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Opioids and Organs: How Overdoses Affect the Supply and Demand for Organ Transplants

As the incidence of fatal drug overdose has quadrupled in the U.S. over the past two decades, patients awaiting organ transplants may be unintended beneficiaries. We use Vital Statistics mortality data, merged with the universe of transplant candidates in the U.S. from the Scientific Registry of Transplant Recipients, to study the extent to which the growth in opioid-related deaths affects the supply of deceased organ donors and transplants. Using two separate identification strategies, we find that opioid-related deaths led to more than 22,000 organ transplants in the U.S. between 2008 and 2018. We find that transplant centers are increasingly recovering organs from overdose victims for transplant, with the association between opioid-related deaths and organ donors more than doubling between 2008 and 2018. We also present evidence that transplant candidates are more willing to use organs from those who died of opioid-related causes when organ shortages are relatively severe.

JEL: I11, I18

I. Introduction

According to the Organ Procurement and Transplantation Network (OPTN), organ donation from deceased donors in the US reached an all-time high in 2020 for the tenth consecutive year.[1] As the supply of organ donors has grown, the composition of the donor pool has dramatically shifted, with the fraction of all deceased donors who died via drug overdose rising from less than 1 percent in 1995 to 13.1 percent in 2018. The share of donors dying via overdose is now as large as the share killed in motor vehicle accidents, a sobering reflection of the opioid epidemic that has produced a fourfold increase in annual overdose deaths between 1999 and 2019 (Centers for Disease Control and Prevention, 2020).

While ending the opioid epidemic is a first-order priority, the potential effects on the supply of organ donors allows insights into an organ allocation system that generates massive shortages. As of November 2021, more than 109,000 persons awaited organ transplants, and nearly 4,000 transplant candidates died in 2020 alone. In the current system, donated organs from deceased donors are typically allocated first to waitlisted transplant candidates in the geographic region where the organ was recovered (OPTN, 2017). Given the heterogeneity in the geographic concentration of the opioid epidemic in the United States, the effects of the epidemic on organ donation potentially highlight inefficiencies in the process for matching donated organs to those with the greatest need. For example, opioid overdose deaths in Massachusetts rose by 248 percent between 2010 and 2017, and the corresponding number of organ donors who died via drug intoxication rose by 389 percent.[2] In contrast, opioid overdose deaths rose by only 40 percent in Iowa over the same period, and the number of donors from drug intoxication remained

[1] https://optn.transplant.hrsa.gov/news/annual-record-trend-continues-for-deceased-organ-donation-deceased-donor-transplants/

[2] All numbers of donations and transplants come from the authors' calculations from the Scientific Registry of Transplant Recipients, described below.

roughly unchanged. Differential growth rates in deceased organ donations have the potential to differentially affect transplant candidates' access to organs and transplant outcomes.

We use mortality data from the National Vital Statistics System (NVSS) and restricted-use data on transplant candidates and recipients from the Scientific Registry of Transplant Recipients (SRTR) to study the extent to which the growth in fatal drug overdoses affects the supply of deceased organ donations. Our central estimates, based on specifications that use within-geographic area variation in overdoses over time, imply that 100 opioid-related deaths lead to roughly seven additional organ transplants. These estimates imply that the opioid crisis resulted in more than 22,000 organ transplants in the US between 2008 and 2018, accounting for seven percent of all transplants during that period.

We find evidence that the link between opioid-related deaths and organ transplants is not merely mechanical. Specifically, that link is stronger in areas with greater excess demand for transplants, suggesting that transplant candidates (and their doctors) are more willing to accept organs from overdose victims when the alternatives are less abundant. We also find that the association between opioid-related deaths and organ transplants increased sharply over time; as the opioid epidemic worsened, candidates and doctors were increasingly willing to accept overdose victims' organs, possibly reflecting increasingly accurate information about the quality of organs from these donors.

Existing research (Dickert-Conlin et al., 2019; Fernandez et al., 2013; Lemont, 2019; Choi, 2019) shows that transplant candidates respond dramatically to shocks to the supply of deceased-donor organs by joining transplant waiting lists and, in the case of kidneys, by increasingly opting for transplants from deceased donors instead of living donors. We find little evidence of such responses in the context of opioid-related shocks. Specifically, the surge in organs due to drug intoxication deaths did not crowd out living donors, and we find only modest evidence that transplant candidates systematically joined waitlists in areas with the largest opioid-related supply shocks. We speculate that the gradual increase in organ supply due to the opioid epidemic, rather than the discrete shocks studied in previous research, may not be salient to most transplant candidates. Additionally, candidates may (largely incorrectly) perceive that the quality of organs donated due to drug-related deaths may be lower than the quality of organs obtained through other circumstances of death.

Finally, we use an alternate identification strategy based on Alpert et al. (2021), who find that Purdue Pharma marketed OxyContin less aggressively in states that required triplicate prescription forms for opioids. As a result, states with these "triplicate" requirements experienced relatively few opioid overdose deaths through the first two decades of the 21st century. Using triplicate requirements as a plausibly exogenous source of variation in opioid-related deaths, we estimate that there were 4.08 fewer monthly opioid-related deaths per million population in triplicate areas relative to non-triplicate areas, along with 0.11 fewer organ donors and 0.32 fewer transplants. The corresponding instrumental variables estimates imply that 100 opioid-related deaths lead to 2.7 additional organ donors and 7.9 additional transplants, slightly larger than our central estimates based on intertemporal variation within geographic areas. We again find that the association between opioid-related deaths and donors grew sharply over time, with each opioid-related death leading to more than twice as many transplants in 2015-2018 compared to 2008-2011.

In Section II, we provide details on the opioid epidemic and how it relates to organ transplants. We present our estimates of how drug overdoses affect the supply of organ donations and transplants in Section III, and Section IV considers how shocks to organ supply influences transplant candidates' behaviors. We present instrumental variables estimates based on "triplicate status" laws in Section V, and we conclude in Section VI.

II. Institutional Background and Descriptive Evidence on the Opioid Epidemic

A. The Opioid Epidemic

To measure opioid overdose deaths, we use data from the National Vital Statistics System (NVSS) Multiple Cause of Death mortality files.[3] These data include information from the death certificate for every reported death of a resident in the US. Column (1) of Table 1 shows that the annual number of drug overdose deaths, which include deaths due to opioid, anesthetic, sedative, and stimulant intoxication, more than quadrupled from 16,761 in 1999 to 67,553 in 2018. Opioids represent a major contributor to the dramatic increase in drug overdose deaths. Column (5) shows that 70 percent of drug overdose deaths in the U.S. in 2018 (= 46,882 / 67,553) involved an opioid, compared to fewer than half of all drug overdose deaths at the turn of the century. A broader measure of the fatality consequences from the opioid epidemic includes all *opioid-related deaths*, not just those listing drug overdose as the underlying cause of death; column (9) shows that these deaths increased by more than a factor of five between 1999 and 2018, from 8,608 to 48,150.[4]

Table 1 also highlights that overdose and opioid-related deaths are concentrated among young adults and men. Those aged 18-49 represented almost 70 percent (= 33,298 / 48,150) of all opioid-related deaths in 2018, as shown in Column (10). Likewise, almost 70 percent (= 32,918 / 48,150) of those who died of opioid-related deaths were men.

[3] We use the Multiple Cause of Death Files with County Identifiers, 1999-2018, as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program. We include all ICD-10 codes that list drug overdose as the underlying cause of death: (X40-44, X60-64, X85, Y10-14).

[4] This classification includes deaths in which one of the multiple causes of death is coded as opioid-related (ICD-10 codes T40.0, T40.1, T40.2, T40.3, T40.4, and T40.6).

Opioid overdose death rates also vary considerably across states (Ruhm, 2017). In 2018, the states with the highest rates of opioid-related deaths were West Virginia, Delaware, and Maryland (428, 375, and 362 per million population, respectively), while South Dakota, Nebraska, and Hawaii had the lowest opioid overdose death rates (32, 35, and 42 per million population, respectively). Similarly, growth rates of opioid-related deaths varied dramatically by state, with deaths in New Jersey, Pennsylvania, and Connecticut growing by 588 percent, 350 percent, and 345 percent, respectively, between 2010 and 2018. In contrast, overdose deaths in the same period declined in Oklahoma, Hawaii and South Dakota by 44 percent, 31 percent, and 27 percent, respectively.

B. The Link between the Opioid Epidemic and Organ Donation and Transplantation

By 2016, several academic and media publications acknowledged the link between the opioid epidemic and the market for organ transplants. The April 2016 issue of *Journal of Transplantation* reprinted a report (Rudd et al., 2016) that suggested that the epidemic "…may have an impact on the organ donor pool." Similarly, Goldberg et al. (2016) documented the increases in the number of donors whose deaths were due to drug intoxication between 2003 and 2014, showing that the increases varied markedly by organ and geographic area. Hickman et al. (2018) documented the substantial cross-country variation in the share of drug overdose deaths that convert to organ donors.

At the same time, numerous newspaper articles highlighted the link between drug overdoses and organ donors while addressing the viability of organs from donors who died via drug overdoses. The *Washington Post* (Izadi, 2016) quoted David Klassen, the chief medical officer for the United Network for Organ Sharing: "[T]ruthfully, people who are dying of drug overdoses are young and tend to be otherwise healthy. In many ways, they are ... potentially excellent donors, from an organ quality standpoint." Seelye (2016) and Wenner (2016) reported that victims of drug overdose might be high-risk donors because they practice other risky behaviors that are associated with HIV and hepatitis C, but even these diseases can be treated or cured in the unlikely case that the transplant recipient contracts the disease. In any case, the risk of contracting a disease from a transplant is typically less salient than the risk of death due to not receiving an organ at all.

To put more structure on the link between the opioid epidemic and organ donation and transplantation, Figure 1 depicts a stylized process from an opioid-related death to an organ transplant. The process broadly has two stages – the supply side, where a death from an opioid-related cause converts to a donor, and the demand side, where a donor's organs are transplanted into transplant candidates.

Supply side: The Opioid Epidemic and Organ Donation

Almost all deceased organ donors are brain dead at the time of organ recovery, meaning that all brain function has irreversibly stopped. Because the heart continues to beat for some time after brain death occurs, current medical technology allows for respiration via a ventilator, so the internal organs receive oxygenated blood and remain viable for transplantation.[5] When a person experiences an opioid overdose, their breathing often slows or stops, causing hypoxia (reduced oxygen to the brain) that potentially leads to brain death.

If a person receives mechanical ventilation after an opioid-related death, the next step in the process is an evaluation of the organ quality by the attending physician. Some conditions

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[5] In contrast, organs deteriorate rapidly following cardiac deaths and are therefore unsuitable for transplantation, except in extraordinary circumstances in which patients with non-survivable brain injuries who are not brain dead (because they retain some minimal brain stem function) become donors. See http://www.organtransplants.org/understanding/death/ for more details.

categorically prevent a person from becoming a donor – such as active cancer or systemic infection – but these conditions are relatively rare among those who experience brain death.[6] Passing the quality screening to donate an organ is not sufficient to become an organ donor; the individual or their family must also consent to the donation. Individuals can do so by indicating their preference on their driver's license or by registering on a state registry. First-person consent laws and the Revised Uniform Anatomical Gift Act (UAGA), which covers most states, require health care professionals to abide by the potential donor's consent to recover organs. Without first person consent, health care professionals will seek permission from the potential donor's next-of-kin.[7] According to Wenner (2016), 83 percent of potential donors who died of drug overdose ultimately become donors, compared to only 63 percent of the general population of potential donors. This difference appears to stem from relatively high donor registration rates among overdose victims: 46 percent of overdose victims are registered donors, compared to 29 percent of the overall population of potential donors.

