both the reformulation of Oxycontin and the implementation of must-access PDMPs have produced mixed effects. While Buchmueller and Carey (2018) show that PDMPs reduced prescription opioid misuse, Kim (2021) finds that PDMPs led to increased overdose deaths as users substituted to illicit substances. Similarly, Havens et al. (2014) and Wolff et al. (2020) find that the reformulation of OxyContin led to a reduction in prescription drug misuse, while other research shows that the reformulation led to an increase in heroin-related crime and deaths and increased rates of child maltreatment (Alpert et al., 2018; Evans et al., 2019; Mallatt, 2022; Evans et al., 2022).

While restricting access to substances may have ambiguous effects, strategies that *increase* access to resources for substance users tend to have at least weakly positive effects in terms of reducing overdose deaths. As an example, increasing access to Naloxone, which is used to prevent overdoses from being fatal, can reduce overdose mortality (Smart et al., 2021).[6] Similarly, Guo et al. (2024) and Endersby (2026) find that laws which increase the numbers of prescribers of medications for opioid use disorders (MOUD), which can reduce opioid cravings and mitigate withdrawal symptoms, led to increases in MOUD prescribing and reductions in overdose deaths.[7]

Against this backdrop, FTS is somewhat unique in two ways. First, while the aforementioned strategies operate by affecting access, substituting to alternative substances, or providing emergency overdose treatment, FTS is simply an information treatment about the risk of using a particular substance. Second, because of the lethality of fentanyl, FTS can help fentanyl-averse drug users avoid fentanyl contaminated substances, and may lead to risk reducing behaviors even among those seeking fentanyl (Goldman et al., 2019; Park et al., 2021; Gelberg et al., 2025). Therefore, they have the *potential* to offer great lifesaving benefits if sufficiently utilized.

[5] Must-access provisions require prescribers to check a patient's prescription history before prescribing controlled substances.

[6] However, some researchers have raised concerns about whether increased access to Naloxone leads to increased risky behavior by users (Doleac and Mukherjee, 2022), while others have pointed out that relative to saving lives, these concerns are of second order importance as well as some methodological challenges (Frank et al., 2018; Rees et al., 2019).

[7] Examples of MOUDs include methadone and buprenorphine.

3 Data

Our primary data source is the restricted-access *Multiple Cause of Deaths-Detailed* (MCOD) data from the CDC. The MCOD data contain information on deaths from individual-level death certificates, detailing the underlying cause(s) of death from 2009 through 2021. The MCOD data also provide location of death (county and state) as well as demographics of the deceased, including age, race, ethnicity, and gender. In the MCOD dataset, underlying causes of death are coded using the International Classification of Diseases, Tenth Revision, Clinical Modification standardized coding system (ICD-10-CM). Using these codes, we calculate two measures of overdose death rates: opioid-related drug poisoning deaths and synthetic opioid-related drug poisoning deaths for each county year. We start by identifying deaths potentially from drug poisonings for each county year using the following ICD-10-CM codes: X40-X44 (accidental poisonings), X60-X64 (intentional self-poisonings), X85 (assaults by drugs), and Y10-Y14 (drug poisonings of undetermined intent). We then use information from the MCOD's record-axis conditions to construct county-year totals specifically for all opioids and synthetic opioids (e.g. fentanyl).[8] Death rates are calculated per 100 population, where county population data are gathered from the U.S. Census Bureau.

Information on the legality of FTS and dates of any related changes in paraphernalia laws were taken from the Legislative Analysis and Public Policy Association (2022) and The Network for Public Health Law (2024). We cross referenced these with individual state statutes when necessary. A summary of legalization dates by state (and relationship to treatment status) is reported in Appendix Table A1.[9]

Additional county-level data on opioid prescription rates were gathered from the CDC. We obtained county-year demographic characteristics including age, race, ethnicity, and gender from the U.S. Census Bureau. County-level labor market data including unemployment rates are from the Bureau of Labor Statistics local area unemployment statistics (LAUS).

[8]Axis conditions T40.0-T-40.4 and T40.6 indicate the cause of the poisoning death was opioid-related, specifically from opium (T40.0), heroin (T40.1), opioids (T40.2), methadone (T40.3), synthetic opioids including fentanyl (T40.4) and other/unspecified narcotics (T40.6).

[9]Note that in Appendix Table A1, the variable "Legal?" refers to whether FTS is legal at the time of submission/publication. The date of legalization informs whether the state legalized FTS during our sample period, 2009 through 2021.

Figure 1: Total and Synthetic Opioid Deaths by Year, United States

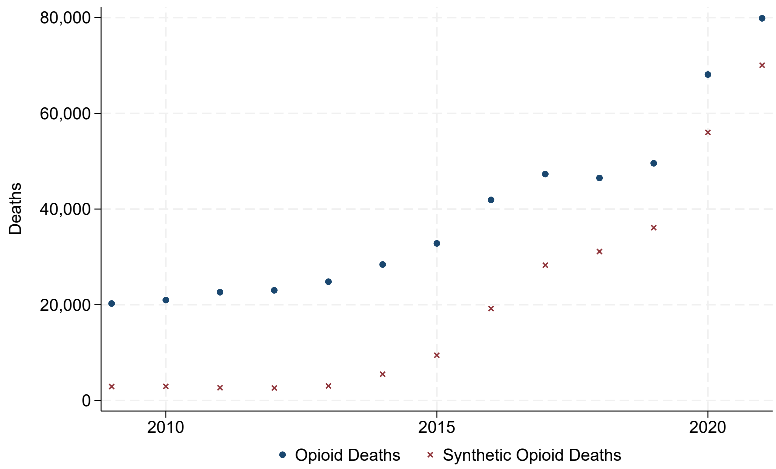


Figure 1 depicts how sharply opioid overdose deaths have increased from 2009 to 2021, and how the share of synthetic opioid deaths has grown during the same period. In 2010, around the time that OxyContin was reformulated, there were approximately 20,000 overdose deaths from opioids, but deaths from synthetic opioids were close to zero. However, after 2013, deaths from synthetic opioids began to increase, as illicitly produced fentanyl was increasingly incorporated into other illicit substances as an adulterant (Ciccarone, 2019). By 2020, synthetic opioids had become the dominant substance cited in overdose deaths, crowding out nearly all other overdose deaths from other narcotics.

Table 1 contains summary statistics for observed county-years in states where FTS are legal or were legalized during the sample period (Ever Legal) and counties in states where FTS is not legal during our sample period (Never Legal). Generally, the two groups are quite similar in terms of demographics and unemployment rates. However, the number of total opioid overdose deaths and synthetic opioid overdose deaths are slightly higher in the treated counties, Ever Legal.

4 Methods

Our empirical analysis has two components, one for each of the primary research questions. We first examine whether simply legalizing FTS reduced countywide opioid poisoning deaths rates. We then turn to the four county-level case studies to examine whether more hands-on community

Table 1: Summary Statistics for Counties by Ever Treated Status

	Never Legal		Ever Legal	
Variable	Mean	Std. Dev.	Mean	Std. Dev.
Outcome Variables				
Synthetic Opioid Overdose Deaths	6.510	36.963	6.985	40.359
Total Opioid Overdose Deaths	12.419	48.399	13.702	54.328
Synthetic Opioid Overdose Deaths per 100 Pop.	0.003	0.008	0.005	0.010
Total Opioid Overdose Deaths per 100 Pop.	0.008	0.013	0.011	0.013
Demographic Variables				
Percent White Population	0.853	0.161	0.851	0.161
Percent Black Population	0.095	0.148	0.084	0.137
Percent Hispanic Population	0.104	0.155	0.075	0.104
Percent Aged 0-14 Years	0.191	0.031	0.179	0.027
Percent Aged 15-19 Years	0.066	0.011	0.064	0.011
Percent Aged 20-24 Years	0.063	0.024	0.061	0.022
Percent Aged 25-34 Years	0.118	0.021	0.116	0.021
Percent Aged 35-44 Years	0.117	0.015	0.118	0.015
Percent Aged 45-54 Years	0.131	0.018	0.136	0.018
Percent Aged 55-64 Years	0.136	0.021	0.143	0.020
Percent Aged 65 Years and Older	0.176	0.047	0.184	0.047
Total Population (in 1000's)	106.941	362.667	96.734	273.102
Economic Variables				
Unemployment Rate	6.301	2.943	6.548	3.034
Opioid Prescriptions per 100 Pop.	71.208	44.809	72.008	45.631
Observations	23,223		17,016	

Ever Legal contains counties in states where FTS was always legal and counties in states where FTS was legalized at some point during the sample period, 2009-2021 harm reduction strategies to increase access to FTS, impacted county overdose death rates.

