What Fueled the Illicit Opioid Epidemic? New Evidence from a Takeover of White Powder Heroin Markets*

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Abstract

In recent years, the majority of drug overdose deaths in the U.S. have involved illicitly-produced opioids (primarily heroin and fentanyl), overtaking prescription opioids as the main driver of the opioid epidemic. In this paper, we document a previously unexplored shift in heroin markets that played a critical role in driving this transition: the takeover of white powder heroin production by Mexican Drug Trafficking Organizations (DTOs) from Colombian DTOs beginning in 2012, which resulted in heroin that was adulterated with fentanyl and more variable in potency. Using a difference-in-differences approach that exploits the fact that white powder heroin markets were exposed to these heroin quality shocks while black tar heroin markets were not, we find that they increased heroin and fentanyl death rates by roughly 230% and 890%, respectively, from 2012 to 2019. Previously studied legal market interventions cannot explain these effects, and we shed light on key aspects of the evolving epidemic that were thus far unexplained. We conclude that shocks to heroin quality are a major determinant of the transition to the illicit opioid waves of the epidemic.

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The ongoing overdose epidemic now stands as one of the worst public health crises in U.S. history, taking more than one million lives in less than 25 years (CDC 2021). There have been three waves of this epidemic, each involving a different form of opioids: prescription opioids in the 1990s and early 2000s, heroin beginning in the early 2010s, and synthetic opioids, primarily illegally-produced fentanyl, ever since (see Figure 1). Understanding the drivers of rising heroin and fentanyl mortality is crucial for designing new interventions to combat the illicit opioid waves of the epidemic, as historic investments in programs aimed at addressing the first wave—such as reducing prescription opioid initiation and expanding access to opioid addiction treatment (CBO 2022)—have so far failed to reduce overdose death rates significantly.

This paper provides the first causal evidence that a geographically concentrated shock to heroin quality was a key driver of the heroin and fentanyl waves of the opioid epidemic. Using annual data on undercover heroin purchases by the Drug Enforcement Administration (DEA), we first show that illicit drug supply chains established sticky links between domestic geography, heroin source countries, and the formulations of heroin sold. By the 1990s, geography was a strong predictor of both the type and origin of heroin available in U.S. cities (Ciccarone 2009). In eastern cities, heroin was a predominantly white powder produced in Colombia to mimic Southeast Asian heroin that became popular during the 1970s. Meanwhile, in western cities, heroin was predominantly black tar and produced in Mexico. Starting in the early 2010s, Mexican Drug Trafficking Organizations (DTOs) took over white powder heroin production from Colombian DTOs in the east. Black tar heroin production in the west remained unchanged.

We highlight two changes in heroin quality that coincided with the Mexican DTO takeover in cities where white powder heroin was prevalent but not in black tar heroin markets. First, white powder heroin became more variable in potency. Second, white powder heroin was increasingly adulterated with fentanyl, a synthetic opioid that is 20 to 50 times more potent than heroin (Volkow and Collins 2017). Ethnographic research suggests that fentanyl was more easily incorporated into white powder heroin markets compared to black tar heroin markets, particularly in the early stages, because the visual similarity between fentanyl and white powder heroin made it hard for users to detect adulteration before use (Mars et al. 2018, 2019).

We next estimate the causal effects of these heroin quality shocks on mortality. To do so, we use restricted death records for all U.S. counties from 2000 to 2019 and exploit the natural experiment resulting from the Mexican DTO takeover exclusively affecting cities with white powder heroin markets. We compare changes in overdose mortality post-takeover for commuting zones that historically had white powder heroin markets with those that had black tar heroin markets. Commuting zones supplied primarily black tar heroin serve as an effective control group, as there was no observed change in heroin production during this period, and users were better able to detect potential fentanyl contamination in their supply. However, cities with black tar heroin markets faced other potential causes of increased death rates studied in the literature, including the August 2010 reformulation of the blockbuster painkiller OxyContin to be abuse-deterrent, which aimed to reduce prescription opioid misuse by making it harder to crush or inject (Alpert et al. 2018; Evans et al. 2019; Powell and Pacula 2021).

Consistent with the shocks to heroin quality being exogenous, we do not observe differential pre-trends in mortality between white powder and black tar heroin markets for eleven years

prior to the Mexican DTO takeover. Then, immediately with the onset of the takeover in 2012, we find significant increases in heroin and fentanyl mortality in white powder heroin markets relative to black tar heroin markets. These increases continue to grow over time and show that the takeover by Mexican DTOs amplified the trajectory of the overall opioid epidemic, consistent with dynamic spillovers in opioid use (Cutler and Donahoe 2024). In total, we estimate that the heroin quality shocks caused heroin and fentanyl death rates to increase by 234% and 890%, respectively, from 2012 to 2019. We also show that these increases are not explained by other causes of rising illicit opioid death rates that have been examined in the literature, such as exposure to the OxyContin reformulation (Alpert et al. 2018; Evans et al. 2019; Powell and Pacula 2021), state-level policies intended to curb prescription opioid diversion (Kim 2021; Balestra et al. 2021), trade (Moore et al. 2023), or changes in enforcement.

Our main contribution to the literature is establishing a new and significant driver of the transition from the prescription opioid wave to the heroin and fentanyl waves of the epidemic. The prevailing hypothesis for these transitions, with vastly different policy implications, is that they resulted from unintended consequences of interventions aimed at reducing legal opioid supply. We revisit the effects of the two primary interventions studied in the literature—the OxyContin reformulation and state-level Prescription Drug Monitoring Programs (PDMPs), which aim to enhance oversight and accountability in prescribing and dispensing—to assess how they, along with the takeover of white powder heroin production, contribute to the rise in illicit opioid mortality after 2010. We find that the impacts of the OxyContin reformulation and PDMPs on illicit opioid mortality remain significant but are smaller than previously thought. Our estimates suggest these interventions can together explain approximately 40% of combined increases in heroin and fentanyl mortality from 2010 to 2019, with the remaining 60% resulting from shocks to heroin quality due to the takeover of production by Mexican DTOs.

Our work also highlights the importance of variable product quality and information asymmetries in illicit drug markets. We document substantial variation in heroin source countries, formulations, and potency across cities and over time. Because the quality of illicit drugs is noncontractible and can only be determined after consumption, users are particularly vulnerable to market changes that affect their mortality risk (Nelson 1970; Galenianos et al. 2012). The associated information and search frictions create a moral hazard problem, as sellers have an incentive to exploit buyers' inability to assess drug quality, often at the expense of safety through adulteration (Galenianos and Gavazza 2017). There is a potential role for government intervention to address this market failure, but programs that monitor illicit drug use and disseminate information about product quality remain significantly underfunded. In fact, many such programs were de-funded as the opioid epidemic unfolded, such as the Arrestee Drug Abuse Monitoring Program and the Heroin Domestic Monitoring Program used in this study. This leaves practitioners, policymakers, and the scientific community in the dark about shifts in illicit drug markets that could be used to inform more responsive public health interventions.

Lastly, our findings shed light on key aspects of the evolving epidemic that have remained unexplained until now. One such aspect is the earlier and disproportionate impact of the fentanyl epidemic on eastern states (Zoorob 2019; Abouk et al. 2021; Moore et al. 2023), despite the prescription opioid epidemic being more widespread across the country. Our analysis provides

the first causal evidence linking these regional disparities to differences in the evolution of heroin supply chains and drug quality between the eastern and western United States.

The second empirical puzzle we can explain is the increasing burden of the opioid epidemic on non-White populations. Despite historically low exposure to the prescription opioid epidemic, Black and Hispanic Americans have faced significant increases in illicit opioid mortality in recent years (Ruhm 2022). The main alternative explanation for the transition to illicit opioids—that it resulted from unintended consequences of efforts to curb prescription opioid supply—predicts that illicit opioid mortality would primarily increase among Whites, given their higher rates of prescription opioid misuse. However, the heroin quality shock we study affected all racial and ethnic groups using heroin, underscoring the limitations of interventions focused solely on regulating opioid prescribing, as these policies fail to address newly impacted populations who may have initiated heroin or fentanyl use without prior prescription opioid exposure.

1 Data

Our paper combines several sources of data. First, to better understand heroin trafficking—specifically the organizations involved in its production, distribution, and retail, and how these dynamics evolved over time—we use federal intelligence information from the DEA's annual Heroin Domestic Monitoring Program (HDMP) and Heroin Signature Program (HSP) reports. The HDMP, which was defunded in 2016 and is no longer in operation, historically provided yearly data on the geographic sources of heroin, along with its type and purity, at the street level for approximately 31 U.S. cities during the years reports were released: 1992, 1993, 2006, 2011, 2013, 2014, 2015, and 2016.[1] In some cases, additional years of data are included in these reports (e.g., the 2006 report back-fills prices and origin information for 2004 and 2005), providing us with a more consistent panel covering 2004 to 2006 and 2009 to 2016. The HSP offers national-level data on the purity and geographic source of all types of heroin in the U.S. from 1999 to 2018, but it is not disaggregated by area or heroin type.

While these are the best possible data in terms of tracking changes to heroin supply over time, there are limitations to using them. First, they are based on undercover purchases made by DEA agents in retail heroin markets. Thus, the data are not independent samples of retail heroin supply: they reflect the intelligence and priorities of the DEA. Because of this, we generally expect that changes to the drug environment (e.g., new entrants) will be measured with some lag. An example of this is that the DEA did not develop the capacity to chemically identify Mexican-originating white powder heroin until several years after they had already suspected that it was widely available, which we describe in greater detail in Section 2. Second, we only observe aggregate city-level purchases and are not able to observe key features of the market that could impact mortality, such as variation in potency across buys within markets. Instead, we examine variability across markets. This will lead us to understate true underlying variability of potency, since each observation already represents an average over several samples.

Second, to measure overdose mortality, we obtain micro-data from the CDC's Restricted-Use Vital Statistics Data, which are also known as the Multiple Cause of Death (MCOD) research

[1] Some cities are only available in specific years or as part of the smaller "Geo-probes" program. Our analysis focuses on the 31 cities with consistently available data from 2004 to 2016.

files. NCHS (2021) provide a comprehensive collection of information on all deaths in the United States, which includes details on the decedent, the county and year of occurrence, the underlying cause of death, and multiple conditions (if applicable) since 1999. To code causes of death (e.g., prescription opioids, heroin, and fentanyl overdoses), we follow coding conventions used by the CDC (CDC 2021). We focus on the pre-COVID pandemic period. Figure 1 highlights the three waves of the opioid epidemic using these data.

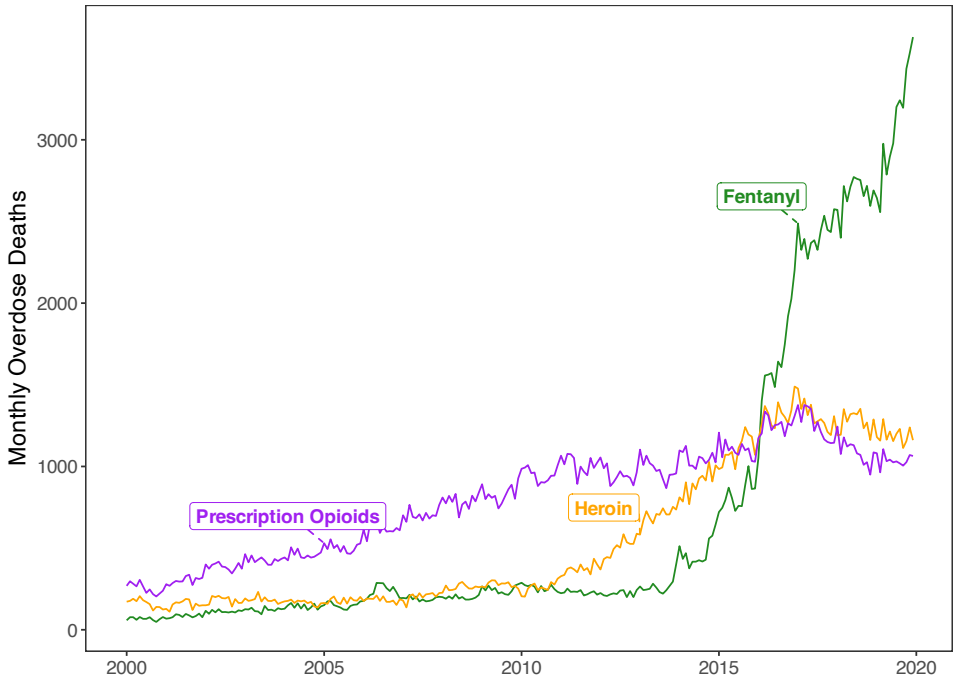


Figure 1: Monthly U.S. Overdose Deaths by Opioid Type

Notes: Monthly mortality data are from the National Vital Statistics System (NVSS). We use the following ICD-9 codes for overdose death types: T40.2 for prescription opioids, T40.1 for heroin, and T40.4 for fentanyl.

Third, to examine prescription opioid distribution across space and time, we use the Automation of Reports and Consolidated Orders System (ARCOS) database. These data contain the record of every controlled substance shipped in the United States from 2006 to 2019. Each record contains the DEA number, address, name, and business type for both the reporter and the buyer, as well as information on each transaction, such as the transaction date, opioid drug name, quantity, strength, and Morphine Milligram Equivalent (MME) conversion factor. This allows us to examine shipments of, for example, generic oxycodone or OxyContin, at any level of temporal or geographical aggregation. Lastly, we obtain data used in the literature, cited as they appear, to control for variables previously shown to be associated with illicit opioid deaths, such as state-level OxyContin misuse rates, state policies, and trade flows.

2 Background on U.S. Heroin Supply

This section helps contextualize our empirical setting and results by presenting background information on the U.S. heroin supply and how it has evolved over time. We highlight a

significant geographic division between white powder and black tar heroin markets that was present since the 1990s. We then show that Mexican DTOs took over white powder heroin markets in the early 2010s, resulting in heroin supply that was ultimately more variable in potency and adulterated with illicit fentanyl.

2.1 The Transformation of the U.S. Heroin Market

In the early 1970s, heroin was supplied to the largest and most lucrative heroin markets in the eastern U.S. as a white powder that was sourced from the Golden Triangle of Southeast Asia. In the 1990s, Colombian Drug Trafficking Organizations (DTOs) developed a "mimic" white powder heroin to compete for market share (DEA 1994). Owing in part to the infrastructure they developed to distribute cocaine in the 1980s, Colombian DTOs were able to sell their heroin at a lower cost than traffickers coming from Southeast Asia and took over as the dominant suppliers in the east (Rosenblum et al. 2014). Meanwhile, Mexican DTOs established dominance in the heroin markets of the west. There, they produced different types of heroin that resembled black tar and, to a lesser extent, brown powder (DEA 1994).

The result of this is that in the early 2000s, the U.S. heroin market was geographically segmented (DEA 2013, p. 3). Figure 2 highlights this phenomenon by showing that areas further east were supplied white powder heroin and those further west were supplied black tar heroin, where the dividing longitude is approximately -91 degrees; suppliers in the east were almost exclusively Colombian, while those in the west were Mexican.[2] Note that one crude marker cited in DEA reports for this division of supply is the Mississippi River, but there is no evidence this was an explicit boundary and we observe some cities that straddle the river (e.g., St. Louis) receiving a mix of both types of heroin. These differences endured over time because heroin users developed sticky tastes for the types of heroin they were sold (Ciccarone 2009).

The means of trafficking heroin into the U.S. by the Colombian and Mexican groups also differed in fundamental ways. Colombian DTOs used couriers who concealed or swallowed packages of heroin and smuggled them on flights destined for the U.S., principally the John F. Kennedy (NY), Miami (FL), Newark (NJ), and San Juan (PR) international airports (DEA 2001). In contrast, Mexican DTOs smuggled heroin across the U.S.-Mexico border, primarily in San Diego, CA and El Paso, TX (DEA 2001).

In the early 2000s, several factors pushed Colombian DTOs to abandon heroin trafficking. First, in 1997, the U.S. and Colombia re-instated a treaty that permitted narcotics traffickers to be extradited to the U.S. As a result, leaders of the most prolific Colombian cartels such as Fabio Ochoa Vásquez (Medellin cartel) and Don Berna (AUC) were arrested, extradited, and imprisoned in the U.S. throughout the early 2000s.[3] Second, Al-Qaeda's attacks on the U.S. on September 11th, 2001 caused airport security to tighten and allegedly raised the risks of smuggling drugs through airports and shifted trafficking to the U.S.-Mexico border, where

[2]Data from the HDMP from 2004-2011 indicate 99% of white powder heroin was produced in Colombia and just 1% was produced in Southeast Asia.

