Can Redrawing Boundaries Save Lives?

Evidence from a Reform of the Kidney Allocation System

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October 2024

Abstract

In the United States, about 5 percent of those waiting for kidney transplants die each year, while a similar number of donated kidneys are discarded before they can be matched to a recipient. I study a reform of the kidney allocation system that involved re-drawing the areas within which donated organs are matched to patients from fixed regions to circles around each donor hospital. To estimate the causal effects of the reform, I exploit the sharp timing of its implementation as well as variation in the predicted changes in relative supply across transplant centers. I create a novel dataset consisting of detailed administrative information on the universe of donated organs, transplant candidates, and transplant centers using SRTR transplant registry data. I find that the reform led to a 17 percent decrease in the share of donated kidneys that were discarded and reduced mortality among transplant candidates. I document important distributional effects – kidney recipients after the reform were more likely to have extended dialysis history and reside in counties with higher marginalized populations.

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1 Introduction

Kidney transplant serves as an important treatment strategy, widely recognized for extending life expectancy and enhancing quality of life for patients with kidney failure relative to dialysis (Wolfe et al. 1999; Held et al. 2016). Demand for donated kidneys is substantial; in recent years, over 100,000 Americans were on the transplant waitlist for kidneys from deceased donors, which represent the major source of donated kidneys.[1] However, evidence suggests that there is room for improvement in how donated kidneys are allocated – more than 4000 candidates die each year before getting a kidney transplant, while a similar number of kidneys are discarded before they are matched to a recipient.[2]

Similar to publicly provided goods and services, donated organs in the U.S. are distributed through a system that uses catchment areas.[3] Transplant candidates are prioritized if they are registered at transplant centers within the same county group ("service area") as a donor hospital where deceased donor organs are recovered, with some minor exceptions. The system is associated with significant geographical variation in organ usage and transplant access, which may be due in part to the fact that the service areas were not designed to balance the availability and demand for donated organs across regions (Adler et al. 2016; King, Husain, and Mohan 2019). In light of this, discussions on modifying the boundaries are ongoing, but the design of service area remains an open question. Use of broader service areas can draw a larger pool of potential recipients, especially for hard-to-match organs, and can reduce disparities in waiting time across the nation. Smaller service areas, on the other hand, reduce transportation costs, which are linked to better post-transplant health outcomes.

This paper examines the trade-off in the geographic scope of service areas by exploiting a reform that removed county-group service areas for the first time since the deceased donor

1. Deceased donor kidneys account for 77 percent of all kidney transplants in 2021 (Lentine et al. 2023).

2. In 2019, 4,163 donated kidneys intended for transplant were discarded, and 46 percent were not used due to unviability before they could be successfully matched to a recipient. In the same year, 7,703 candidates either died or became too sick for a transplant while waiting for an offer.

3. Local catchment area is used to decide which households are eligible in the context of school assignment in public education (Cullen, Jacob, and Levitt 2005), vaccines (Pathak et al. 2024), and food assistance programs (Marcus and Yewell 2022), for instance.

kidney allocation system was established in the U.S. Starting on March 15, 2021, the county-group service areas were replaced with a 250-nautical-mile radius around each donor hospital. I provide evidence that the reform is expected to expand average service area size and redistribute kidney access from regions with high access to those with low access during the pre-reform period. Part of this improvement could be undermined if the reform led to behavioral changes, such as decreased organ donation decisions, decreased organ acceptance behavior, or increased new waitlist enrollment choices among regions with increased kidney access after the reform.

I start the analysis by exploring how the policy changed use of donated kidneys and composition of transplant recipients. I deploy a regression discontinuity design that compares outcomes of donated kidneys that enter in the allocation system within a small time window from March 15, 2021 and thus are allocated under different service area definitions. The identifying assumption is that factors other than the policy change evolve smoothly through the cut-off date when kidneys enter the allocation system. Using administrative data that includes detailed information on all donated organs, donors, and transplant candidates, I construct a sample consisting of donated kidneys entering the allocation system within 196 days of the reform. I find no evidence of discontinuous changes in the density of donated kidneys or donor characteristics around the cut-off. These results indicate that the reform did not change organ supply but redistributed how kidneys are allocated in the short run.

The reform has an immediate effect on where kidneys are allocated and how they are utilized for transplant. The likelihood of kidneys being matched successfully with transplant recipients within these county groups decreases by 23.4 percentage points (43 percent). The reform improves the use of donated kidneys; the likelihood of kidneys being discarded decreases by 3.8 percentage points (17 percent), driven by a 3.3 percentage point (26 percent) reduction in discards due to wait time. The additional kidneys tend to be of lower quality and are more likely to be recovered in major metropolitan areas, areas with high kidney access during the pre-period, and near transplant centers that are predicted to experience a

decrease in access to kidneys after the reform.