4.1 The Effects of legalizing FTS

To examine the effects of legalizing FTS on overdose deaths, we rely on event studies and difference-in-differences specifications. We first start with a standard two-way fixed effects (TWFE) model of the following form:

$$y_{cst} = \alpha + \beta legal_{st} + \gamma X_{cst} + \mu_c + \lambda_t + \epsilon_{cst} \tag{1}$$

where y_{cst} denotes the synthetic opioid overdose death rate for county c, in state, s, at year t; $legal_{st}$ is a dummy variable equal to 1 if a state has legalized FTS usage in state s year t; and X_{cst} represents a vector of county- and time-varying covariates including the unemployment rate, demographic characteristics, and in some cases, opioid prescription rates. Finally, μ_c and λ_t capture county and year fixed effects respectively. Because states legalized FTS usage at different times we also implement staggered-treatment difference-in-differences models including those from Callaway and Sant'Anna (2021) and De Chaisemartin and d'Haultfoeuille (2023).

We also estimate a dynamic event study specification, which allows us to examine the post-policy effects in the years after each state legalized FTS usage, and determine whether there are any pre-policy differences between the treatment and control groups. Due to the staggered timing of state FTS legalization, we define τ_s as the legalization date, and estimate an event study model of the following form:

$$y_{cst} = \sum_{j=2}^{J} \delta_j lag_{st} + \sum_{k=1}^{K} \gamma_k lead_{st} + \beta_2 X_{cst} + \mu_c + \lambda_t + \epsilon_{cst} \tag{2}$$

$$\begin{aligned}
(lag)_{st} &= \mathbf{1}[t \leq \tau_s - J], \\
(lag)_{st} &= \mathbf{1}[t = \tau_s - j] \ \ \forall j \in \{1, \ldots, J-1\}, \\
(lead)_{st} &= \mathbf{1}[t = \tau_s + k] \ \ \forall k \in \{1, \ldots, K-1\}, \\
(lead)_{st} &= \mathbf{1}[t \geq \tau_s + K],
\end{aligned} \tag{3}$$

We also estimate event studies based on the staggered treatment models from Callaway and Sant'Anna (2021) and De Chaisemartin and d'Haultfoeuille (2023).

4.2 Synthetic Control Analysis of Local Initiatives

Next, we examine the effects of county-level initiatives to increase access to FTS, in four specific cases: New Castle, DE; Essex, MA; Frederick, MD; and Baltimore MD. While other counties have implemented harm reduction plans (of which FTS may be a large part), we chose these four locations because implementation began during our sample period, as well as the differences in the agency or entity primarily responsible, and the availability of information regarding key features of their respective programs. Details of each county's harm reduction strategy are provided in Appendix Section A.2.

Harm reduction initiatives (and many other public health initiatives more generally) do not lend themselves to a difference-in-differences type of approach. These initiatives tend to vary between locations along several dimensions and each intervention is tailored to suit the needs of the specific location or based on resource constraints faced by the local organization.[10] Because virtually all of these initiatives entail multiple treatments that can affect overdose mortality, these analyses should not be interpreted as evaluating the effect of FTS *per se*, but evaluating the effect of an intervention in which FTS is one of the harm reduction tools offered.

In cases such as these, methodological approaches involving binary (or continuous single-index) treatments with well defined untreated groups are infeasible. Therefore, following Abadie and Gardeazabal (2003) and Abadie et al. (2010), we implement a synthetic control approach to construct a 'counterfactual' composite of each county. This approach uses weighted mixtures of other "control" counties to generate a synthetic counterfactual version of each treated county by matching pre-initiative trends in overdose death rates. The key assumption in this approach is that, were it not for the harm reduction initiative, overdose deaths in New Castle, DE, for example, would follow the same path as a weighted average of these control counties, such as: Franklin

[10] For example, interventions can vary on whether they offer educational components, the frequency of distribution of FTS, whether naloxone is distributed as well, whether there are referrals to care for conditions frequently co-occurring with SUD, number of locations, hours of operation, etc.

County, OH; Burlington County, NJ; Mercer County, NJ; and others. More formally, we estimate the treatment effect from each harm reduction initiative as:

$$Y_{cst} - \sum_{c' \neq c}^{K} Y_{c't} W_{c'} \tag{4}$$

where $W_{c'}$ is a weight for control county c'.

Overdoses in a county are driven by a number of factors, including characteristics of the population, the substance use environment, and the policy environment. Importantly, the policy environment is not determined in a vacuum, but is driven by some combination of policymaker preferences and community need. Furthermore, policies change and evolve over time. As an example, the harm reduction strategies in Essex, MA started as a police initiative where officers would identify at-risk individuals and help them get substance use treatment. However, over time, it expanded to training officers to use Narcan, and to distribute FTS. Using this synthetic control model, we can match overdose death rates in the treated county with overdose death rates in the synthetic counterfactual version up until the roll-out of FTS distribution, and then examine how overdose death rates differ in Essex, MA versus its synthetic control after Essex, MA began distributing FTS.

A separate synthetic control model is estimated for each of the four county case studies: New Castle, DE; Baltimore, MD; Fredrick, MD; and Essex, MA, and the control group consists only of counties that never legalized FTS.[11] In the results section that follows, we report the counties comprising each synthetic control group, the weights assigned to each, and the pre-and-post treatment trajectory of overdose death rates for both the treated county and its respective synthetic control.

[11] We also exclude counties located in any of the treatment group states (DE, MD, or MA) from the control group. However, this is only relevant for Massachusets, as the two other states had already legalized FTS during our sample time period.

5 Results

5.1 Difference-in-Difference Estimates of the Effects of Legalizing FTS

The results for both the difference-in-differences specification and the event studies show that on average, legalizing FTS by itself did not affect overdose deaths. Table 2 Columns 1-5 report results from the canonical two-way fixed effects estimator. Results indicate that, if anything, legalizing FTS is associated with a weak increase in overdose deaths. The results are similar regardless of whether the sample is restricted to a balanced panel, weighted by population, or if the treatment group only contains counties where the legal status was changed from illegal to legal during our sample period (i.e. counties in "always legal" states are excluded). In Columns 6 and 7 we report results from the staggered difference-in-differences models, developed by Callaway and Sant'Anna (2021) and De Chaisemartin and d'Haultfoeuille (2023), and the treatment effects are largely the same as those from the TWFE models.

Figures 2 and 3 contain results from event studies under the TWFE framework, as well as the staggered difference-in-differences models. Specifically, in Figure 2 we focus on synthetic opioid deaths only, whereas in Figure 3 we estimate the effect on all opioid-related deaths. There are two key takeaways from these results. First, the almost significant results from Table 2 are likely attributable to pre-treatment trends and/or time varying treatment effects, as the TWFE coefficients are nearly statistically significant during the pre-treatment period. Second, in specifications that account for staggered adoption, the estimated post-treatment effects are all statistically insignificant and centered around zero. These results indicate that legalizing FTS did not significantly affect either synthetic or total opioid overdose deaths rates. In Appendix Figure A1 we run a similar model, but also include county opioid prescription rates (per 100 population) as an additional explanatory variable. The results are virtually identical to those in Figure 2.

The distribution of overdose death rates across counties is highly skewed, with many counties reporting 0 deaths in a given year. We therefore run a similar model, but with the natural logarithm of synthetic opioid overdose death rates as the dependent variable. These results are presented in Appendix Figure A2, and the conclusions are largely the same as those in Figure 2.

5.1.1 Heterogeneous Effects and Information Asymmetries

The above results show that legalizing FTS did not significantly affect opioid or synthetic opioid poisoning death rates at the mean. However, to the extent that synthetic poisoning deaths are driven by information imperfections *and* legalization by itself increased access to FTS, we may expect more pronounced effects in demographic or geographic subsets of the sample. We examine three subsamples where the potential for significant benefits from legalization is greatest.

First, we examine the effects of FTS legalization on *accidental* opioid overdose deaths specifically, as determined by the medical examiners and/or toxicology reports, and present these results in Appendix Figure A3. Given that the purpose of testing equipment is to help fentanyl-averse users avoid fentanyl exposure, FTS are designed to specifically prevent these types of deaths. These results associated with accidental deaths are largely similar to the main estimates. However, estimates from the staggered models suggest that legalization led to a small reduction in accidental opioid overdose deaths, but only three-plus years after legalization.

Next, Figure 4 reports the event study results by age group. Previous work in the economics and psychology literature has shown that risk aversion and receptivity to information treatments may vary with age (Dohmen et al., 2011; Albert and Duffy, 2012). Focusing on the results associated with the staggered adoption models, we find some evidence to suggest that legalization may have reduced synthetic opioid overdose death rates among those between 15 to 24, 25 to 34,and 35 to 44 years of age, however the effects are only significant three-plus years after legalization. Conversely, the three year post-treatment coefficient for those aged 55 to 64, and 65 and up is positive, suggesting that overdose deaths among the oldest age groups increased following legalization. Generally, it seems that the legalization of FTS had modest effects for younger users who may be more receptive to information treatments, but the results do not uncover a strong gradient in age-specific results.

