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The fentanyl shock: Synthetic opioids and the supply of organ donors

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The Fentanyl Shock: Synthetic Opioids and the Supply of Organ Donors*

Omar Martin Fieles-Ahmad†, Selina Schulze Spuentrup‡

May 2026

Abstract

We study how the diffusion of illicit synthetic opioids affected the supply of deceased organ donors in the United States after 2012. As fentanyl spread rapidly from east to west, it produced sharp, uneven increases in overdose mortality across states. We first study the arrival of fentanyl as a dichotomous shock in a difference-in-differences framework at the organ procurement organization (OPO) level, contrasting regions east and west of the Mississippi River due to drug-market segmentation. We then turn to the intensive margin using a state-level IV approach that leverages the westward diffusion of fentanyl over time, with exposure measured using fentanyl mortality. Both approaches show that fentanyl exposure caused large increases in overdose-driven donor supply and transplanted organs, revealing how a lethal epidemic reshaped the availability of transplantable organs.

Keywords: organ donation, fentanyl

JEL: I11, I18

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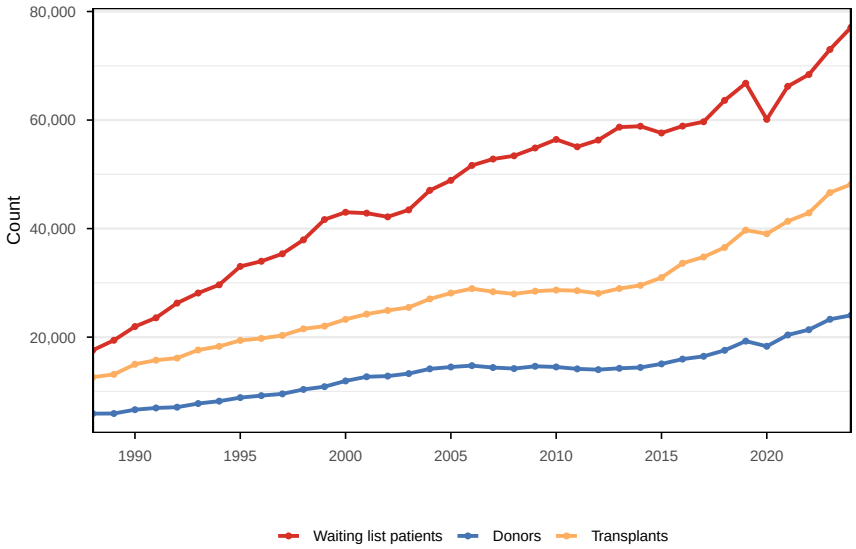
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1 Introduction

Despite steady growth in organ donation over the past three decades, the United States continues to face a severe and persistent shortage of transplantable organs. The number of patients on transplant waiting lists expanded rapidly from the late 1980s through the mid-2010s, reaching 67,000 individuals in 2019, followed by a dip in the COVID-19 pandemic. In 2024, the number of patients on the waiting list reached 77,000. The number of transplants and donors (living and deceased) increased much more gradually. Figure 1 illustrates this widening gap between the need for organs and actual availability. Thousands of patients fail to receive a life-saving transplant each year. In recent years alone (2012–2023), on the order of 10,000 to 13,000 candidates annually have either died while waiting or deteriorated to the point of becoming ineligible for transplantation.[1] These figures underscore how even modest shifts in organ supply can yield large benefits for the functioning of the transplant system, with substantial implications for patient survival.

Figure 1: Waiting list patients, donors and organs



Notes: Patients on the transplant waiting list, total donors (living and deceased), and transplants performed (living and deceased) based on Organ Procurement and Transplantation Network (OPTN) (2023).

Over the same period, the United States experienced a sequence of profound shocks to drug-related mortality. Following an initial wave driven by prescription opioids (1999-2010)

[1] Based on own calculations using SRTR data.

and a second wave centered on heroin (2010-2013), a third wave emerged in the early 2010s with the diffusion of illicitly manufactured fentanyl (2013-2019) (Jenkins, 2021). After 2013, fentanyl-related mortality rose sharply and soon overtook all other opioids as the dominant cause of overdose deaths. Between 2012 and 2022, there were 340,000 fentanyl-related deaths in the United States. (Moore et al., 2023). Fentanyl differs sharply from earlier opioids in its extreme potency: it is roughly 50 times stronger than heroin and 100 times stronger than morphine, and doses as small as a few milligrams can be lethal (National Institute on Drug Abuse, 2024; Drug Enforcement Administration, 2020). Consequently, it is no surprise that fentanyl has been labeled as a "weapon of mass destruction" in December 2025 by the White House. Evidence since 2020 further suggests the emergence of a possible fourth wave characterized by polysubstance use involving fentanyl (Pieters, 2023). These patterns are summarized in Figure 2a, which shows both overall opioid mortality and the rapid rise of fentanyl in particular.

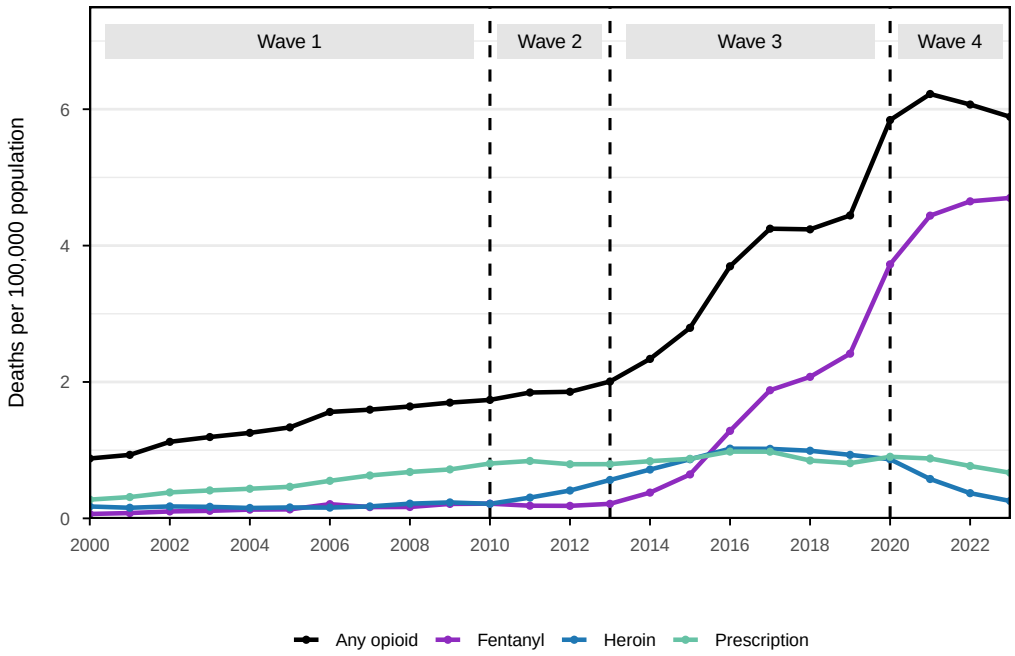
A growing literature shows that overdose mortality affects the supply of deceased organ donors (Cholankeril et al., 2018; Dickert-Conlin et al., 2024; Howell et al., 2025). As fentanyl mortality accelerated, the share of deceased organ donors whose cause of death was drug overdose increased from only a few percent in the early 2000s to more than 15 percent by 2020 (see Figure 2b). In other words, a growing fraction of recovered organs now originates from individuals who died of drug intoxication. This shift mechanically expanded the pool of transplantable organs during a period of extraordinary overdose mortality.

This interplay of opioid mortality and organ donors who died from an overdose raises a forward-looking policy concern. If fentanyl-related deaths have temporarily relaxed organ supply constraints, then successful efforts to suppress illicit synthetic opioids may reverse these gains and substantially tighten organ availability. A sudden contraction in deceased donor supply may translate directly into higher waiting list mortality and greater medical deterioration among candidates unless alternative sources of donation expand. Understanding the magnitude of this mechanism is therefore essential for anticipating how policies aimed at reducing overdose deaths may ripple through the transplant system. In this regard, the paper contributes to the literature on mortality shocks and their respective spillovers on organ donor supply.[2]

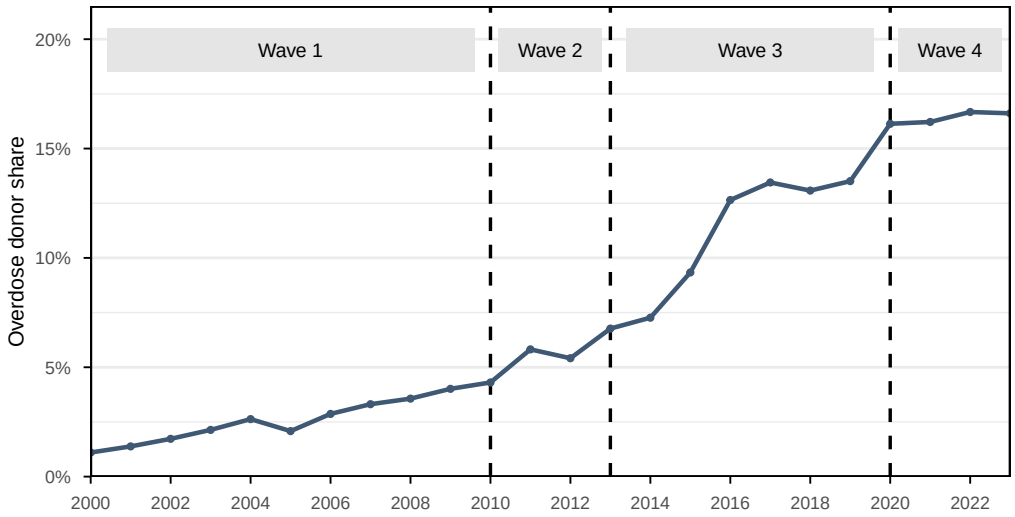
[2]Bilgel (2020) studies gun-related deaths; Brewer (2020) analyzes changes in seat belt enforcement; Dickert-Conlin et al. (2011) and Dickert-Conlin et al. (2019) investigate the repeal of motorcycle helmet laws; Fernandez and Lang (2015) examine reductions in suicide due to mental health parity laws; and Dickert-Conlin et al. (2024) analyze opioid-related mortality.