[3]Colombian DTOs perceived the costs of this extradition treaty to be high. In the mid-1980s, Pablo Escobar waged a domestic terror campaign to intimidate lawmakers to oppose the treaty. Pablo Escobar's group, who referred to themselves as "Los Extraditables", had a motto of "we prefer a grave in Colombia to a prison in the United States" (Butt 2022).

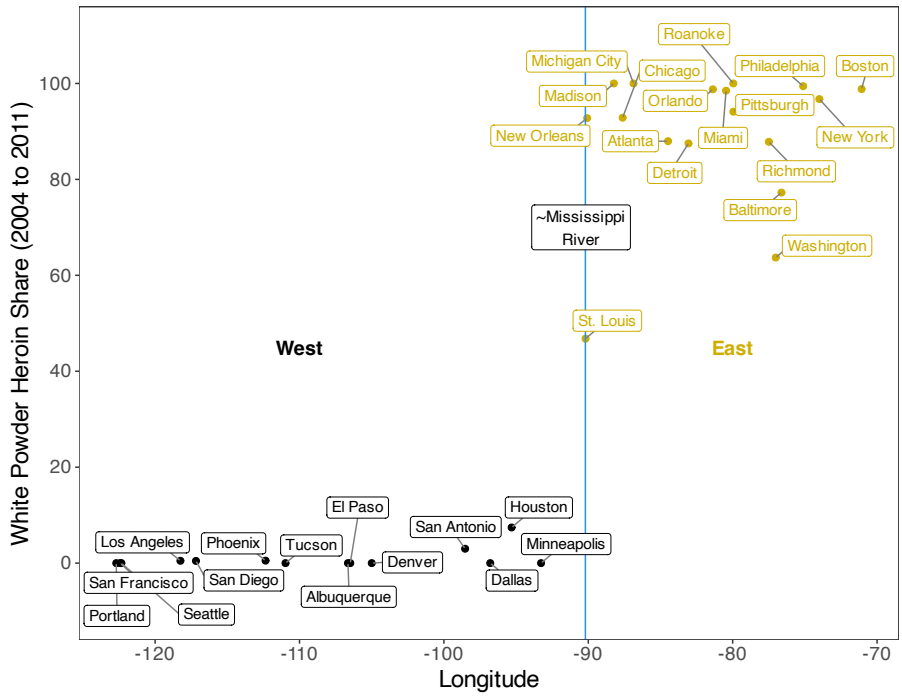


Figure 2: Geographic Segmentation of the U.S. Heroin Market

Notes: The data used to generate this figure comes from the Heroin Domestic Monitoring Program (HDMP) and each dot represents a city that is repeatedly sampled as part of this program. The share of white powder heroin in a given city is calculated by using the total number of exhibits collected by heroin type from 2004 to 2011, excluding exhibits with inconclusive testing (for which we can not confirm type) from the calculation. The centroid of the city is used to plot the longitude.

Mexican DTOs had a geographic comparative advantage (DEA 2003).

Ultimately, Colombian DTOs scaled back trafficking and limited their focus to wholesale production. They sold heroin to Mexican DTOs to traffic across the border and distribute to retail suppliers throughout the U.S. One representative quote from DEA reporting that describes this is as follows:

> "The amount of South American heroin seized in the U.S. Arrival Zone along the Southwest Border—particularly Texas—increased significantly in 2003... Law enforcement reporting indicates that Colombian DTOs are increasingly relying on Mexican DTOs and criminal groups to transport South American heroin to the United States..." (DEA 2005, p. 68)

These events would eventually result in Mexican DTOs taking over the white powder heroin market, but this process was gradual (DEA 2001). Starting in the mid-2000s, Mexican DTOs increasingly sold black tar and brown powder heroin in eastern markets (DOJ 2007, p. 14), but these products never "took off."[4] Mexican DTOs even made a first attempt at introducing fentanyl in white powder heroin markets when they were a small player in these markets, allegedly to provide a product that more closely rivaled the higher potency Colombian white

[4]DEA documents and a retired DEA Subject Matter Expert whom we spoke with, Bernie Malone, allege that this was due to users' and retail sellers' preferences for white powder heroin, which was much more potent (DOJ 2007, p.15)

powder heroin (DOJ 2007, p.16). This led to the spike in fentanyl deaths in eastern cities from 2005 to 2007 seen in Figure A.1. The spike ended after the lab that manufactured the fentanyl in Toluca, Mexico was raided by the DEA in May 2006 (CDC 2008). DEA reporting indicates these efforts did not result in violence because Colombian DTOs were willing to cede market share to Mexican DTOs to reduce their exposure to interdiction (DOJ 2009, p.29).

Starting around 2010, Mexican DTOs established emissaries in Colombia to support production and processing as Colombian cartel leadership was dismantled by U.S. law enforcement efforts (Felbab-Brown 2022). Shortly after this, they began mimicking Colombian heroin processing methods and introduced their own white powder heroin to the market. The tipping point for this was 2012-2013. The DEA's 2011 HDMP report notes an increase in heroin exhibits for which chemical origin analyses results were inconclusive, which it notes could be due to Mexican produced white powder heroin or mixed Colombian and Mexican heroin, but notes that Colombian DTOs remained the main producer of white powder heroin. The 2012 report was never released. However, by 2013, the market was clearly experiencing a significant transition, as indicated on the first page of the 2013 HDMP report:

> "Since the inception of the HDMP, the formal signature for Mexico has encompassed both brown and black tar Mexican produced heroin. Over the last several years however, DEA's Special Testing and Research Laboratory (SFL1) has tracked the phenomenon of alleged Mexican white powder heroin (AMW) produced from opium harvested in Mexico... Of particular interest is the fact that 57 of the 64 (89.1%) heroin exhibits classified as UNK which displayed the characteristics of alleged Mexican white heroin were purchased east of the Mississippi River, in cities identified as traditional SA [Colombian] heroin markets... This is likely an indication that the current retail heroin market in each of these cities is in transition and that Mexican drug trafficking organizations (DTOs) continue to expand their role in white heroin markets." (DEA 2016, p. 1)

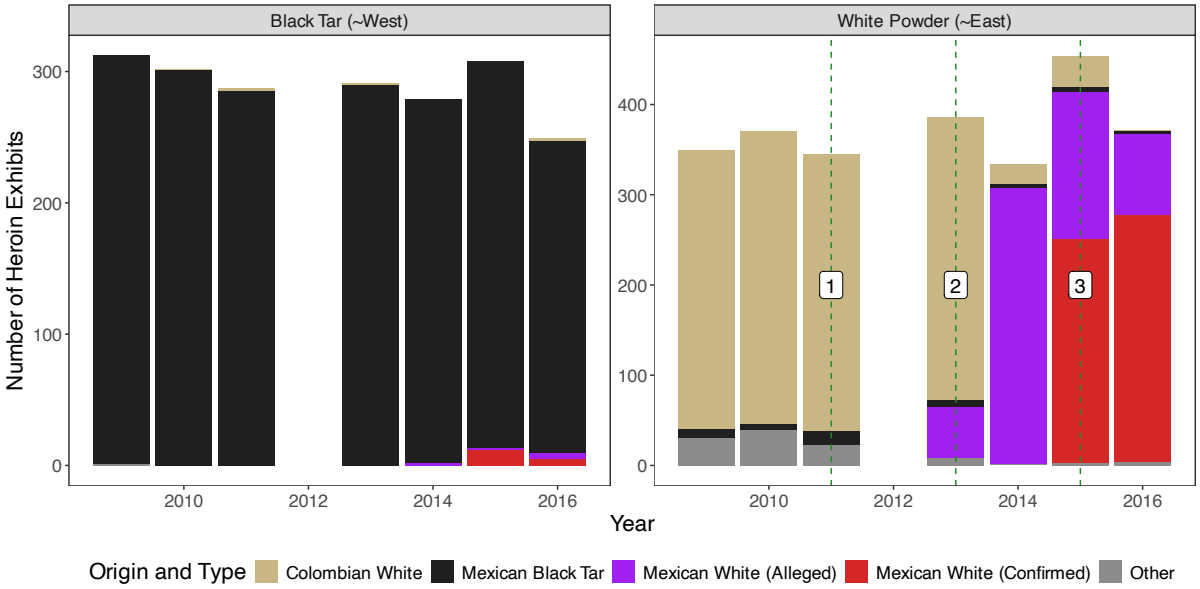
The timing of the transition is summarized in Panel A of Figure 3. In 2013, the DEA reports the first data on white powder heroin that it suspects as coming from Mexico, accounting for 13% of all exhibits in white powder markets.[5] In 2014, 74% of exhibits in white powder markets were suspected Mexican heroin. By 2015, the DEA developed the ability to chemically identify Mexican-originating white powder heroin and half of white powder heroin exhibits were confirmed as originating in Mexico (an additional 23% were inconclusive Mexican or Colombian heroin).[6] Over the same time, Colombian DTOs exited white powder heroin markets. In 2016, 71% of white powder heroin was confirmed as originating in Mexico and fewer than 1% originated in Colombia (vs. 60% in 2011). Critically to the identification strategy that we present below, western markets were unaffected by the takeover and black tar heroin from Mexico continued to comprise the vast majority of heroin sold there.

[5] Data from 2012 were excluded as the HDMP report was not released in that year.

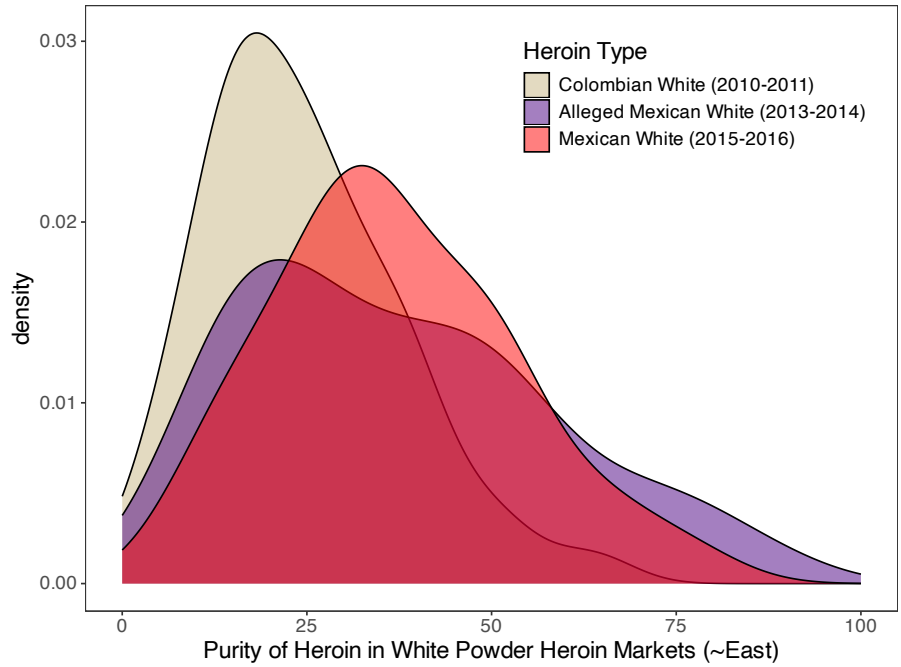
[6] Developing the test for which country heroin is sourced from requires analyzing a sample that is known to be produced in the lab of a given country to compare subsequent samples to. Following entry of a new type of heroin, it would take some time for the DEA to be able to locate such a lab and obtain samples. This explains the long lag time to develop the tests.

Figure 3: Heroin Origin, Type, and Purity across Time and Space

Panel A: Heroin Origin and Type in White Powder versus Black Tar Markets



Panel B: Heroin Purity by Type in White Powder Markets



Panel A Notes: Data come from the Heroin Domestic Monitoring Program (HDMP). 2012 is excluded due to lack of an HDMP report and counts of heroin exhibits with inconclusive origin that year. This figure presents the total exhibits by market, type, and year. In the right panel, 1. In 2011, the DEA first reports suspicions of Mexican DTOs mixing Mexican and Colombian heroin or producing white powder heroin that mimics Colombia processing methods, but that Colombian white powder remains the dominant type. 2. In 2013, the DEA first identifies suspected Mexican white powder heroin and inconclusive origin heroin that mimics Colombian heroin in the HDMP report. 3. In 2015, the DEA first implements a test to confirm Mexican white heroin.

Panel B Notes: Data come from the Heroin Domestic Monitoring Program (HDMP). This figure shows the distribution of purity of Colombian white heroin just before the Mexican DTO entry (2010-11), suspected Mexican white heroin during the first two years it is reported (2013-2014), and confirmed Mexican white heroin after testing was available (2016-2016). Appendix Figure A.2 shows the distribution of overall purity for both eastern (white powder) and western (black tar) heroin markets for reference.

2.2 Changes in Heroin Product Quality

We next discuss changes to white powder heroin quality that occurred as as the result of the Mexican DTO takeover, and that could lead to higher mortality from heroin use. First, Panel B of Figure 3 shows the distribution of heroin purity exhibits across markets and years for Colombian white powder heroin just before the takeover (2010-2011), white powder heroin that the DEA suspected was from Mexico but before it could be confirmed (2013-2014), and confirmed Mexican white powder heroin (2015-2016). As shown in the figure, both the alleged and confirmed Mexican white powder heroin was higher purity on average than than the Colombian white powder heroin that came before it. Further, the tail of the distribution and probability of very high purity heroin (e.g., above 75% pure) is much greater. This greater variability would result in a much greater probability of a person using more heroin than they had developed a tolerance to, which is a key factor in an overdose (White and Irvine 1999).

The next and likely even more consequential change that we observe is the increasing presence of fentanyl in white powder heroin supply after Mexican DTOs took over the market. Fentanyl is a synthetic opioid that is 20-50 times more potent than heroin. Because of its high potency, small variations in quality (which are common in illicit drug markets) can trigger an overdose.[7] Ethnographic studies indicate the shift to fentanyl began in the same areas that Mexican DTOs took over (eastern cities like Baltimore and Massachusetts) and at essentially the same time that the takeover occurred (2012-2013) (Ciccarone et al. 2017; Mars et al. 2018, 2019). For example, one study asked a 30-year-old man who had been using heroin for 18 years about changes to heroin supply in Massachusetts (Ciccarone et al. 2017, p. 148):

> Q: So the heroin that is out there right now, how long has that been around? Have there been any changes?
>
> *A: It's been changing, like 3-1/2 years ago, maybe 4. 2012–2013, it's like that's when like the bullshit started coming in. Like mother-fucker's realized, if I got 3 grams of dope I can put 3 grams of bullshit on it.*
>
> Q: What do you mean by bullshit?
>
> *A: Like cut. Well, the fake cut or fentanyl or whatever [. . .]*

The first DEA data validating user reports of fentanyl contaminating white powder heroin supply appeared in the 2014 combined HDMP and HSP report. The report noted that 21 total heroin samples purchased through the program in 2014 contained fentanyl, and retroactively noted that 7 exhibits from 2013 contained fentanyl (DEA 2015, p. 23).[8] The report also noted that all samples containing fentanyl were purchased in eastern cities where white powder heroin was prevalent. Later HSP reports note the shares of different types of heroin that contained fentanyl. By 2018, fentanyl was detected in roughly one-quarter (23%) of all white powder heroin samples but still fewer than 1% of black tar heroin samples (DEA 2020, p. 10). In terms of deaths, fentanyl death rates escalated dramatically in eastern states starting around 2013,

[7] A lethal dose of fentanyl for most individuals is just 2 milligrams (DEA 2024). Analyses of heroin and fentanyl samples show variation in quality of this amount is very common (Larnder et al. 2022).

[8] The lack of noting fentanyl in the 2013 report, despite it later being clarified that it was present in 2013 data, highlights the lag between changes to heroin markets and what shows up in the DEA documentation.

building off the much smaller epidemic in the mid-2000s that occurred when Mexican DTOs were a much smaller player in the white powder heroin market (see Figure A.1).

Ethnographic literature (including the quote noted above) suggests that because of the higher risks of fentanyl, many heroin users preferred heroin that did not include it (Ciccarone et al. 2017; Mars et al. 2018, 2019). To understand why Mexican DTOs still began to replace heroin supply with fentanyl-based products, it is important to note that heroin and other illicit drugs are classic examples of experience goods (Nelson 1970). Buyers are not able to observe the purity of drugs or what they are adulterated with until after they have consumed them, and there are no institutions to enforce quality in an illicit market. Therefore, sellers face incentives to rip off consumers (particularly high-cost sellers selling to new customers) through adulterating their products (Galenianos et al. 2012; Galenianos and Gavazza 2017). At the import level, fentanyl is approximately 99% cheaper than heroin due to its compactness, lower trafficking costs, and synthetic production, which eliminates the need for costly agricultural inputs (Pardo and Reuter 2020). As a result, it is an attractive adulterant from the perspective of heroin sellers. Further, it is easy to adulterate white powder heroin with fentanyl without consumers' knowledge because fentanyl is also a white powder and looks very similar (but looks different compared to black tar) (see Appendix Figure A.3).