Once consent is obtained, the donor enters the organ allocation process in the donation service area (DSA) where they died. The 58 DSAs in the United States broadly follow state boundaries, although large states have multiple DSAs, while some DSAs include multiple states or portions of states. An Organ Procurement Organization (OPO) evaluates potential donors in each DSA, arranges for surgical removal of organs, and arranges for the distribution of donated organs to waitlisted candidates.[8]

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[6] See https://www.organdonor.gov/about/donors.html (accessed February 9, 2021) for more details. In personal conversations, administrators of the Association of Organ Procurement Organizations suggest that stigma surrounding drug use is not likely an issue at this stage of the process and that physicians are likely to designate any viable donor as such.

[7] Howard (2007) estimates that donation rates among all potential donors range from 51 to 60 percent, primarily due to low consent rates.

[8] Appendix Table A1 shows the complete list of OPOs and the states in which they are headquartered. Each OPO reviews a candidate's application based on its own criteria, which generally include medical and mental health

Upon identification of an organ donor, each transplantable organ (kidneys, liver, heart, lungs, pancreas, and intestines) is considered for recovery. Most donors have at least one organ recovered for transplant, but few have all eight organs recovered.[9] Six percent of organs are not recovered because authorization is not requested (usually because of donor age) and another three percent are not recovered because authorization from the family is not granted (usually because of emotional, cultural, or family-conflict reasons). Another 40 percent of organs are not recovered because of poor organ quality, a donor's medical history, or because the OPO could not locate a transplant candidate who wanted the organ in time.

In summary, Figure 1 highlights the roles of mechanical and behavioral mechanisms for converting opioid-related deaths to organ donations. The behavioral roles include decisions of whether to ventilate a patient, how to evaluate organ quality, and whether to pursue consent for the person to become an organ donor. These decisions potentially depend on many factors, including information about the quality of organs from drug intoxication donors, the demand for organs from drug intoxication donors, and the availability of outside options, such as the supply of organs from donors who died due to other causes.

Demand side: The Opioid Epidemic and Organ Transplantation

Transplant candidates seeking a deceased-donor transplant must first register with one of roughly 300 transplant centers in one or more of the 58 DSAs. About six percent of all

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conditions, the quality of the candidate's support system, the probability of surviving the transplant surgery, and the ability to follow up with post-transplant medical care (https://unos.org/transplantation/faqs/).

[9] These numbers are authors' calculations from the Scientific Registry of Transplant Recipients described in detail later in this section.

transplant candidates register on multiple waiting lists in different DSAs, a process known as "multilisting".[10]

When a deceased-donor organ becomes available in a DSA, the DonorNet computer system generates a pool of eligible recipients from the waitlist based on blood type, other compatibility measures, and candidates' willingness to accept the quality of the organ offered (OPTN, 2015). Within the pool of potential candidate matches, the system generates a ranking of candidates, typically based on geographic distance from the donor organ, time on the waitlist, quality of the match, and medical urgency status of the candidate.[11] The weight given to (and measurement of) each of these characteristics varies by organ and over time, but geographic distance from the donor organ is usually one of the most influential characteristics due to the need to transplant an organ quickly after the donor's death occurs.

The OPO offers the deceased donor's organ to the candidate with the best match in the DSA's pool of matches, making the geographic unit defined by the DSA a critical variable in the process. If the candidate accepts the organ, the transplant occurs; otherwise, the OPO offers the organ to the next person on the list. The next offer may be made within the DSA or, if no match is found within the DSA, outside the DSA.[12] If no match is found for the organ, it may not be recovered at all, as described above, or it may be discarded after being recovered. About six percent of organs from donors are recovered for transplant but subsequently discarded due to

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[10] In order to multilist, a candidate needs to be accepted at the additional center, which includes being able to arrive in time to the center to receive a transplant if an organ were to become available. See http://optn.transplant.hrsa.gov/learn/about-transplantation/transplant-process/ for more details.

[11] There are exceptions to this geographic allocation process. Sharing arrangements exist between OPOs inter- or intra-regionally, although OPTN's Board of Directors must approve such arrangements. Some organs have unusual policies; for example, liver donations are offered first to the most medically needy within regions that contain multiple DSAs.

[12] In the SRTR data, we estimate that about 2/3 of all organs are transplanted in the same DSA in which they are procured. This share has grown over time, with the highest share for kidneys and combined kidney/pancreas transplants.

poor organ quality or the inability to find a match. Four percent of organs from deceased donors are recovered for purposes other than transplant, primarily for research. Approximately 39 percent of all donated organs are ultimately transplanted, represented by the final box in Figure 1.

The decision process of candidates to accept an offer of an organ highlights the roles of discretion in the process from an opioid-related death to a transplant.[13] For some context, Agarwal et al. (2020) show that between 2000 and 2010, the median number of biologically compatible offers for a single kidney before an offer is accepted is 51. The opioid epidemic might influence these decisions on multiple dimensions. First, a higher supply of organs may induce candidates to be more selective about which organs they choose and more likely to turn down organs to wait for a higher quality one (Agarwal et al., 2020). Second, because the increased supply of organs in the opioid epidemic comes from donors who engaged in risky behavior, there may be concerns, substantiated or exaggerated, about organ quality.

Several recent editorials argue that misperceptions about the quality of organs from drug overdose donors led to underutilization of organs generated by the opioid epidemic. Goldberg et al. (2016) urged the medical community to maximize the utilization of potential donors labeled as "increased risk". In a Special Article for the journal *Transplantation*, Weiner et al. (2017) made the same plea, suggesting that "due to concerns over disease transmission (HIV, hepatitis B, and hepatitis C virus), these donors are underused by the transplant community." Maghen et al. (2019), in a letter to the editor in the *New England Journal of Medicine*, suggested that the views on the acceptability of organs from drug users is changing:

> "Rather than discarding organs obtained from drug users because of the risk of human immunodeficiency virus infection or hepatitis C virus infection, diligent

[13] Genie et al. (2020) show heterogeneity in transplant candidates' willingness to wait for kidneys based on patient characteristics and the design of the allocation system.

> and specific screening methods now permit some organs that were previously considered to be unacceptable to be acceptable for transplantation, with a lower risk for recipients than the risk of turning down the donated organ altogether."

The changing views on the acceptability of organs from drug users stem in large part from research about safety and transplant outcomes. Numerous studies of heart, lung (Durand, 2018, Mehra et al. 2018, Phillips et al, 2019), liver (Gonzalez and Trotter, 2018), and kidney (Chute et al., 2018, Tullius and Rabb, 2018) transplantation find that donors from opioid-related deaths are younger and healthier along many dimensions than donors from other mechanisms of death.[14] While these same studies show that drug overdose donors are more likely to have other health conditions, such as higher rates of hepatitis C, they generally conclude that outcomes of transplants from donors who died from drug-related causes are favorable compared to transplants from donors who died due to other mechanisms.

While not shown in Figure 1, the option of a living donation, primarily for kidneys but occasionally for livers and lungs, may affect the path from an opioid-related death to an organ transplant. The decision to choose a living donor depends on the availability of a compatible, willing donor and, among other things, the probability of receiving an offer from a deceased donor. Thus, an increase in the supply of deceased organ donors because of the opioid epidemic may reduce transplant candidates' incentives to pursue living-donor transplants.

[14] For example, the medical director of the Heart Transplant Program at the University of Utah Health reports that data from the Program shows "no significant difference in survival between recipients of organs from donors who died of drug overdose and recipients from donors who died of blunt head injury for heart transplantation." See https://www.healio.com/hepatology/transplantation/news/online/%7Bc95305eb-691c-409c-9cad-d184ed02ade9%7D/organs-donated-after-drug-overdose-safe-for-transplantation (accessed May 23, 2021).

Data on organ donations and transplants

This study uses data from the Scientific Registry of Transplant Recipients (SRTR). The SRTR data system includes data on all donors, wait-listed candidates, and transplant recipients in the US, 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. The SRTR data, which comes from hospitals and immunology laboratories, include detailed donor-level information such as the cause, circumstance, and mechanism of death; which organs were recovered, discarded, and transplanted; and relevant health markers, such as age, gender, and the geographic location of the donor. SRTR data also include candidate-level information such as time spent on the waitlist, transplant centers at which each candidate is registered, health markers, demographics such as zip code of residence, reason for leaving the waitlist and follow-up health data for those who receive a transplant. Donors can be matched with the transplant recipient if a transplant takes place.

We use the variable *mechanism of death* to identify donors who died from a “drug intoxication” (DI), which we view as roughly corresponding to the drug-related overdoses in NVSS. The other categories of *mechanism of death* include gunshot / stab wounds, asphyxiation, blunt injury, cardiovascular, drowning, electrical, intracranial hemorrhage / stroke, natural causes, seizure, SIDS, “none of the above”, and “not reported”. SRTR also codes a *cause of death* for each donor. Approximately 93 percent of all donors whose death is coded as a “drug intoxication” receive “anoxia”, defined as injury to the brain due to lack of oxygen, as their cause of death; “cerebrovascular/stroke” and “other” make up the remainder.

Table 2 and Figure 2 show the dramatic rise in the number of deceased organ donors whose mechanism of death is listed as DI. While the number of donors from all other mechanisms combined rose by roughly 62 percent between 1999 and 2018 (from 5,765 to 9,322), the analogous number from DI rose by more than 2,000 percent (from 65 to 1,401). Men represent about 70 percent of all opioid-related deaths in the NVSS data, but they are only about 55 percent (= 834 / 1,401 in 2018) of all DI organ donors. Table 2 also shows that the concentration of fatalities due to drug overdoses among young adults in the NVSS data mirrors the share of donors whose death mechanism is DI. Between 80 and 90 percent (= 1,256 / 1,401 in 2018) of all DI donors are 18 to 49 years old, while just over 50 percent (= 4,851 / 9,822 in 2018) of donors from a mechanism other than DI are 18 to 49.

Although donors from drug intoxications are substantially younger and, presumably, in better health than donors from other mechanisms, Table 3 shows that the number of organs transplanted per deceased donor is low relative to some other mechanisms of death. For example, 3.17 organs are transplanted per donor who died due to drug intoxication, compared to 4.39 and 3.64 organs per donor among those who died from gunshot wounds and blunt injuries, respectively. These findings are surprising considering the relatively high donor consent rates among victims of drug overdoses (Wenner, 2016), and they possibly reflect relatively low demand for the organs from DI donors.

C. Hypotheses and Graphical Evidence of the Link between Opioid-Related Deaths and Organ Donation

Given the existing allocation process and the link between opioid overdose and brain death, we hypothesize that the number of organ donors and organ transplants from deceased donors who died of drug overdoses will be positively correlated with the number of drug overdose fatalities. While this relationship is likely to be primarily mechanical as more brain deaths result in more donors, the potential for behavioral responses leads to two related hypotheses: first, the association between the number of transplants from organ donors who died of drug overdoses and the number of drug overdose fatalities will increase over time. We speculate that organs may be more likely to be recovered and / or accepted by transplant candidates as medical procedures for treating conditions associated with drug use (such as Hepatitis C or HIV) improve, understanding of organ quality from DI deaths increases, or stigma about organs recovered from DI deaths change over time.

Second, the number of transplants from organ donors who died of drug overdoses will be more positively correlated with the number of drug overdose fatalities in DSAs with relatively high levels of excess demand for deceased organs. High levels of excess demand may induce increased efforts to convert potential transplants to actual transplants because transplant candidates are less likely to receive an organ in time from a donor who did not die of drug-related causes.

On the demand side, we hypothesize that an increase in the supply of organ donors from drug related deaths will affect the waitlist for deceased organs by increasing the number of organ transplant candidates who register on the waitlist. We also hypothesize that a positive deceased-donor supply shock will crowd out living-donor transplants.