Finally, and as discussed in Section 2, the 2010 reformulation of OxyContin was an important supply-side intervention that led some substance users to substitute to heroin, causing an increase in overdose death rates. This effect was especially prevalent in areas with higher exposure to prescription opioids prior to reformulation (Alpert et al., 2018). In this light, we examine whether the legalization of FTS had heterogeneous treatment effects across counties with lower (higher) opioid prescription rates prior to the reformulation of OxyContin. These results are presented in Appendix Figure A4. There may be some evidence to suggest that legalizing FTS led to a slight reduction in overdose death rates among high exposure counties, however, this negative effect is only apparent three-plus years after legalization and only for estimates associated with the De Chaisemartin and d'Haultfoeuille (2023) model.

Together, these results show that legalizing FTS, by itself, had small effects (if any effects at all) on opioid poisoning deaths, even among subsets of the sample most likely to benefit from that legalization. It is also true that legalizing FTS may have heterogeneous effects based on the context in which they were legalized. If FTS were legalized as part of a comprehensive harm reduction solution to avoid overdose deaths, FTS legalization may help prevent overdose deaths. If legalized in isolation or in settings where individuals with SUD are fentanyl-seeking, legalizing FTS may have no impact or even adverse effects. To that end, we use the methods from the previous section to estimate individual event study models for each county that legalized FTS during our sample period. These estimates are reports in Figure 5. Each line in Figure 5 represents a different event study model that contains a sample of all counties in the control group (never legal counties) and one county in the treatment group.[12] The graph shows considerable variation in post-legalization outcomes across treated counties. While the post-treatment event study graph path is centered around our estimated average treatment effect of zero, a number of counties do, in fact, see a reduction in synthetic opioid overdose death rates, while many others see an increase in overdose death rates. However, on average the effects are centered at zero. In the following section, we examine case studies from four county-level community-based harm reduction initiatives (New Castle, DE; Essex, MA; Baltimore, MD; and Frederick, MD), and whether any of these broader based initiatives led to reductions in synthetic opioid overdose death rates. To that end, two of the four counties we subsequently examine are highlighted in Figure 5: Baltimore, MD and Frederick, MD.[13] We find that the legalization of FTS had no impact on syntehtic opioid overdose death rates

[12] In this case, the treatment group only contains counties that legalized FTS during the sample period, it does not contain any counties where FTS was always legal.

[13] In contrast, New Castle, DE is not included because FTS was not legalized in Delaware until 2021, which is the last year of our sample period, while Essex, MA is not included because FTS was not legalized in Massachusetts

in Baltimore County but led to a modest reduction in Frederick County.

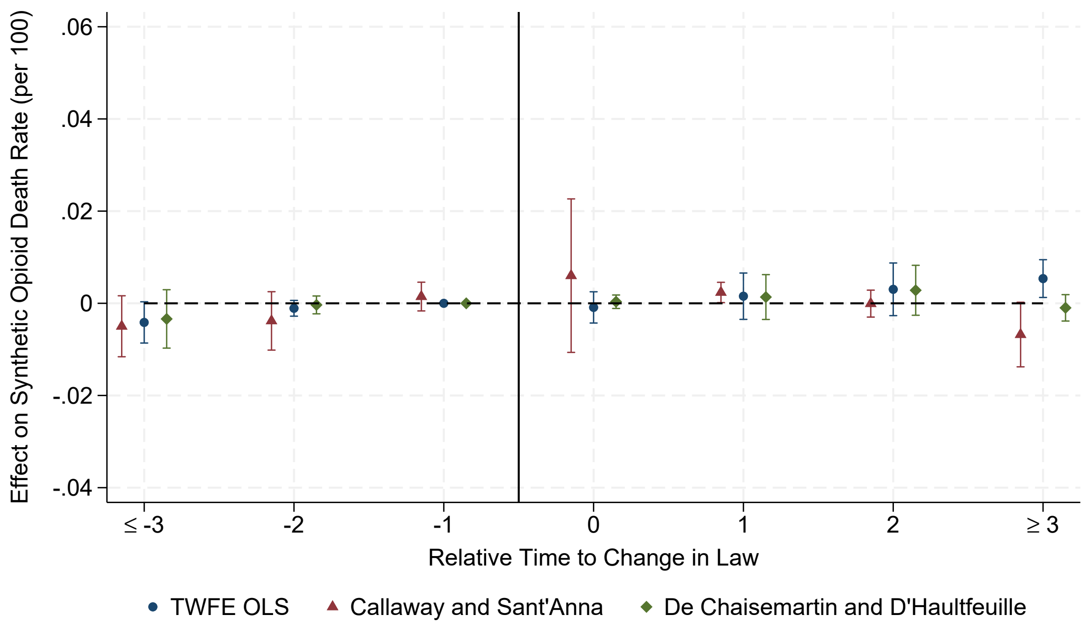
until 2022.

Table 2: Difference in Difference Results for Synthetic Overdoses

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Legalization	0.004	0.004	0.004	0.004	0.001	0.003	0.001
	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)	(0.004)	(0.001)
Observations	39,975	40,239	39,975	40,239	12,064	12,064	39,975
Model	TWFE	TWFE	TWFE	TWFE	TWFE	CS	DCDH
Treatment Group	Always Legal or Legalized	Always Legal or Legalized	Always Legal or Legalized	Always Legal or Legalized	Legalized	Legalized	Always Legal Legalized
Population Weights	Yes	Yes	No	No	No	No	No
Balanced Panel	Yes	No	Yes	No	Yes	Yes	Yes
Sample Mean	0.004	0.004	0.004	0.004	0.005	0.005	0.004
Mean if Legal	0.009	0.009	0.009	0.009	0.011	0.011	0.009

Columns (1)-(5) contain estimates from canonical Two-Way Fixed Effects models. Colum (6) contains results from the Callaway Sant'Anna estimator while results in Column (7) are estimated using D'Haultfouille and DeChaisemartin's estimators for staggered treatment Difference-in-Differences. Synthetic overdoses are measured as the county synthetic overdose death rate per 100 population. Specifications include county and year fixed effects; percent female, white, black; percent of the population under age 15, between 15 and 19, between 20 and 24, between 25 and 34, between 35 and 44, between 45 and 54, and between 55 and 64; and the unemployment rate.

Figure 2: Event Study Comparison: Synthetic Opioid Death Rates



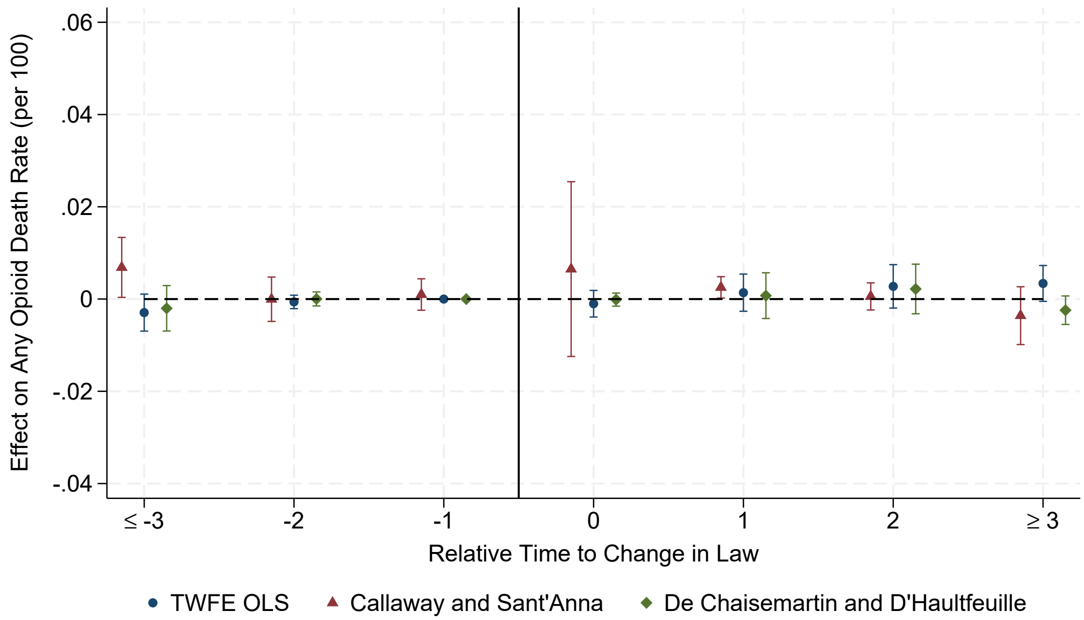
Note: Specifications include county and year fixed effects; percent female, white, black; percent of the population under age 15, between 15 and 19, between 20 and 24, between 25 and 34, between 35 and 44, between 45 and 54, and between 55 and 64; and the unemployment rate.