The reform changes the composition of transplant recipients. As expected, given the increase in the size of the service areas, the recipients are located further away from the donor hospitals and kidneys spend more time in transport after the reform. In addition, the results suggest that the reform increased equity — candidates living in counties with larger marginalized populations are more likely to receive kidney transplants after the reform. I also find evidence that candidates with extended dialysis history, who typically have higher health risks due to longer wait times, are more likely to receive kidney transplants post-reform.

Next, I examine how the reform affected the health outcomes of transplant candidates. I employ a difference-in-differences design estimated with a monthly panel of transplant centers to isolate changes in the health outcomes from the changes in the composition of transplant recipients. While all transplant candidates are subject to the reform, the extent of its impact varies across transplant centers depending on changes in available kidneys. Importantly, the administrative data include the exact locations of all transplant centers and donor hospitals, allowing me to assign each to their pre- and post-reform service areas. Using the pre-reform data, I calculate predicted changes in access to kidneys by transplant center and use this as a proxy for treatment intensity to examine the effects on mortality of transplant candidates.

The number of deaths on the waitlist decreases by 1.7 percent after the reform for an additional predicted kidney access. The decrease in pre-transplant deaths is not driven by changes in living donor kidney transplants or changes in the number of newly listed candidates but by an increase in deceased donor kidney transplants. There are no changes in the number of transplant recipients experiencing adverse health outcomes within 3-12 months of transplant before and after the reform. It is reassuring that increases in predicted kidney access cause important improvements in the health outcomes of transplant candidates, especially given that the additional kidneys used for transplant after the reform are often marginal and stored longer before transplant, both factors associated with a higher risk of graft failure.

Taken together, the results indicate that the reform resulted in non-trivial gains. Based on the estimates from the main findings, a back-of-the-envelope calculation suggests that the reform increased the number of deceased donor kidney recipients by 816 annually, which is comparable to 4 percent of total deceased donor kidney recipients in 2021. This additional number of transplant recipients indicates that the reform may have saved 5,712 years of life with a higher quality of life compared to dialysis. Besides saving lives, improving the efficacy of use of donated kidneys may have generated $119 million savings for Medicare, as patients with permanent kidney failure constitutes over 6 percent of total Medicare spending and their program eligibility expires three years after a kidney transplant (CMS 2022; USRDS 2023).

This paper makes several contributions to the literature. First, to my knowledge, this is the first work to provide causal estimates on the role of geographic boundaries in the allocation system. The findings of this paper contribute to existing studies showing a strong association between the county-based service area boundaries and disparities in access to organ transplants (Adler et al. 2016; Goldberg et al. 2015). Most closely related to my work, OPTN Report (2022) and Rausch, Niederhaus, and Forbes (2022) provide descriptive evidence but show mixed findings on the use of kidneys associated with the reform.[4] By using causal frameworks, I can evaluate the policy while avoiding issues such as time-varying confounding factors. In addition to organ allocation, the findings also contribute to prior broader work analyzing how changes in patient catchment areas influence health care utilization and health outcomes (Agha, Ericson, and Zhao 2023; Finkelstein, Gentzkow, and Williams 2016).

Second, this paper builds on existing works on the design of the organ allocation system. Much of this research falls within the market design literature: waitlist design for deceased donor kidney transplants (Agarwal et al. 2021; Ashlagi, Monachou, and Nikzad 2024; Agar-

4. OPTN Report (2022) compares the discard rates between kidneys recovered 1-12 months before the reform and those recovered 0-11 months after the reform and reports that the discard rate increased from 22 to 25 percent. Rausch, Niederhaus, and Forbes (2022) compares the discard rate between kidneys recovered 3.5 months before and those recovered 3.5 months after the reform and documents that the discard rate decreased from 24 to 22 percent.

wal, Hodgson, and Somaini 2020) and kidney-exchange program for living donor kidney transplants (Roth, Sönmez, and Ünver 2004; Agarwal et al. 2019).[5] As the reform was the first to change how service areas are defined in the kidney allocation system, previous works examine alternative approaches to designing the waitlist within the county-based boundary regime. This paper adds to the literature by providing empirical evidence that having a tighter market in kidney access can lead to finding transplant candidates willing to accept kidneys within their short shelf life.

Third, this paper relates to prior works exploring policy alternatives to mitigate regional disparities in publicly provided goods and services. For donated organs for transplant, these papers include provision of affordable air travel services to help candidates list in multiple service areas (Ata, Skaro, and Tayur 2017) and offering travel support for living donor transplants (Fernandez, Howard, and Kroese 2013). This paper also connects to prior research examining school bus programs for students to attend schools outside their neighborhoods (Angrist et al. 2022; Setren 2024) and policies aimed at expanding access to healthcare by reimbursing veterans for visits to private providers outside designated VA facilities (Rose et al. 2021; Russo 2023). This paper provides evidence that redistributing kidney access through service area redesign can improve both the efficiency and equity of the allocation system, with relatively low policy implementation costs.