Figure 2: The four waves of the U.S. opioid crisis and the changing composition of deceased organ donors

(a) Opioid overdose deaths per 100,000 population



(b) Share of deceased organ donors from drug overdoses



Notes: Panel (a) plots opioid overdose mortality rates per 100,000 population. Panel (b) shows the share of deceased organ donors who died from an overdose, measured as a percentage of all deceased organ donors. Vertical dashed lines indicate the onset of successive waves of the U.S. opioid epidemic. Mortality data are from the Centers for Disease Control and Prevention (2025). Organ donor data are from the Organ Procurement and Transplantation Network (OPTN) / Scientific Registry of Transplant Recipients (SRTR).

This paper studies how the diffusion of illicit synthetic opioids affected the supply of deceased organ donors and transplantable organs in the United States after 2012. We assemble administrative data linking donor records, transplant outcomes, fentanyl-related mortality, and law-enforcement drug seizures.[3] We exploit the east-to-west diffusion of fentanyl as a quasi-experimental shock using two complementary empirical strategies. This allows us to investigate the impact of the fentanyl crisis first as a dichotomous shock, i.e., early vs. late fentanyl exposure, and second at the intensive margin, i.e., how much of the fentanyl mortality translates into organ donations.

First, we implement an Organ Procurement Organization (OPO) level difference-in-differences design that compares regions with early fentanyl entry to those with delayed exposure arising from the longstanding segmentation of heroin markets east and west of the Mississippi River. This approach follows the paper by Garcia et al. (2025).

Second, we estimate a state-level instrumental-variables design inspired by Zoorob (2019) that interacts longitude with time to capture the westward spread of synthetic opioids, isolating predicted variation in fentanyl exposure from broader opioid trends. We use fentanyl mortality as a proxy for the spread of the drug in our main specification and complement it in a robustness check with fentanyl seizures as an alternative proxy.

Across both strategies, we find that fentanyl exposure caused large and economically meaningful increases in the supply of deceased overdose donors and organs. The magnitude of these effects implies that a nontrivial share of the recent expansion in organ availability can be directly attributed to the synthetic opioid crisis. At the same time, the results highlight an important policy tradeoff: as fentanyl-related deaths decline, the transplant system may face renewed and potentially acute organ scarcity unless complementary measures—such as changes in procurement practices, donor registration, or incentives for living donation—are implemented.

The remainder of the paper proceeds as follows. Section 2 describes the data sources used in the analysis. Section 3 outlines the empirical strategy and presents two complementary research designs: an OPO-level difference-in-differences approach that exploits sharp east–west differences in the timing of fentanyl entry, and a state-level IV approach that

[3]This study uses data from the Scientific Registry of Transplant Recipients (SRTR). The SRTR data system includes data on all donor, wait-listed candidates, and transplant recipients in the U.S., submitted by the members of the Organ Procurement and Transplantation Network (OPTN). The Health Resources and Services Administration (HRSA), U.S. Department of Health and Human Services provides oversight to the activities of the OPTN and SRTR contractors.

leverages the westward diffusion of fentanyl over time to instrument for fentanyl mortality. Section 4 presents the main results from both approaches, documenting substantial increases in overdose donors and organs recovered following fentanyl exposure. Section 5 conducts a series of robustness and validation exercises, including bandwidth selection, donut specifications, placebo timing tests, sensitivity checks for violations of the parallel trends assumption, continuous-exposure specifications and using seizures as an alternative endogenous variable in the IV specification. Section 6 explores heterogeneity across organ types and donor characteristics. Section 7 concludes.

2 Data

2.1 OPO Data

Our primary data source is the Scientific Registry of Transplant Recipients (SRTR), which maintains comprehensive administrative records on all organ donors, waitlist patients, and transplant recipients in the United States since 1987. The SRTR database is compiled from reports submitted by members of the Organ Procurement and Transplantation Network (OPTN) and operates under the oversight of the U.S. Department of Health and Human Services through the Health Resources and Services Administration (HRSA). The data contain detailed donor-level information collected from hospitals and immunology laboratories, including demographic characteristics, clinical indicators, the circumstances of death, and the organs that were discarded or transplanted. Donors can also be linked to transplant recipients when a transplant occurs.

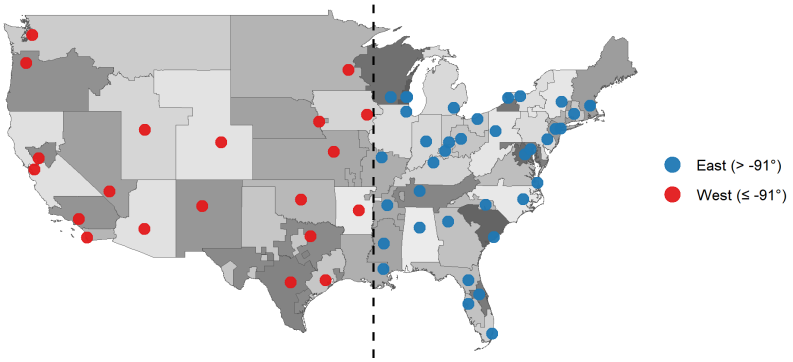
We aggregate the donor-level records to the level of organ procurement organizations (OPOs), which are responsible for coordinating organ recovery within geographically defined service areas. The United States is served by 58 OPOs, each covering a distinct region. Our analysis focuses on the period 2000–2019. The resulting panel contains 1,160 OPO–year observations. Our main outcomes capture organ donation following drug-related deaths, measured both as the number of donors and the number of organs transplanted. We use the SRTR variable "mechanism of death" to identify these cases. Individuals recorded as "drug intoxication" are included in this group, which broadly captures deaths attributable to drugs. From these records, we construct two primary outcomes: the annual number of overdose donors and the number of transplanted organs recovered from overdose donors.

Following Garcia et al. (2025), we exploit the longstanding segmentation between eastern

white-powder-heroin markets and western black-tar heroin markets by dividing OPOs into "East'' and "West'' using a longitude threshold of $-91°$, approximately the median longitude of the Mississippi River. This historical segmentation is relevant because fentanyl was initially introduced as an adulterant in powder heroin markets, leading the synthetic opioid shock to emerge earlier in the eastern United States before gradually spreading westward. OPO locations are geocoded using the ZIP codes of their administrative centers.

Figure 3 shows the location of the 58 OPO centers and their corresponding service areas, together with the East–West classification based on the median Mississippi River longitude.

Figure 3: OPO center locations



Notes: OPO centers (ZIP-code geocoded) and East-West assignment. The corresponding OPO service areas are shaded in grey. The dividing longitude ($-91°$) is the median longitude of the Mississippi River.

Descriptive figures illustrating OPO geography, pre-trends, and the timing of changes in overdose donors appear in Section 3.1.

2.2 State Data

The state–year panel, covering the years 2012 to 2019, combines information on deceased organ donors from the SRTR/OPTN donor and donor-disposition files with drug-related mortality from the CDC Multiple Cause of Death (MCOD) files and drug-seizure data from the Drug Enforcement Administration's (DEA) National Forensic Laboratory Information System (NFLIS).[4] Donors are classified as overdose donors when the recorded mechanism

[4]We use the NFLIS-based seizure measures exclusively for robustness checks to assess whether our results are sensitive to measuring fentanyl exposure earlier in the drug supply chain rather than at the point of consumption.

of death is drug intoxication. For organ-level outcomes, we retain all transplanted organs (disposition code 6) and assign grafts to clinically meaningful categories: kidney, liver, heart, and lung. OPTN records correspond to transplanted grafts rather than whole organs; accordingly, partial grafts—such as left- or right-lobe liver segments or single- versus double-lung grafts—are counted as one transplant within their respective organ category. All transplanted organs, including pancreas, intestine, and other graft types, contribute to the total number of organs recovered from overdose donors.

Fentanyl exposure is measured using fentanyl-related overdose mortality (ICD-10 T40.4)[5], with population denominators taken directly from the MCOD files. Mortality offers a geographically precise and behaviorally relevant indicator of fentanyl's arrival and intensity in local drug markets. We also control for overdose deaths from other prominent drugs (heroin, methadone, and other opioid deaths). As additional measures of the drug environment in a robustness check, we construct state–year seizure rates for fentanyl, heroin, cocaine, methamphetamine, and oxycodone. The resulting IV estimation sample contains 392 state–year observations for 48 continental states and the District of Columbia.

The instrumental-variables strategy follows the logic in Zoorob (2019), who documents that illicit fentanyl first entered the United States through the Northeast and subsequently spread westward. To capture this directional diffusion, we construct an instrument equal to the interaction of state longitude with calendar year. This approach leverages the geographic ordering of states, with eastern states at lower (more negative) longitudes experiencing earlier exposure, together with the well-established temporal pattern of fentanyl's westward expansion. Summary statistics for all variables used in the IV regressions appear in Table 1.

[5]This ICD code designates other synthetic narcotics which is frequently used to identify fentanyl mortality (see e.g. Moore et al. (2023)).

Table 1: Summary statistics for the state–year IV estimation sample, 2012–2019

Variable	Mean	SD	Min	Max
Donation outcomes (per 100,000 population)				
Overdose donors	0.345	0.299	0.000	2.465
OD organs – total	1.059	0.942	0.000	8.524
OD organs – kidney	0.547	0.497	0.000	4.827
OD organs – liver	0.270	0.229	0.000	1.643
OD organs – heart	0.133	0.135	0.000	1.232
OD organs – lung	0.077	0.091	0.000	0.719
OD organs – other	0.031	0.044	0.000	0.312
Mortality (per 100,000 population)				
Fentanyl deaths	6.376	8.322	0.000	39.498
All overdose deaths	20.494	9.792	0.000	62.948
Heroin deaths	4.089	3.390	0.000	18.445
Methadone deaths	1.227	0.826	0.000	4.274
Other opioid deaths	5.016	3.260	0.000	22.966
Seizures (per 100,000 population)				
Fentanyl seizures	13.008	27.910	0.000	163.620
Cocaine seizures	58.253	48.184	1.747	329.708
Meth seizures	119.217	124.824	0.000	667.522
Oxycodone seizures	14.142	14.020	0.000	96.635
Heroin seizures	49.689	49.651	0.582	349.119

Notes: 392 state–year observations (2012–2019). All per-capita variables use population denominators from the MCOD files. Fentanyl seizure data are missing for three observations in the estimation sample (389 non-missing values). The IV sample includes 48 continental states and the District of Columbia.