5.2 Case Studies of Comprehensive Community Interventions

Results in the previous section show that legalizing FTS, by itself, did not significantly affect county-level synthetic opioid overdose death rates at the mean. However, for legalization to have had significant effects, three things would need to be true. First, users would need to have information asymmetries about the substances they were ingesting *and* be fentanyl averse. Second, the legal status of FTS must affect access to FTS. Third, legalizing FTS would have had to increase their demand for FTS. Our estimates from the previous section suggest that these conditions were not met, at least at the mean.

However, FTS legalization may have significant effects depending on the broader SUD and policy environment. FTS may be effective as part of a more comprehensive program to reduce overdose mortality, one that intentionally raises awareness of the benefits of FTS, and seeks to increase both access and demand for FTS. To that end, we identified four counties with well documented FTS distribution strategies as part of a larger harm-reduction initiative: New Castle, DE; Essex, MA; Baltimore, MD; and Fredrick, MD. Using synthetic control methods we examine

Figure 3: Event Study Comparison: Death Rates from Any Opioids

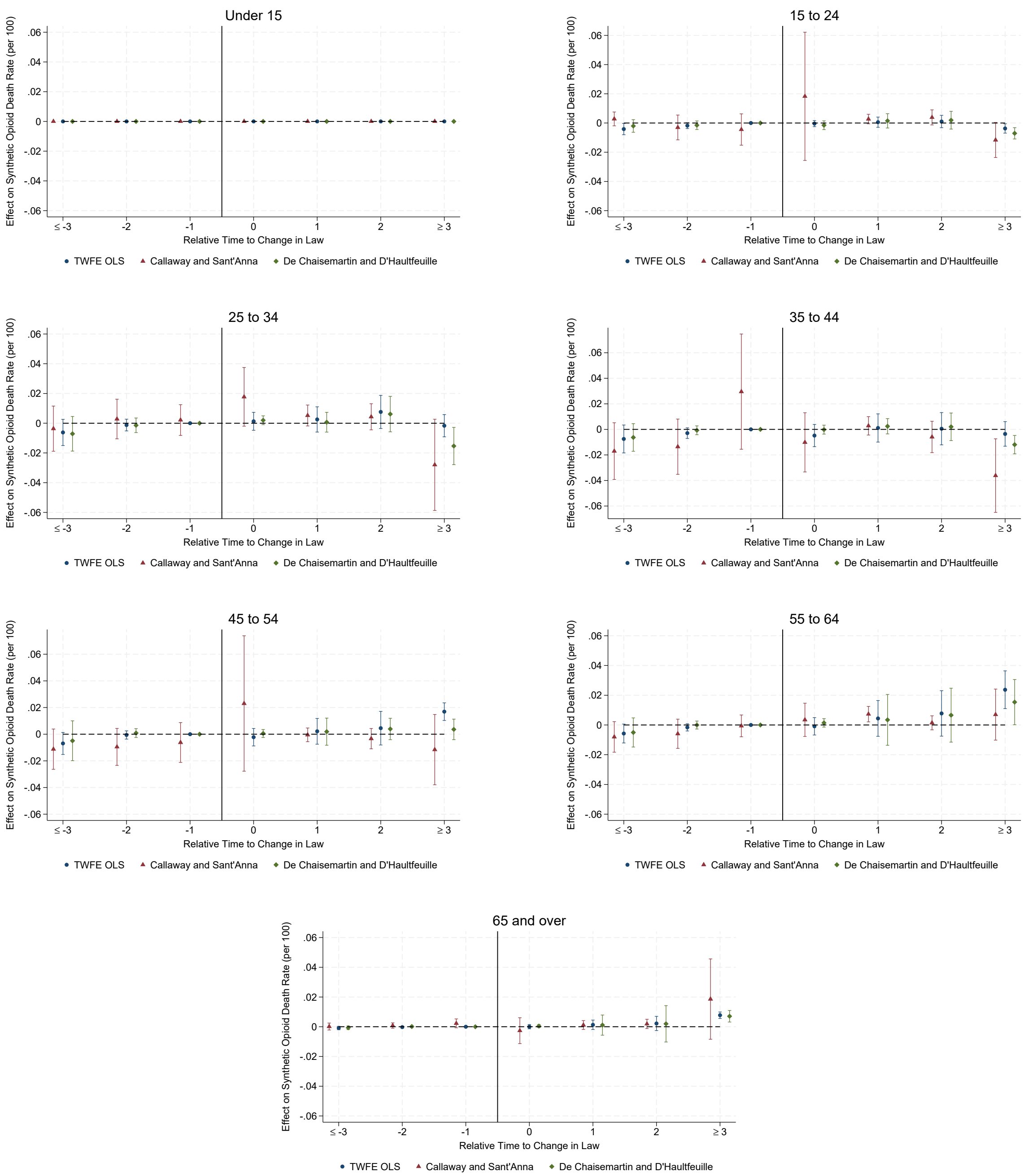


Note: Specifications include county and year fixed effects; percent female, white, black; percent of the population under age 15, between 15 and 19, between 20 and 24, between 25 and 34, between 35 and 44, between 45 and 54, and between 55 and 64; and the unemployment rate.

whether the efforts from any of these counties have been more successful in reducing overdose death rates. For these analyses, we estimate a separate synthetic control model for each county with a harm reduction strategy that includes FTS distribution individually. This allows us to examine separate effects for different harm reduction strategies with different bundles of features. One important difference across these four initiatives is the agency or stakeholder that administers the harm reduction program. For example, in New Castle, DE the initiative is administered by a counseling and community center, in Essex, MA the program is run by local police departments, and in both Baltimore, MD, and Frederick, MD, the programs are administered by their respective county health departments.

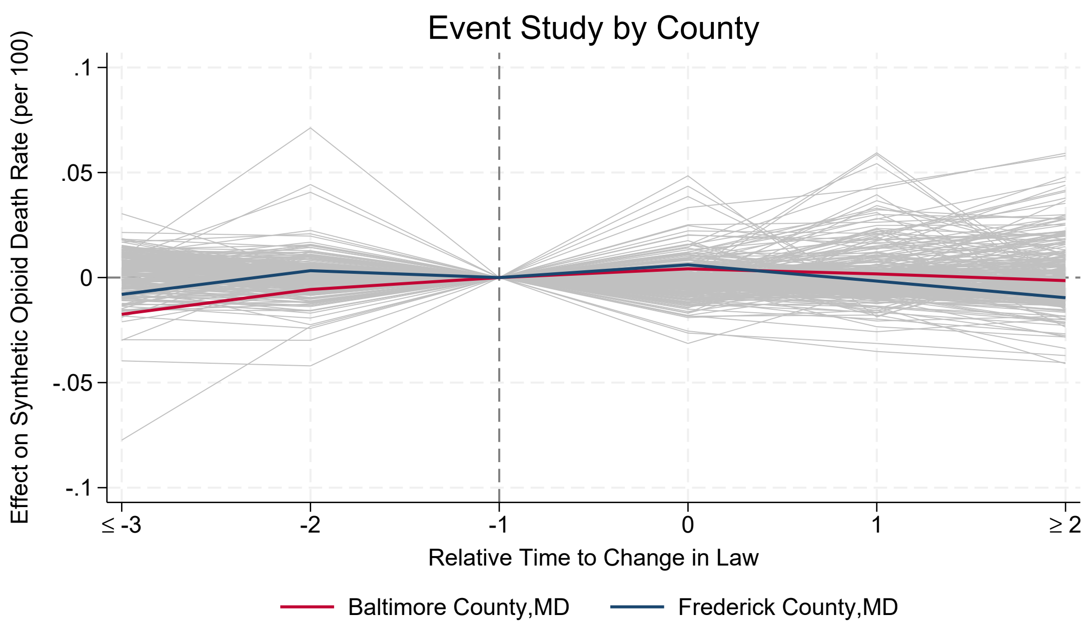
Figures 6-8 and Figures 9-11 contain synthetic control estimates from Baltimore, MD and Frederick, MD, respectively, both of which began their community harm reduction strategies in 2018. Figures 6 and 9 show the trajectory of synthetic opioid overdose death rates for Baltimore and Frederick, respectively, relative to their synthetic control counterpart from 2009 through 2021. Both graphs show lower overdose death rates after treatment relative to their synthetic

Figure 4: Event Study Comparison: Synthetic Opioid Death Rates by Age



Note: Specifications include county and year fixed effects; percent female, white, black; percent of the population under age 15, between 15 and 19, between 20 and 24, between 25 and 34, between 35 and 44, between 45 and 54, and between 55 and 64; and the unemployment rate.