3 The Effects of Heroin Quality Shocks on Overdose Mortality

In this section, we describe the methodology used to estimate the causal effects of changes in heroin quality due to the Mexican DTO takeover of white powder heroin markets and present the associated results. We conduct our primary analysis in commuting zones where we know the heroin purity, source, and type, based on the 31 cities that are tracked in the DEA's HDMP reports, but we also expand the analysis nationwide using longitude as a proxy for exposure to the takeover.[9] We find significant and growing increases in heroin and fentanyl overdose deaths in white powder heroin markets relative to black tar markets after the shocks to heroin quality. We then examine the impacts by race and pre-existing heroin use, as well as control for alternative explanations for the increases in illicit opioid mortality suggested in the literature.

3.1 Methodology

We examine the causal impacts of the shock to heroin quality by exploiting variation in commuting zones' exposure to the DTO takeover, driven by differences in their initial share of heroin purchases that were white powder, with the following event-study specification:

$$Y_{ct} = \rho_t \text{White_Powder_Market}_c + \lambda_c + \gamma_t + \nu_{ct}, \tag{1}$$

where Y_{ct} are overdose death rates per 100,000 in commuting zone c in year t. In our main specification, we define a commuting zone as a white powder heroin market ($\text{White_Powder_Market}_c$) if it has an above median share of pre-Mexican DTO takeover heroin purchases being white powder (2004 to 2011). λ_c and γ_t are commuting zone and year fixed effects, respectively, and

[9] Appendix Table B.1 provides summary statistics by heroin market type and Appendix Figure A.4 shows the raw trends in illicit opioid deaths by market type.

regressions are population-weighted. Standard errors are clustered at the commuting zone. The coefficients of interest are therefore ρ_t, normalizing the year before the DTO takeover (2011) to zero, which capture the year-by-year differences in within-changes among commuting zones that are exposed to the DTO takeover relative to ones that are not.

We also estimate an average effects version of Equation (1) with

$$Y_{ct} = \beta(\text{White_Powder_Market}_c \times \text{Post_Mexican_DTO_Takeover}_t) + \lambda_c + \gamma_t + \varepsilon_{ct}, \quad (2)$$

where all variables are defined as before except for Post_Mexican_DTO_Takeover, which is an indicator variable for the period from 2012 to 2019. The coefficient of interest is therefore β, which captures the average mortality impact among commuting zones that are exposed to the Mexican DTO takeover relative to ones that are not.

Lastly, to extend our analysis nationwide, we replace the variable White_Powder_Market$_c$ in Equations (1) and (2) with Eastern_Market$_c$ and use all contiguous U.S. commuting zones, instead of only ones that we have HDMP data for. The decision to use longitude as a delineation for exposure to the DTO takeover is driven by what we observe in Figure 2: a clear geographic segmentation of the U.S. heroin market at around -91 degrees. Thus, the treatment variable Eastern_Market$_c$ is a binary indicator for being east of -91 degrees as the longitude. However, the results are not sensitive to using alternative thresholds to divide areas into east and west.

3.2 Primary Empirical Results and Robustness Checks

The top panel of Figure 4 provides the event study for heroin overdose deaths from estimating Equation (1).[10] First, we do not observe a significant pre-trend in heroin mortality between commuting zones with white powder versus black tar heroin markets for over ten years prior to the Mexican DTO takeover. Then, we see an immediate and dynamic increase in the heroin death rate in white powder heroin markets relative to black tar heroin markets that coincides with the Mexican DTO takeover of white powder heroin markets and lasts for approximately five years. Afterwards, it slowly declines but remains significant. The bottom panel shows that as the heroin death rate declines in white powder heroin markets, those same markets experience a dynamic and large increase in fentanyl overdose death rates.[11] Figure A.8 presents the event study for the nationwide analysis and results are very similar.

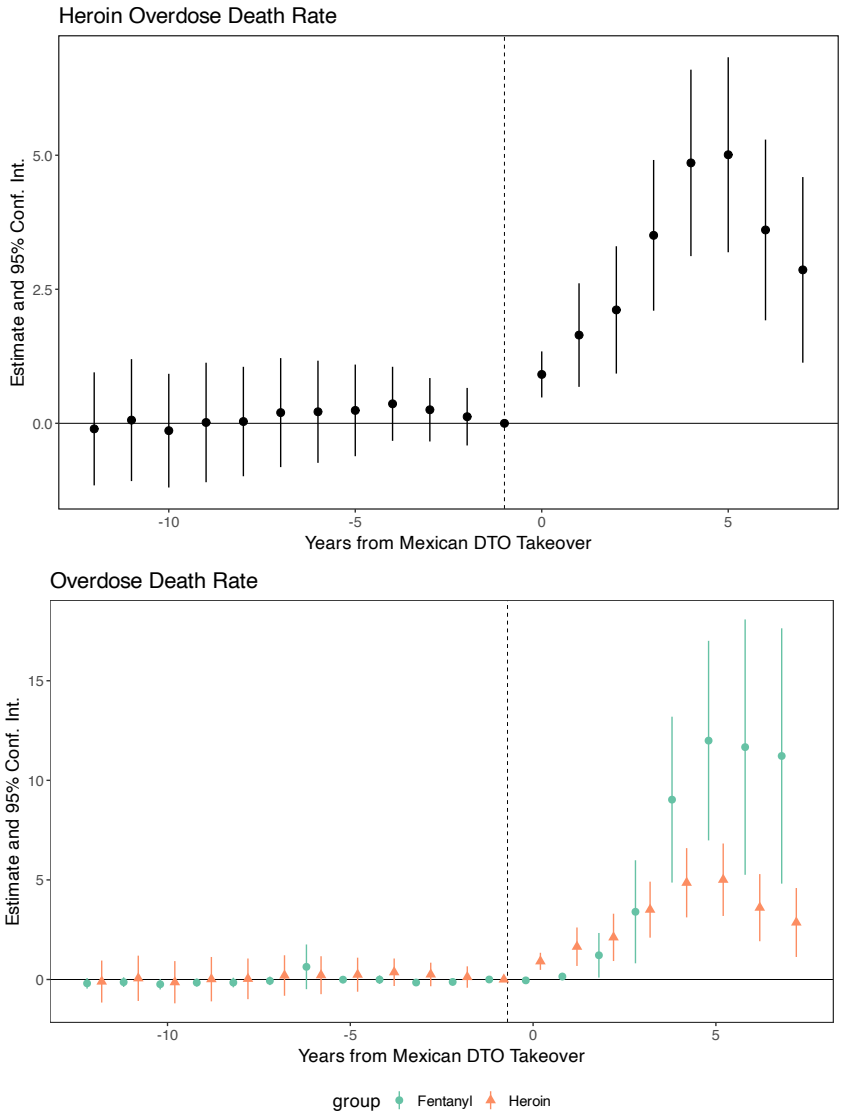
We next estimate Equation (2) and present the average mortality impacts of the takeover of white powder heroin markets in Table 1.[12] We first use the sample of commuting zones that had a city participating in the HDMP (Panel A). The average effect from the top panel of Figure 4 is in Column (1), namely an increase in heroin overdose deaths of 2.958 per 100,000 (234% change from the pre-treatment mean). The average effect for fentanyl from the bottom panel of Figure 4 is in Column (2), which shows an increase of 6.128 overdose deaths per 100,000 (890%). The

[10] Appendix Figure A.5 re-estimates Equation (1) for heroin overdose death rates but uses a leave-one-out procedure. Appendix Figure A.6 removes population-weighting from the regressions and Appendix Figure A.7 repeats the event study analysis for additional outcomes, namely mortality from heroin and fentanyl, only fentanyl, and only heroin.

[11] The Mexican DTOs' experimentation with fentanyl in eastern markets referenced in Section 2 and observed in Figure A.1 can be seen in event time -6 for fentanyl overdose deaths in Figure 4.

[12] Appendix Table B.2 replicates Table 1 but removes population weighting. Appendix Tables B.3 amd B.4 utilize different pre-takeover white powder heroin treatment definitions.

Figure 4: The Dynamic Mortality Impacts of the Mexican DTO Takeover



Notes: These figures present the ρ_t coefficients from estimating Equation (1). The White Powder Heroin treatment indicator variable is defined as having an above median share of total pre-takeover heroin purchases being white powder. The models include commuting zone and year fixed effects, standard errors are clustered at the commuting zone, and the regressions are population weighted. Outcomes are overdose deaths per 100,000 and the sample includes 31 commuting zones where we have HDMP data on heroin type. The top panel is only heroin overdose deaths, while the bottom panel presents both heroin and fentanyl overdose deaths. The Mexican DTOs' experimentation with fentanyl in eastern markets referenced in Section 2 and observed in Figure A.1 can be seen in event time -6 for fentanyl overdose deaths.

last two columns of Table 1 show that the increase in overdose mortality is unique to opioids and is specifically driven by heroin and fentanyl, as Columns (1) and (2) sum approximately to Column (3), and Column (4) is small and imprecisely estimated. Finally, Panel B of Table 1 extends the analysis nationwide, producing similar coefficients.

Table 1: Average Mortality Impacts of the Mexican DTO Takeover

Panel A: HDMP Analysis

	Heroin (1)	Fentanyl (2)	Any Opioids (3)	Non-Opioids (4)
(White Powder Market)X(Post-Takeover)	2.958***	6.128***	10.61***	-0.6699
	(0.6849)	(1.440)	(2.100)	(0.7479)
Pre-treatment mean	1.2656	0.68862	4.2519	5.3102
R^2	0.79029	0.63468	0.73355	0.79862
Observations	620	620	620	620

Panel B: Nationwide Analysis

	Heroin (1)	Fentanyl (2)	Any Opioids (3)	Non-Opioids (4)
(Eastern Market)X(Post-Takeover)	2.908***	6.490***	11.04***	0.6179*
	(0.3039)	(0.5351)	(0.8293)	(0.3632)
Pre-treatment mean	0.37930	0.90609	3.8417	3.4198
R^2	0.70405	0.61588	0.70684	0.73837
Observations	13,820	13,820	13,820	13,820

Notes: This table presents the β coefficients from estimating Equation (2). In Panel A, the White Powder Heroin treatment indicator variable is defined as having an above median share of total pre-takeover heroin purchases being white powder and in Panel B, the East Binary treatment variable is equal to one for commuting zones east of -91 degrees longitude. The sample in Panel A is only commuting zones that had a city that participated in the Heroin Domestic Monitor Program (HDMP) and in Panel B, it is all commuting zones in the contiguous United States. Post-Takeover is an indicator for 2012 and after. The models include commuting zone and year fixed effects, standard errors are clustered at the commuting zone, and the regressions are population weighted. Outcomes are overdose deaths per 100,000 and the sample includes only commuting zones where we have HDMP data.

We then test alternative explanations for our results (Figure 5) by re-estimating Equation (2) for commuting zones with a city in the HDMP, but now add controls for other potential drivers of rising heroin death rates suggested in the literature. We first test for the possibility that previously studied legal market interventions may impact our results. We control for pre-reformulation OxyContin shipments using ARCOS data in a commuting zone (as a continuous and binary variable in two separate specifications) and interact it with an indicator variable for the post-2010 period (i.e., after OxyContin was reformulated), and we do not see any significant attenuation of our results. Next, we add a triple interaction term between pre-reformulation OxyContin, being in a white powder heroin market, and post-reformulation (as well as the double interactions between these variables). This is to control for the possibility that OxyContin and white powder heroin are closer substitutes than OxyContin and black tar heroin, leading to more substitution in white powder than black tar heroin markets. We again do not see attenua-

tion of our results. Moreover, Appendix Table B.5 shows that the coefficient on the interaction term between OxyContin shipments, white powder heroin markets, and post-reformulation is negative, showing differentially greater substitution from OxyContin to white powder heroin cannot explain the differential rise in heroin death rates in these cities.

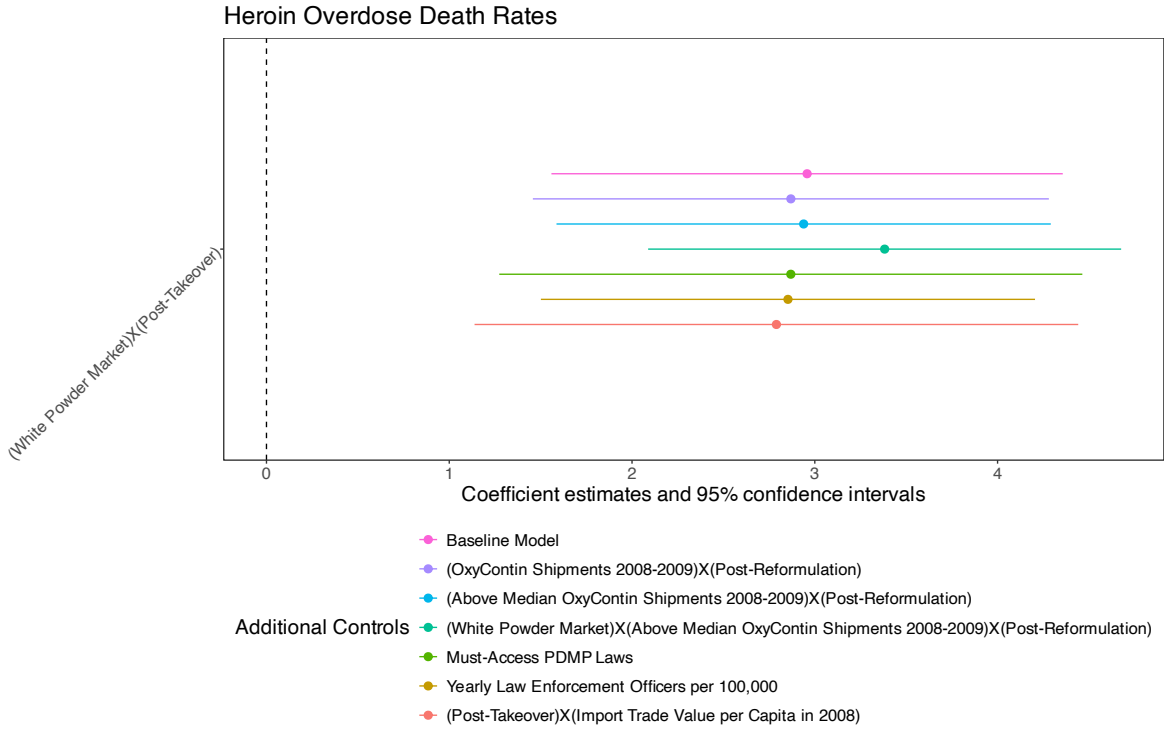


Figure 5: The Average Mortality Impacts of the Mexican DTO Takeover

Notes: This figure presents the β coefficients from estimating Equation (2) with different control variables. The White Powder Heroin treatment indicator variable is defined as having an above median share of total pre-takeover heroin purchases being white powder, and Post-Takeover is an indicator for 2012 and after. The models include commuting zone and year fixed effects, standard errors are clustered at the commuting zone, and the regressions are population weighted. Outcomes are overdose deaths per 100,000 and the sample includes only commuting zones where we have HDMP data. Appendix Table B.5 is the table version.

Next, we include indicators for the period after a state passes a must-access Prescription Drug Monitoring Program, a state-level policy intended to prevent prescription opioid diversion that prior literature shows increased illicit opioid death rates (Kim 2021; Balestra et al. 2021). These exercises show that our main coefficient of interest, the β for heroin overdose death rates, is very stable and suggests that our results are not affected by policies intended to reduce prescription opioid misuse. The remainder of Figure 5 explores whether enforcement or trade affects our main results. More specifically, we first control for the yearly number of officers per 100,000 in a given commuting zone using Law Enforcement Officers Killed and Assaulted (LEOKA) data. This is our best nationwide measure of whether enforcement changed during our sample period. Second, we use the same trade data as in Moore et al. (2023), namely those from the U.S. Census' Trade Online portal on imports in 2008 based on the "state of destination" code. This is meant to capture smuggling of fentanyl via legal trade packages. We interact it with a post-takeover indicator variable. Both of these exercises show that our main coefficient of interest is again very stable. Appendix Figure A.9 and Appendix Table B.6 repeat this for the nationwide analysis and yield similar conclusions.