3 Empirical Strategy

3.1 OPO Difference-in-Differences

To investigate the fentanyl wave of the opioid crisis as a dichotomous shock, our difference-in-differences design uses OPO-level data for 2000–2019. The OPOs are responsible for the authorization, testing, recovery of donor organs, and transport to the transplant hospital. Each donor can be matched to a specific OPO. Matching organs to specific transplant centers is technically also possible, but organs can be allocated across the country and thus often do not correspond to the region of origin of the organ. This approach exploits the longstanding

segmentation of U.S. heroin markets documented by Ciccarone (2009). Eastern markets historically relied on white powder heroin, which can be easily adulterated with fentanyl. In contrast, western markets were dominated by black-tar heroin, which is not easily mixed with fentanyl. As a result, fentanyl penetrated eastern heroin markets years before it reached western ones.

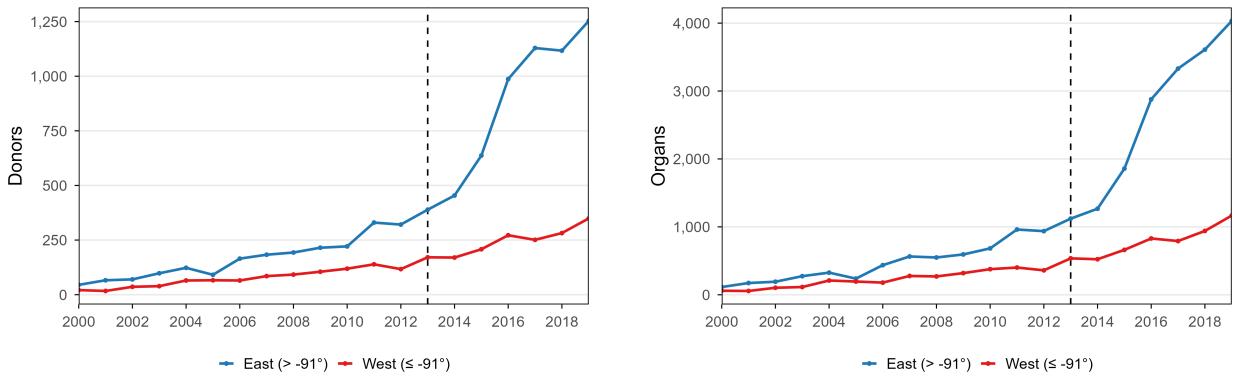
Each OPO center is geocoded using the latitude and longitude of its five-digit ZIP code. Following Garcia et al. (2025), we use the median longitude of the Mississippi (-91°) cutoff.

Figures 4a and 4b document the differential timing of increases in overdose donors and overdose-donor organs. Eastern OPOs experience an early and rapid rise starting in 2013, while western OPOs show delayed and more gradual increases as fentanyl later diffuses westward. These patterns parallel the geographic spread documented in Garcia et al. (2025) and provide the identifying variation for the difference-in-differences design.

Figure 4: Trends in overdose-related organ donation, East vs. West

(a) Overdose donors

(b) Overdose-donor organs



Notes: Overdose donors and organs from overdose donors transplanted, East vs. West, 2000–2019.

We estimate the following difference-in-differences specification:

$$Y_{ot} = \delta \left(\text{East}_o \times \text{Post}_t \right) + \alpha_o + \lambda_t + \varepsilon_{ot}, \tag{1}$$

where Y_{ot} denotes the outcome of interest for OPO o in year t, namely the number of overdose donors or the number of organs recovered from overdose donors. East_o is an indicator for OPOs located east of the Mississippi River, and Post_t is an indicator equal to one for years from 2013 onward. The coefficient δ captures the differential change in outcomes for eastern OPOs after the arrival of fentanyl relative to western OPOs.

The specification includes OPO fixed effects α_o, which absorb time-invariant differences across OPOs, and year fixed effects λ_t, which capture shocks common to all OPOs. Standard errors are clustered at the OPO level. Following Garcia et al. (2025), the post-period begins in 2013. Certainly, the fentanyl shock does not comprise an exactly dated policy intervention but there are compelling arguments for why 2013 marks the beginning of the third wave of the opioid crisis. Following the reformulation of prescription opioids in the early 2010s to be abuse-deterrent, the second opioid wave in 2010 to 2013 characterized by heroin as a substitute was relatively short-lived (Ciccarone, 2019). Mars et al. (2019) describe heroin being prone to supply shocks and thus shortages. Specifically, global heroin production shrunk by 46% between 2009 and 2013. Hence, illicit fentanyl has been used to adulterate heroin since it is relatively cheap and easy to synthesize. Even once global opium production recovered in 2015, synthetic substitutes persisted on the drug market.

Because fentanyl eventually diffuses into western markets as well, exposure differences between East and West diminish over time. Garcia et al. (2025) describe the diffusion of fentanyl accelerating in the west in 2017 as its usage expanded beyond heroin, i.e., for mixing with cocaine. Accordingly, δ captures the effect of earlier fentanyl exposure rather than a permanent treatment contrast. The specification identifies how OPOs responded when fentanyl first entered their surrounding illicit markets, holding fixed OPO-specific characteristics and nationwide shocks.

3.2 State-Level Panel: Baseline OLS and IV Design

The complementary state-year panel for 2012–2019 to study how fentanyl exposure (FentDeaths) relates to overdose donors and organs recovered from overdose donors, each measured per 100,000 population. Each donor is matched to their respective home state. As a benchmark, we estimate:

$$Y_{st} = \beta \, \text{FentDeaths}_{st} + \boldsymbol{\Theta}' \mathbf{X}_{st} + \phi_s + \lambda_t + \varepsilon_{st}, \tag{2}$$

where Y_{st} denotes either overdose donors or organs recovered from overdose donors per 100,000 population in state s and year t.[6] State fixed effects ϕ_s absorb time-invariant differences across states, year fixed effects λ_t capture nationwide shocks, and $\mathbf{X}_{st}$ includes detailed overdose mortality from heroin, methadone, and other opioids. All standard errors in this specification—and throughout the state-level instrumental-variables analysis—are

[6]The state is identified as the deceased donor's home state.

clustered at the state level.

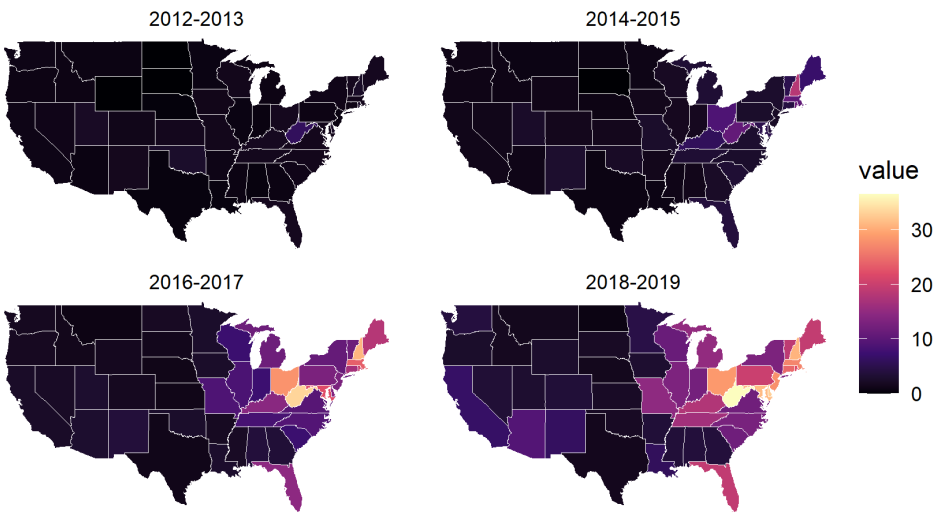
This specification controls for many confounders, yet two identification challenges remain. First, we do not observe whether overdose donors died from fentanyl. Increases in overdose donors may reflect mortality from substances that are not separately identified in mortality records—including synthetic analogues, stimulants, or polysubstance mixtures. As a result, the OLS coefficient may partly reflect changes in other drugs, even when controlling for observable opioid deaths. Second, fentanyl mortality may reflect broader shifts in local drug markets—changes in drug potency, supply networks, or enforcement—that could independently influence the composition of donors. Even detailed mortality controls cannot guarantee that OLS separates fentanyl-specific variation from correlated market dynamics.

To address these concerns, we use the geography-by-time instrument introduced by Zoorob (2019). Fentanyl spread across the United States along a clear east–west gradient over this period. The interaction of state longitude with a linear time trend generates variation in fentanyl exposure driven by this spatial diffusion rather than by state-specific drug-market shocks.

Figure 5 illustrates this pattern using two-year averages of fentanyl deaths per 100,000 population. The map highlights two key features relevant for identification. First, fentanyl mortality emerges earliest and most intensively in states in the eastern portion of the country. Second, increases spread westward only gradually, with many central and western states showing relatively low fentanyl mortality early in the sample but sharp rises only in later years. This staggered geographic progression matches historical evidence on fentanyl's entry into illicit markets and provides the core exogenous variation used in the instrument.[7]

[7]Appendix Figures A.1, A.2, and A.3 show complementary maps for fentanyl seizures, overdose donors, and the share of donors who died from overdose (two-year averages).

Figure 5: Fentanyl deaths per 100,000 population



Notes: The figure shows fentanyl deaths per 100,000 population (two-year averages). The spatial pattern highlights the east–west gradient in fentanyl's diffusion over the 2012–2019 period, with higher mortality levels appearing earlier in eastern states and spreading westward over time.

The first stage is:

$$\text{FentDeaths}_{st} = \pi_1(\text{Long}_s \times t) + \mathbf{\Gamma}'\mathbf{X}_{st} + \phi_s + \lambda_t + \eta_{st}. \tag{3}$$

Zoorob (2019) used the same interaction to instrument fentanyl seizures. Conceptually, our first stage parallels the reduced-form relationship in that work: geography interacted with time predicts fentanyl-related harm. We use mortality rather than seizures because mortality captures where fentanyl is actually consumed, while seizures may reflect variation in policing or interception of drugs in transit. Robustness checks later show that results are similar when seizures are used instead.