To illustrate the correlation between drug related deaths and organ donations, we aggregate the mortality and organ donation data to the DSA level, using a county crosswalk provided by the SRTR. We normalize our measures of deaths and donations by the population data from the National Cancer Institute to generate measures per million DSA residents.

The top panel of Figure 3 provides graphical evidence of the dramatic increase in opioid-related deaths per capita and the variation across the DSAs. We divide 57 DSAs into quintiles based on their 2018 opioid-related deaths per million residents as calculated in the Vital Statistics Data.[15] The DSAs in the top quintile in 2018 also tended to be in the top quintile prior to 2010, but the differences between the top quintile and the other four began to widen dramatically in 2012. For example, the top quintile had 79 opioid-related deaths per million in 2008, compared to 48 in the lowest quintile. By 2018, the top quintile had more than six times as many opioid-related deaths per million as the bottom quintile (307 versus 51).

The bottom panel of Figure 3 shows changes over time in organ donations per capita from DI donors. We again categorize the 57 DSAs into quintiles based on 2018 opioid-related deaths per capita. The patterns are similar to those in the top panel, in that the DSAs in the top quintile of opioid-related deaths per capita have the highest level of DI organ donors in 2018 (8.24 per million, compared to 5.05, 4.48, 2.95 and 1.59 per million in the fourth through first quintiles, respectively). Moreover, the variation across the quintiles increased dramatically since 2010, with the ratio of the top quintile to the bottom exceeding five in recent years (for example, 8.24 / 1.59 = 5.1 in 2018).

Figure 4 shows the variation across quintile and time in the probability that an opioid-related death produces an organ donor. Recall from Figure 1 that a donation requires brain death, mechanical ventilation, a determination that the organs are of sufficiently high quality, and the procurement of donor consent. In the full sample, roughly 1.5 percent of all those who died from opioid-related causes become organ donors, but as the figure shows, this "conversion rate"

[15] There are 58 DSAs in the United States; however, we exclude Puerto Rico's DSA because we do not have mortality data all years in our sample, so we exclude this DSA from our analysis. The 1st quintile contains the following OPOs in DSAs: AROR, CADN, CAGS, CAOP, HIOP, IAOP, MSOP, MWOB, NEOR, TXGC, TXSA, and TXSB. The 2nd quintile contains the following DSAs: ALOB, AZOB, CASD, CORS, GALL, INOP, LAOP, MNOP, OKOP, ORUO, and WALC. The 3rd quintile contains the following DSAs: DCTC, FLFH, NCCM, NCNC, NYAP, NYRT, PADV, SCOP, TNMS, UTOP, VATB, and WIUW. The 4th quintile contains the following DSAs: FLMP, FLUF, FLWC, ILIP, MIOP, MOMA, NJTO, NMOP, NVLV, NYFL, and TNDS. The 5th quintile contains the following DSAs: KYDA, MAOB, MDPC, NYWN, OHLB, OHLC, OHLP, OHOV, PATF, CTOP, and WIDN.

increased dramatically over time, from less than one percent in 1999 to approximately three percent in 2018. These trends are similar across quintiles, even though the DSAs in the upper quintiles have very different experiences with opioid-related deaths than those in the lower quintiles.

III. Opioid-Related Deaths and the Supply of Organ Donors and Transplants

To further investigate the links between opioid-related deaths and organ transplants, we estimate DSA- and month-specific organ donation and transplantation rates as a function of the number of opioid-related deaths in that DSA and month. We restrict our sample to begin in 2008 to focus on the period with the largest variation in opioid-related deaths, and we use monthly data to capture the within-year variation in death rates. We begin by estimating the following model via OLS:

(1) $$Y_{st} = \alpha_s + \delta_t + \gamma Deaths_{st} + \beta' X_{st} + \varepsilon_{st} \ ,$$

where Y_{st} is a measure of the number of deceased organ donors or transplants, s indexes the DSA, t indexes the month-year, and $Deaths_{st}$ is a measure of the number of opioid-related deaths. We measure Y_{st} and $Deaths_{st}$ per million DSA residents using National Cancer Institute county population estimates. All specifications include a full set of DSA (α_s) and month-year (δ_t) indicators to capture unobservable DSA characteristics that are constant within a DSA over time and time characteristics that are fixed within a month across DSAs, respectively.

The vector X_{st} includes time-varying DSA-level unemployment rates, along with measures of several policies that might be correlated with opioid-related deaths and organ donation. For example, one such policy is motorcycle helmet laws, which Dickert-Conlin et al. (2019) show are strongly associated with the number of organ donors who died in motor vehicle accidents. We construct measures of the share of a DSA's population that was covered by a universal motorcycle helmet law in each year. We also include the share of the DSA covered by the Revised Universal Anatomical Gift Act (UAGA), which mandates that the wishes of registered organ donors do not need to be confirmed by the family of the deceased. Anderson (2015) estimates that kidney donations increased by five to seven percent following the adoption of the UAGA revisions.

We include the share of the DSA covered by a Naloxone Access Law that allows lay responders to administer the drug naloxone, which can reverse an opioid overdose. Rees et al. (2019) find that these laws reduce opioid-related deaths by 9 to 11 percent. We also include the share of the DSA covered by Prescription Drug Monitoring Programs (PDMPs) and Mandatory PDMPs (MPDMPs), which collect data on opioid prescriptions and act as a data-sharing network between institutions and providers.[16] Studies such as Buchmueller and Carey (2018), Meinhofer (2018), and Wen et al. (2017) find that MPDMP programs reduce opioid misuse.[17] Finally, we include measures of the share of the DSA covered by medical and recreational marijuana laws, given recent findings that marijuana access / legalization reduces opioid mortality (Chan et al., 2020 and Powell et al., 2019).[18] Note that the estimates throughout are essentially identical when we exclude the full set of organ donation and drug law control variables.[19] Finally, we weight all observations by the population in that DSA and year.

The first three columns of Table 4 present estimates of γ from specification (1) based on models in which the dependent variable is the number of DI donors per million DSA residents.

[16] See, for example, http://www.pdaps.org/datasets/pdmp-implementation-dates, http://www.pdaps.org/datasets/prescription-monitoring-program-laws-1408223416-1502818373, and https://www.pdmpassist.org/State.

[17] Grecu et al. (2018) do not find evidence that PDMP affect mortality related to prescription drugs, but they do find that prescription drug abuse is responsive to PDMP.

[18] We thank Serena Phillips and Mike Pesko for sharing data they received from Rosalie Pacula as part of the OPTIC Vetted Policy Data Warehouse. Smart and Pacula (2019) describe these data in more detail.

[19] To conserve space, we do not present results from specifications that exclude law controls; these are available upon request.

Because we also measure $Deaths_{st}$ per million DSA residents, the estimates measure the effect of one additional death on the supply of organ donors. In column (1), we use the number of opioid-related deaths as our measure of $Deaths_{st}$. We estimate that each opioid-related death increases the supply of DI organ donors by 0.0202, with a standard error of 0.0015. In columns (2) and (3), we use opioid overdoses and all drug overdoses, respectively, as the measure of $Deaths_{st}$. In each case, the point estimates and standard errors are nearly identical to those in column (1).

Columns (4)-(6) show the estimated effect of opioid overdose deaths on total transplants from DI donors.[20] The estimate in column (4) implies that each additional opioid-related death leads to 0.0633 transplanted organs. Note that this estimate is roughly three times as large as that in column (1), consistent with the descriptive statistics presented in Table 3 showing that each DI donor donates roughly three organs for transplant. The estimates in columns (4)-(6) are again insensitive to the particular measure of $Deaths_{st}$ we use, so we focus on opioid-related deaths in all specifications hereafter.

To put these estimates in context, note that Table 1 shows that opioid-related deaths increased by approximately 4,000 per year between 2012 and 2018 (from 24,126 to 48,874). The estimates in Table 4 imply that these 4,000 additional annual deaths led to *annual* increases of roughly 80 organ donors and 240 organ transplants.

Table 5 presents estimates of the association between opioid-related deaths and organ donors by gender and age. Based on Table 2, we expect the absolute effects of opioid overdose deaths on DI donation rates to be largest among those donors who are most likely to be involved

[20] In most cases, each organ transplant maps one-to-one to a transplant candidate. In some rare cases, two organs, such as two lungs, go to one recipient; alternatively, a single liver can be split into two segments and transplanted into two recipients. There are also some dual-organ transplants (heart-lung and kidney-pancreas) that are coded as two transplants, even though a single recipient receives both organs.

in overdose deaths: men and those aged 18-49. The top row of Table 5 shows that each drug-related death increases the supply of male organ donors who died due to DI by 0.0116 (0.0013) and increases the supply of female organ donors who died due to DI by 0.0086 (0.0008), implying that men account for 57 percent of the marginal effect of DI deaths on organ donation. Column (1) also shows that donors from opioid-related deaths between the ages of 18 and 49 account for approximately 91 percent (= (0.0109 + 0.0074) / 0.0202) of the marginal effect of DI deaths on organ donations due to DI. The concentration of the effects of opioid-related deaths on donors among men and those aged 18 to 49 suggests that responses to DI deaths, rather than other changes in the donation environment, drive our results.

IV. Behavioral Responses to Opioid-Related Deaths

Effects of Supply Shocks on Organ Utilization

To test the hypothesis that organ recovery surgeons are increasingly utilizing a higher percentage of opioid-related deaths in transplants, we estimate the following specification:

(2) $$Y_{st} = \alpha_s + \delta_t + \gamma_1(Deaths_{st} * I_{2008-2011}) + \gamma_2(Deaths_{st} * I_{2012-2014}) + \gamma_3(Deaths_{st} * I_{2015-2018}) + \beta' X_{st} + \varepsilon_{st} ,$$

where Y_{st} is donors or transplants per million population. We interact the number of opioid deaths per million population in the DSA with indicators for each of three calendar-time periods, 2008 to 2011, 2012 to 2014, and 2015 to 2018, which broadly correspond to low, moderate, and high levels of opioid deaths as the opioid epidemic worsened.[21]

[21] We also estimated specifications in which we include interactions between the number of opioid deaths per million population in the DSA and indicators for each year from 2008 to 2018. The estimates from these specifications yield similar conclusions to those reported in Table 6.

The estimates from (2), shown in Table 6, imply that the association between opioid-related deaths and the number of donors and transplants doubled over time. Specifically, column (1) shows that each opioid-related death increased the number of DI donors by 0.0099 in 2008-2011, by 0.0164 in 2012-2014, and by 0.0209 in 2015-2018. Likewise, Column (2) shows that each additional DI death increased transplants by an average of 0.0347, 0.0522, and 0.0652 in the 2008-2011, 2012-2014, and 2015-2018 periods, respectively.[22]

We further assess whether the link between opioid-related deaths and transplants reflects behavioral changes by considering whether the DSAs with larger organ shortages have higher conversion rates than those with smaller shortages. For each DSA, we generate a measure of excess organ demand in the 2008-2011 period (before the dramatic rise in opioid-related deaths). We calculate the average number of transplant candidates who join organ waitlists each month – which measures waitlist inflows – and then divide by the average number of monthly transplants, which measures waitlist outflows. We use this net-inflow measure to capture excess demand for transplants, defining DSAs with above-median values as "high excess demand" and those with below-median values as "low excess demand". We then estimate equations (1) and (2) for the two groups.