Figure 5: Event Studies for Every County in which the State Legalized FTS



Note: Each line represents a different event study model that contains a sample of all counties in the control group (never legal counties) and one county in the treatment group (made legal during sample period). Specifications include county and year fixed effects; percent female, white, black; percent of the population under age 15, between 15 and 19, between 20 and 24, between 25 and 34, between 35 and 44, between 45 and 54, and between 55 and 64; and the unemployment rate.

counterparts, however the reduction in overdose deaths is more pronounced in Frederick County. To examine this further, Figures 7 and 10 plot placebo tests for each county. These graphs plot the difference in overdose death rates between the treated county and its synthetic control (dark line) along with the differences for each placebo county. The placebo counties are calculated by considering each control county in the donor pool as the treated county and then constructing synthetic controls for each county in the donor pool. If many of the placebo counties (gray lines) show larger declines than the true estimate, then the estimated effects shown in Figures 6 and 9 are probably not driven by the distribution of FTS by the true treatment county. In Frederick County we see the decline in overdose death rates after they started distributing FTS is stronger than virtually all other placebo counties (Figure 10). In Baltimore County, the decline is stronger than most, but not all counties (Figure 7). While the services offered in both counties are highly similar, there are demographic and geographic differences between Baltimore and Frederick County that may contribute to the differences in results between these initiatives. Most importantly, Fentanyl-related deaths in Baltimore County were five-times higher than Frederick County in 2019, were higher than all other Maryland counties that year, and only trailed its neighbor, Baltimore City (Maryland Department of Health , 2020). Given this disproportionate burden, it will likely take more resources, time, and effort to reduce overdose deaths in Baltimore County relative to Frederick County. However, regardless of the magnitude, interventions in both places were overseen by public health departments, and included regular FTS distribution schedules and locations, as well as information on SUD treatment and access to naloxone. Finally, Figures 8 and 11 show the composition of each state's synthetic control group.[14]

Figures 12-14 contain results from the synthetic control analysis for Essex, MA. In contrast to the harm reduction programs in Baltimore and Frederick, which are administered by local health departments, the program in Essex, MA is administered by local police departments. The initiative started in 2015 as a referral service to help at-risk users seek treatment, but over time it expanded, and in 2020 they began a pilot program to distribute FTS. Compared to the synthetic version of Essex, we find that observed overdose deaths from synthetic opioids also decreased following the FTS pilot program in 2020. Finally, results for New Castle, DE (Figures 15-17) are less definitive. Importantly, the Delaware initiative also started as a pilot program, in which individuals could pickup a safe injection kit, which included FTS, from a drop in center. We find that this initiative did not impact overdose death rates during our sample period, which ends in 2021. Importantly, while Delaware did legalize FTS in 2021 (the last year of our sample), the intervention began in 2019 when FTS were still technically illegal. Furthermore, this initiative has since expanded to include overdose and disease prevention vending machines, offering free harm reduction supplies.[15] Subsequently, the Delaware Department of Health and Social Services began distributing FTS in 2022.[16]

[14] In addition, Appendix Figure A5 shows which variables were used to create the synthetic control group and their respective weights for each of the four counties.

[15] https://brandywinecounseling.com/harm-reduction-vending-machines/

[16] https://brandywinecounseling.com/dph-launches-new-fentanyl-test-strip-distribution/

Figure 6: Baltimore, MD: Observed and Synthetic Control Deaths from Synthetic Opioids

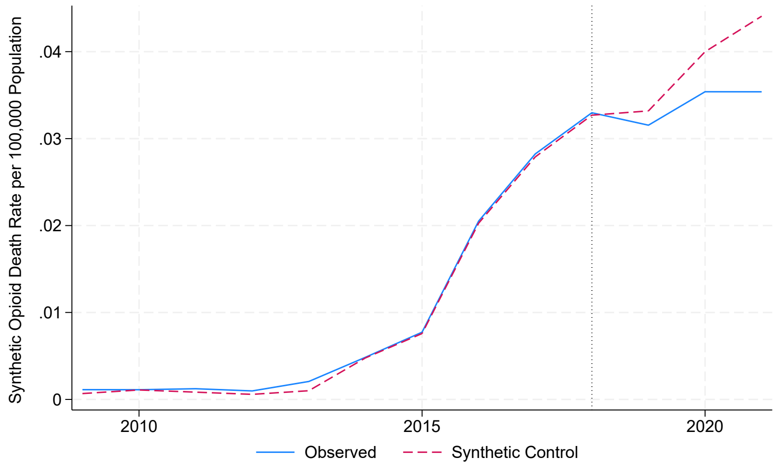


Figure 7: Baltimore, MD: Placebo Tests for Treatment Effect Strength

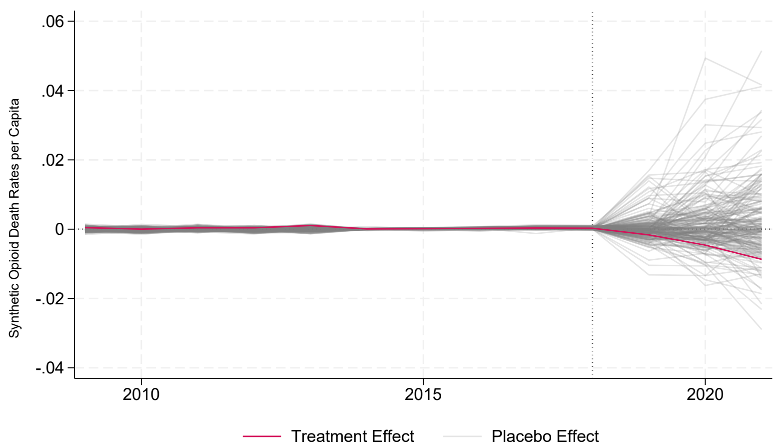


Figure 8: Baltimore, MD: Synthetic Control Weights

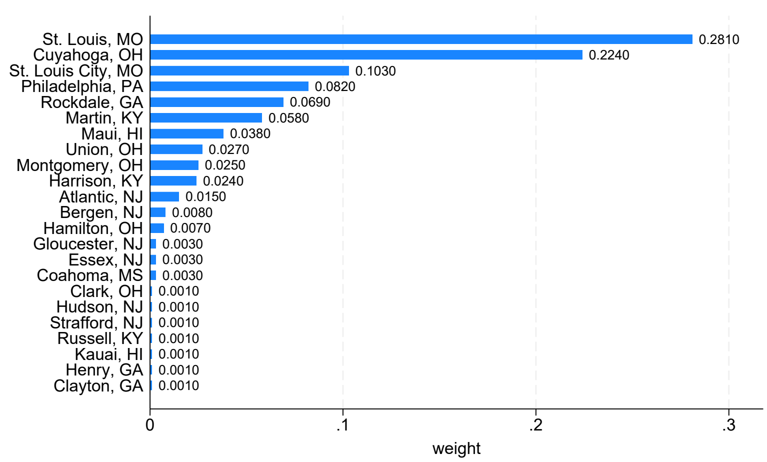


Figure 9: Frederick, MD: Observed and Synthetic Control Deaths from Synthetic Opioids