The second stage is:

$$Y_{st} = \beta\,\widehat{\text{FentDeaths}}_{st} + \mathbf{\Theta}'\mathbf{X}_{st} + \phi_s + \lambda_t + \varepsilon_{st}. \tag{4}$$

Here, β captures the causal effect of fentanyl-related mortality on the number of overdose donors or organs recovered from overdose donors, using only the portion of fentanyl variation explained by the east–west diffusion process. This design isolates geographically driven shifts in fentanyl exposure that are plausibly unrelated to state-specific changes in drug markets or OPO behavior.

The identifying assumption is that the interaction of longitude and time affects organ donation only through its effect on fentanyl exposure. This assumption is supported by evidence that the spread of fentanyl followed a geographically structured supply shock rather than pre-existing trends in overdose mortality. Zoorob (2019) shows that prior overdose mortality is only weakly predictive of fentanyl exposure, while geography strongly predicts its diffusion, consistent with a supply-driven process tied to regional drug market structure. In particular, fentanyl first penetrated eastern powder-heroin markets—where it can be easily mixed—before spreading westward into black-tar heroin markets. These patterns suggest that the instrument captures exogenous variation in the timing of fentanyl exposure driven by supply-side geographic diffusion. The relevance of the instrument is discussed in Section 4.2.

4 Main Results

4.1 OPO-level Results

The OPO-level evidence exploits differences in the timing of fentanyl exposure across U.S. illicit drug markets. Eastern markets experienced fentanyl penetration several years earlier than western markets, creating plausibly exogenous variation in exposure timing across OPOs. We use this variation to estimate how organ donation activity responds when fentanyl first enters an OPO's surrounding market.

Figure 6 reports event-study estimates from a two-way fixed effects difference-in-differences design comparing OPOs in eastern and western U.S. drug markets. The corresponding two-way fixed effects coefficient summarizes the average treatment effect (ATE), capturing the effect of earlier fentanyl exposure relative to OPOs that had not yet experienced fentanyl penetration at the same point in time.

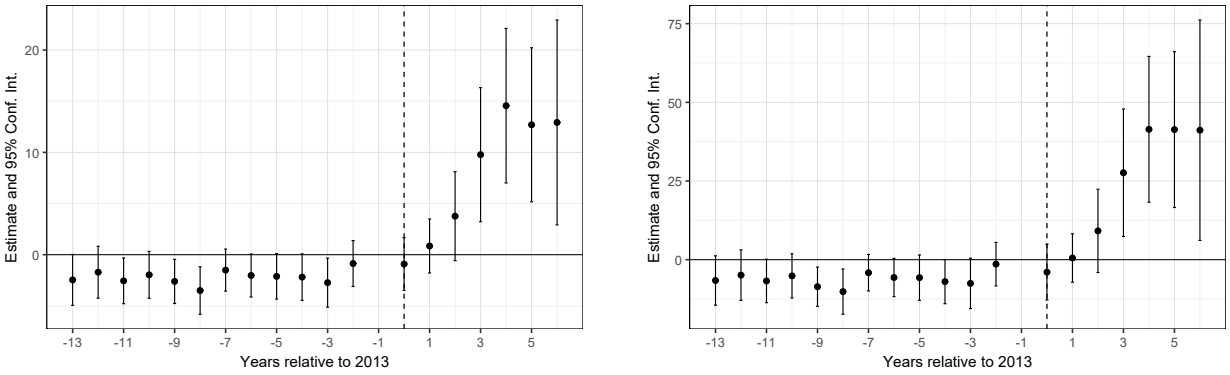
The estimated ATE is 9.686 additional overdose donors per OPO-year (SE = 3.068) and 28.128 additional organs recovered from overdose donors per OPO-year (SE = 9.651). These effects are statistically significant and economically large. In the pre-fentanyl period (2000–2012), OPOs averaged 4.09 overdose donors and approximately 11.9 organs recovered from overdose donors per OPO-year. Relative to these baselines, earlier fentanyl exposure is associated with increases of more than 200% in overdose donors and recovered organs at affected OPOs.

The event-study coefficients show no evidence of differential pre-trends between eastern and western OPOs prior to 2013. Following the onset of fentanyl exposure, outcomes diverge sharply and remain elevated throughout the post-period. Because fentanyl diffusion eventually reaches western drug markets as well, these estimates should be interpreted as ATEs reflecting earlier exposure rather than permanent differences in donation activity.

Figure 6: OPO-level event study

(a) Overdose donors per OPO

(b) Overdose-donor organs per OPO



Notes: OPO-level event-study estimates around 2013 comparing OPOs east of the Mississippi River (longitude $> -91°$; treatment) to OPOs west of the Mississippi (control). Outcomes are overdose donors per OPO and overdose-donor organs per OPO. Estimates are relative to 2012. Points denote coefficient estimates and bars indicate 95 percent confidence intervals. Both specifications include OPO and year fixed effects.

4.2 State-Level Results

The second set of results uses state-level variation to estimate the effect of fentanyl mortality on organ donation outcomes. We relate changes in fentanyl deaths within states to changes in overdose donors and recovered organs, controlling for state and year fixed effects. Secondly, we complement this analysis by controlling for mortality from other drugs (heroin, methadone, and other opioids). In a third specification, we instrument fentanyl mortality using geographic diffusion over time.

Table 2 reports estimates from state-year regressions relating fentanyl mortality to overdose organ donation outcomes. Columns (1) and (2) present two-way fixed effects OLS specifications, while column (3) instruments fentanyl mortality using geographic diffusion interacted with time. All specifications include state and year fixed effects, and standard errors are clustered at the state level.

Across specifications, fentanyl mortality is positively and precisely associated with both overdose donors and organs recovered from overdose donors. The estimated coefficients are stable across OLS and IV models and remain similar when controlling for mortality from other opioids, suggesting that the relationship is not driven by correlated trends in non-fentanyl drug deaths. While the IV estimates are modestly larger than their OLS counterparts, the magnitudes remain in the same range, indicating broadly consistent effects across identification strategies.

In the preferred IV specification, an increase of one fentanyl death per 100,000 population is associated with approximately 0.0203 additional overdose donors per 100,000 and 0.0676 additional overdose-donor organs per 100,000. Given the scale of fentanyl mortality observed during the study period, these estimates imply economically meaningful changes in organ donation supply attributable to fentanyl exposure. Putting this into perspective relative to the 2012 mean of 0.17 overdose donors, a standard deviation increase in fentanyl deaths per 100,000 (SD = 8.322) leads to a 0.169 increase in overdose donors per 100,000. Relative to the 2012 mean, this is an increase by around 100%.

Taken together, the results provide robust evidence that rising fentanyl mortality translated into increases in both the number of overdose donors and the volume of organs recovered from those donors. The similarity of estimates across specifications, combined with a strong first-stage ($F = 47.8$) in the IV models, supports the interpretation that fentanyl exposure played a central role in shaping organ donation patterns during this period.

Table 2: Fentanyl mortality and organ donation

	Overdose donors		
	OLS	OLS	IV
	(1)	(2)	(3)
Fentanyl deaths	0.0192***	0.0187***	0.0203***
	(0.0045)	(0.0029)	(0.0027)
Other drug mortality controls	No	Yes	Yes
State fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	392	392	392
Clusters (States)	49	49	49
K-P F statistic			47.8

	Overdose-donor organs		
	OLS	OLS	IV
	(1)	(2)	(3)
Fentanyl deaths	0.0619***	0.0611***	0.0676***
	(0.0142)	(0.0095)	(0.0097)
Other drug mortality controls	No	Yes	Yes
State fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	392	392	392
Clusters (States)	49	49	49
K-P F statistic			47.8

Notes: State-year panel, 2012–2019. Outcomes and fentanyl mortality are measured per 100,000 population. All specifications include state and year fixed effects. "Other drug mortality controls" include deaths attributed to heroin, methadone, and other opioids. Column (3) instruments fentanyl mortality using geographic diffusion interacted with time. Standard errors in parentheses are clustered at the state level. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

5 Robustness Checks

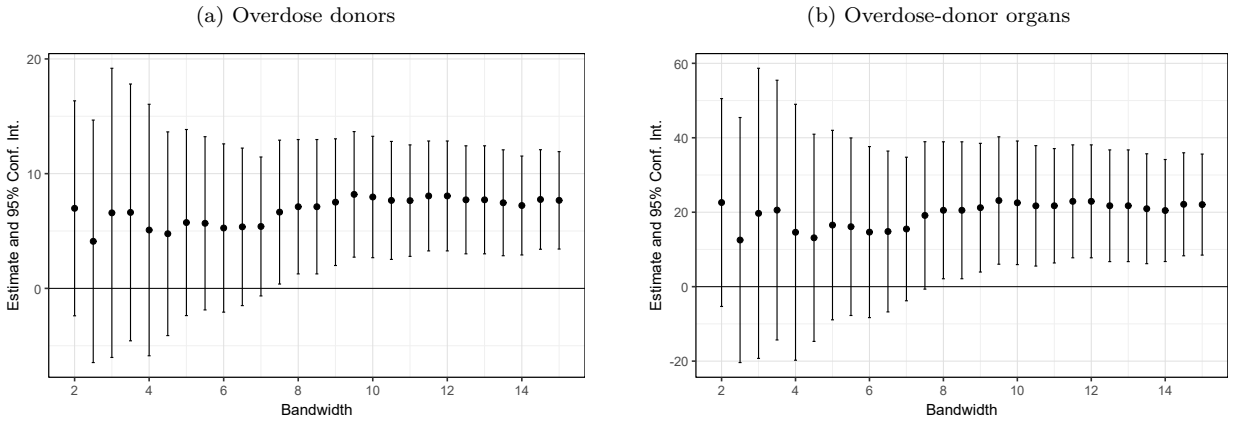
5.1 OPO Checks

5.1.1 Bandwidth Selection

To examine the sensitivity of the difference-in-differences design to the choice of geographic comparison group, we re-estimate the baseline specification using alternative longitude bandwidths around the East–West cutoff. Figure 7 reports the resulting treatment-effect estimates for overdose donors and overdose-donor organs across a range of bandwidth choices. Across specifications, the estimated coefficients remain consistently positive and of comparable magnitude. This stability indicates that the estimated effect is not driven by a particular choice of geographic comparison group or by distant regional contrasts between the East and West.