Comparing Columns (1) and (2) in Table 7, we estimate that an additional opioid-related death leads to 0.0228 additional organ donors in high excess demand DSAs and 0.0156

[22]Note that the ratio of transplants to donors declined from roughly 3.5 in the 2008-2011 period to 3.1 in the 2015-2018 period. There may be competing effects over time in the relationship between donors and transplants – a higher donor supply means that candidates can be more selective and, therefore, the number of transplants may not increase even if the stigma of organs from DI donors decreases. In unreported specifications, we analyze the recovery rate, which is the number of organs recovered for transplant divided by all the organs listed for disposition. We find that the recovery rate is positively correlated with the number of opioid-related deaths in a DSA-month-year. The mean recovery rate is 49.5 percent, and each additional opioid-related death increases the recovery rate by 0.099 percentage points. Because the recovery rate is established largely before transplant candidates (and their doctors) make selectivity decisions, this result confirms that transplant candidates may respond to higher supplies with higher selectivity.

additional organ donors in low excess demand DSAs. This differential is consistent with the notion that medical professionals in areas with larger shortages are more aggressive in converting deaths to donations. Columns (3) and (4) show that in all three periods, the point estimates are larger in the high excess demand DSAs, again implying that areas with deeper organ shortages have relatively high conversion rates. The estimates also increase substantially over time, more than doubling in both groups of DSAs. Columns (5)-(8) present results from specifications that use transplants as dependent variables, with estimates that parallel the patterns shown in columns (1)-(4).

In Table 8, we further examine differences in donor conversion patterns across DSAs by presenting estimates of the number of organ transplants that are allocated to recipients at centers within a recovering DSA compared to those at centers outside of the recovering DSA. The estimates in columns (1) and (3) show that in high excess demand DSAs, each opioid-related death leads to 0.0458 transplants at hospitals in the recovering DSA and 0.0257 transplants outside of that DSA (note that these numbers sum to 0.0715, the estimate in column (5) of Table 7). In other words, 36 percent (= 0.0257 / 0.0715) of the additional DI organs recovered in a DSA are "exported" out of that DSA. In comparison, the estimates in columns (5) and (7) show that slightly more than 50 percent (= 0.0248 / (0.245 + 0.248)) of organs recovered in low excess demand DSAs are exported out of the DSA.[23] These differences again suggest that transplant surgeons in high excess demand DSAs are relatively motivated to retain and use organs from DI donors.

[23] We find that DI donor organs are disproportionately likely to be exported relative to other mechanisms of death. The overall "export rates" across all mechanisms of death are roughly 30 and 43 percent among *high excess demand* and *low excess demand* DSAs, respectively.

Table 8 also reveals variation across DSAs in intertemporal patterns. In high excess demand DSAs, the estimates in column (2) grew more quickly than those in column (4), implying that the share of organs that were transplanted outside the DSA declined over time. In contrast, in low excess demand DSAs, the number of in-DSA transplants (as shown in column (6)) grew more slowly than the number of out-of-DSA transplants (column (8)), implying that the share of organs that were transplanted out of the DSA grew, particularly from the 2008-2011 to 2012-2014 periods.

Taken together, the estimates in Tables 6-8 suggest that behavioral responses play important roles in the conversion of potential donors who died of opioid-related causes to actual donors and transplants. Transplant candidates and medical professionals appear to be more willing to use organs from those who died of opioid-related causes when organ shortages are more severe and as the opioid epidemic deepened. In addition, available organs from DI donors were less likely to be exported out of DSAs where organs were scarce, and this phenomenon appears to have strengthened over time.

Effects of Supply Shocks on Waitlist Additions

Given the extreme shortage of organs for transplants and the geographic-based allocation system for deceased organs, a positive organ supply shock might also induce additional transplant candidates to join that DSA's waitlist. Dickert-Conlin et al. (2019) show that repeals of state-level motorcycle helmet laws generate large and lasting increases in waitlist inflows. They find that these demand-side responses are driven almost entirely by kidney transplant candidates, who are on average more sensitive to expected waiting time than other candidates because they have dialysis as a substitute for a transplant. Additionally, those who multilist and live outside the DSA that experienced the shock – both indications of candidates who have more resources and / or knowledge of the system – are especially likely to join waitlists in response to supply shocks.

We test the predictions of Dickert-Conlin et al. (2019) in the context of the opioid epidemic by asking whether transplant candidates are more likely to join transplant waitlists in DSAs that are most affected by the opioid epidemic. We estimate the following model:

(3) $$Additions_{st} = \alpha_s + \delta_t + \gamma(Deaths)_{st} + \beta' X_{st} + \varepsilon_{st} ,$$

where $Additions_{st}$ measures DSA waitlist additions per million DSA residents, s indexes the DSA, t indexes the month, and $Deaths_{st}$ is the number of opioid-related deaths per capita in that DSA and month. All specifications again include a full set of DSA (α_s) and month-year indicators (δ_t), and the vector X_{st} represents the same set of DSA-time varying variables as in equation (1). We weight each observation by the DSA's population in that year.

Column (1) of Table 9 presents the estimates of the effect of opioid-related deaths on total waitlist additions. We also include organ-specific estimates in light of Dickert-Conlin et al.'s (2019) findings that kidney candidates are more responsive to supply shocks than are candidates awaiting other organs.[24] The estimate in the top row indicates that 100 additional opioid overdose deaths result in an average of 0.77 more waitlist additions, which is statistically insignificant and small compared to the baseline level of waitlist additions of 15.3247 per million DSA residents. The organ-specific estimates show that increases in opioid-related deaths significantly increase waitlist inflows only in the case of livers: 3.08 additions in response to 100 additional opioid-related deaths in a DSA. The coefficients on opioid-related deaths are small

[24] Analogous estimates of the association between opioid-related deaths and organ-specific DI transplants are available upon request.

and not uniformly positive for the other organs; notably, the estimate for kidneys is negative, in contrast to the findings of Dickert-Conlin et al. (2019).[25]

Columns (2) through (4) provide insight about which, if any, candidates might respond to the organ supply shocks induced by the opioid epidemic. Using zip code data for candidates and transplant centers, we generate separate counts of waitlist additions for those who live inside and outside of the DSA's boundaries. Liver waitlist inflows induced by opioid-related deaths are concentrated among candidates who live in the DSA, and there is no indication that multilisted candidates respond to the increase in the number of available organs. In sum, we find very little evidence that any transplant candidates respond to the supply shocks induced by opioid-related deaths. These findings contrast sharply with the effects of supply shocks induced by repeals of statewide motorcycle helmet laws (Dickert-Conlin et al., 2019).

Living Donor Crowd-Out

Previous research documents substantial substitution away from living-donor transplants in response to deceased-donor supply shocks, especially among kidney candidates, who account for nearly all living-donor transplants (Choi, 2019; Dickert-Conlin et al., 2019; Fernandez et al., 2013; Lemont, 2019; Sweeney, 2010). In Table 10, we present estimates from models analogous to specification (1) above, except that the dependent variable measures the number of living-donor organ transplants in a DSA in each month.

As Table 10 shows, there is little evidence that opioid-driven supply shocks influence candidates' decisions to pursue living-donor transplants. The estimate in column (1) suggests

[25] Although these estimates capture how waitlist additions respond to differential changes in opioid-related deaths within the DSA, they may understate true waitlist responses. Dickert-Conlin et al. (2019) argue that supply shocks have spillover effects to other DSAs: a supply shock in one DSA may reduce expected waiting times in other DSAs if transplant candidates list in the DSA with the supply shock rather than other DSAs, in turn inducing inflows onto waitlists not directly affected by the shocks themselves.

that for 100 additional opioid-related deaths, the number of living-donor transplants decreases by 0.45 (with a standard error of 0.49). This estimate is statistically insignificant and small in comparison to the estimated effect on deceased-donor transplants of 6.33 from Table 4, suggesting that if any crowd-out of living donors exists, it is small relative to the direct effect on deceased-donor transplants.

Overall, we find little evidence that transplant candidates respond to increases in the supply of DI-donated organs. Notably, we find no evidence of a waitlist response or any crowd-out of living donors among kidney transplant candidates. The relatively muted response may stem from misperceptions that organs from DI donors are of relatively low quality in comparison to other donated organs. Moreover, unlike a discrete, salient change such as the repeal of a motorcycle helmet law, geographic variation in the intensity of the opioid epidemic may not be easily observable to transplant candidates and their doctors.

V. Estimates Based on State-Level "Triplicate Status" Laws

The estimates shown thus far are based on specifications that leverage variation over time within DSAs for identification. Although there is no obvious reason to suspect that such variation in opioid-related deaths is related to unobservable determinants of the supply of organ donors and transplants, we have no way to test this possibility. In this section, we present estimates based on an alternative source of variation: the "triplicate status" of the states in which DSAs are headquartered.

As Alpert et al. (2021) describe, triplicate laws mandate that doctors "use state-issued triplicate prescription forms when prescribing Schedule II controlled substances (which includes many opioids)." The prescriber keeps one copy of the prescription, the pharmacist keeps the second, and the pharmacist files the third with a state agency. We define a state-level "triplicate status" indicator that captures whether such a program was in place at the time of OxyContin's launch in 1996, as OxyContin played a crucial role in the early years of the opioid epidemic. Alpert et al. (2021) show that in states that had triplicate laws in place in 1996 – California, Idaho, Illinois, New York, and Texas – Purdue Pharma did not market OxyContin as aggressively as they did in other states. As a result, drug overdose death rates were persistently lower in triplicate states than in non-triplicate states throughout the first two decades of the 21st century.

Using NVSS and SRTR data from 1999-2018, in Figure 5 we present the raw time series of opioid-related deaths (top panel) and DI donors (bottom panel) in triplicate and non-triplicate DSAs. Consistent with Alpert et al.'s (2021) findings, the top panel shows that opioid-related deaths were higher in non-triplicate DSAs, with the gap growing steadily from 2012 onward. The bottom panel shows that DI donor rates were roughly identical across triplicate and non-triplicate DSAs until 2006, when the trends diverged. In both panels, the gaps between triplicate and non-triplicate DSAs became especially pronounced starting in 2016.

In order to leverage triplicate status to estimate the effects of opioid deaths on the market for organ transplants, we first estimate reduced-form specifications via OLS:

(4) $$Y_{st} = \delta_t + \gamma(Triplicate)_s + \beta' X_{st} + \varepsilon_{st} ,$$

where Y_{st} includes opioid-related deaths, donors, or transplants. $Triplicate_s$ is a binary indicator of whether a DSA's OPO is headquartered in a triplicate state, δ_t is a set of month-year fixed effects, and X_{st} include the same DSA-level time-varying controls as in the specifications shown above. We do not include DSA-level fixed effects because a DSA's triplicate status as of 1996 is time-invariant.

Column (1) of Table 11 shows estimates of γ using opioid-related deaths as the dependent variable. We estimate that in each month there were 4.0786 fewer opioid-related deaths per million DSA residents in triplicate DSAs relative to non-triplicate DSAs.[26] In column (3), we use DI donors as the dependent variable, finding that there were 0.1093 fewer DI donors per million residents in triplicate DSAs.

Column (7) presents the IV estimate of the effect of opioid-related deaths on DI organ donors, using $Triplicate_s$ as an instrument for opioid-related deaths. The estimate of 0.0268 (0.0051), which is identical to the ratio of the reduced-form estimates in column (3) to column (1), is slightly larger than our central estimate of 0.0202 shown in Table 4, although the two are statistically indistinguishable at conventional significance levels. Similarly, column (5) presents the reduced-form effect of triplicate status on transplants from DI donors, and column (9) shows the implied IV estimate of opioid-related deaths on these transplants. Again, the IV estimate is slightly larger than the OLS estimate in Table 4 (0.0789 versus 0.0633), but the two are not statistically distinguishable.