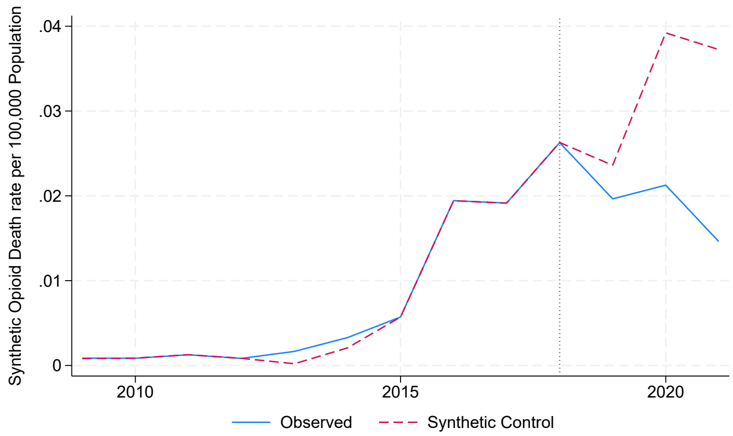


Figure 10: Frederick, MD: Placebo Tests for Treatment Effect Strength

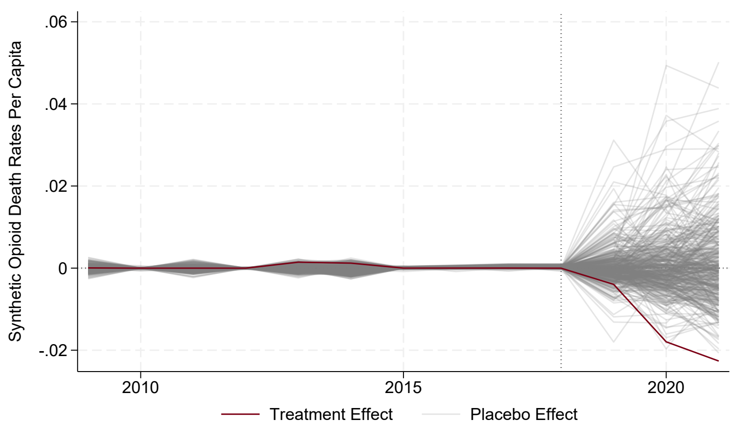


Figure 11: Frederick, MD: Synthetic Control Weights

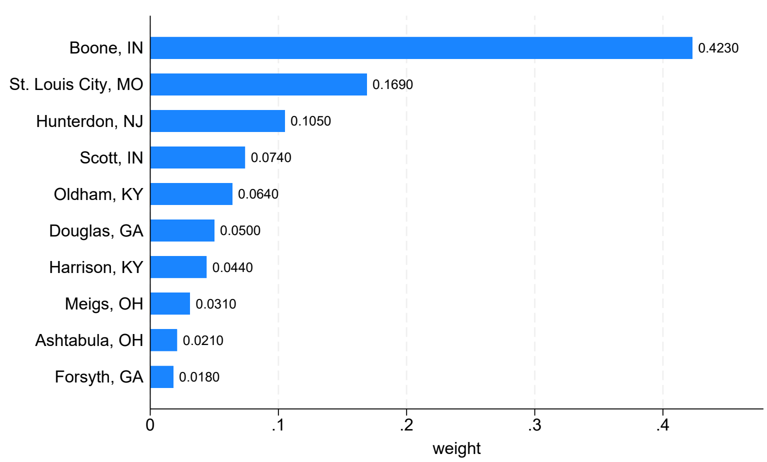


Figure 12: Essex, MA: Observed and Synthetic Control Deaths from Synthetic Opioids

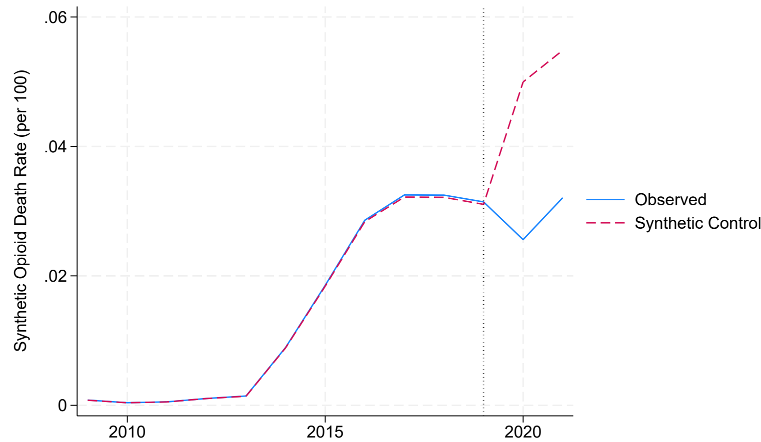
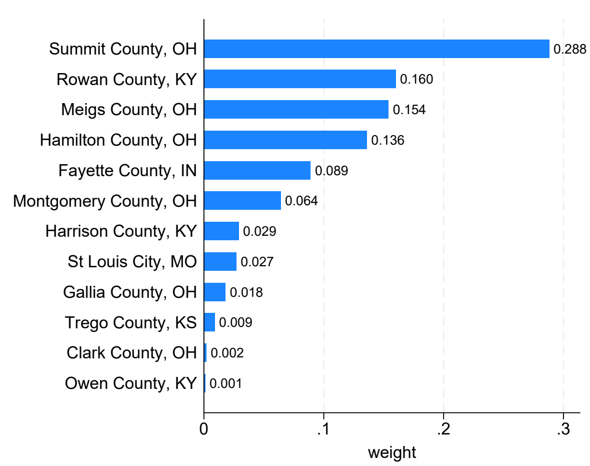


Figure 13: Essex, MA: Placebo Tests for Treatment Effect Strength

Figure 14: Essex, MA: Synthetic Control Weights



Notes:

Figure 15: New Castle, DE: Observed and Synthetic Control Deaths from Synthetic Opioids

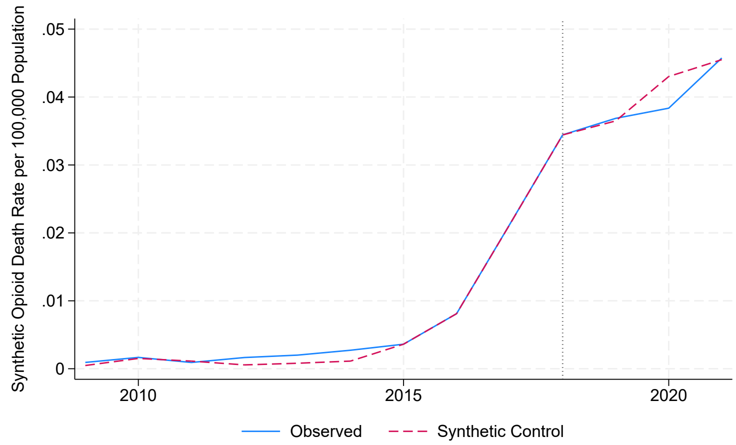


Figure 16: New Castle, DE: Placebo Tests for Treatment Effect Strength

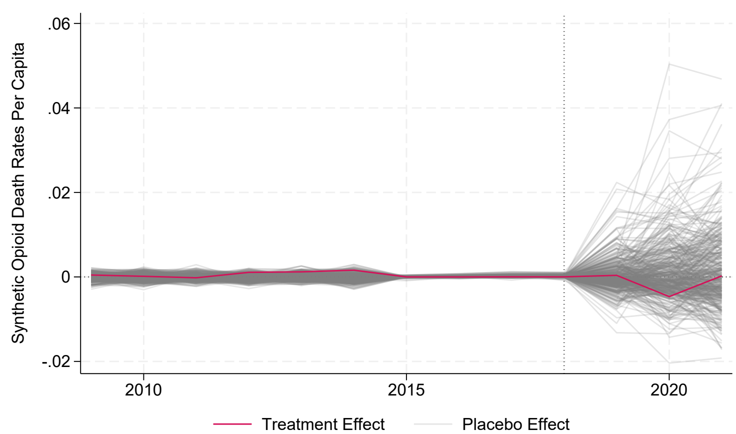
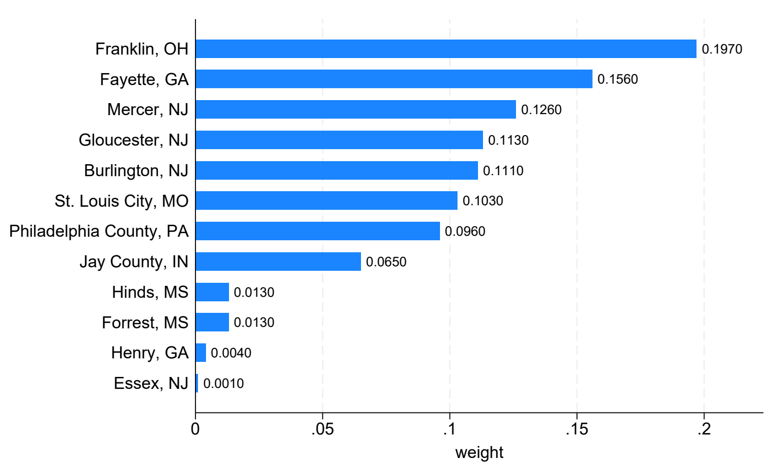


Figure 17: New Castle, DE: Synthetic Control Weights



Notes:

6 Conclusion

In this paper, we examine the effects of two types of policy interventions aimed at increasing access to FTS on countywide overdose death rates. First, we examine the effects of legalizing FTS, and find that this law change, on its own has no impact on overdose mortality. We also examine the effects of FTS legalization across different age groups and across counties with varying exposure to prescription opioids, and find that there are no large effects among groups more likely to be risk averse or areas where FTS could have the greatest benefits. These results do not imply that FTS are not effective harm reduction measures. Rather, they indicate that simply making FTS legal, without efforts to increase demand for FTS, or to increase access to FTS as well as complementary services (narcan, medications for opioid use disorder, counseling, etc.) is insufficient on its own. Nonetheless, legalizing FTS and removing barriers that may limit access to FTS, is still an important first step. Second, we examine whether local harm reduction strategies, which provide a multitude of harm reduction services, including FTS, impact overdose death rates. These local strategies differ in a number of dimensions, but in general we find that they lead to a reduction in countywide overdose death rates.