As a final robustness exercise, we conduct a permutation test to examine how unusual the increases in opioid mortality in the 31 HDMP markets following the Mexican DTO takeover were relative to overall variability in opioid mortality in these cities over this period. For each outcome of interest, we randomize with replacement which commuting zone that participated in the HDMP gets "treated," then run Equation (2) 1,000 times using a new sample each time. Appendix Figure A.10 presents the distribution of the placebo coefficients obtained from these regressions, where the dotted vertical red line is our estimated coefficient. Our estimated increases in heroin and fentanyl mortality for cities exposed to the Mexican DTO takeover were above the 99^{th} percentile of their respective placebo estimate distributions.

3.3 Explaining the Opioid Epidemic's Demographic Transition

In this section, we estimate the impact of the Mexican DTO takeover on illicit opioid death rates across racial groups. As motivation, the left panel of Appendix Figure A.11 shows that prescription opioid death rates are significantly higher for White individuals and follow a different trend compared to Black individuals. However, the right panel shows that the burden of illicit opioid deaths is relatively similar between the two groups, both in terms of levels and trends. This empirical fact is surprising within the context of current literature that attributes most of the rise in illicit opioid death rates to unintended consequences of efforts to reduce prescription opioid use, as one would predict increases would be greater for White individuals who were much more commonly misusing prescription opioids.

In terms of analysis, Panel A of Table 2 shows an overall increase in the illicit opioid death rate of 9.086 per 100,000 (a 465% increase) in Column (1) for the HDMP commuting zones. Columns (2) through (5) then show estimates for different racial and ethnic groups, weighted by their respective populations. The estimated coefficients for White, Black, and Hispanic groups are all large, statistically significant, and similar to the overall effect in Column (1), but they are not statistically different from each other.[13] The estimates for Native Americans are also relatively large but imprecise. When we extend the analysis nationwide in Panel B of Table 2, we observe similar results, except for Native Americans, whose coefficient is considerably larger than in Panel A and is statistically significant. This difference is likely explained by the smaller Native American population in the HDMP cities. Overall, these results show the takeover and shocks to heroin product quality help explain the demographic transition of the epidemic whereby Black and Hispanic individuals are increasingly impacted in the heroin and fentanyl waves (Ruhm 2022; Mulligan 2024), despite much lower exposure to the prescription opioid wave.

3.4 Susceptibility to a Heroin Supply Shock

As a final exercise, we extend our national analyses and leverage additional variation in treatment exposure based on pre-takeover heroin use. Specifically, we hypothesize that commuting zones with higher pre-takeover heroin use were more vulnerable to a heroin quality shock that in-

[13] For the comparison between White and Black, the t-statistic for the equality of coefficients is 0.590. For White and Hispanic, the t-statistic is 1.318, and for Black and Hispanic, the t-statistic is 0.089. Appendix Figure A.12 provides an alternative comparison of the impacts by race using a unified model.

Table 2: Average Mortality Impacts of the Mexican DTO Takeover by Race and Ethnicity

Panel A: HDMP Analysis

	Illicit Opioids (1)	White (2)	Black (3)	Hispanic (4)	Native (5)	Other (6)
(White Powder Market)X(Post-Takeover)	9.086***	10.11***	7.183	6.740***	1.898	0.3359
	(1.801)	(1.815)	(4.622)	(1.803)	(6.545)	(0.5619)
Pre-treatment mean	1.9542	2.3932	1.7228	0.97985	1.8861	0.17207
R^2	0.73292	0.77177	0.64474	0.62686	0.50906	0.52743
Observations	620	620	620	620	620	620

Panel B: Nationwide Analysis

	Illicit Opioids (1)	White (2)	Black (3)	Hispanic (4)	Native (5)	Other (6)
(Eastern Market)X(Post-Takeover)	9.399***	10.27***	8.429***	7.141***	9.655***	0.7076*
	(0.7124)	(0.7455)	(1.493)	(1.031)	(2.501)	(0.3801)
Pre-treatment mean	1.2845	1.4867	0.89547	0.49928	1.8187	0.35244
R^2	0.69061	0.69475	0.57544	0.57436	0.27024	0.24626
Observations	13,500	13,500	13,500	13,500	13,500	13,500

Notes: This table presents the β coefficients from estimating Equation (2) for overdose deaths for each race category. In Panel A, the White Powder Heroin treatment indicator variable is defined as having an above median share of total pre-takeover heroin purchases being white powder and in Panel B, the Eastern Market treatment variable is equal to one for commuting zones east of -91 degrees longitude. The sample in Panel A is only commuting zones that had a city that participated in the Heroin Domestic Monitor Program (HDMP) and in Panel B, it is all commuting zones in the contiguous United States. Post-Takeover is an indicator for 2012 and after. The models include commuting zone and year fixed effects, standard errors are clustered at the commuting zone, and the regressions are population weighted. Outcomes are overdose deaths per 100,000 and the sample includes only commuting zones where we have HDMP data. Appendix Figure A.12 provides an alternative comparison of the impacts by race using a unified model.

creased death rates conditional on use. To proxy for pre-takeover heroin use, we use pre-takeover heroin death rates averaged over two different time periods: 2005–2011 and 2005–2009. The latter serves as a proxy for heroin use before the OxyContin reformulation, which may have contributed to increased heroin use in 2010–2011, and is the time period used by Alpert et al. (2018) for their OxyContin misuse measure. The results for using heroin death rates from 2005 to 2011 are in Panel A of Table 3 and Column (1) shows that heroin death rates increased by 1.797 deaths per 100,000 (474%) in eastern white powder heroin markets after the Mexican DTO takeover, and by an additional 0.1453 deaths per 100,000 (38%) for each additional heroin death per 100,000 in the pre-takeover period. The effects are even larger for fentanyl (Column 2) and total opioid overdose deaths (Column 3). Column (4) shows small and insignificant changes in non-opioid drug overdose deaths.

Table 3: Average Mortality Impacts of the Mexican DTO Takeover by Pre-Existing Heroin Use

Panel A: Pre-Mexican DTO Takeover (2005 to 2011)

	Heroin (1)	Fentanyl (2)	Any Opioids (3)	Non-Opioids (4)
(Eastern Market)X(Post-Takeover)	1.797***	3.611***	6.968***	0.0469
	(0.3605)	(0.6045)	(0.9676)	(0.4214)
(2005-2011 Heroin Death Rate)X(Post-Takeover)	0.0717**	0.0250	0.1257**	0.0464
	(0.0312)	(0.0159)	(0.0606)	(0.0304)
(2005-2011 Heroin Death Rate)X(Eastern Market)X(Post-Takeover)	0.1453***	0.3970***	0.5502***	0.0735
	(0.0533)	(0.0900)	(0.1553)	(0.0459)
Pre-treatment mean	0.37930	0.90609	3.8417	3.4198
R^2	0.74754	0.65606	0.74451	0.74502
Observations	13,820	13,820	13,820	13,820

Panel B: Pre-OxyContin Reformulation (2005 to 2009)

	Heroin (1)	Fentanyl (2)	Any Opioids (3)	Non-Opioids (4)
(Eastern Market)X(Post-Takeover)	1.921***	3.782***	7.246***	0.2366
	(0.3487)	(0.6179)	(0.9382)	(0.4154)
(2005-2009 Heroin Death Rate)X(Post-Takeover)	0.0873**	0.0271	0.1529*	0.0700
	(0.0423)	(0.0206)	(0.0821)	(0.0438)
(2005-2009 Heroin Death Rate)X(Eastern Market)X(Post-Takeover)	0.2137***	0.6020***	0.8353***	0.0798
	(0.0726)	(0.1388)	(0.2251)	(0.0607)
Pre-treatment mean	0.37930	0.90609	3.8417	3.4198
R^2	0.73770	0.65194	0.73929	0.74277
Observations	13,820	13,820	13,820	13,820

Notes: This table presents the coefficients from estimating Equation (2) with additional interaction terms. The Eastern Market binary treatment variable is equal to one for commuting zones east of -91 degrees longitude and Post-Takeover is an indicator for 2012 and after. In Panel A, we use Heroin $OD_{c,2005-2011}$, the heroin overdose death rate from 2005 to 2011, while in Panel B, we use Heroin $OD_{c,2005-2009}$, the heroin overdose death rate from 2005 to 2009. The models include commuting zone and year fixed effects, standard errors are clustered at the commuting zone, and the regressions are population weighted. Outcomes are overdose deaths per 100,000 and the sample includes all commuting zones in the contiguous United States.

Panel B of Table 3 shows stronger results if we instead use heroin death rates from 2005 to 2009 at baseline and thus the shock had larger effects on death rates in areas with more heroin use even prior to OxyContin being reformulated. Furthermore, we find that these effects are not driven by areas with more OxyContin shipments in eastern markets in the pre-period.

Taken together, the evidence of this subsection strongly suggests an exogenous shock to existing heroin users/markets over this period, as opposed to an increase in the number of heroin users.

4 The Overall Determinants of Heroin and Fentanyl Mortality

In this final section, we integrate our findings with prior literature, which concluded that policy interventions aimed at reducing prescription opioid abuse—namely the OxyContin reformulation and must-access Prescription Drug Monitoring Programs (PDMPs)—were the primary drivers of the opioid epidemic's transition to heroin and fentanyl. To do so, we estimate state-level event study models that replicate this prior literature, then incorporate controls for changes in heroin quality in eastern states following the Mexican DTO takeover of white powder heroin production. Our findings indicate that the contributions of the OxyContin reformulation and PDMPs to the rise in heroin and fentanyl mortality rates are still significant but much smaller than previously believed. Specifically, we estimate that 40% of the increase in heroin and fentanyl deaths through 2019 is jointly explained by these interventions, with the remaining 60% driven by heroin quality shocks resulting from the Mexican DTO takeover.

4.1 Background on Policy Interventions

In response to the first wave of the opioid epidemic, numerous interventions were introduced during the 2010s to combat prescription opioid abuse. A central conclusion in the literature examining these legal market interventions is that they backfired by stimulating demand for illicit opioids, which are pharmacological substitutes for prescription opioids, and caused the majority of the transition of the epidemic to heroin and fentanyl. This includes the reformulation of OxyContin (a widely abused prescription opioid) to be abuse-deterrent (Alpert et al. 2018; Evans et al. 2019) and the adoption of state-level programs that require physicians to screen patients for risky opioid prescribing histories before prescribing them opioids (PDMPs) (Kim 2021; Balestra et al. 2021). However, key results in this literature overlook the heroin quality shocks we identify, which is a potentially significant omission given that the Mexican DTO takeover of white powder production occurred around the same time (2012) as the OxyContin reformulation (August 2010) and the state-level adoption of must-access PDMPs (post-2012).

Studying the overall determinants of the rise in heroin and fentanyl mortality, inclusive of all these policy interventions and shocks, is crucial for two reasons. First, from a policy evaluation perspective, it is important to assess the independent effects of the OxyContin reformulation and must-access PDMPs on illicit opioid mortality after adjusting for the impact of shocks to heroin quality. If the effects of these interventions on illicit opioid mortality are different than previously believed, then their costs and benefits should be reevaluated. Second, the literature suggests that these policies—particularly the OxyContin reformulation—were the main driver of the transition to the heroin and fentanyl waves of the opioid epidemic (Alpert et al. 2018; Evans et al. 2019), with some studies positing that the epidemic may have abated if the reformulation had not occurred (Powell and Pacula 2021). If these conclusions are incorrect, it calls for a rethinking of interventions to curb the epidemic and prevent further mortality increases.

4.2 Empirical Framework

To study the contribution of policy and heroin quality shocks to the illicit opioid waves of the epidemic, we extend Alpert et al. (2018) and Powell and Pacula (2021), as their study designs allow for a straightforward incorporation of variables indicating regional exposure to the white powder heroin takeover and state adoption of must-access PDMPs.[14] Aggregating our mortality data to the state-level to match these papers, we estimate

$$Y_{st} = \alpha_s + \gamma_t + \delta_t \text{OxyMisuse}_s^{Pre} + \beta_t \text{White_Powder_Market}_s + \Phi_r \text{PDMP}_s \times \theta_{r(s,t)} + \epsilon_{st}, \quad (3)$$

where the first four terms are the same as in Equation (1) of Alpert et al. (2018). Y_{st} are state-year overdose death rates, where we separately present results for heroin, synthetic opioids (mostly fentanyl), any illicit opioid (heroin or fentanyl), and any opioid (which also includes prescription opioids, methadone, and unspecified opioids). α_s and γ_t are state and year fixed effects, respectively, to adjust for time-invariant factors affecting opioid mortality across states and time-varying factors that affect all states across years. $\delta_t \text{OxyMisuse}_s^{Pre}$ interacts year fixed effects with each state's fixed pre-reformulation rate of OxyContin misuse, drawn from the 2004-2009 National Survey on Drug Use and Health. We normalize the 2009 coefficient (the year before reformulation) to zero. Thus, the δ_t coefficients identify differential changes in illicit opioid mortality rates after the reformulation for states with one percentage point higher pre-reformulation prevalence of OxyContin misuse.

The remaining terms are included to examine and account for other factors driving opioid deaths. First, $\beta_t \text{White_Powder_Market}_s$ interacts year effects with the same variable to identify exposure to the Mexican DTO takeover of white powder heroin markets from Section 3: being east of -91 degrees longitude and measured based on a state's centroid. We normalize the 2011 coefficient (the year before the takeover) to zero. The β_t coefficients therefore identify differential changes in mortality in white powder heroin markets that were exposed to heroin quality shocks after 2011, as in Section 3, but are estimated at the state-level to be consistent with research on the OxyContin reformulation and PDMPs.[15]

Second, PDMP_s captures states that adopted must-access PDMPs and $\theta_{r(s,t)}$ are indicators for years relative to adoption in each treated state. Dates for must-access PDMP implementation come from Horwitz et al. (2021). We omit the year prior to adoption for normalization. Thus, the Φ_r coefficients estimate differential changes in opioid mortality for states that implemented must-access PDMPs each year relative to implementation. We bin relative periods prior to thirteen years or more before treatment for graphing purposes, though results were not sensitive

[14] Evans et al. (2019) estimate a national trend break specification, which shows that the timing of the national trend break in heroin death rates coincided with the month after OxyContin was reformulated (September 2010). It is difficult to extend their analysis to incorporate controls for regional heroin quality shocks and other state policies due to the lack of cross-sectional variation in their primary model. Thus, we focus on extending Alpert et al. (2018) and Powell and Pacula (2021) who use cross-sectional variation instead.

[15] Note that states are larger areas than commuting zones, potentially leading to measurement error in states with cities that fall on both sides of the border and likely have different types of heroin markets. As an example, St. Louis in Missouri would be classified as a white powder heroin market whereas Kansas City in Missouri would be classified as a black tar heroin market in our commuting zone-level specification. In our state-level specification, all of Missouri is classified as a black tar market due to its centroid being west of -91 degrees. This type of measurement error would be expected to bias our estimates towards the null.

to this choice. Because PDMP treatment timing is differential, $\theta_{r(s,t)}$ are not balanced in the post period. However, as explained below, our main goal is to estimate the effects of each type of intervention in the average area through 2019 rather than a balanced treatment effect for each relative year. Thus, we use the unbalanced relative year data, rather than binning or trimming, and quantify the effects for the average state in each year through 2019. We use two-way fixed effects models for our main results, but we also report results for PDMPs in the Appendix using the Callaway and Sant'Anna (2021) estimator. Lastly, ϵ_{st} is an error term.

For estimation, we weight regressions by state population and cluster standard errors at the state-level. After presenting event study coefficients, we decompose the overall effects of the OxyContin reformulation, PDMPs, and the Mexican DTO takeover of white powder heroin production on the annual heroin and fentanyl mortality rates for the average area from 2010 to 2019. This entails multiplying the coefficients by weights that indicate exposure to each shock in the average area each year from 2010 to 2019. For the OxyContin reformulation, this is $\frac{\bar{p}}{2019-2010}\sum_{t=2010}^{2019}\times\hat{\delta}_t$, where $\bar{p}$ is the population-weighted prevalence of pre-reformulation OxyContin misuse in the U.S. (0.57%). For the Mexican DTO takeover, this is $\frac{\mu}{2019-2010}\sum_{t=2012}^{2019}\hat{\beta}_t$, where μ is the share of people living in white powder heroin markets (0.58). Lastly, for PDMPs, this is $\frac{1}{2019-2010}\sum_{t=2012}^{2019}\sum_{r=0}^{R}\hat{\Phi}_r\times\bar{\theta}_{r(t)}$ where $\bar{\theta}_{r(t)}$ denotes the population-weighted share of states that implemented a PDMP r years before year t.[16] We also add the effects of the OxyContin reformulation and PDMPs together to get the total effects of both policy interventions. We estimate standard errors for these linear combinations using the Delta method and use them to construct confidence intervals.