The even-numbered columns in Table 11 present the estimates separately for the 2008-2011, 2012-2014, and 2015-2018 periods. The estimated gaps in opioid-related deaths, DI donors, and DI transplants between triplicate and non-triplicate DSAs grew steadily over time. The gaps in donors and transplants were roughly three times larger in 2015-2018 than in 2008-2011; because these gaps grew more quickly than the corresponding gaps in opioid-related deaths, the IV estimates in columns (8) and (10) have also grown (from 0.0141 to 0.0320 in the case of donors and from 0.0356 to 0.969 in the case of transplants). These patterns echo those

[26] Alpert et al. (2021) find that non-triplicate states would have experienced 4.49 fewer annual drug overdose deaths from 1996-2017 per 100,000 residents if they had been triplicate states. Converting this estimate to monthly deaths per million residents yields 3.74 (= 4.49 × 10 /12), similar to the estimate in the Table 11 that uses data from 2008-2018.

shown above in Table 6, although the IV estimates are slightly larger than the OLS estimates in all cases.

In sum, the use of triplicate status as an instrumental variable yields nearly identical conclusions to those from the OLS estimates presented above in Section III. The similarly of the two sets of results, which are based on markedly different identifying assumptions, suggests that our estimates capture a causal link between opioid-related deaths and organ donors and transplants.

Finally, we also use the triplicate instrumental variable approach to estimate the effects of opioid-related deaths on waitlist additions and living donor crowd-out. The results, which we include in Appendix Table A2, again provide no evidence that transplant candidates respond to opioid-induced organ supply shocks, either by changing their listing behavior or by substituting away from living-donor transplants.

VI. Conclusions

The paper investigates whether those awaiting organ transplants may be unexpected beneficiaries of the opioid crisis. Organ donations due to drug intoxication (DI) increased more than tenfold since 2000, and the rate of increase accelerated in recent years as the opioid crisis deepened. Our central estimates suggest that every 100 opioid-related deaths result in two additional organ donors – primarily among donors aged 18-49 – and six additional transplants. While the opioid crisis is undoubtedly a tragedy, it profoundly affected the lives of thousands of transplant recipients. Between 2008 and 2018, there were more than 340,000 opioid-related deaths in the US, and our central estimates imply that these deaths resulted in nearly 7,000 additional organ donors and more than 22,000 organ transplants.

We find that transplant centers have increasingly recovered DI organs for transplant, as the conversion rate from an opioid-related death to an organ donor more than doubled from 2008-2011 to 2015-2018. Additionally, we find that transplant candidates appear to be more willing to use organs from those who died of opioid-related causes when organ shortages are more severe, suggesting that these organs may be viewed as "acceptable" but inferior to organs from other donors.

In contrast to previous research that finds that transplant candidates respond strongly to supply shocks – both by joining waitlists and, in the case of kidneys, by substituting away from living donors to deceased donors – we find little evidence of behavioral responses along these dimensions. The perceived quality of organs from opioid-related deaths may be responsible for these relatively small demand responses. The modest increases in waitlist registrations that we do find are concentrated among liver candidates, who face low survival rates without a transplant. These candidates may not have the luxury to be selective, implying that they might be responsive to a change in the supply from a source of organs potentially perceived to be of lower quality.

Because organs are allocated based on geographical boundaries, the impact of the opioid crisis on the market for transplantable organs is distributed heterogeneously across the United States. Our results suggest that candidates in areas with high levels of opioid-related deaths are likely to have more opportunities for transplants than those in areas less affected by the opioid epidemic, irrespective of their medical need. Such differential impacts raise questions about the efficacy of an organ allocation system based heavily on arbitrary geographic boundaries.

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Table 1: Drug Overdose Deaths, Opioid-related Deaths, and Opioid Overdose Deaths by Year, Age, and Gender

	Drug Overdoses				Opioid Overdoses				Opioid-related Deaths			
	All	Young (18-49)	Male	Female	All	Young (18-49)	Male	Female	All	Young (18-49)	Male	Female
Year	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1999	16761	13282	11199	5562	8013	6819	5966	2047	8608	7300	6429	2179
2000	17322	13666	11502	5820	8347	7036	6097	2250	8986	7523	6536	2450
2001	19277	15051	12585	6692	9422	7720	6682	2740	10062	8215	7143	2919
2002	23410	18048	14952	8458	11840	9533	8102	3738	12579	10052	8584	3995
2003	25710	19551	16358	9352	12897	10248	8783	4114	13665	10771	9294	4371
2004	27385	20465	17103	10282	13725	10692	9094	4631	14555	11241	9628	4927
2005	29832	21765	18752	11080	14925	11326	9773	5152	15757	11895	10351	5406
2006	34412	24806	21900	12512	17535	13139	11602	5933	18448	13729	12176	6272
2007	36038	25094	22325	13713	18535	13547	11955	6580	19307	13965	12454	6853
2008	36499	24947	22504	13995	19612	14047	12784	6828	20379	14474	13231	7148
2009	37076	24843	22647	14429	20465	14409	13172	7293	21357	14892	13733	7624
2010	38319	25297	23007	15312	21099	14727	13360	7739	22067	15250	14003	8064
2011	41363	27166	25025	16338	22794	15934	14473	8321	23768	16451	15084	8684
2012	41533	26712	25142	16391	23181	15909	14751	8430	24126	16388	15341	8785
2013	43995	27541	26824	17171	25056	16815	16003	9053	26031	17276	16609	9422
2014	47076	29648	28829	18247	28641	19318	18415	10226	29645	19823	19033	10612
2015	52479	33701	33034	19445	33092	22755	21685	11407	34166	23262	22359	11807
2016	63635	41990	41556	22079	42203	29716	28466	13737	43444	30347	29234	14210
2017	70347	46613	46684	23663	47610	33480	32371	15239	48874	34107	33125	15749
2018	67553	43758	45090	22463	46882	32663	32142	14740	48150	33298	32918	15232

Source: Authors calculations from the NVSS multiple-cause-of-death mortality files.

Table 2: Deceased Organ Donors by Mechanism of Death (Drug Intoxication or Other), Year, Age, and Gender

	Drug Intoxication Death				All Other Mechanisms of Death			
Year	All	Young (18-49)	Male	Female	All	Young (18-49)	Male	Female
1999	65	58	32	33	5765	3002	3315	2450
2000	66	58	35	31	5924	3047	3451	2472
2001	84	70	47	37	5999	3113	3531	2468
2002	107	96	57	50	6089	3224	3640	2449
2003	138	113	75	63	6324	3282	3721	2603
2004	188	145	91	97	6964	3556	4019	2945
2005	158	135	79	79	7437	3800	4345	3092
2006	230	194	135	95	7793	3998	4649	3144
2007	268	227	148	120	7826	4027	4734	3092
2008	285	240	153	132	7708	3929	4583	3125
2009	322	272	168	154	7701	3836	4560	3141
2010	342	299	179	163	7604	3942	4506	3098
2011	473	412	238	235	7657	3998	4528	3129
2012	441	394	231	210	7707	4075	4592	3115
2013	560	496	309	251	7714	3984	4601	3113
2014	625	554	374	251	7977	4216	4793	3184
2015	848	770	501	347	8236	4313	4987	3249
2016	1262	1149	763	499	8717	4606	5197	3520
2017	1384	1225	798	586	8907	4683	5403	3504
2018	1401	1256	834	567	9322	4851	5662	3660

Notes: Authors' calculations from the SRTR data. "All Other Mechanisms of Death" include Gunshot / Stab wound, Blunt Injury, Seizure, Stroke, SIDS, Asphyxiation, Cardiovascular, Drowning, Electrical, Natural Causes, and "None of the above."

Table 3: Average Number of Organs Transplanted per Donor, by Mechanism of Death

Mechanism of Death:	Total	Kidney	Liver	Heart	Lung	Pancreas	Intestine
Gunshot Wound	4.39	1.77	0.88	0.59	0.80	0.31	0.03
Blunt Injury	3.64	1.72	0.78	0.46	0.44	0.21	0.03
Stab	3.58	1.75	0.77	0.38	0.48	0.19	0.01
Asphyxiation	3.45	1.72	0.76	0.38	0.37	0.19	0.03
Drowning	3.27	1.78	0.74	0.45	0.13	0.12	0.06
Electrical	3.27	1.77	0.70	0.39	0.26	0.12	0.03
Seizure	3.26	1.60	0.68	0.37	0.45	0.14	0.03
Drug Intoxication	**3.17**	**1.54**	**0.79**	**0.36**	**0.37**	**0.09**	**0.01**
None of the Above	2.99	1.51	0.69	0.34	0.32	0.11	0.03
Death from Natural Causes	2.65	1.42	0.65	0.24	0.27	0.07	0.01
Intracranial Hemorrhage/Stroke	2.61	1.25	0.74	0.17	0.38	0.05	0.01
SIDS	2.49	0.99	0.49	0.79	0.00	0.09	0.13
Cardiovascular	2.33	1.29	0.66	0.15	0.18	0.05	0.01
Unknown	1.41	0.18	0.18	0.59	0.47	0.00	0.00

Source: Authors' calculations using 2008-2018 SRTR data.

Table 4: Estimates of the Effect of Drug-Related Deaths on Organ Donations and Transplants

	Dependent Variable:					
	Drug Intoxication Donors			Transplants from DI Donors		
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)
Opioid-Related Deaths	0.0202			0.0633		
	(0.0015)			(0.0059)		
Opioid Overdoses		0.0206			0.0645	
		(0.0015)			(0.0058)	
Drug Overdoses			0.0205			0.0648
			(0.0019)			(0.0070)
Mean of Dependent Variable:		0.1834			0.5727	

Notes: Cell entries represent estimates from six different regressions. All estimation samples consist of 57 DSAs from 2008 to 2018 (N=7524). The unit of observation is a DSA-month. All models include indicators for month-years and DSAs, DSA unemployment rates and a set of policies related to donation and drug overdose outcomes. Standard errors, listed in parentheses, are robust to clustering within DSA over time. Sample means for relevant dependent variables listed in brackets, with all variables measured per million DSA residents.

Table 5: Estimates of the Effect of Opioid-Related Deaths on Organ Donations Due to Drug Intoxication, by Gender and Age

	Pooled	Men	Women
	(1)	(2)	(3)
Overall	0.0202	0.0116	0.0086
	(0.0015)	(0.0013)	(0.0008)
	[0.1834]	[0.1051]	[0.0783]
Age Categories:			
<18	0.0002	0.0002	0.0000
	(0.0001)	(0.0001)	(0.0001)
	[0.0042]	[0.0021]	[0.0021]
18-34	0.0109	0.0060	0.0050
	(0.0010)	(0.0007)	(0.0005)
	[0.1080]	[0.0661]	[0.0419]
35-49	0.0074	0.0047	0.0027
	(0.0008)	(0.0007)	(0.0004)
	[0.0562]	[0.0304]	[0.0259]
50-64	0.0015	0.0007	0.0008
	(0.0003)	(0.0002)	(0.0002)
	[0.0144]	[0.0063]	[0.0082]
65+	0.0002	0.0001	0.0001
	(0.0001)	(0.0001)	(0.0000)
	[0.0005]	[0.0002]	[0.0002]

Notes: Cell entries represent estimates from 18 separate regressions with organ donors by age and gender category as the dependent variable and opioid-related deaths as the independent variable. All estimation samples consist of 57 DSAs from 2008 to 2018. The unit of observation is a DSA-month. All models include indicators for DSAs and month-years and a set of DSA-month variables described in the text. Standard errors, listed in parentheses, are robust to clustering with DSA over time. Sample means for relevant dependent variables are listed in brackets, with all variables measured per million DSA residents.