Narrower bandwidths restrict attention to OPOs located closer to the cutoff, which plausibly face more similar regional environments but also reduce the amount of identifying variation available for estimation. As the bandwidth narrows, estimates become less precise. Restricting the sample to OPOs closer to the cutoff reduces geographic heterogeneity but also substantially reduces sample size and cross-sectional variation, which weakens statistical power. As a result, confidence intervals widen for very narrow bandwidths. Statistical significance starts to emerge for an intermediate window of approximately $\pm 7°$, where the comparison balances geographic similarity with sufficient variation in treatment exposure.

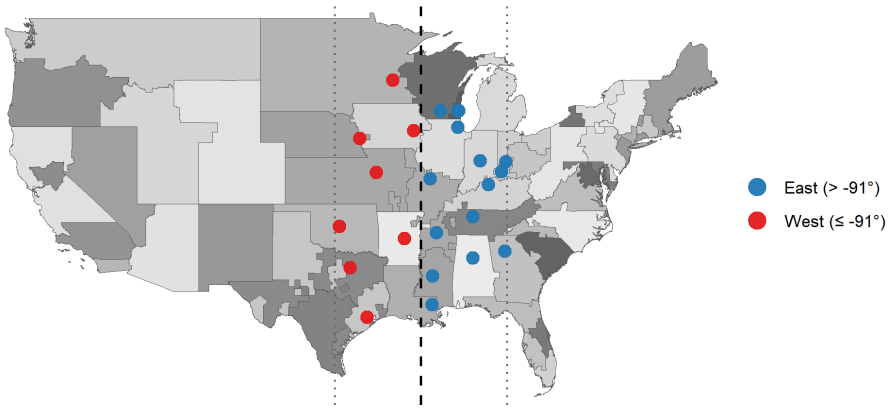
Figure 7: Alternative bandwidths



Notes: Sensitivity of difference-in-differences estimates to bandwidths around the longitude cutoff. Coefficients are displayed with 95 percent confidence intervals.

Figure 8 illustrates the geographic distribution of OPO centers within this ±7° window, which includes 8 western and 15 eastern OPOs. This restriction limits the comparison to OPOs operating in broadly similar regional contexts while retaining meaningful differences in the timing of fentanyl diffusion. Taken together, the results suggest that the main difference-in-differences findings are robust across a wide range of geographic comparisons, with point estimates that are stable but precision that varies with the amount of available identifying variation.

Figure 8: OPO locations with smaller bandwidth



Notes: OPOs within ±7° of the longitude cutoff. The corresponding OPO service areas are shaded in grey. The dividing longitude (-91°) is the median longitude of the Mississippi River.

5.1.2 Donut Specification

To assess whether our results are driven by observations located close to the geographic cutoff, we implement a "donut" specification that progressively excludes OPOs within increasingly wide bands around the −91° longitude threshold separating eastern and western drug markets. In particular, we remove all OPOs located within d degrees of the cutoff, where d ranges from 0 up to 13° on each side.

This exercise is motivated by the geographic distribution of OPOs shown in Figure 3. While the −91° line provides a natural partition between eastern and western drug markets, some OPO service areas lie close to the boundary and may overlap regions with different timing of fentanyl penetration. This raises the possibility that treatment assignment is less sharp for OPOs near the cutoff. The donut specification addresses this concern by excluding these potentially ambiguous cases.

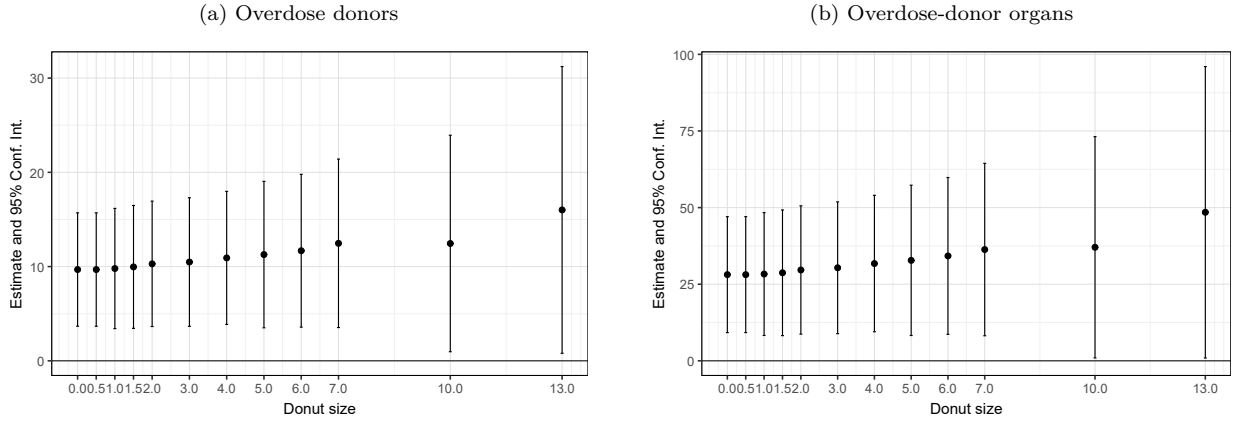
Figure 9 reports estimates from our baseline specification after removing OPOs within the specified distance from the cutoff. Across both outcomes, the estimated effects remain remarkably stable when excluding observations near the threshold. For moderate donut sizes (up to roughly 5–6°), point estimates are largely unchanged and, if anything, increase slightly relative to the baseline specification.

These patterns indicate that the main results are not driven by ambiguity in treatment assignment or local heterogeneity at the geographic boundary. If the estimates were sensitive to misclassification near the cutoff, one would expect the effects to attenuate when these observations are removed. Instead, the stability of the estimates suggests that the discontinuity captures a genuine difference in exposure timing across regions.

As the donut becomes large, confidence intervals widen due to the reduction in sample size. For example, increasing the donut to 10° or more removes a substantial share of OPOs on both sides of the cutoff, leading to a loss of precision. Nevertheless, point estimates remain positive and significant across all specifications.

Overall, the donut analysis supports the validity of the baseline design by showing that the estimated effects are not driven by OPOs located near or overlapping the treatment boundary.

Figure 9: Donut robustness around the −91° longitude cutoff



Notes: The figure reports difference-in-differences estimates excluding OPOs located within a symmetric band of width d (in degrees of longitude) around the −91° cutoff, with d ranging up to 13° on each side. Points denote coefficient estimates and bars indicate 95 percent confidence intervals. All specifications include OPO and year fixed effects, with standard errors clustered at the OPO level.

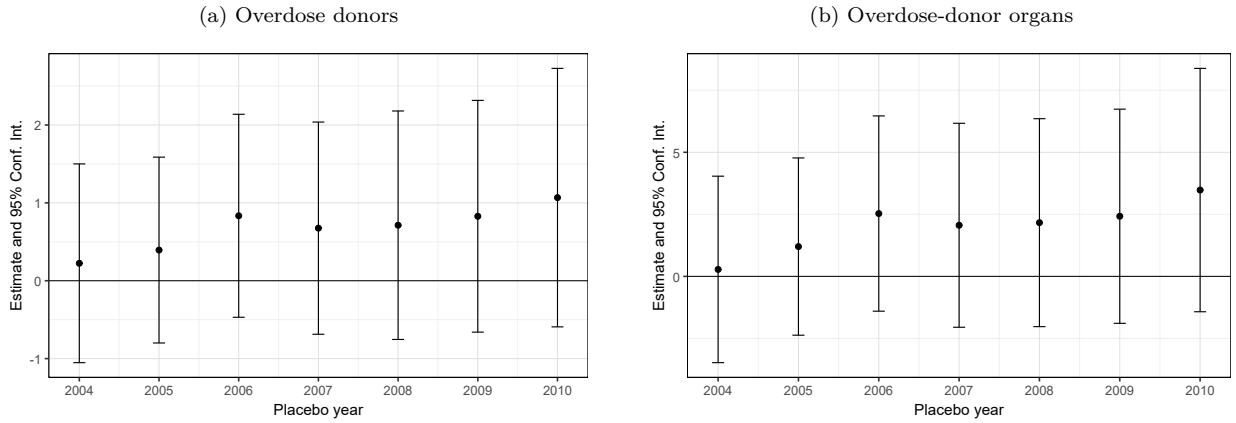
5.1.3 Placebo Treatment Timing

Another concern with the difference-in-differences design is that the estimated effects might reflect differential pre-existing trends between eastern and western OPOs, rather than responses to the arrival of fentanyl. To probe this possibility, we conduct a series of placebo tests that assign "fake" treatment years entirely within the pre-fentanyl period.

Specifically, we re-estimate the baseline two-way fixed effects specification multiple times, each time designating a placebo treatment year between 2004 and 2010. For each placebo year, the sample is restricted to the pre-2013 period, and we estimate the interaction between an indicator for being located east of the longitude cutoff and an indicator for being in the post-placebo period. Because fentanyl had not yet entered illicit drug markets during these years, any systematic, nonzero estimates would point to spurious treatment effects driven by differential trends rather than the fentanyl shock itself.

Figure 10 reports the resulting placebo estimates for overdose donors and overdose-donor organs. Across all placebo treatment years, the estimated coefficients are small and statistically indistinguishable from zero, with confidence intervals that consistently include the null. Importantly, there is no systematic pattern of positive effects emerging prior to 2013, despite the use of the same geographic comparison and fixed-effects structure as in the main analysis.

Figure 10: Placebo treatment years



Notes: Placebo difference-in-differences estimates using fake treatment years in the pre-fentanyl period (before 2013). Points denote estimated coefficients and bars indicate 95 percent confidence intervals.

These placebo results provide reassurance that the main difference-in-differences estimates are not driven by latent pre-treatment dynamics between eastern and western OPOs. If

anything, the absence of systematic positive effects in the pre-period contrasts sharply with the sizable and precisely estimated increases observed following the actual post-2013 fentanyl exposure, reinforcing the interpretation of the main results as responses to the timing of fentanyl's arrival rather than to underlying regional trends.

5.1.4 Sensitivity to Violations of Parallel Trends

We assess the robustness of our difference-in-differences estimates to deviations from the parallel trends assumption using the approach of Rambachan and Roth (2023). This framework allows for bounded violations of parallel trends by constructing confidence intervals that remain valid under controlled departures from the identifying assumption.

The analysis is based on the event-study estimates and focuses on aggregate treatment effects formed as weighted averages of post-treatment coefficients. Guided by the dynamic patterns documented in Section 4.1, we concentrate on the average effect over post-treatment years 3 to 6, which corresponds to the period in which outcomes have stabilized following the initial adjustment to the fentanyl shock.