One final methodological point is that this decomposition is of the total impacts of both policy shocks and the Mexican DTO takeover of white powder heroin, inclusive of dynamic spillovers (e.g., people becoming addicted to fentanyl supplied by Mexican DTOs and information about them spreading through the market). They also partly include the effects of the earlier and longstanding prescription opioid epidemic, as there were more people addicted to opioids and transitioning to using heroin from prescription opioids (and thus impacted by the heroin quality shocks) than if the prescription opioid epidemic had not occurred. We refer interested readers to Alpert et al. (2022) and Cutler and Donahoe (2024) for analyses of these additional factors and their contribution to the opioid epidemic.

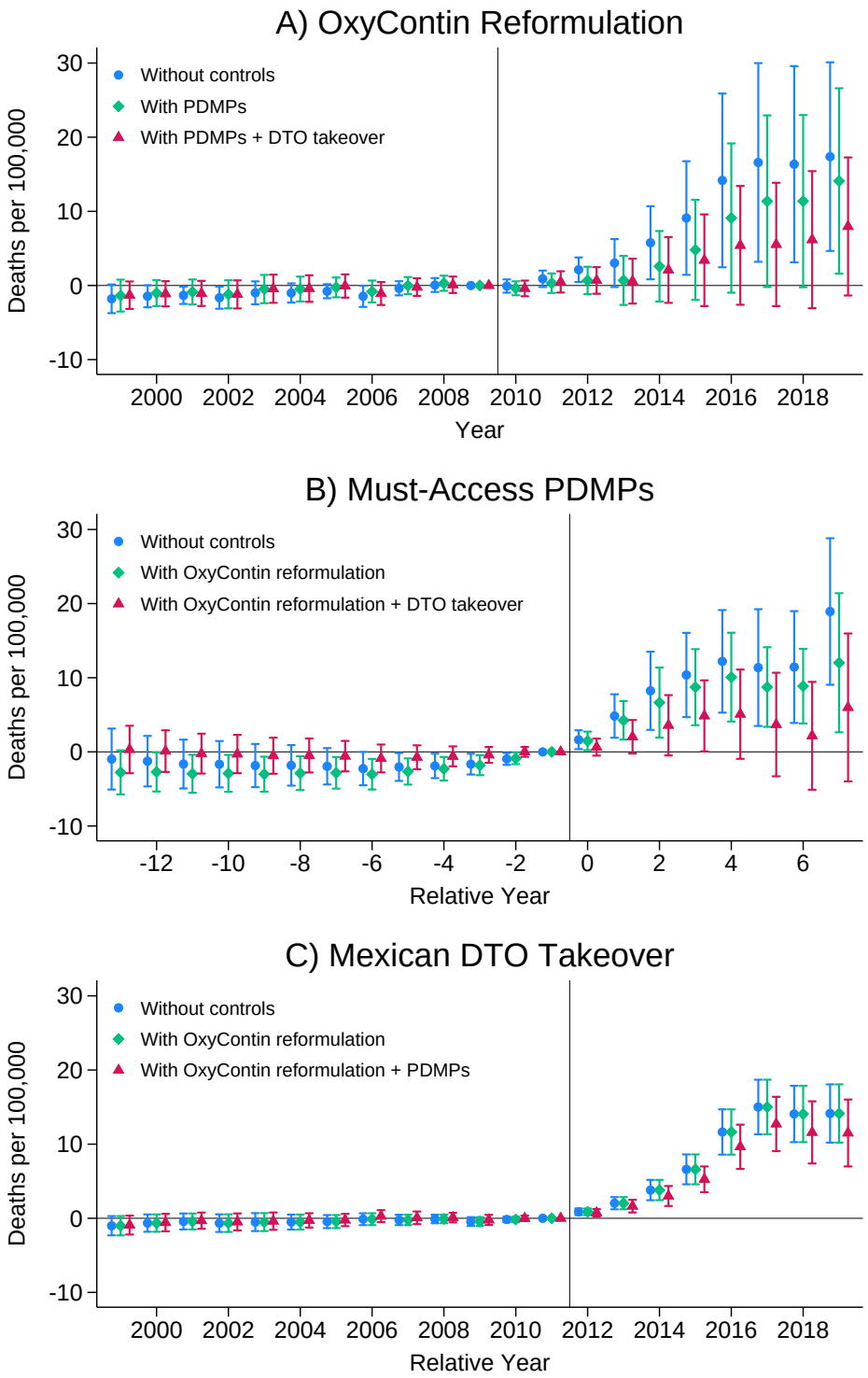
4.3 Replication and Extension

Event study coefficients from estimating Equation (3) for illegal opioid mortality rates are presented in Figure 6. We present results by first including each set of terms in the model individually, then sequentially adding terms to capture other interventions and/or the heroin quality shock itself. Consistent with prior research (the specifications without other controls), Panel A shows large increases in illicit mortality due to the OxyContin reformulation of the magnitude reported in prior literature (Alpert et al. 2018; Powell and Pacula 2021). However, after controlling for must-access PDMPs and the takeover, the event study coefficients attenuate significantly (by 63% in total). The estimated increases, which only begin several years after

[16] The sum begins in 2012 because that is the year the first state (West Virginia) implemented a must-access PDMP (Horwitz et al. 2021).

the reformulation in the specifications with other controls, are also fairly imprecise.

Figure 6: Determinants of Rising Illicit Opioid Death Rates



Notes: The figure presents estimates of the event study coefficients for the impacts of the OxyContin reformulation, must-access PDMPs, and the Mexican DTO takeover of white powder heroin on illicit opioid (heroin or synthetic opioid) mortality using Equation (3), sequentially adding controls for the other terms in the model.

For must-access PDMPs (Panel B of Figure 6), we find significant increases in illicit opioid

mortality shortly after their implementation in all specifications. However, the estimates are also smaller in magnitude and less precise after controlling for the OxyContin reformulation and the takeover (attenuating by 65% in total). Results that use the Callaway and Sant'Anna (2021) estimator to account for the differential treatment timing of PDMPs are reported in Figure A.13 and are similar but show greater attenuation and estimates that are quite imprecise.

In contrast to the attenuation in the estimated effects of policy interventions, controlling for the effects of both the OxyContin reformulation and PDMPs has fairly limited effects on the estimates of the DTO takeover on mortality (Panel C of Figure 6) and results remain large and statistically precise (attenuating only 18%). This reveals a significant bias in estimates of the effects of the OxyContin reformulation and must-access PDMPs on illicit opioid mortality that do not control for regional shocks to heroin quality that were unfolding over the same period. It also provides further evidence that the takeover was a key and independent contributor to the rise in illicit opioid mortality, using the same methodology as in prior literature. Results for heroin and fentanyl deaths separately are presented in Figures A.14 and A.15 and further show that the OxyContin reformulation and must-access PDMPs had smaller effects on each separate wave of the epidemic after accounting for exposure to the white powder heroin takeover, and that the takeover was an independent contributor to each wave.

4.4 Decomposition

Decomposition estimates are reported in Table 4 and show the contribution of both policy interventions and the Mexican DTO takeover of white powder heroin to average annual increases in heroin, fentanyl, and illicit opioid (heroin or fentanyl) mortality from 2010 to 2019 nationally (relative to 2009). Our main findings are as follows. First, the Mexican DTO takeover of white powder heroin supply and the heroin quality shocks that resulted are the quantitatively most important contributor to both the heroin and fentanyl waves of the epidemic after 2010. The takeover alone can explain as much as 51% of the heroin wave, 72% of the fentanyl wave, and 60% of the heroin and fentanyl waves combined.

Second, legal market interventions also appear to have contributed to the illicit opioid waves of the epidemic, but their overall contribution is estimated to be smaller than prior literature indicates and also fairly imprecise. Collectively, the point estimates indicate that the OxyContin reformulation and PDMPs explain roughly 40% of the heroin and fentanyl waves of the epidemic combined, but the 95% confidence interval is fairly wide and indicates the possibility of a null or larger contribution. They also suggest that PDMPs were a greater contributor to rising heroin mortality than OxyContin reformulation, but that the OxyContin reformulation was a greater contributor to later increases in synthetic opioid deaths than PDMPs. Though, confidence intervals for the overall impacts of each specific type of intervention are fairly wide.

We illustrate the dynamics of the decomposition for the combined heroin and fentanyl waves of the epidemic in Figure 7. The figure plots average illicit opioid death rates over time and three counterfactuals. The first counterfactual restricts the OxyContin reformulation effect equal to 0 and thus plots trends in death rates if the OxyContin had not been reformulated. As shown, death rates would have been lower, but they still would have increased sharply following the shocks to heroin quality due to the Mexican DTO takeover of white powder heroin. The results

Table 4: Decomposition of Changes in Average Annual Opioid Death Rates (Nationwide)

	Heroin	Fentanyl	Illicit Opioids
	(1)	(2)	(3)
Mexican DTO Takeover	1.49	3.32	3.64
	[0.90, 2.09]	[2.19, 4.45]	[2.45, 4.84]
Policy Intervention Total	0.48	2.44	2.86
	[-1.13, 2.08]	[-0.29, 5.18]	[-0.11, 5.83]
By Intervention			
OxyContin reformulation	0.10	1.59	2.01
	[-1.51, 1.71]	[-1.26, 4.44]	[-1.08, 5.11]
Must-access PDMPs	0.38	0.85	0.85
	[0.02, 0.73]	[-0.21, 1.91]	[-0.15, 1.85]
Average increase (rel. 2009)	2.91	4.60	6.05

Notes: Decomposition of changes in heroin, synthetic opioid (fentanyl), and illicit opioid (heroin or fentanyl) from 2010 to 2019 based on interacting coefficients from Equation 3 with weights proportional to the impact of each intervention/shock in the average state (see the text for more details) and post-2010 year. 95% confidence intervals are presented in brackets and use standard errors that were constructed via the Delta method. The bottom row presents the average annual change in each cause of death from 2010 to 2019 for comparison.

for PDMPs are similar. However, without either of these interventions or the takeover, illicit opioid death rates would have been predicted to flatten out and slightly fall. The figure also illustrates that the takeover is increasingly the more important factor in explaining the illicit opioid waves of the epidemic as time progresses.

5 Conclusion

This paper identifies a new and significant driver of the transition from the prescription opioid wave to the heroin and fentanyl waves of the opioid epidemic: heroin quality shocks stemming from the takeover of white powder heroin production by Mexican DTOs in the early 2010s. Our findings reveal that these shocks, characterized by increased variability in heroin potency and fentanyl adulteration, explain 60% of the rise in heroin and fentanyl mortality from 2012 to 2019, with previously studied policy interventions accounting for the remaining 40%. This challenges the dominant narrative that legal interventions, such as the OxyContin reformulation and must-access PDMPs, were the primary drivers of the epidemic's transition to its illicit phases.

More broadly, we document significant variation in heroin quality, source countries, potency, and adulterants across markets and over time. These factors have profound implications for understanding mortality risks associated with opioid use, yet they remain insufficiently prioritized in both research and public health policy. Illicit drug markets are highly dynamic, and the lack of robust systems to track shifts in drug production and quality hinders the ability of policymakers and practitioners to respond effectively. For instance, fentanyl's earlier and more devastating impact in eastern states reflects the geographic segmentation of heroin markets, underscoring the critical role of regional dynamics in shaping the epidemic's trajectory.

A key implication of our findings is the need to broaden the scope of public health responses to include supply-side shocks and market-driven changes in drug quality. Current policy ap-

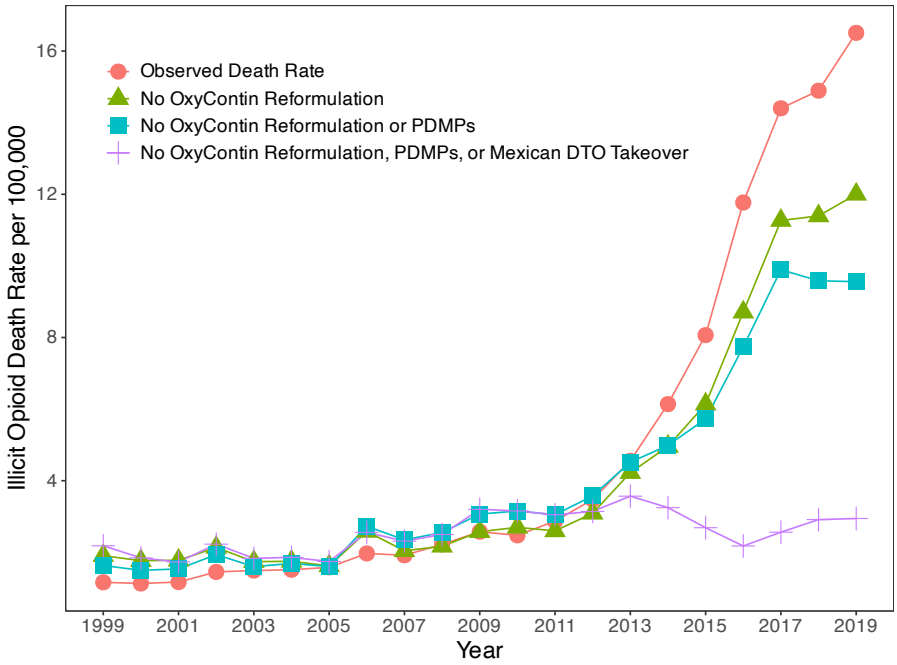


Figure 7: Counterfactual Trends in Heroin and Fentanyl Mortality Rates Without Legal Market Interventions or the Mexican DTO Takeover

Notes: This figure presents trends in national illicit opioid (heroin or fentanyl) death rates from 1999 to 2019 and counterfactual trends under three separate scenarios: (1) if OxyContin had not been reformulated (green line with triangle markers), (2) if must-access PDMPs had also not been implemented (blue line with square markers), and (3) if there had also not been a change in heroin production from Colombian to Mexico (purple line with pluses). We estimate these counterfactuals using Equation 3.

proaches, which predominantly focus on reducing prescription opioid initiation and expanding treatment for opioid addiction, may not fully address the emerging challenges posed by the heroin and fentanyl waves of the epidemic. While investments in drug market surveillance and early warning systems could provide valuable insights into emerging drug trends, more research is needed to assess their potential impact on mitigating future crises. Programs like the Arrestee Drug Abuse Monitoring Program and the Heroin Domestic Monitoring Program, which once provided useful information on drug market dynamics, could also benefit from further evaluation to determine whether they should be revitalized or restructured to meet current needs. Future work should explore how changes in economic incentives, policy interventions, and drug market dynamics interact to influence the quality and lethality of illicit drugs. A more comprehensive understanding of these factors could guide more tailored strategies that address the complexities of the ongoing opioid epidemic.

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A Additional Figures

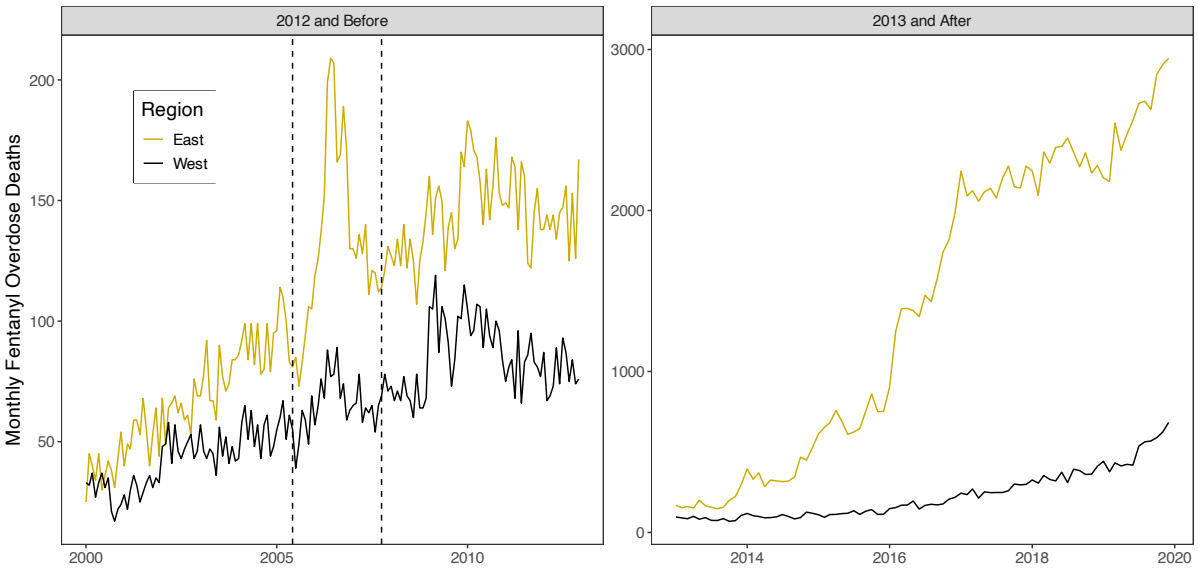


Figure A.1: Monthly Fentanyl Overdose Deaths

Notes: Data are from the National Vital Statistics System, where we use the ICD-9 code of T40.4 for fentanyl, and the delineation for East and West is the Mississippi River. The left panel highlights the short fentanyl epidemic that occurred when Mexican DTOs made a first attempt at introducing fentanyl in white powder heroin markets (between the two hashed vertical lines). They were a small player in these markets at the time and it led to a spike in fentanyl deaths in eastern cities that ended after the lab that manufactured the fentanyl in Toluca, Mexico was raised in May 2006 (CDC 2008).