The applied microeconomics literature, particularly in health, is heavily populated with papers examining effects of policy changes (including changes in legality) on relevant outcomes. More often than not, changes in statutes are credibly linked to changes in outcomes of interest. While some of that is likely due to publication bias, it is also true that in many cases, changes in statutory legality are sufficient to affect utilization and final outcomes. However, substance use disorder is a complicated problem with origins in social determinants, and mitigating harms from the SUD epidemic will likely require more than low hanging fruit in the form or regulatory changes. More hands-on solutions, like community harm reduction efforts should be viewed as a key contributor in reducing drug overdose deaths, but there is no 'one size fits all' best practice for maximizing harm reduction (Carver et al., 2023). Local variation and context matter considerably. Further support for these initiatives could help public health agencies and other partners develop and expand harm reduction efforts that best suit their respective communities.

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A Appendix

A.1 Appendix Tables and Figures

Table A1: Legality of Fentanyl Test Strips and Year of Legalization, by State

State	Legal?	Year Legalized	Treated
Alabama	Yes	2022	
Alaska	Yes	No Statute	
Arizona	Yes	2021	
Arkansas	Yes	2023	
California	Yes	2023	
Colorado	Yes	2019	
Connecticut	Yes	2022	
Delaware	Yes	2021	
District of Columbia	Yes	2019	
Florida	Yes	2023	
Georgia	Yes	2023	
Hawaii	Yes	2023	
Idaho	Yes	2024	
Illinois	Yes	2024	
Indiana	No	N/A	
Iowa	No	N/A	
Kansas	Yes	2023	
Kentucky	Yes	2023	
Louisiana	Yes	2022	
Maine	Yes	2021	
Maryland	Yes	2018	
Massachusetts	Yes	2024	

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Table A1 – *continued from previous page*

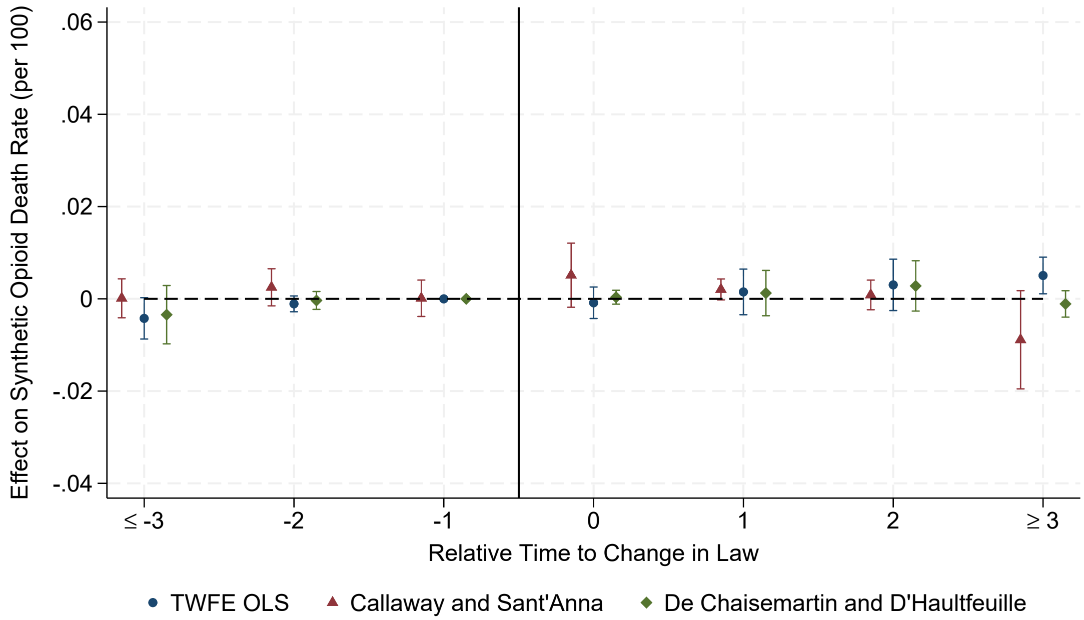
State	Legal?	Year Legalized	Treated
Michigan	Yes	1988	
Minnesota	Yes	2021	
Mississippi	Yes	2023	
Missouri	Yes	2023	
Montana	Yes	2023	
Nebraska	Yes	No Statute	
Nevada	Yes	2021	
New Hampshire	Yes	2023	
New Jersey	Yes	2024	
New Mexico	Yes	2022	
New York	Yes	No Statute	
North Carolina	Yes	2019	
North Dakota	No	N/A	
Ohio	Yes	2023	
Oklahoma	Yes	2021	
Oregon	Yes	2023	
Pennsylvania	Yes	2023	
Rhode Island	Yes	2018	
South Carolina	Yes	No Statute	
South Dakota	Yes	2023	
Tennessee	Yes	2022	
Texas	No	No	
Utah	Yes	2023	
Vermont	Yes	No Statute	
Virginia	Yes	2019	

Continued on next page –

Table A1 – *continued from previous page*

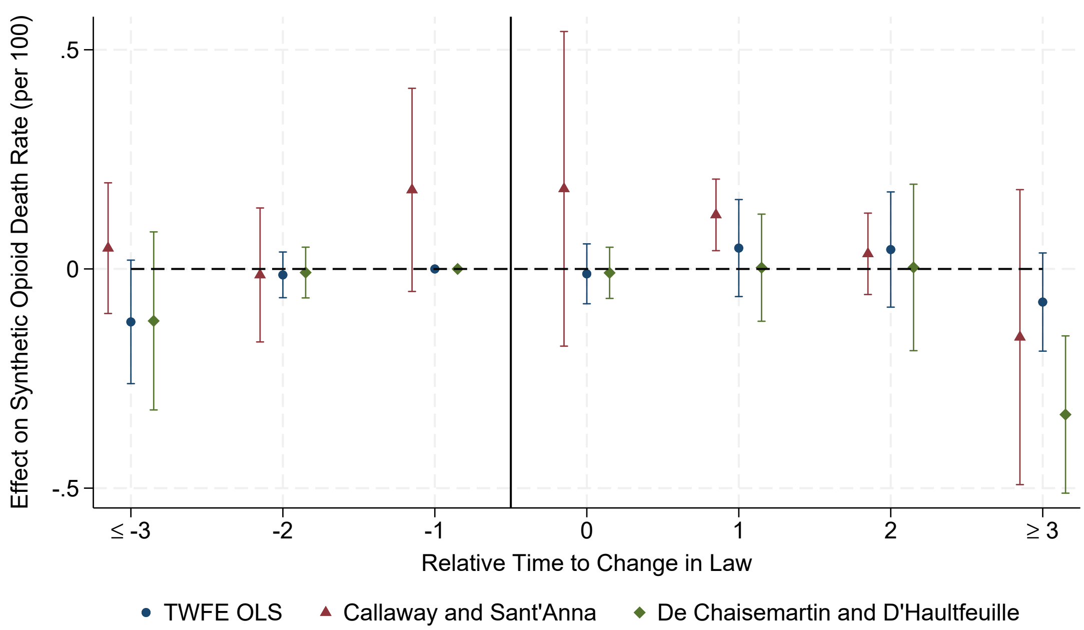
State	Legal?	Year Legalized	Treated
Washington	Yes	2023	
West Virginia	Yes	2022	
Wisconsin	Yes	2022	
Wyoming	Yes	No Statute	

Figure A1: Event Study Comparison: Synthetic Opioid Death Rates, Controlling for Opioid Prescriptions