Figure 11 reports sensitivity results under two complementary frameworks. The relative magnitudes approach allows post-treatment deviations from parallel trends to be proportional to the largest pre-treatment differences, governed by the parameter $\bar{M}$. The smoothness approach instead permits gradual drift in untreated potential outcomes, controlled by a curvature parameter M.

Across both outcomes, the estimated effects remain robust to smooth deviations from parallel trends. Under the smoothness framework, confidence intervals remain strictly positive over a wide range of admissible values of M, indicating that the results are not driven by gradual differential trends between eastern and western drug markets.

Under the relative magnitudes framework, the estimates are somewhat more sensitive but remain robust to moderate violations. Confidence intervals remain positive unless one allows for post-treatment deviations that are comparable in magnitude to the largest pre-treatment differences. This pattern is consistent across both overdose donors and organs transplanted from overdose donors.[8]

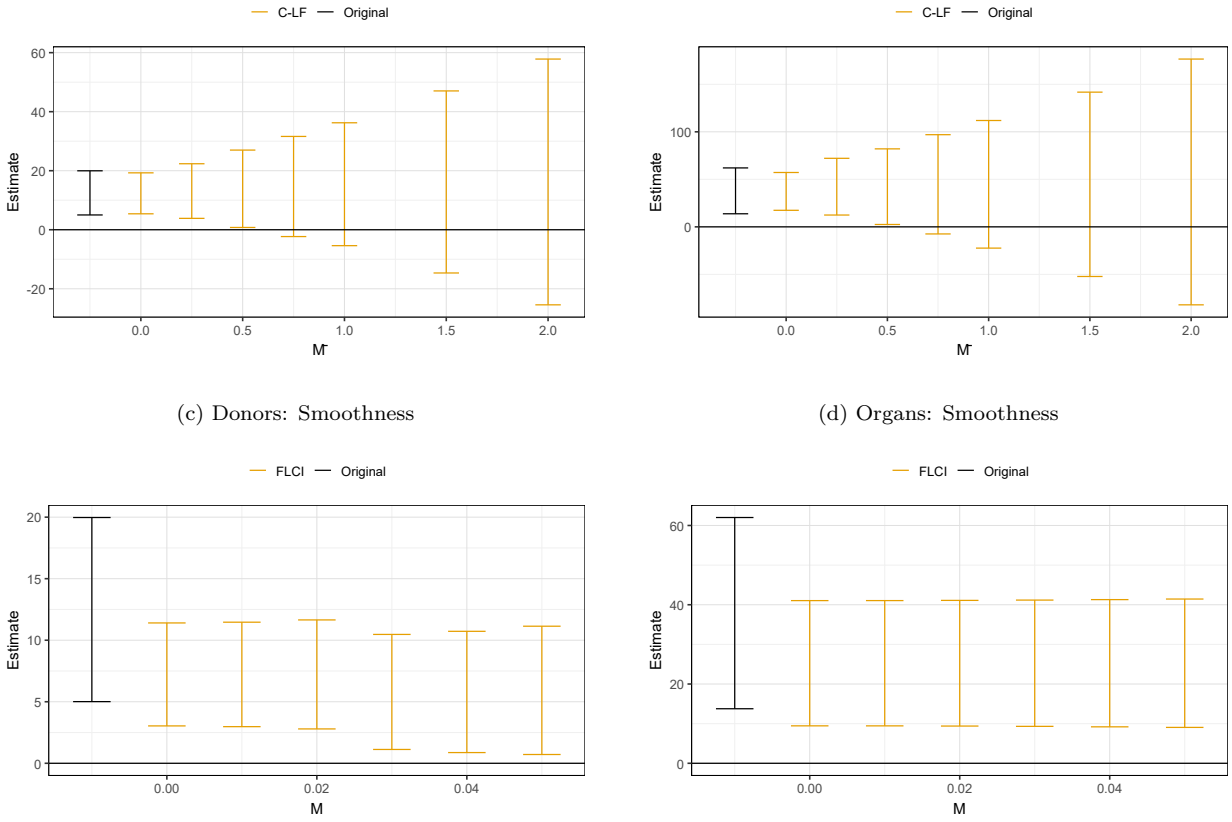
[8]For completeness, analogous sensitivity analyses for the average effect over all post-treatment years (0–6), which yield qualitatively similar but slightly more conservative results can be found in the Appendix (see Figure A.4).

Taken together, these findings support the interpretation that the main results are not driven by plausible departures from parallel trends. The stronger robustness observed for later post-treatment periods aligns with the event-study evidence, which shows a gradual increase followed by a plateau in outcomes after the mid-2010s.

Figure 11: Sensitivity to violations of parallel trends (years 3–6)

(a) Donors: Relative magnitudes

(b) Organs: Relative magnitudes



(c) Donors: Smoothness

(d) Organs: Smoothness

Notes: The figure reports sensitivity of the estimated treatment effects to violations of parallel trends using the framework of Rambachan and Roth (2023). Black intervals correspond to conventional confidence intervals under parallel trends. Orange intervals are robust confidence intervals that remain valid under bounded deviations from parallel trends, constructed using conditional least favorable (C-LF) and fixed-length confidence interval (FLCI) methods under either the relative magnitudes ($\bar{M}$) or smoothness (M) assumptions. Estimates correspond to the average treatment effect over post-treatment years 3–6.

5.1.5 OPO Reduced Form

As an additional check, we further examine the geographic diffusion mechanism underlying the empirical analysis by checking whether similar patterns are visible at the level of in-

dividual OPOs using a continuous measure of exposure. Rather than relying on a binary East–West comparison, we exploit longitudinal variation in OPOs' geographic location to assess whether overdose donation activity evolves differently across space over time.

At the OPO level, we do not observe a direct measure of fentanyl exposure comparable to state-level mortality or seizure data. Instead, we construct a reduced-form specification that interacts an OPO's longitude with a linear time trend, capturing whether OPOs located further east—where fentanyl arrived earlier—experience systematically faster growth in overdose-related donation outcomes. We restrict the sample to the 2012–2019 period to align the OPO-level analysis with the state panel and include OPO and year fixed effects. Standard errors are clustered at the OPO level. Table 3 reports the corresponding reduced-form estimates.

Table 3: Reduced-form effects of fentanyl exposure at the OPO level

	Overdose donors	Overdose-donor organs
	(1)	(2)
Longitude × time trend	0.0826**	0.2692**
	(0.0322)	(0.1070)
OPO fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Observations	464	464
Clusters (OPOs)	58	58
Adjusted R^2	0.769	0.746

Notes: The table reports reduced-form estimates from OPO–year regressions. The dependent variable in column (1) is the number of overdose donors per OPO-year, and in column (2) the number of organs recovered from overdose donors per OPO-year. The regressor is a longitude-by-time trend, which serves as the reduced form of the instrument used in the state-level IV analysis. All specifications include OPO and year fixed effects. Standard errors in parentheses are clustered at the OPO level. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

The estimated longitude-by-time interaction is positive and statistically significant for both outcomes. For overdose donors, the coefficient is 0.0826 (SE = 0.0322), statistically significant at the 5 percent level. For overdose-donor organs, the corresponding estimate is 0.2692 (SE = 0.1070), also significant at the 5 percent level. These estimates indicate that, over time, OPOs located further east experienced larger increases in overdose donation activity relative to more western OPOs.

While the magnitude of these coefficients is modest and the specification explains only a limited share of within-OPO variation—as expected in a parsimonious reduced-form regression—the direction, timing, and statistical significance of the effects closely mirror the main findings from both the state-level instrumental variables analysis and the OPO-level difference-in-differences design.

This exercise is not intended to yield a causal estimate of fentanyl exposure at the OPO-level. Rather, it serves as an additional sanity check for the geographic diffusion mechanism underlying the instrumental variables strategy. The fact that a continuous measure of east–west exposure produces consistent and statistically significant patterns in disaggregated OPO-level data reinforces the interpretation that the primary results reflect the spatial spread of fentanyl over time rather than artifacts of aggregation or modeling choices.

5.2 State-Level Checks

5.2.1 Alternative Endogenous Variable

As a robustness check, we re-estimate the state-level specifications using fentanyl seizures per 100,000 population as the endogenous measure of fentanyl exposure. Fentanyl seizures are the primary exposure variable in Zoorob (2019), and using them here allows us to assess whether our findings depend on measuring fentanyl exposure at the point of consumption (mortality) rather than earlier in the distribution process.

Table 4 presents OLS and IV estimates that parallel the baseline analysis but replace fentanyl mortality with seizures. Across specifications, higher fentanyl seizure rates are associated with increases in overdose donors and overdose-donor organs, and the estimated coefficients remain statistically significant for both outcomes. These patterns are robust to the inclusion of controls for seizures of other drugs, including cocaine, methamphetamine, oxycodone, and heroin.

Fentanyl seizures are, however, a noisier indicator of local fentanyl exposure than mortality. Seizure data reflect enforcement intensity in addition to underlying drug supply, and the location of a seizure may not coincide with where fentanyl is ultimately consumed. Consistent with this, the first-stage relationship in the IV specifications is weaker than in the mortality-based analysis, although Kleibergen–Paap F-statistics remain above conventional thresholds for weak instruments.

Overall, the seizure-based results corroborate the main findings while highlighting the ad-

Table 4: Robustness: fentanyl seizures and organ donation

	Overdose donors		
	OLS	OLS	IV
	(1)	(2)	(3)
Fentanyl seizures	0.0030***	0.0031**	0.0101***
	(0.0009)	(0.0013)	(0.0026)
Other drug seizure controls	No	Yes	Yes
State fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	403	403	389
Clusters (States)	51	51	49
K-P F statistic			17.0

	Overdose-donor organs		
	OLS	OLS	IV
	(1)	(2)	(3)
Fentanyl seizures	0.0099***	0.0104**	0.0328***
	(0.0026)	(0.0041)	(0.0081)
Other drug seizure controls	No	Yes	Yes
State fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	403	403	389
Clusters (States)	51	51	49
K-P F statistic			17.0

Notes: State-year panel, 2012–2019. Outcomes and seizure measures are per 100,000 population. All specifications include state and year fixed effects. "Other drug seizure controls" include cocaine, methamphetamine, oxycodone, and heroin seizures. Column (3) instruments fentanyl seizures using geographic diffusion interacted with time. Standard errors in parentheses are clustered at the state level. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

vantages of using fentanyl mortality to capture the location and timing of exposure, i.e., fentanyl seizures are a much noisier measure of exposure. The persistence of positive effects across both measures suggests that the relationship between fentanyl diffusion and overdose-related organ donation is not driven by the specific choice of exposure variable.