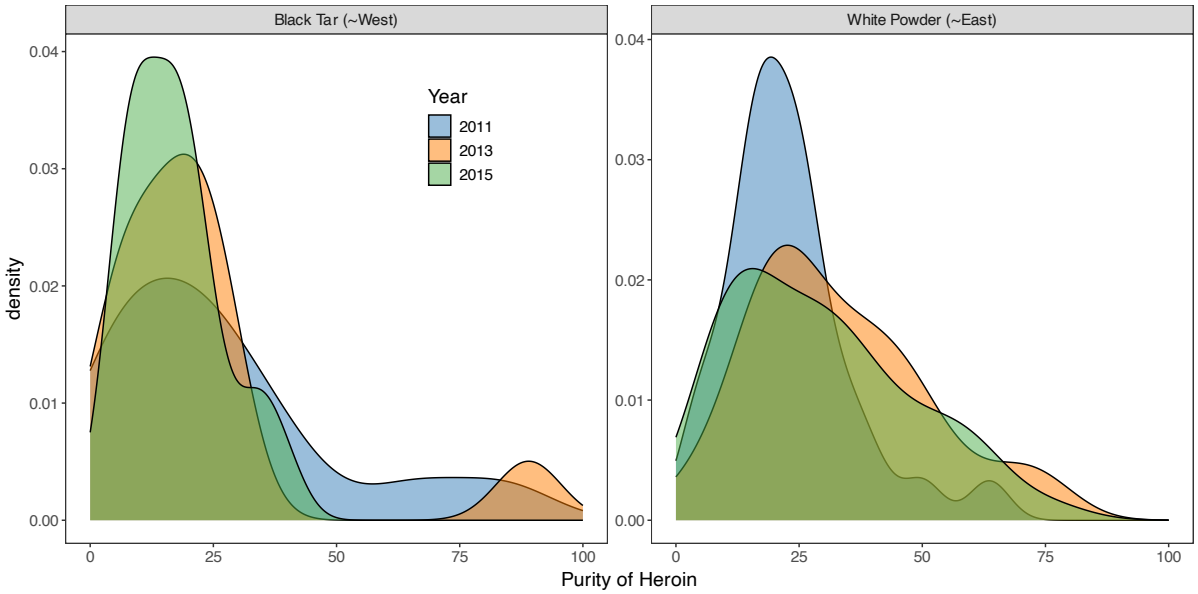


Figure A.2: Distribution of Heroin Potency Before and After the Mexican DTO Takeover of White Powder Markets

Notes: The data used in this figure are from the Heroin Domestic Monitoring Program (HDMP), and exhibits with unknown type or source are removed. The takeover of white powder heroin production by Mexican DTOs occurred in 2012.

Figure A.3: Images of black tar heroin, white powder heroin, and illicit fentanyl

A) Black tar heroin



B) White powder heroin



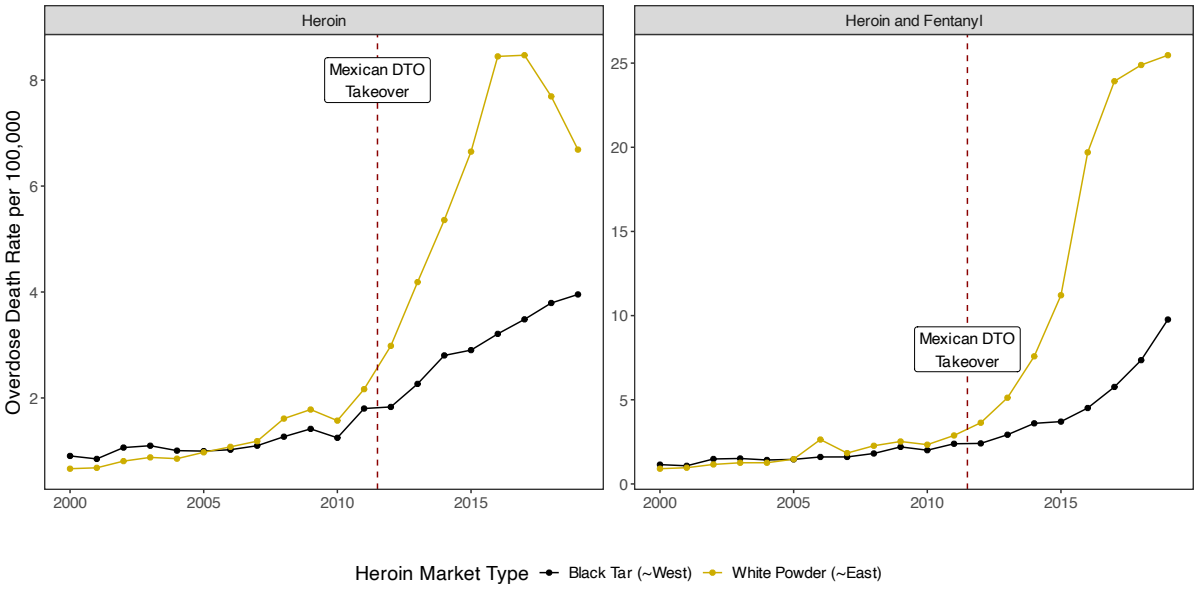
C) Fentanyl



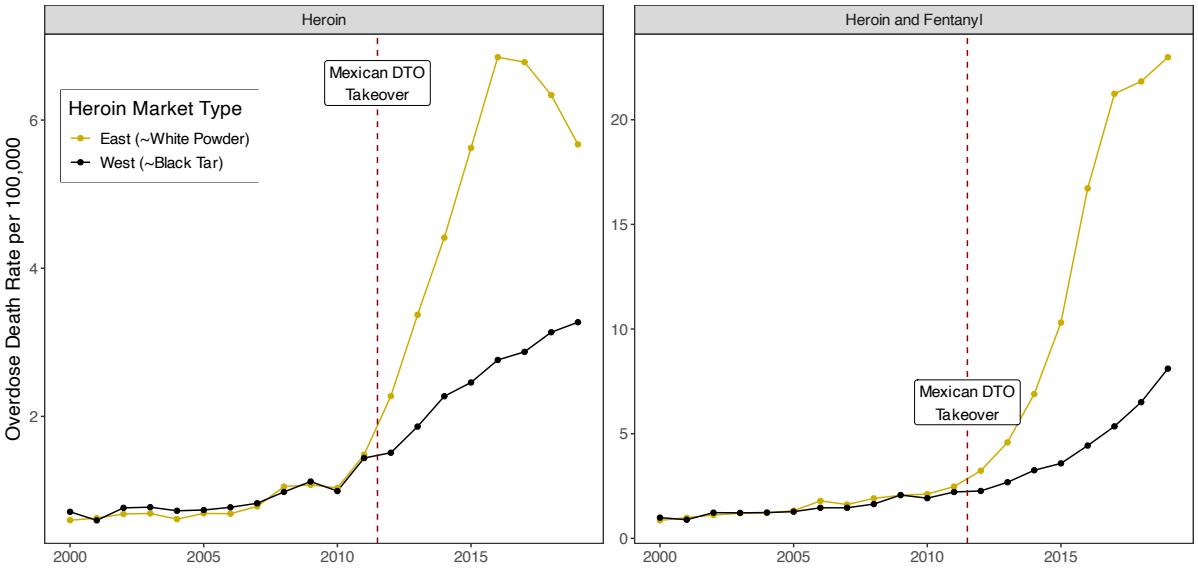
Notes: Images are obtained from here, here, and here, respectively.

Figure A.4: Yearly Illicit Opioid Overdose Death Rates by Market Type

Panel A: HDMP Sample



Panel B: Nationwide Sample



Notes: This figure presents illicit opioid overdose death rates over time using National Vital Statistics System's restricted mortality data. In Panel A, we limit the sample to commuting zones that had a city that participated in the HDMP. In Panel B, we use data for the contiguous US and define heroin markets by whether they are East or West of the Mississippi River (longitude of -91).

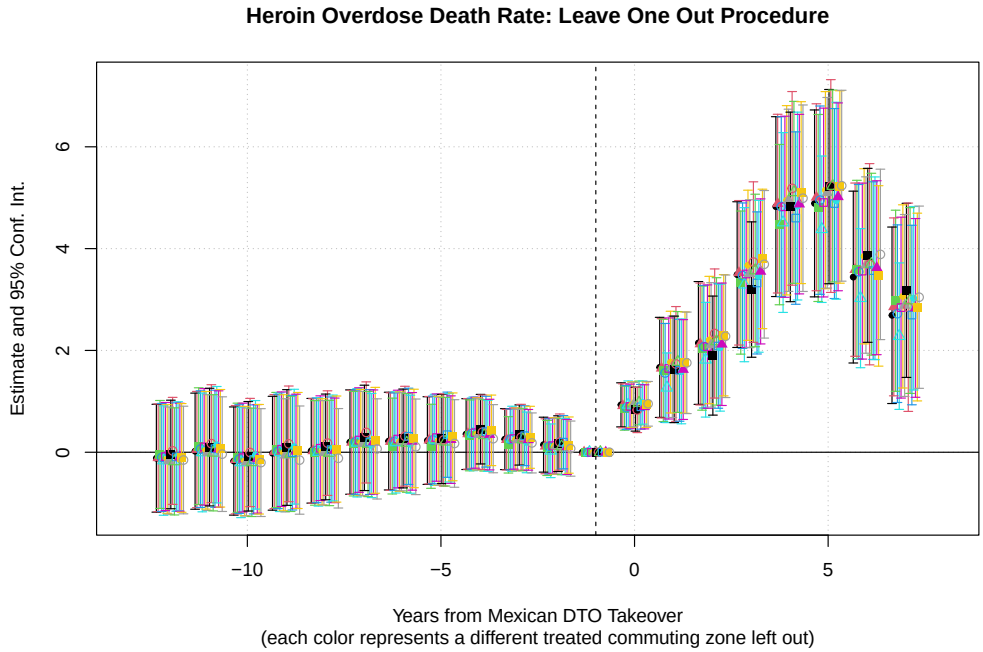
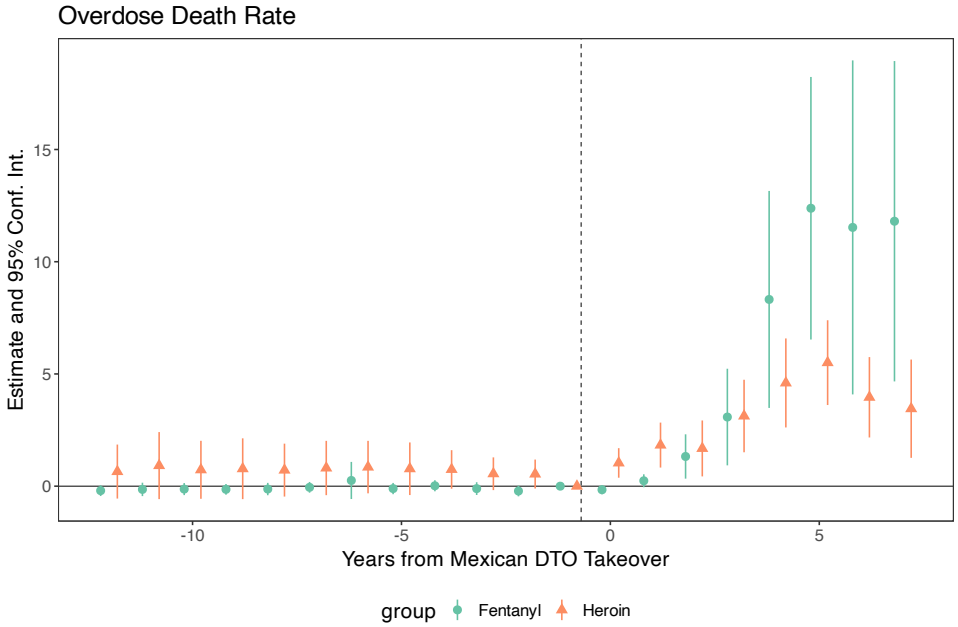


Figure A.5: The Dynamic Mortality Impacts of the Mexican DTO Takeover (HDMP Markets)

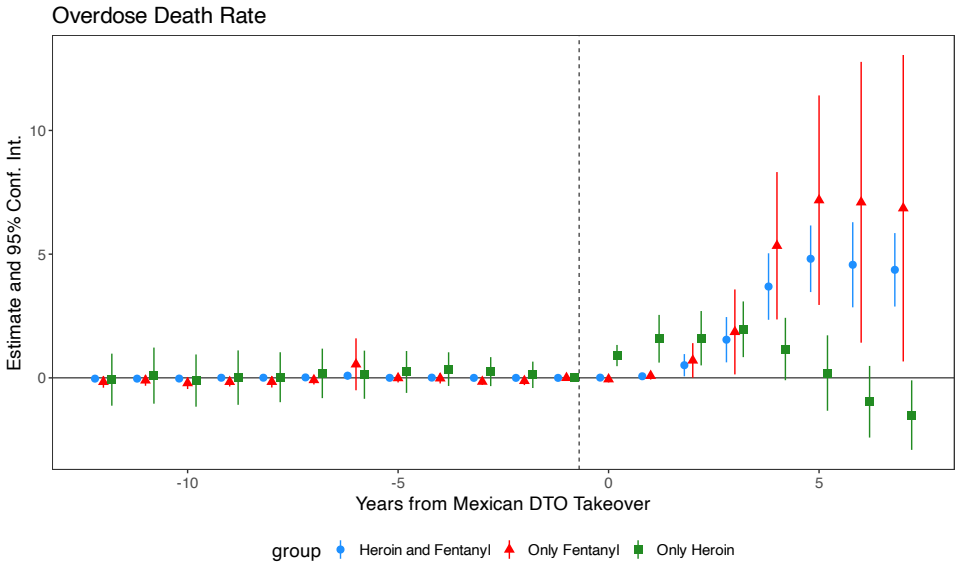
Notes: This figure present the ρ_t coefficients from estimating Equation (1) for different samples, namely each one has a different treated commuting zone removed to test whether one is driving the results. Treatment is defined as having an above median share of total pre-takeover heroin purchases being white powder. The models include commuting zone and year fixed effects, standard errors are clustered at the commuting zone, and the regressions are population weighted. The outcome is heroin overdose deaths per 100,000 and the sample includes only commuting zones where we have HDMP data.