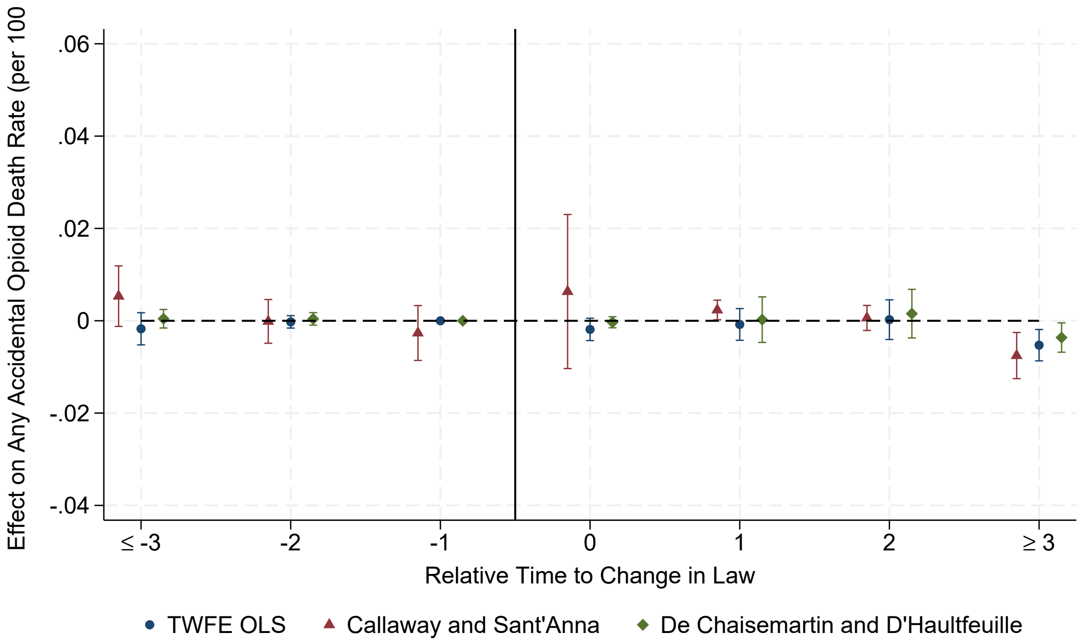
Note: Specifications include county and year fixed effects; opioid prescriptions per 100 population, percent female, white, black; percent of the population under age 15, between 15 and 19, between 20 and 24, between 25 and 34, between 35 and 44, between 45 and 54, and between 55 and 64; and the unemployment rate.

Figure A2: Event Study Comparison: Natural Log of Synthetic Opioid Death Rates



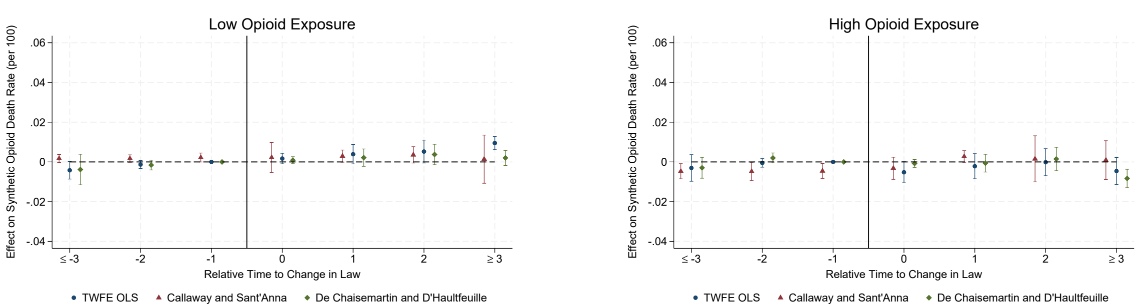
Note: Specifications include county and year fixed effects; opioid prescriptions per 100 population, percent female, white, black; percent of the population under age 15, between 15 and 19, between 20 and 24, between 25 and 34, between 35 and 44, between 45 and 54, and between 55 and 64; and the unemployment rate.

Figure A3: Event Study Comparison: Any Accidental Opioid Death Rates



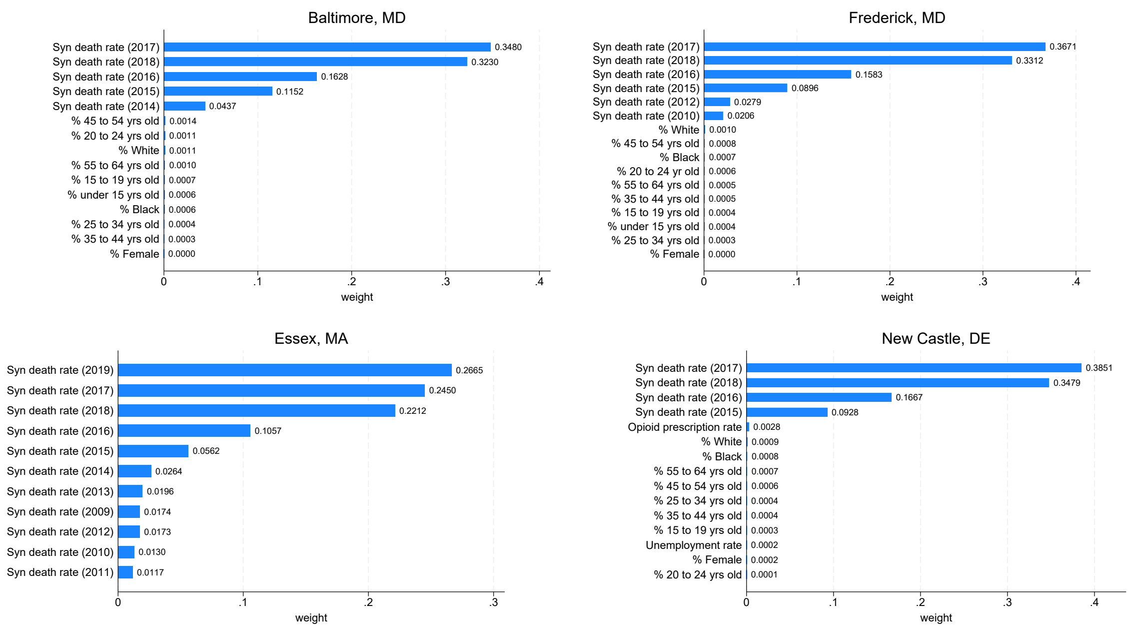
Note: Specifications include county and year fixed effects; opioid prescriptions per 100 population, percent female, white, black; percent of the population under age 15, between 15 and 19, between 20 and 24, between 25 and 34, between 35 and 44, between 45 and 54, and between 55 and 64; and the unemployment rate.

Figure A4: Event Study Comparison: Synthetic Opioid Death Rates, Pre-OxyContin Reformulation Low Opioid Exposure vs High Opioid Exposure Counties



Notes: Low-exposure (high-exposure) counties are the 1,310 (1,310) counties with opioid prescriptions per 100 population below (at or above) the sample median of 83.9. Specifications include county and year fixed effects; opioid prescriptions per 100 population, percent female, white, black; percent of the population under age 15, between 15 and 19, between 20 and 24, between 25 and 34, between 35 and 44, between 45 and 54, and between 55 and 64; and the unemployment rate.

Figure A5: Optimal Covariate Weights



A.2 County Harm Reduction Strategies

Baltimore, MD, Treatment Date Mid-2019

Baltimore County offers a full list of harm reduction services, including the distribution of sterile syringes, FTS, and Narcan (overdose prevention medication), as well as rapid STD testing and syringe disposal, at consistent times and places every week.[17]. The harm reduction program started in 2018 with syringe exchanges, treatment referrals, and STD testing, and expanded to FTS distribution in August of 2019.[18]

Frederick, MD, Treatment Date Late-2018

Similar to Baltimore County, the county health department in Frederick County, MD offers a wide range of harm reduction services at a consistent time and place, including:sterile syringes, FTS, narcan, and STI testing, through its Street Safe Program.[19] They will also delivery supplies to those without access to transportation. The Fredrick County health department also provides an up-to-date monthly calendar online as well as consistent communication through their website and social media. The distribution of FTS first appeared on their online calendar through their Syringe Services Program in November 2018.[20]

Essex, MA, Treatment Date 2020

In Essex County, MA, the Gloucester police department introduced the Angel Program in the summer of 2015, which provided a no-arrest screening and referral service to those seeking substance misuse treatment (Schiff et al., 2017; Davoust et al., 2021). The program matched over 400 individuals to treatment centers in its first year (PAARI, 2016). Through a non-profit initiative, the Police Assisted Addiction and Recovery Initiative (PAARI) expanded to over 28 police departments in Essex County, starting in 2017, and also began training officers to use Narcan.[21] More importantly, they then received a grant from the Massachusetts Department of Public Health and began distributing Fentanyl Test Strips in April 2020 (Case et al., 2020). At

[17] see https://www.baltimorecountymd.gov/departments/health/health-services/harm-reduction

[18] According to email correspondence with the Baltimore County Health Department.

[19] see https://health.frederickcountymd.gov/549/Street-Safe-Program.

[20] see https://health.frederickcountymd.gov/calendar.aspx?view=list&year=2018&month=11&day=16

[21] see https://paariusa.org/2017/07/11/new-p-r-project-aims-increase-addiction-recovery-connections-resources-essex-county/

that time, 11 Massachusetts police departments participated in this pilot program, four of which were located in Essex County (Beverly, Ipswich, Lynn, and Methuen Police Departments).

New Castle, DE, Treatment Date Late-2018

In New Castle, DE, the Brandywine Counseling and Community Center (BCCS) started an FTS pilot program in November 2018, which was expanded to other parts of the state in 2019. The BCCS drop in center provided fentanyl test strips in a safe injection kit which also included naloxone. They also provided safe sex kits, drug treatment referrals, and information on harm reduction techniques (Park et al., 2021).