Table 6: Estimates of the Effect of Opioid-Related Deaths on Organ Donations Due to Drug Intoxication and Transplants from Drug Intoxication Donors, by Year

	Dependent Variable	
	Drug Intoxication Donors	Transplants from Drug Intoxication Donors
	(1)	(2)
2008-2011 × Opioid Deaths	0.0099	0.0347
	(0.0038)	(0.0126)
2012-2014 × Opioid Deaths	0.0164	0.0522
	(0.0025)	(0.0074)
2015-2018 × Opioid Deaths	0.0209	0.0652
	(0.0013)	(0.0055)
Mean of dependent variable	0.1834	0.5727

Notes: Cell entries in columns (1) and (2) represent estimates from two separate regressions. All estimation samples consist of 57 DSAs from 2008 to 2018. The unit of observation is a DSA-month. All models include indicators for DSAs and month-years and a set of DSA-month variables described in the text. Standard errors, listed in parentheses, are robust to clustering with DSA over time. Sample means for relevant dependent variables are listed in brackets, with all variables measured per million DSA residents.

Table 7: Estimates of the Effect of Opioid-Related Deaths on Organ Donations Due to Drug Intoxication and Transplants from Drug Intoxication Donors, by Excess Demand for Organs

	Dependent variables:							
	Drug Intoxication Donors				Transplants from Drug Intoxication Donors			
Independent variables:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Opioid Deaths	0.0228	0.0156			0.0715	0.0494		
	(0.0017)	(0.0019)			(0.0069)	(0.0065)		
2008-2011 × Opioid Deaths			0.0100	0.0062			0.0347	0.0232
			(0.0041)	(0.0028)			(0.0130)	(0.0088)
2012-2014 × Opioid Deaths			0.0207	0.0109			0.0642	0.0374
			(0.0035)	(0.0021)			(0.0091)	(0.0066)
2015-2018 × Opioid Deaths			0.0224	0.0183			0.0705	0.0567
			(0.0017)	(0.0022)			(0.0063)	(0.0080)
Mean of dependent variable	0.1778	0.1927	0.1778	0.1927	0.5622	0.5903	0.5622	0.5903
DSAs	29	28	29	28	29	28	29	28
DSAs with high excess organ demand	x		x		x		x	
DSAs with low excess organ demand		x		x		x		x

Notes: Cell entries represent estimates from 8 different regressions. All estimation samples consist of DSAs from 2008 to 2018. The unit of observation is a DSA-month. All models include indicators for DSAs and month-years and a set of DSA-month variables described in the text. We define DSAs with excess demand above the median as *high excess demand* and those below the median as *low excess demand*. Standard errors, listed in parentheses, are robust to clustering with DSA over time. Sample means for relevant dependent variables are listed in brackets, with all variables measured per million DSA residents.

Table 8: Estimates of the Effect of Opioid-Related Deaths on Transplants from Drug Intoxication Donors Occurring in-DSA or out of the DSA, by Time and Excess Demand for Organs

	In-DSA		Out of DSA		In-DSA		Out of DSA	
Independent variables:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Opioid Deaths	0.0458		0.0257		0.0245		0.0248	
	(0.0067)		(0.0030)		(0.0054)		(0.0041)	
2008-2011 x Opioid Deaths PC		0.0152		0.0195		0.0145		0.0086
		(0.0118)		(0.0066)		(0.0058)		(0.0062)
2012-2014 x Opioid Deaths PC		0.0418		0.0223		0.0151		0.0222
		(0.0075)		(0.0063)		(0.0048)		(0.0042)
2015-2018 x Opioid Deaths PC		0.0451		0.0255		0.0278		0.0287
		(0.0060)		(0.0030)		(0.0071)		(0.0040)
DSAs	29	29	29	29	28	28	28	28
DSAs with high excess organ demand	x	x	x	x				
DSAs with low excess organ demand					x	x	x	x

Notes: Cell entries represent estimates from 8 different regressions; in all columns, the dependent variable measures transplants from Drug Intoxication donors. All estimation samples consist of DSAs from 2008 to 2018, and the unit of observation is a DSA-month. All models include indicators for DSAs and month-years and a set of DSA-month variables described in the text. We define DSAs with excess demand above the median as *high excess demand* and those below the median as *low excess demand*. Standard errors, listed in parentheses, are robust to clustering with DSA over time. Sample means for relevant dependent variables are listed in brackets, with all variables measured per million DSA residents.

Table 9: Estimates of the Effect of Opioid-Related Deaths on Waitlist Additions by Organ, Location, and Multilisting Status

	All	In-DSA	Out-of-DSA	Multilisters
	(1)	(2)	(3)	(4)
All organs	0.0077	0.0005	0.0073	0.0000
	(0.0268)	(0.0202)	(0.0124)	(0.0137)
	[15.3247]	[11.8349]	[3.4898]	[3.9471]
Kidneys	-0.0166	-0.0190	0.0024	0.0014
	(0.0248)	(0.0212)	(0.0087)	(0.0115)
	[9.5178]	[7.5643]	[1.9536]	[2.8602]
Liver	0.0308	0.0226	0.0082	0.0026
	(0.0125)	(0.0084)	(0.0050)	(0.0035)
	[3.1586]	[2.3555]	[0.8031]	[0.4914]
Heart	0.0003	0.0015	0.0013	-0.0002
	(0.0040)	(0.0016)	(0.0048)	(0.0006)
	[1.0468]	[0.8067]	[0.2401]	[0.1158]
Lungs	0.0013	0.0025	-0.0011	-0.0004
	(0.0048)	(0.0026)	(0.0028)	(0.0006)
	[0.6760]	[0.4341]	[0.2419]	[0.0770]
Pancreas	-0.0034	-0.0020	-0.0014	-0.0014
	(0.0014)	(0.0008)	(0.0008)	(0.0008)
	[0.1294]	[0.0864]	[0.04300]	[0.0469]
Intestines	-0.0006	-0.0002	-0.0004	-0.0002
	(0.0012)	(0.0001)	(0.0012)	(0.0002)
	[0.0506]	[0.0203]	[0.0303]	[0.0085]

Notes: The table represents 35 different regressions where the dependent variable in column 1 is the number of DI transplants by organ, provided for reference purposes, and the dependent variable in columns 2-5 is the number of wait list additions by category. All estimation samples consist of 57 DSAs from 2008 to 2018. The unit of observation is a DSA-month. All models include indicators for DSAs and month-years and a set of DSA-month variables described in the text. Standard errors, listed in parentheses, are robust to clustering with DSA over time. Sample means for relevant dependent variables are listed in brackets, with all variables measured per million DSA residents.

Table 10: Estimates of the Effect of Opioid-Related Deaths on Living-Donor Transplants

	All Organs	Kidneys	All Except Kidneys
Independent variable:	(1)	(2)	(3)
Opioid Deaths	-0.0045	-0.0073	0.0028
	(0.0049)	(0.0059)	(0.0016)
	[1.5207]	[1.4613]	[0.0594]

Notes: Cell entries represent 3 separate regressions, where the dependent variable is the number of living-donor transplants: overall, kidneys only, and all organs except kidneys. All estimation samples consist of 57 DSAs from 2008 to 2018. The unit of observation is a DSA-month. All models include indicators for DSAs and month-years and the DSA-month controls described in the text. Standard errors, listed in parentheses, are robust to clustering with DSA over time. Sample means for relevant dependent variables are listed in brackets, with all variables measured per million DSA residents.

Table 11: Estimates of the Effect of Opioid-Related Deaths on Organ Donations Using DSA Triplicate Status

	Reduced-form estimates of the effects of *Triplicate Status* on						Instrumental Variables Estimates of the Effect of *Opioid-Related Deaths* on			
	Opioid-Related Deaths		*DI Donors*		*Transplants from DI Donors*		*DI Donors*		*Transplants from DI Donors*	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
All years	-4.0786		-0.1093		-0.3219		0.0268		0.0789	
	(0.6639)		(0.0209)		(0.0655)		(0.0051)		(0.0162)	
2008-2011		-3.1342		-0.0555		-0.1495		0.0141		0.0356
		(0.6638)		(0.0156)		(0.0462)		(0.0065)		(0.0193)
2012-2014		-3.8789		-0.0917		-0.2627		0.0231		0.0655
		(0.6107)		(0.0190)		(0.0579)		(0.0044)		(0.0139)
2015-2018		-4.7756		-0.1526		-0.4627		0.0320		0.0969
		(1.0236)		(0.0345)		(0.1074)		(0.0060)		(0.0190)
Sample Means of Dependent Variable:	8.8764		0.1834		0.5727		0.1834		0.5727	

Notes: The table represents six different first stage and reduced form regressions, plus the corresponding four instrumental variables regressions. All estimation samples consist of DSAs from 2008 to 2018. The unit of observation is a DSA-month. All models include month-year indicators and a set of DSA-month variables described in the text. Standard errors, listed in parentheses, are robust to clustering with DSA over time. Dependent variables are measured per million DSA residents.

Figure 1: Stylized Representation of the Path from Opioid-Related Death to Organ Transplant