Figure A.6: The Dynamic Mortality Impacts of the Mexican DTO Takeover (No Weights)



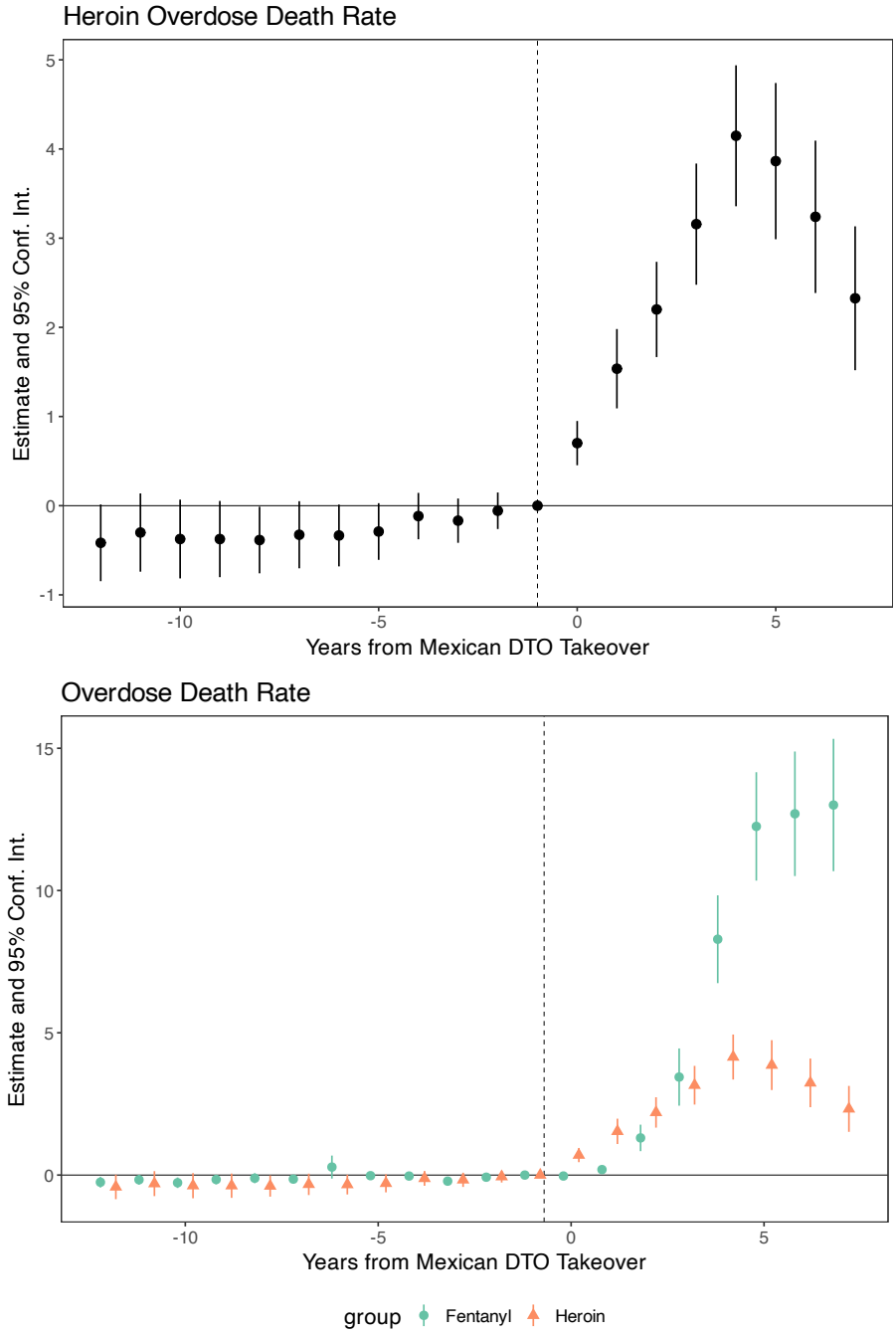
Notes: These figures present the ρ_t coefficients from estimating Equation (1). Treatment is defined as having an above median share of total pre-takeover heroin purchases being white powder. The models include commuting zone and year fixed effects, standard errors are clustered at the commuting zone, but the regressions are not population weighted (as they are in the other exhibits). Outcomes are overdose deaths per 100,000 and the sample includes 31 commuting zones where we have HDMP data on heroin type.

Figure A.7: The Dynamic Mortality Impacts of the Mexican DTO Takeover (HDMP Markets)



Notes: These figures present the ρ_t coefficients from estimating Equation (1). Treatment is defined as having an above median share of total pre-takeover heroin purchases being white powder. The models include commuting zone and year fixed effects, standard errors are clustered at the commuting zone, and the regressions are population weighted. Outcomes are overdose deaths per 100,000 for heroin and fentanyl, only fentanyl, and only heroin, and the sample includes only commuting zones where we have HDMP data.

Figure A.8: The Dyanmic Mortality Impacts of the Mexican DTO Takeover (Nationwide)



Notes: These figures present the ρ_t coefficients from estimating Equation (1). The models include commuting zone and year fixed effects, standard errors are clustered at the commuting zone, and the regressions are population weighted. Outcomes are overdose deaths per 100,000 and the sample includes all commuting zones in the contiguous United States. The top panel is only heroin overdose deaths, while the bottom panel presents both heroin and fentanyl overdose deaths.

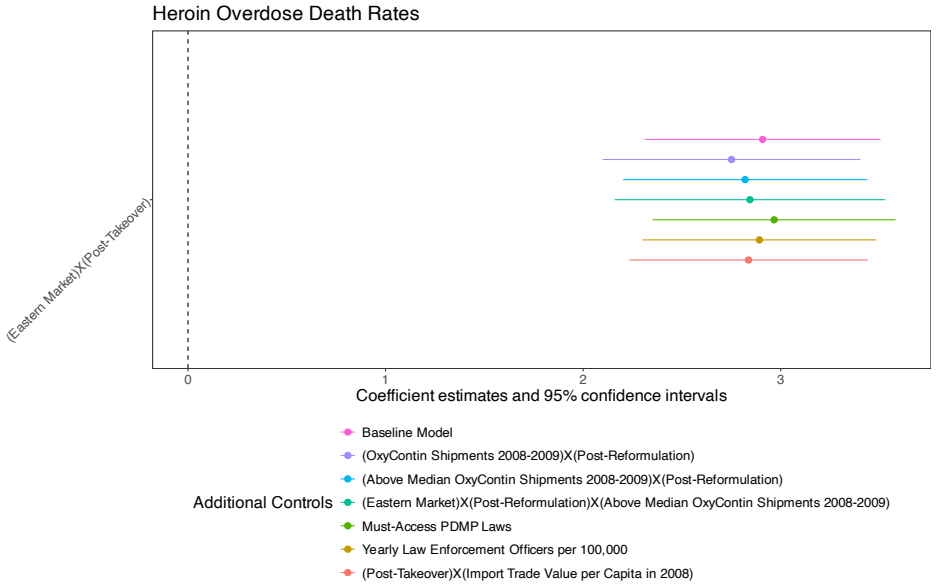
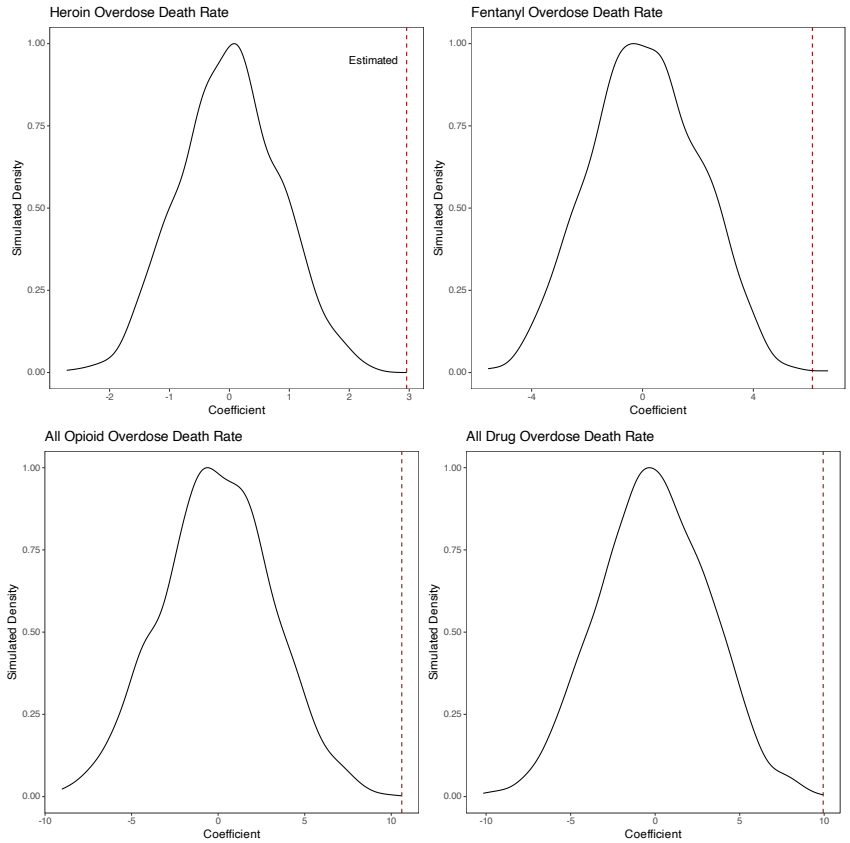


Figure A.9: The Average Mortality Impacts of the Mexican DTO Takeover (Nationwide)

Notes: This figure presents the β coefficients from estimating Equation (2) with different control variables. The Eastern Market binary treatment variable is equal to one for commuting zones east of -91 degrees longitude and Post-Takeover is an indicator for 2012 and after. The models include commuting zone and year fixed effects, standard errors are clustered at the commuting zone, and the regressions are population weighted. Outcomes are overdose deaths per 100,000 and the sample includes all commuting zones in the contiguous United States.

Figure A.10: Permutation tests for HDMP market analysis



Notes: For these tests, we randomize which commuting zone gets "treated" and then run Equation (2) 1000 times using a new sample each time. The figures present the distribution of coefficients obtained from these regressions. The dotted vertical red line is the estimated coefficient.

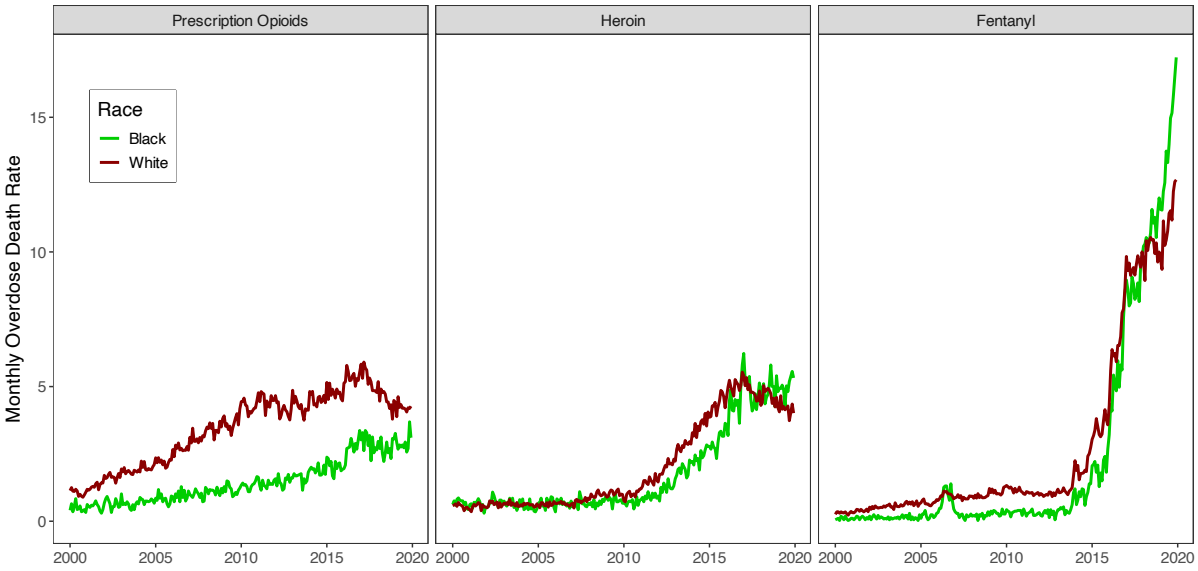


Figure A.11: Monthly Trends in Opioid Overdose Deaths by Race and Opioid Class

Notes: Monthly mortality data are from the National Vital Statistics System (NVSS). We use the following ICD-9 codes for overdose death types: T40.2 for prescription opioids, T40.1 for heroin, and T40.4 for fentanyl. Rates are calculated separately by race and opioid class.

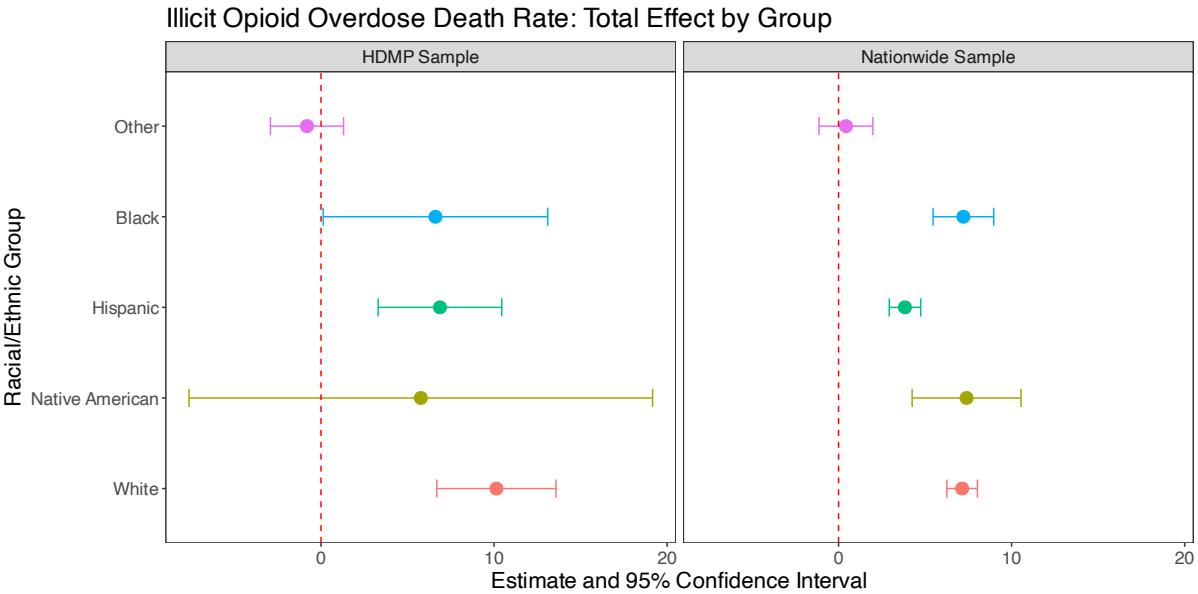


Figure A.12: Average Mortality Impacts of the Mexican DTO Takeover by Race/Ethnicity

Notes: This figure presents the total effects for each race group within a unified model. The models include an interaction between the White Powder Heroin treatment indicator (left panel, defined as having an above median share of total pre-takeover heroin purchases being white powder) and the Eastern Market treatment indicator (right panel, equal to one for commuting zones east of -91 degrees longitude), as well as commuting zone and year fixed effects. The outcomes are illicit opioid overdose deaths per 100,000 (heroin and fentanyl) for each race group and standard errors are clustered at the commuting-zone level. The reference group is "Other," i.e., treatment × post-takeover, and the other race groups are the sum of this estimate and the interaction with their respective race group.