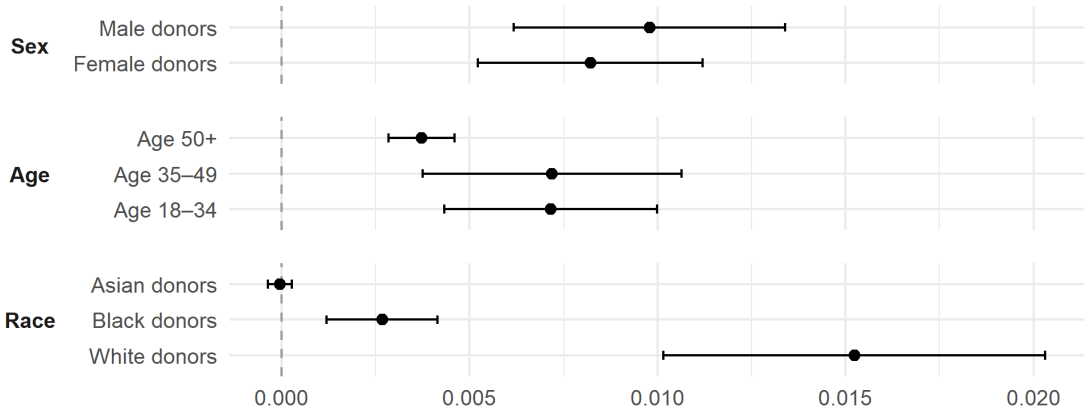
6 Heterogeneous Effects

We next examine whether the effect of fentanyl exposure on organ donation outcomes varies across donor characteristics and organ types. To do so, we estimate heterogeneous effects using the state-level two-way fixed effect regression with the full set of drug mortality controls. The coefficients displayed are thus always with respect to fentanyl deaths per 100,000 state population. We use the state panel for this exercise to allow scaling by subpopulations when it comes to donor characteristics.[9]

Figure 12 reports the coefficients on fentanyl deaths per 100,000 state population, restricting the outcome to donor characteristics depending on sex, age, and race. The regressions are estimated separately for each subgroup and weighted by state population. Effects are positive for both male and female donors, with concentration among donors aged 18–49, with smaller effects for donors aged 50 and above. By race, increases are largest among white donors, with smaller but positive effects for black donors and no detectable effect for Asian donors.

[9]The OPO-level plots equivalents of Figure 12 and 14 look qualitatively similar and can be found in the appendix (see Figure A.5 and A.6).

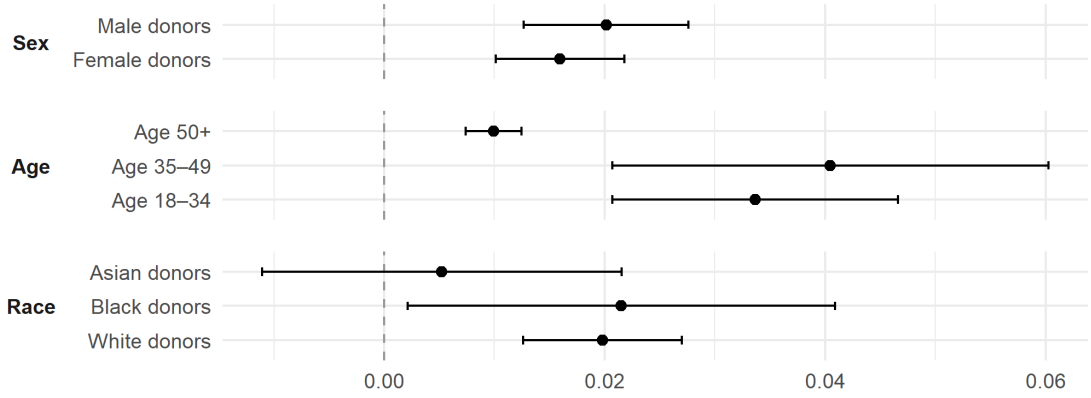
Figure 12: State-level: donor types weighted by state population



Notes: Heterogeneous state-level effects across donor characteristics weighted by the general state population. The coefficients are displayed with 95 percent confidence intervals.

The coefficients are driven by the common denominator (the full state population) and rather illustrate the absolute contribution of a certain group to the overdose donor pool. However, one of the most vulnerable groups with respect to the fentanyl crisis has been African Americans (D'Orsogna et al., 2023). Once the overdose donor subgroups are weighted with their respective subgroup state population (e.g., per 100,000 African American state inhabitants), the coefficients rather represent how fentanyl mortality is associated with the within-group propensity to become an overdose donor (see Figure 13).

Figure 13: State-level: donor types weighted by subgroup population

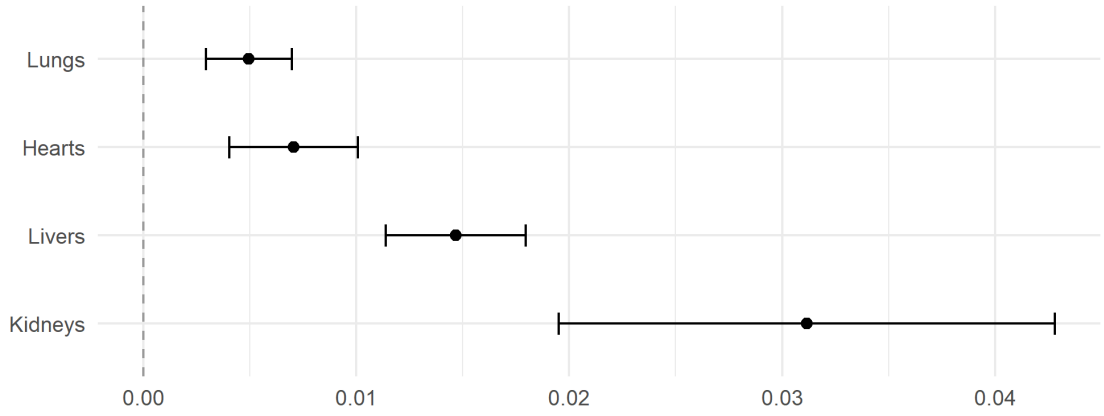


Notes: Heterogeneous state-level effects across donor characteristics weighted by subgroup population. The coefficients are displayed with 95 percent confidence intervals.

Under subgroup-specific population scaling, the point estimate for black overdose donors exceeds that for white donors, reversing the population-weighted ordering, though the difference is not statistically significant. Responses are similar across sex, remain concentrated among younger and prime-age adults, and are small and imprecise for Asian donors.

Figure 14 presents analogous estimates by organ type (weighted by the general state population). The increase in organs recovered from overdose donors is driven primarily by kidneys and livers, with smaller and less precisely estimated effects for hearts and lungs. Since a donor can donate two kidneys, and livers can also be donated in parts, just mechanically the results are driven by those two organ types.

Figure 14: State-level: organ types



Notes: Heterogeneous state-level effects across organ types weighted by the general state population. The coefficients are displayed with 95 percent confidence intervals.

Existing clinical evidence suggests that the increased number of organs from donors who died of an overdose has not adversely affected transplant outcomes. According to Durand et al. (2018) the optimal survival benefit for recipients comes from young trauma-death donors. Organs from overdose-death donors yield outcomes as good as those from trauma-death donors.[10]

7 Conclusion

This paper shows that the fentanyl crisis has had large and consequential effects on the U.S. transplant system. Using complementary sources of variation at the OPO and state level, we document a sharp increase in overdose donors and recovered organs following the diffusion of fentanyl. These effects are robust across identification strategies and placebo tests, and they extend across major organ types.

The results highlight an often-overlooked channel through which the opioid epidemic has reshaped organ procurement and transplantation systems. The expansion of organ supply

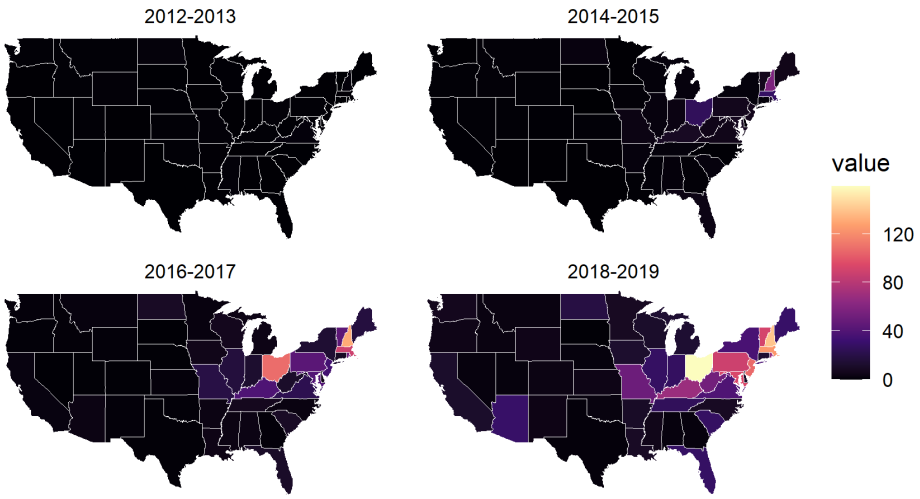
[10]Heart transplants by intoxicated donors, as shown in a meta-analysis and systematic review by Souza et al. (2025) more recently, show no significant long-run differences relative to other deceased-donor transplants.

documented here is mechanically linked to a rise in drug-related mortality, underscoring that the benefits to transplant availability arise from a profound public health failure. In this sense, the fentanyl crisis imposes costs and reallocations that extend well beyond overdose deaths themselves.

Taken together, these findings suggest that policy responses to the opioid crisis and to organ shortages should be considered jointly. Rather than implicitly relying on drug-related mortality to expand organ supply, alternative approaches—such as increased donor registration, improved consent procedures, or opt-out donation systems—may offer ways to relieve pressure on transplant waiting lists without tying organ availability to preventable loss of life.