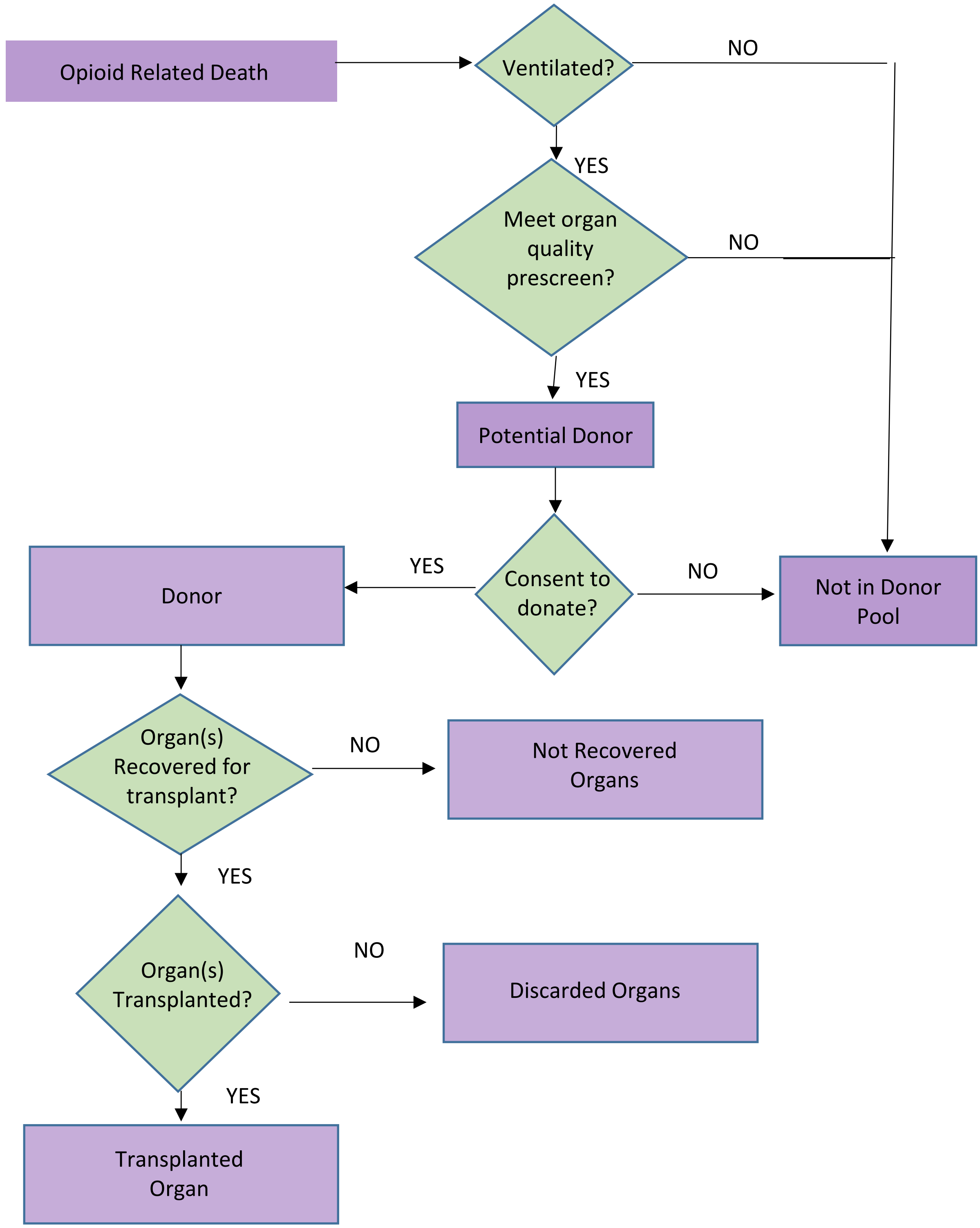
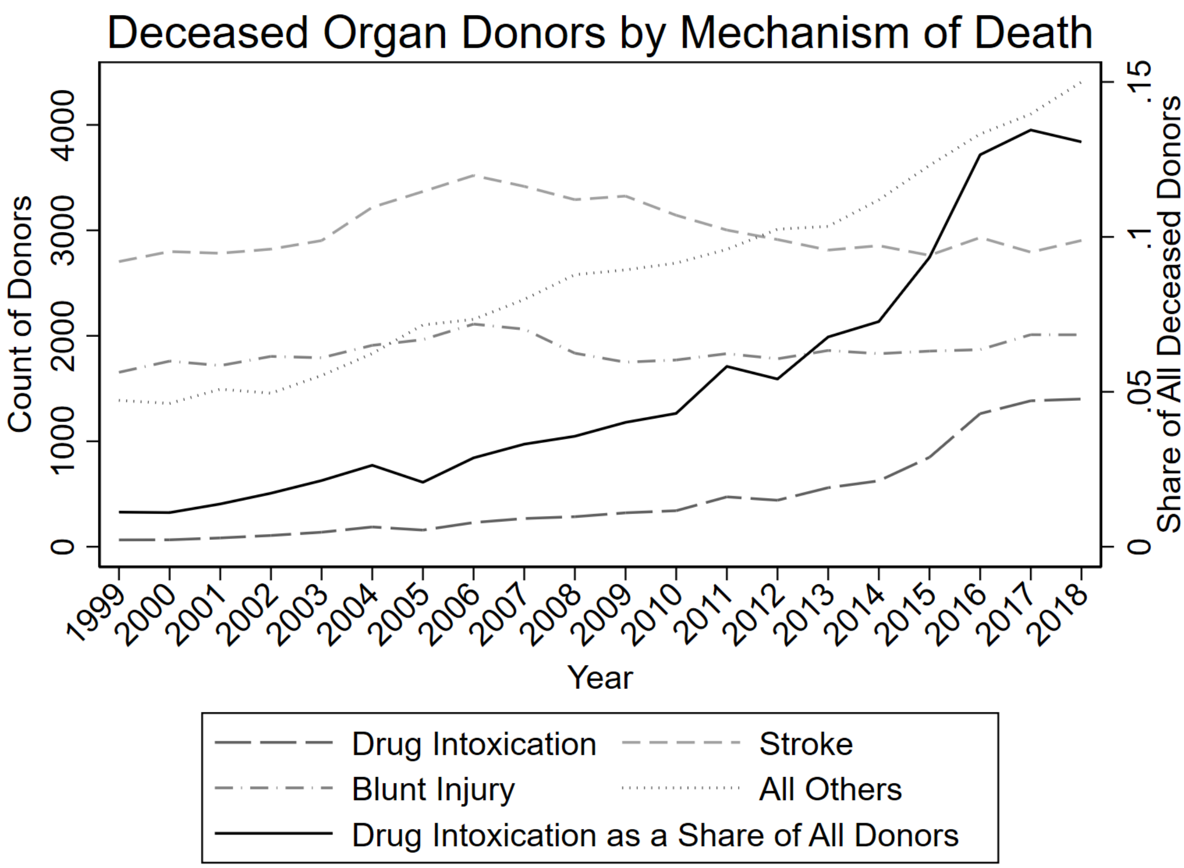
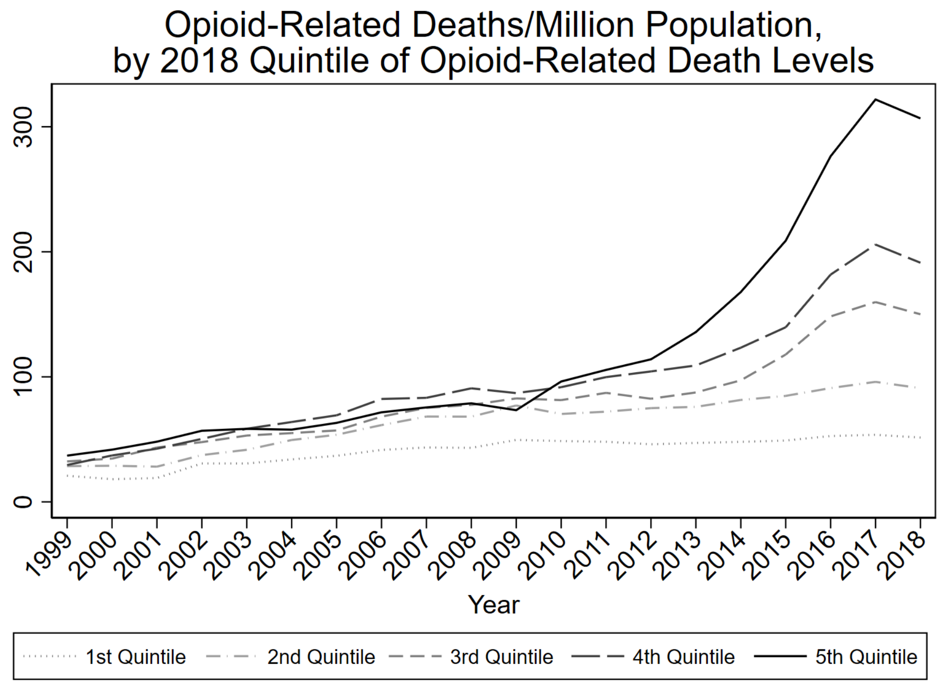


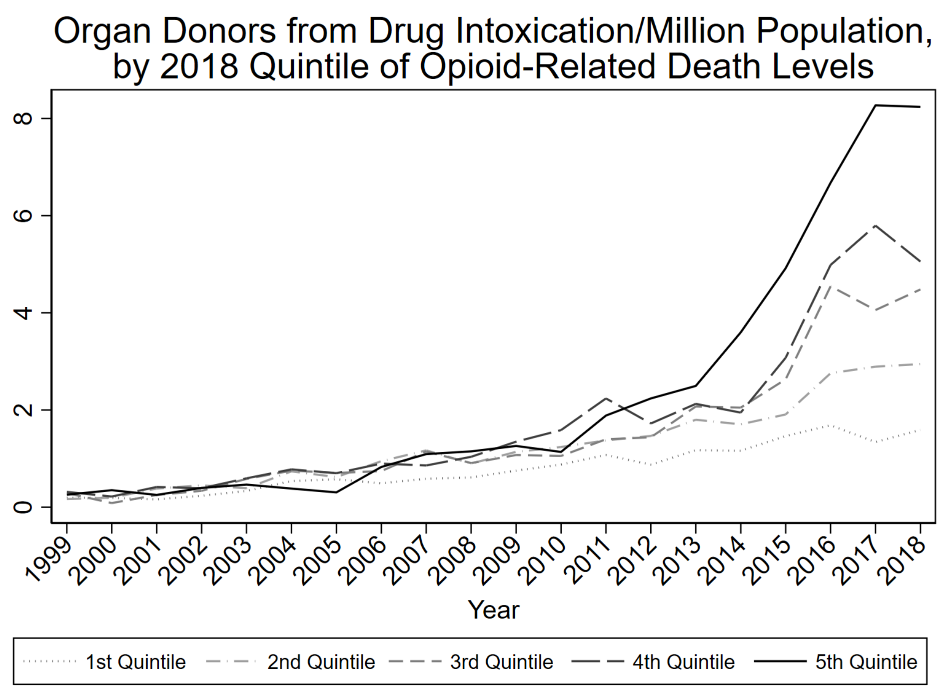
Figure 2



Notes: Authors' calculations from the SRTR data. The figure shows the annual number of deceased organ donors by mechanism of death, where "All others" includes Gunshot / Stab wound, Seizure, SIDS, Asphyxiation, Cardiovascular, Drowning, Electrical, Natural Causes, and "None of the above."

Figure 3

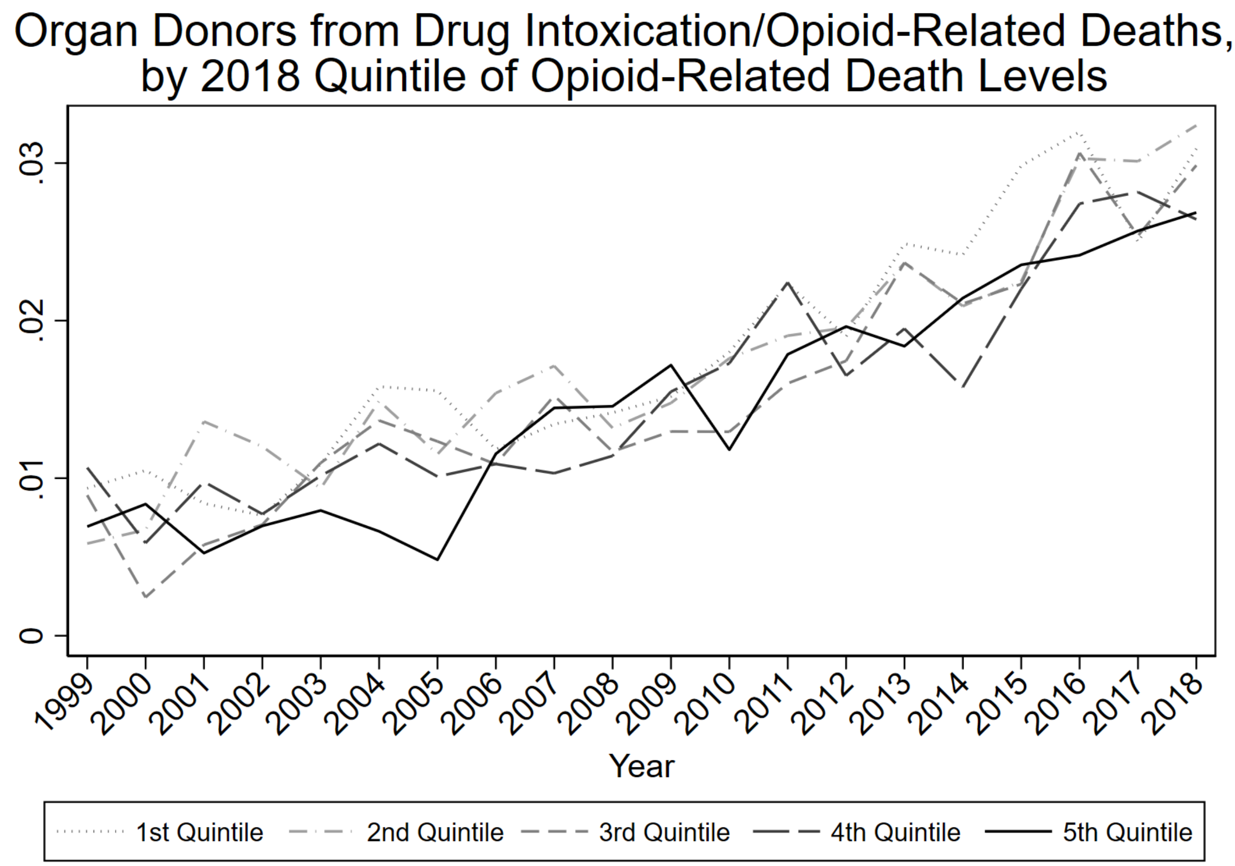




Notes: Authors' calculations from the Vital Statistics Mortality Data and SRTR data. The figure shows the annual number of opioid-related deaths (top panel) and DI organ donors (bottom panel) by million population by quintile. The 1st quintile contains the following DSAs: AROR,