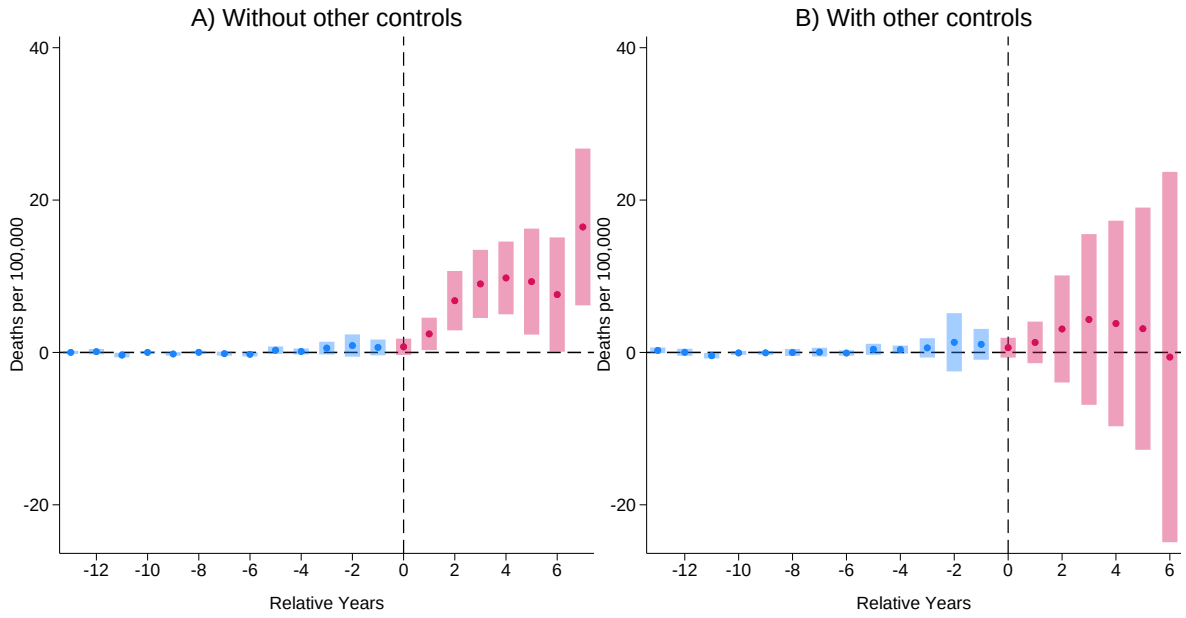
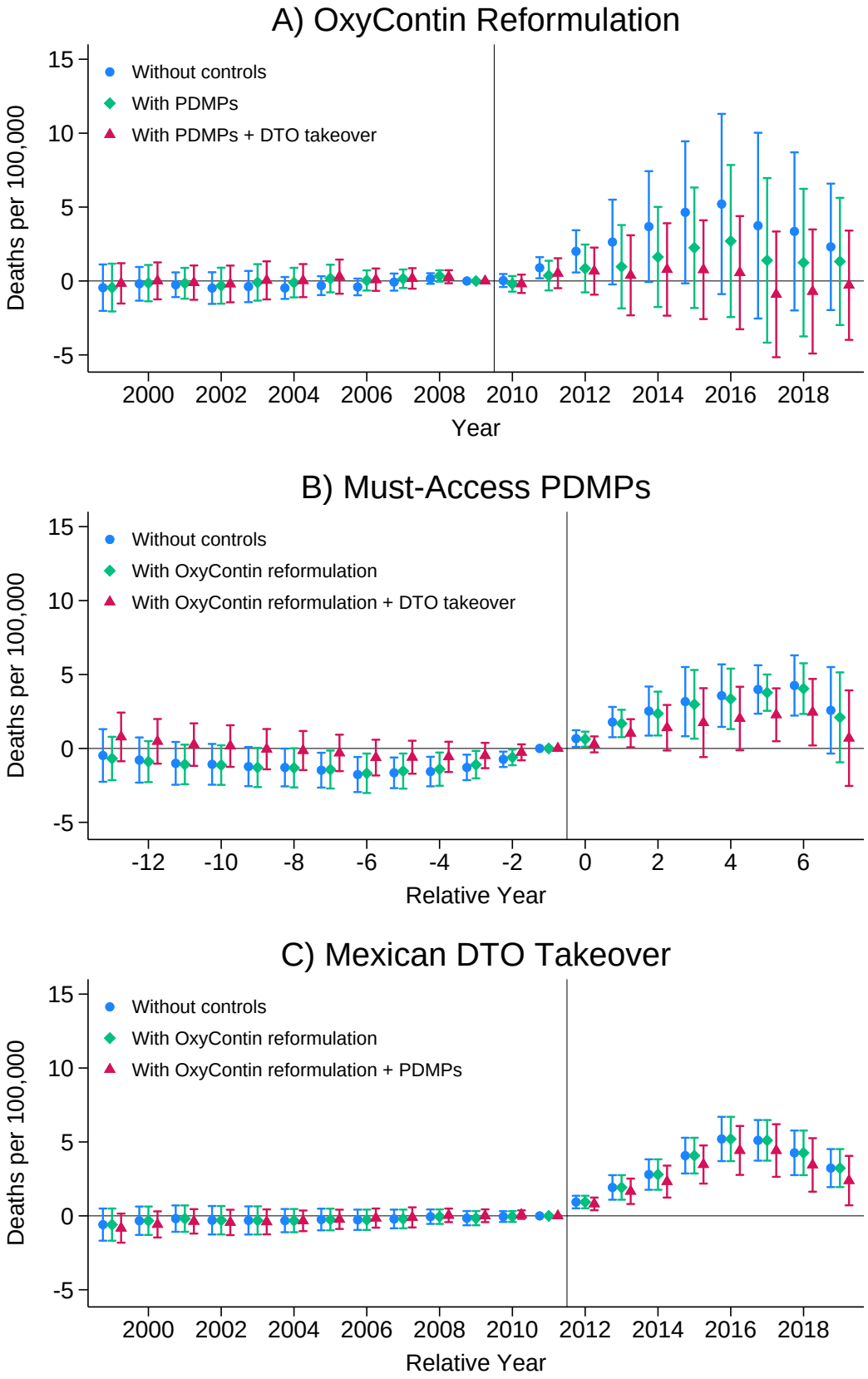


Figure A.13: Updated Analysis of the Effects of Must-Access PDMPs on Illicit Opioid Mortality

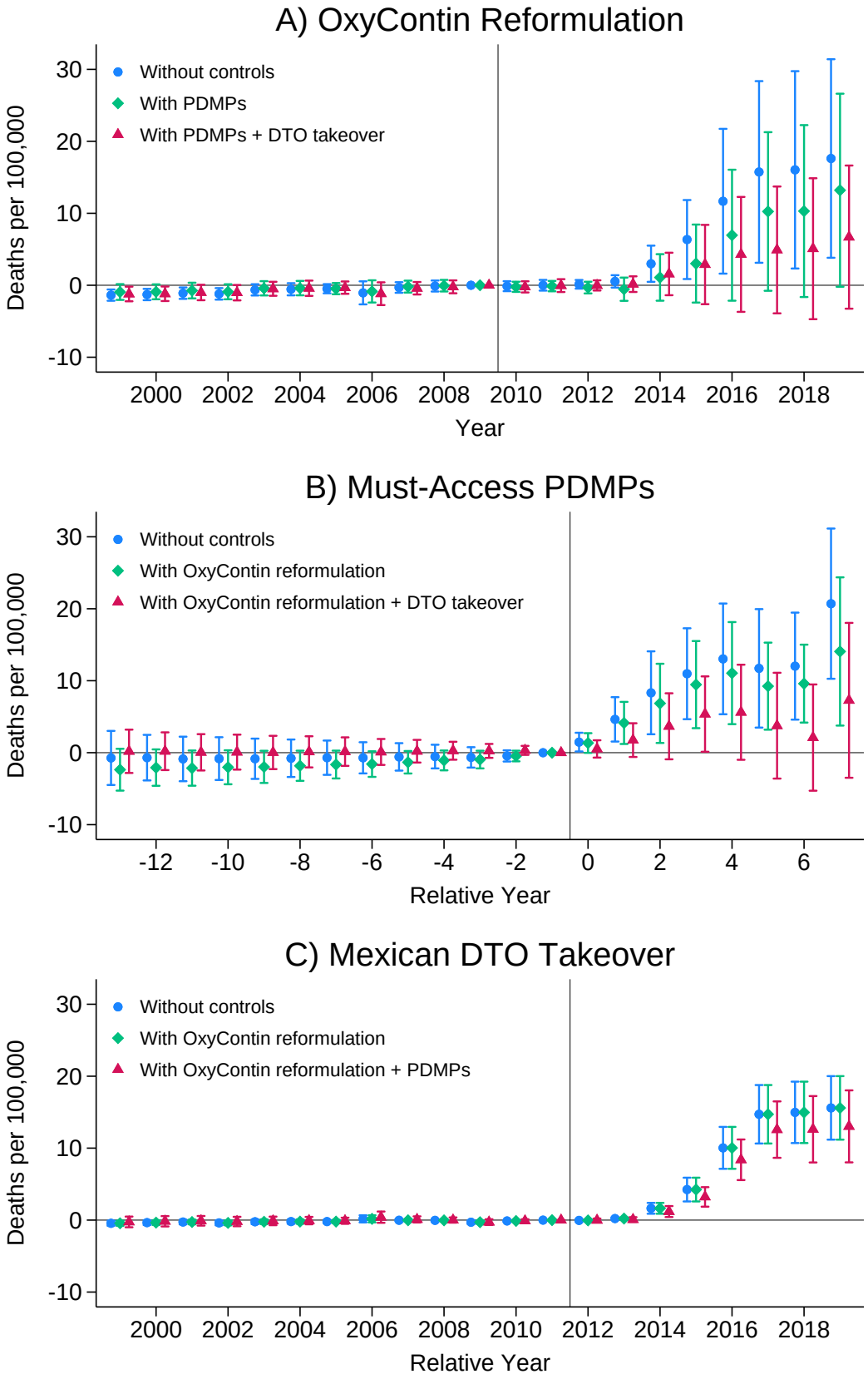
Notes: The figure presents estimates of the event study coefficients for the impacts of Prescription Drug Monitoring Programs on illicit opioid mortality using the estimator described in Callaway and Sant'Anna (2021), with and without controlling for the OxyContin reformulation and regional shocks to heroin quality.

Figure A.14: Determinants of Rising Heroin Death Rates



Notes: The figure presents estimates of the event study coefficients for the impacts of the OxyContin reformulation, must-access PDMPs, and the Mexican DTO takeover of white powder heroin supply on heroin death rates using Equation (3), sequentially adding controls for the other terms in the model. See section 4 of the text for more details.

Figure A.15: Determinants of Rising Synthetic Opioid Death Rates



Notes: The figure presents estimates of the event study coefficients for the impacts of the OxyContin reformulation, must-access PDMPs, and the Mexican DTO takeover of white powder heroin supply on synthetic opioid death rates using Equation (3), sequentially adding controls for the other terms in the model. See section 4 of the text for more details.

B Additional Tables

Table B.1: Characteristics of White Powder and Black Tar Heroin Markets in 2011

	Black Tar (N=15)		White Powder (N=16)			
	Mean	Std. Dev.	Mean	Std. Dev.	Diff. in Means	Std. Error
Prescription Opioid Overdose Death Rate	4.1	2.1	3.7	2.1	-0.4	0.7
Heroin Overdose Death Rate	2.9	2.6	1.9	1.3	-0.9	0.7
Fentanyl Overdose Death Rate	0.7	0.4	0.9	0.4	0.1	0.2
Non-Opioid Overdose Death Rate	6.0	1.7	5.0	2.3	-1.0	0.7
OxyContin Misuse (2004-2009)	1.0	0.7	1.0	0.4	0.0	0.2
Population (100,000s)	39.6	41.0	37.6	29.1	-2.0	12.8
Median Household Income ($1000)	56.1	10.8	60.0	12.1	3.9	4.1
Share White	52.7	17.8	60.5	15.3	7.8	6.0
Share Unemployed	8.2	0.9	8.8	1.8	0.5	0.5
White Powder Heroin Share	2.7	7.8	73.8	19.1	71.1	5.2
Black Tar Heroin Share	86.5	16.1	6.0	7.7	-80.5	4.6

Notes: This table uses CDC mortality data and ACS census data from 2011, the year before the Mexican DTO takeover, to compare our treated and control commuting zones for the HDMP sample. The final two rows, White Powder and Black Tar Heroin Shares, use the DEA's HDMP data from 2004 to 2011.

Table B.2: The Average Mortality Impacts of the Mexican DTO Takeover (No Weights)

	Heroin (1)	Fentanyl (2)	Any Opioids (3)	Non-Opioids (4)
(White Powder Market)X(Post-Takeover)	2.476***	6.144***	9.972***	0.2443
	(0.7209)	(1.585)	(2.438)	(0.6127)
Pre-treatment mean	1.2656	0.68862	4.2519	5.3102
R^2	0.77031	0.62892	0.72764	0.81346
Observations	620	620	620	620

Notes: This table presents the β coefficients from estimating Equation (2). The White Powder Heroin treatment indicator variable is defined as having an above median share of total pre-takeover heroin purchases being white powder, and Post-Takeover is an indicator for 2012 and after. The models include commuting zone and year fixed effects, standard errors are clustered at the commuting zone, and the regressions are not population-weighted (as they are in all other exhibits). Outcomes are overdose deaths per 100,000 and the sample includes only commuting zones where we have HDMP data.

Table B.3: The Average Mortality Impacts of the Mexican DTO Takeover

	Heroin (1)	Fentanyl (2)	Any Opioids (3)	Non-Opioids (4)
(Pre-Takeover White Powder Heroin Share)X(Post-Takeover)	0.0366***	0.0856***	0.1406***	-0.0045
	(0.0100)	(0.0207)	(0.0316)	(0.0091)
Pre-treatment mean	1.2656	0.68862	4.2519	5.3102
R^2	0.77816	0.63771	0.72852	0.79713
Observations	620	620	620	620

Notes: This table presents the β coefficients from estimating Equation (2) using a continuous treatment measure of white powder heroin in the pre-takeover period. Post-Takeover is an indicator for 2012 and after. The models include commuting zone and year fixed effects, standard errors are clustered at the commuting zone, and the regressions are population weighted. Outcomes are overdose deaths per 100,000 and the sample includes only commuting zones where we have HDMP data.

Table B.4: The Average Mortality Impacts of the Mexican DTO Takeover

	Heroin (1)	Fentanyl (2)	Any Opioids (3)	Non-Opioids (4)
(Post-Takeover) × WhitePowderQuartile = 2	-0.6530	0.7123	-0.5360	0.7565
	(0.8112)	(1.056)	(2.026)	(0.5443)
(Post-Takeover) × WhitePowderQuartile = 3	3.104***	6.142***	10.88***	-0.7508
	(0.9098)	(1.905)	(2.758)	(1.105)
(Post-Takeover) × WhitePowderQuartile = 4	2.044**	6.956***	9.710***	0.3028
	(0.7879)	(1.826)	(2.307)	(0.9465)
Pre-treatment mean	1.2656	0.68862	4.2519	5.3102
R^2	0.79617	0.63574	0.73416	0.80229
Observations	620	620	620	620

Notes: This table presents the β coefficients from estimating Equation (2) using a binned treatment measure of white powder heroin in the pre-takeover period, where the reference category is the first quartile. Post-Takeover is an indicator for 2012 and after. The models include commuting zone and year fixed effects, standard errors are clustered at the commuting zone, and the regressions are population weighted. Outcomes are overdose deaths per 100,000 and the sample includes only commuting zones where we have HDMP data.

Table B.5: The Average Mortality Impacts of the Mexican DTO Takeover (HDMP Markets)

	Heroin						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(White Powder Market)X(Post-Takeover)	2.958***	2.869***	2.939***	3.382***	2.869***	2.853***	2.790***
	(0.6849)	(0.6911)	(0.6621)	(0.6336)	(0.7810)	(0.6619)	(0.8086)
(OxyContin Shipments 2008-2009)X(Post-Reformulation)		23.03					
		(14.20)					
(Above Median OxyContin Shipments 2008-2009)X(Post-Reformulation)			0.7926	1.470*			
			(0.6334)	(0.8239)			
(White Powder Market)X(Post-Reformulation)X(Above Median OxyContin Shipments 2008-2009)				-1.324			
				(1.061)			
Post-Must Access PDMP Reform					-0.3407		
					(0.7722)		
Yearly Law Enforcement Officers per 100,000						-0.0080*	
						(0.0046)	
(Post-Takeover)X(Import Trade Value per Capita in 2008)							-7.94×10^{-6}
							(7.92×10^{-6})
Pre-treatment mean	1.2656	1.2656	1.2656	1.2656	1.2656	1.2656	1.2656
R^2	0.79029	0.80376	0.79510	0.79921	0.79073	0.79446	0.79175
Observations	620	620	620	620	620	620	620

Notes: This table presents the β coefficients in the first row from estimating Equation (2) with different control variables. The White Powder Heroin treatment indicator variable is defined as having an above median share of total pre-takeover heroin purchases being white powder, and Post-Takeover is an indicator for 2012 and after. The models include commuting zone and year fixed effects, standard errors are clustered at the commuting zone, and the regressions are population weighted. Outcomes are overdose deaths per 100,000 and the sample includes only commuting zones where we have HDMP data.

Table B.6: The Average Mortality Impacts of the Mexican DTO Takeover (Nationwide)

	Heroin						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(Eastern Market)X(Post-Takeover)	2.908***	2.751***	2.820***	2.844***	2.967***	2.892***	2.837***
	(0.3039)	(0.3323)	(0.3145)	(0.3487)	(0.3129)	(0.3013)	(0.3070)
(OxyContin Shipments 2008-2009)X(Post-Reformulation)		11.40*					
		(6.316)					
(Above Median OxyContin Shipments 2008-2009)X(Post-Reformulation)			0.4915	0.5257**			
			(0.3096)	(0.2647)			
(Eastern Market)X(Post-Reformulation)X(Above Median OxyContin Shipments 2008-2009)				-0.0555			
				(0.4052)			
Post-Must Access PDMP Reform					0.5252**		
					(0.2262)		
Yearly Law Enforcement Officers per 100,000						-0.0019	
						(0.0012)	
(Post-Takeover)X(Import Trade Value per Capita in 2008)							$-2.33 \times 10^{-7***}$
							(6.32×10^{-8})
Pre-treatment mean	0.37930	0.37930	0.37930	0.37930	0.37930	0.37930	0.37930
R^2	0.70405	0.70715	0.70573	0.70573	0.70620	0.70454	0.69906
Observations	13,820	13,820	13,820	13,820	13,820	13,820	13,800

Notes: This table presents the β coefficients in the first row from estimating Equation (2) with different control variables. The Eastern Market binary variable is equal to one for commuting zones east of -91 degrees longitude and Post-Takeover is an indicator for 2012 and after. The models include commuting zone and year fixed effects, standard errors are clustered at the commuting zone, and the regressions are population weighted. Outcomes are heroin overdose deaths per 100,000 and the sample includes all commuting zones in the contiguous United States.