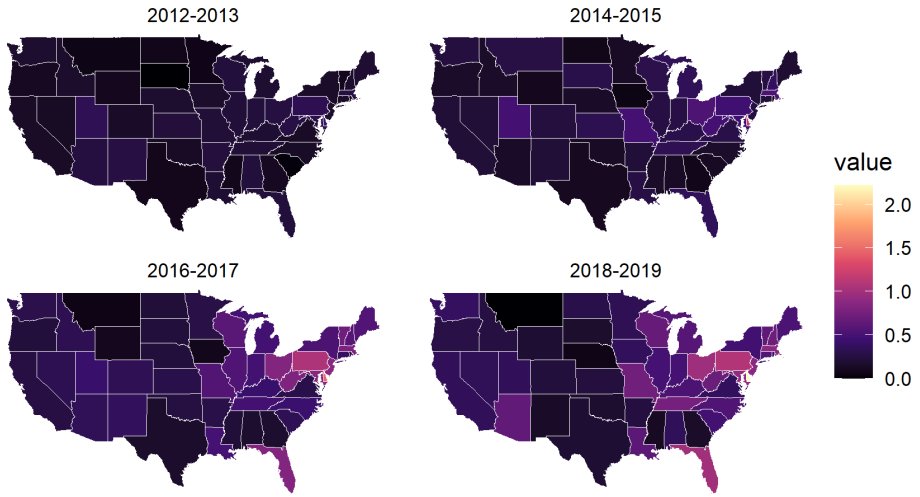
A Appendix

Figure A.1: Fentanyl seizures per 100,000 population



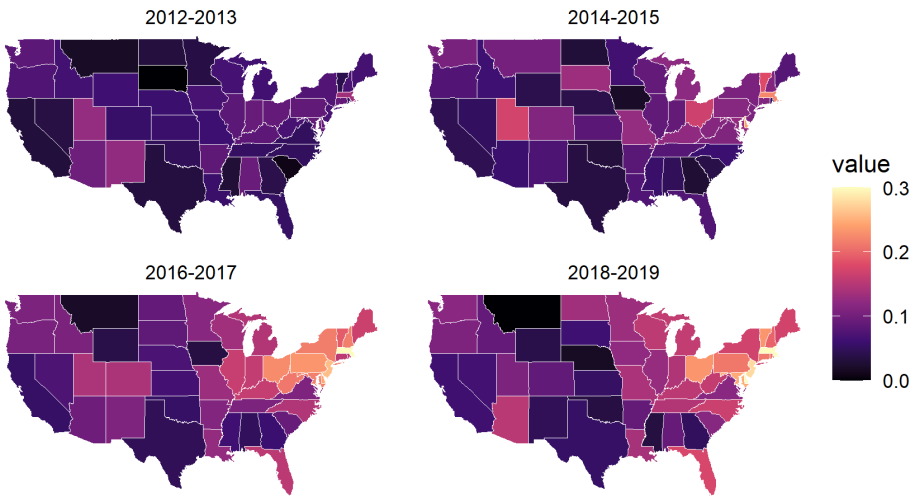
Notes: The figure shows two-year averages of fentanyl seizures per 100,000 population.

Figure A.2: Overdose donors per 100,000 population



Notes: The figure shows two-year averages of overdose donors per 100,000 population.

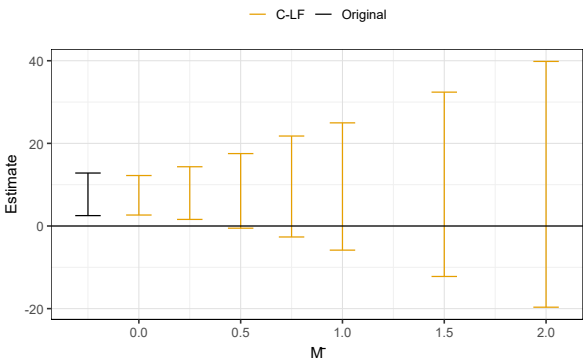
Figure A.3: Share of all donors who died from an overdose



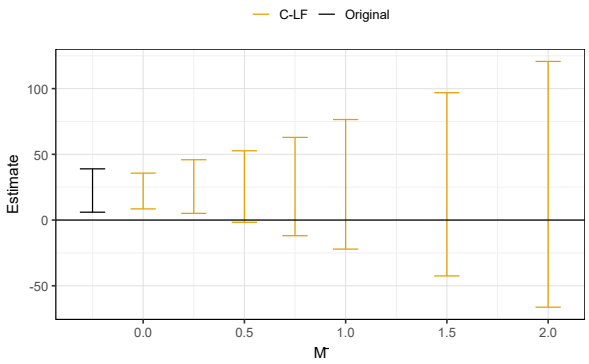
Notes: The figure shows two-year averages of the share of organ donors who died from an overdose, with all deceased organ donors as the denominator.

Figure A.4: Sensitivity to violations of parallel trends (years 0–6)

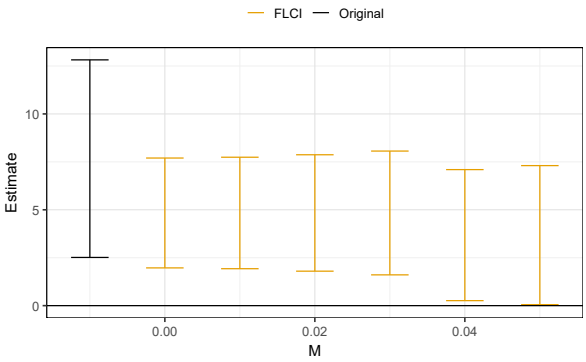
(a) Donors: Relative magnitudes



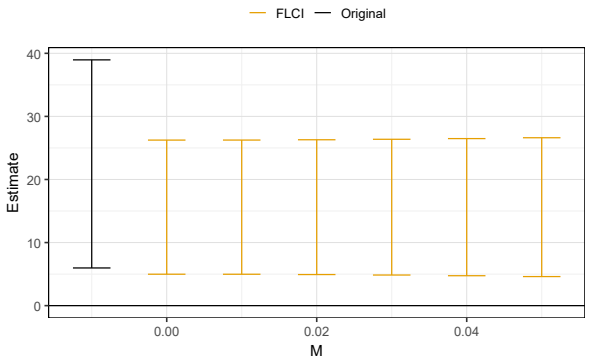
(b) Organs: Relative magnitudes



(c) Donors: Smoothness

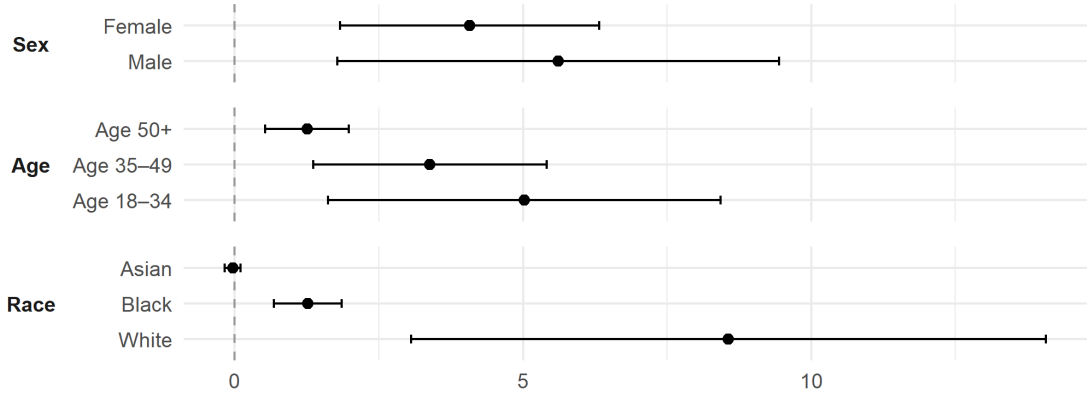


(d) Organs: Smoothness



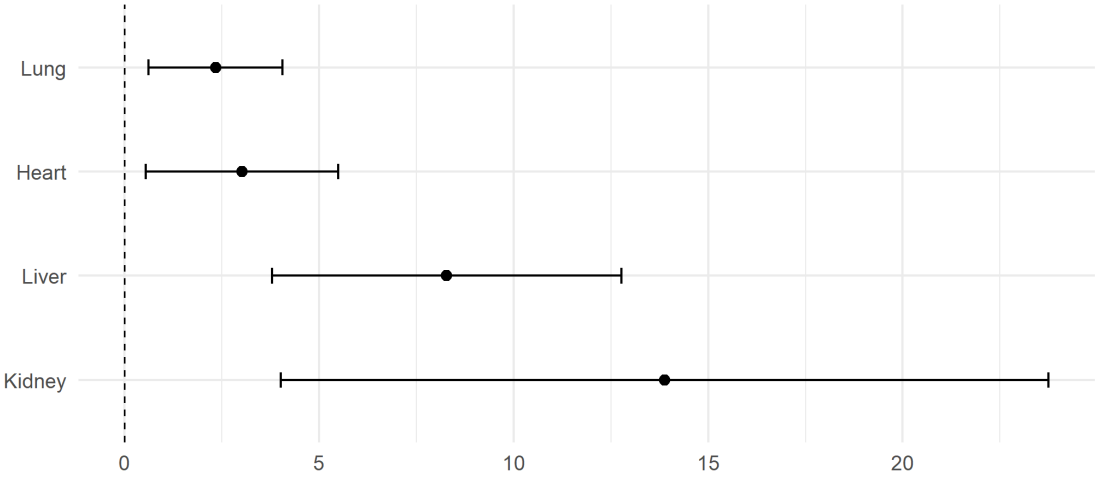
Notes: The figure reports sensitivity of the estimated treatment effects to violations of parallel trends using the framework of Rambachan and Roth (2023). Black intervals correspond to conventional confidence intervals under parallel trends. Orange intervals are robust confidence intervals that remain valid under bounded deviations from parallel trends, constructed using conditional least favorable (C-LF) and fixed-length confidence interval (FLCI) methods under either the relative magnitudes ($\bar{M}$) or smoothness (M) assumptions. Estimates correspond to the average treatment effect over post-treatment years 0–6.

Figure A.5: OPO-level heterogeneous effects across donor characteristics



Notes: Coefficients are displayed with 95 percent confidence intervals.

Figure A.6: OPO-level heterogeneous effects across organ types



Notes: Coefficients are displayed with 95 percent confidence intervals.

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