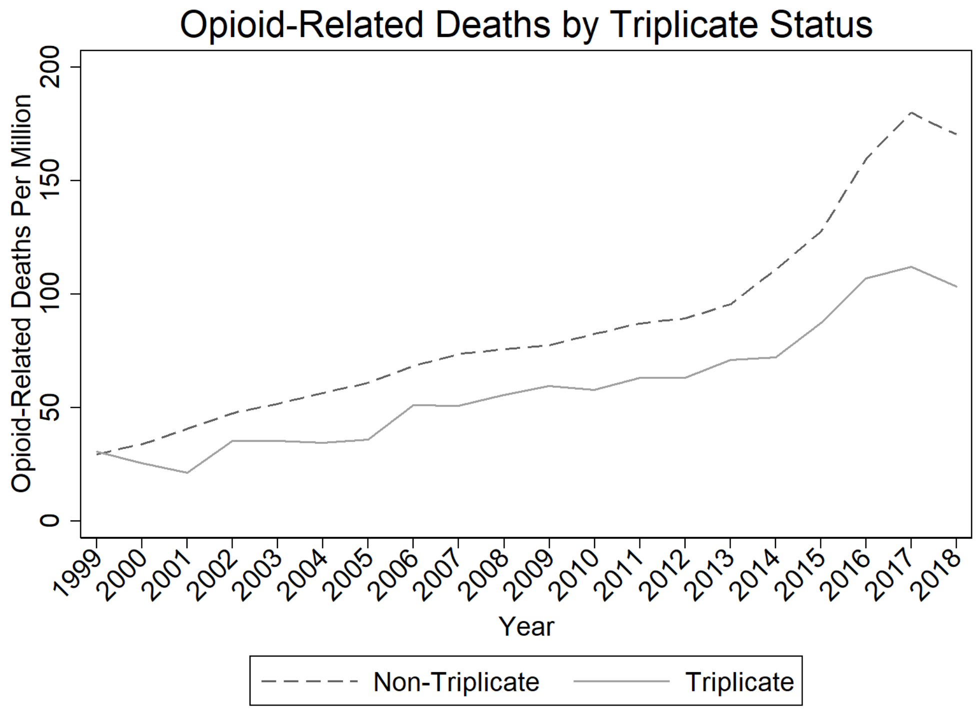
CADN, CAGS, CAOP, HIOP, IAOP, MSOP, MWOB, NEOR, TXGC, TXSA, and TXSB. The 2nd quintile contains the following DSAs: ALOB, AZOB, CASD, CORS, GALL, INOP, LAOP, MNOP, OKOP, ORUO, and WALC. The 3rd quintile contains the following DSAs: DCTC, FLFH, NCCM, NCNC, NYAP, NYRT, PADV, SCOP, TNMS, UTOP, VATB, and WIUW. The 4th quintile contains the following DSAs: FLMP, FLUF, FLWC, ILIP, MIOP, MOMA, NJTO, NMOP, NVLV, NYFL, and TNDS. The 5th quintile contains the following DSAs: KYDA, MAOB, MDPC, NYWN, OHLB, OHLC, OHLP, OHOV, PATF, CTOP, and WIDN. See Appendix Table A1 for the full names of the OPOs that oversee the DSAs and the states in which their OPOs are headquartered.

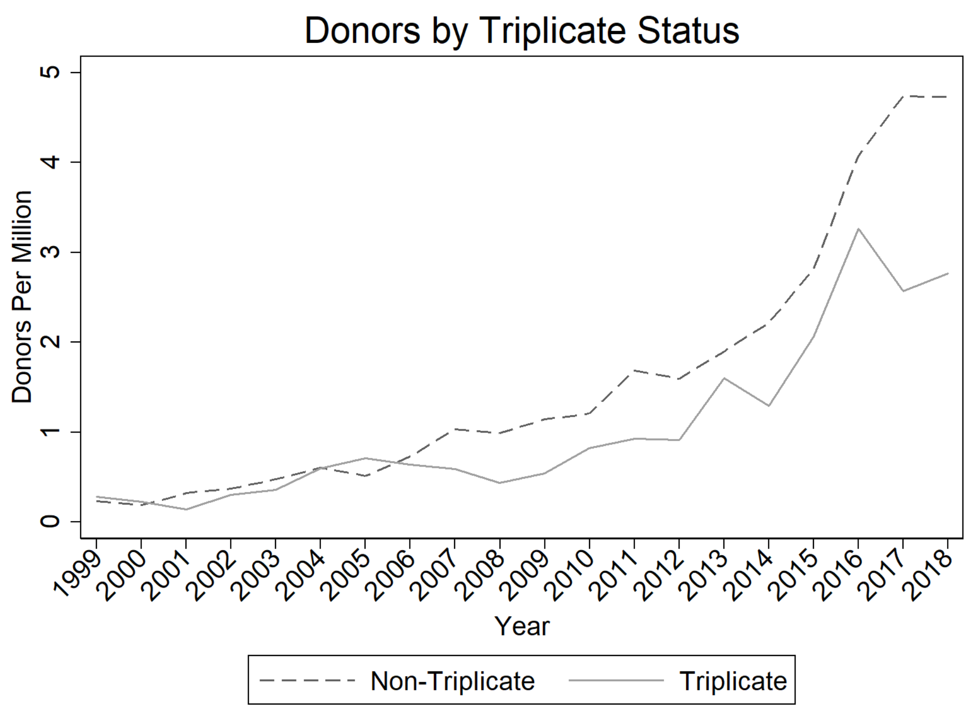
Figure 4



Notes: Authors' calculations from the Vital Statistics Mortality Data and SRTR data. The 1st quintile contains the following OPOs in DSAs: AROR, CADN, CAGS, CAOP, HIOP, IAOP, MSOP, MWOB, NEOR, TXGC, TXSA, and TXSB. The 2nd quintile contains the following DSAs: ALOB, AZOB, CASD, CORS, GALL, INOP, LAOP, MNOP, OKOP, ORUO, and WALC. The 3rd quintile contains the following DSAs: DCTC, FLFH, NCCM, NCNC, NYAP, NYRT, PADV, SCOP, TNMS, UTOP, VATB, and WIUW. The 4th quintile contains the following DSAs: FLMP, FLUF, FLWC, ILIP, MIOP, MOMA, NJTO, NMOP, NVLV, NYFL, and TNDS. The 5th quintile contains the following DSAs: KYDA, MAOB, MDPC, NYWN, OHLB, OHLC, OHLP, OHOV, PATF, CTOP, and WIDN. See Appendix Table A1 for the full names of the OPOs that oversee the DSAs and the states in which their OPOs are headquartered.

Figure 5





Notes: Authors' calculations from the Vital Statistics Mortality Data. The bottom (solid) lines represent the number of annual opioid-related deaths and DI donors per million residents in triplicate DSAs, and the top (dashed) lines represent the number of annual opioid-related deaths and DI donors per million residents in non-triplicate DSAs. Triplicate DSAs (of which there are 12) include those with OPOs headquartered in California, Illinois, New York, and Texas.

Appendix Table A1
Crosswalk of Organ Procurement Organizations and Abbreviations

OPO Abbreviation	OPO	OPO State
ALOB	Legacy of Hope	AL
AROR	Arkansas Regional Organ Recovery Agency	AR
AZOB	Donor Network of Arizona	AZ
CADN	Donor Network West	CA
CAGS	Sierra Donor Services	CA
CAOP	OneLegacy	CA
CASD	Lifesharing - A Donate Life Organization	CA
CORS	Donor Alliance	CO
DCTC	Washington Regional Transplant Community	VA
FLFH	TransLife	FL
FLMP	Life Alliance Organ Recovery Agency	FL
FLUF	LifeQuest Organ Recovery Services	FL
FLWC	LifeLink of Florida	FL
GALL	LifeLink of Georgia	GA
HIOP	Legacy of Life Hawaii	HI
IAOP	Iowa Donor Network	IA
ILIP	Gift of Hope Organ & Tissue Donor Network	IL
INOP	Indiana Donor Network	IN
KYDA	Kentucky Organ Donor Affiliates	KY
LAOP	Louisiana Organ Procurement Agency	LA
MAOB	New England Organ Bank	MA
MDPC	The Living Legacy Foundation of Maryland	MD
MIOP	Gift of Life Michigan	MI
MNOP	LifeSource Upper Midwest Organ Procurement Organization	MN
MOMA	Mid-America Transplant Services	MO
MSOP	Mississippi Organ Recovery Agency	MS
MWOB	Midwest Transplant Network	KS
NCCM	LifeShare Carolinas	NC
NCNC	Carolina Donor Services	NC
NEOR	Live On Nebraska	NE
NJTO	New Jersey Organ and Tissue Sharing Network OPO	NJ
NMOP	New Mexico Donor Services	NM
NVLV	Nevada Donor Network	NV
NYAP	Center for Donation and Transplant	NY
NYFL	Finger Lakes Donor Recovery Network	NY
NYRT	LiveOnNY	NY
NYWN	Upstate New York Transplant Services Inc	NY
OHLB	Lifebanc	OH
OHLC	Life Connection of Ohio	OH

OPO Abbreviation	OPO	OPO State
OHLP	Lifeline of Ohio	OH
OHOV	LifeCenter Organ Donor Network	OH
OKOP	LifeShare Transplant Donor Services of Oklahoma	OK
ORUO	Pacific Northwest Transplant Bank	OR
PADV	Gift of Life Donor Program	PA
PATF	Center for Organ Recovery and Education	PA
PRLL	LifeLink of Puerto Rico	PR
SCOP	We Are Sharing Hope SC	SC
TNDS	Tennessee Donor Services	TN
TNMS	Mid-South Transplant Foundation	TN
TXGC	LifeGift Organ Donation Center	TX
TXSA	Texas Organ Sharing Alliance	TX
TXSB	Southwest Transplant Alliance	TX
UTOP	DonorConnect	UT
VATB	LifeNet Health	VA
WALC	LifeCenter Northwest	WA
WIUW	UW Health Organ and Tissue Donation	WI
CTOP	LIfeChoice Donor Services	MA
WIDN	Versiti Wisconsin, Inc.	WI

Appendix Table A2: Reduced Form Estimates of the Effect of Triplicate Status on Waitlist Additions and Living Donors

	Dependent Variable			
	All Waitlist Additions		All Living Donors	
Independent Variables	(1)	(2)	(3)	(4)
Triplicate Status	2.6632		0.1765	
	(1.1593)		(0.2523)	
2008-2011 × Triplicate		3.7545		0.1427
		(1.3107)		(0.2527)
2012-2014 × Triplicate		2.7223		0.3087
		(1.2112)		(0.2733)
2015-2018 × Triplicate		1.9591		0.3852
		(1.2476)		(0.2565)

Notes: Cell entries represent four different regressions. All estimation samples consist of DSAs from 2008 to 2018. The unit of observation is a DSA-month. All models include indicators for years and a set of DSA-month variables described in the text. Standard errors, listed in parentheses, are robust to clustering with DSA over time. Dependent variables are measured per million DSA residents.