2 Institutional Background

2.1 Deceased Donor Kidneys

Organs may be procured for transplant from either living or deceased individuals ("donors"). While those from living donors are generally given to relatives or spouses[6], deceased donor

5. More broadly, previous works explore factors that affect other aspects of organ donation: determinants of supply in laboratory experiments (Kessler and Roth 2012; Forthcoming; 2014) and in quasi-experimental settings (Dickert-Conlin, Elder, and Moore 2011; Li, Hawley, and Schnier 2013; Schnier et al. 2018) as well as determinants of demand (Dickert-Conlin, Elder, and Teltser 2019; Dickert-Conlin et al. 2024; Choi 2021).

6. Between January 2010 and June 2015, 3.1 percent of all living kidney donations were contributed by "non-directed donors" who generously donated their kidneys to strangers (Organ Procurement and Transplantation Network 2015).

organs enter a centralized allocation system and are matched with an anonymous recipient. This study focuses exclusively on organs from deceased donors, which account for 77 percent of all transplants in the U.S. in 2021 (Lentine et al. 2023).

Individuals can elect to have their organs donated after death by registering on their state's donor registry via the Department of Motor Vehicles, enrolling on the national Donate Life registry online, and including organ donation preferences in their will.[7] In addition, a deceased patient can be put into the donor registry if the next of kin agrees to donate the organs.

When an organ donor is declared deceased in a hospital (henceforth, "donor hospital"), physicians first conduct a medical evaluation to determine whether the donated organs are suitable for transplant.[8] Multiple organs can be recovered from a single deceased donor and each organ type has its own allocation system.[9] This study focuses on transplants using kidneys, which are the most common deceased donor organ transplant, accounting for 19,636 of 36,421 (54 percent) transplant cases in 2022 (Organ Procurement and Transplantation Network 2023).

2.2 Transplant Candidates

In 2023, chronic kidney disease affected one in seven Americans, making it the eighth-leading cause of death (Ahmad, Cisewski, and Anderson 2024). Patients with serious renal disease may be recommended for a transplant by their physicians. End-stage renal disease (ESRD) is characterized by advanced-stage, chronic kidney failure that requires regular dialysis or a kidney transplant for patient survival (Centers for Disease Control and Prevention 2023).

Compared to dialysis, opting for a kidney transplant offers higher life quality and im-

7. Age and definition of eligible death may vary by state and local laws. For instance, individuals below 18 cannot be a registered organ donor upon death nor a living donor unless state or local law allows them to do so.

8. Appendix Figure A.1a is a map of the locations of all donor hospitals for kidneys from 2019-2022.

9. Similarly, transplant centers vary in the types of deceased donor organ transplants they offer. In 2021, among centers providing deceased donor kidney transplants, 30% also offered lung transplants, 55% offered heart transplants, and 60% offered liver transplants. While the types of organs available may vary across county-based service areas, kidney transplants are available in every area.

proved health outcomes as well as generates cost savings for patients. Quality of life for dialysis patients increases 44 percent after a kidney transplant (Whiting 2000), while the annual cost of dialysis and related treatments is $121,000 per patient (Held et al. 2016). To address the high medical costs linked with ESRD treatment, Medicare eligibility is extended to ESRD patients under 65.[10]

To register their name on the waitlist for a kidney transplant, candidates must obtain a referral and then select a transplant center.[11] Once a potential transplant candidate submits their application to a transplant center, a patient assessment is conducted. This assessment involves gathering relevant information for the transplant process. For instance, Estimated post transplant survival (EPTS) score is a measure of the expected post-transplant survival of candidates calculated based on the following four factors: candidate's age, duration on dialysis in years, current diabetes status, and prior organ transplant.

Once a candidate is registered in the system, they may continue to receive dialysis or any other necessary treatments they received prior to joining the waitlist. Transplant candidates have the option to register their name at different transplant centers, a practice known as multi-listing, although this is uncommon.[12] However, it is important to note that registering for more than two transplant centers within the same service area is not permitted.

Patients will then wait for a suitable transplant offer to become available. Upon receiving a transplant, candidates are recommended to attend follow-up visits and adhere to the prescribed immunosuppressant medications to ensure transplant success.

10. Medicare coverage for individuals with ESRD who are under 65 starts either 1) after the third month of dialysis treatment or 2) upon admission to a Medicare-certified hospital for a kidney transplant or necessary pre-transplant healthcare, as long as the transplant occurs within the following two months. For ESRD patients with group health plans from their own or spouses' current employer, Medicare serves as a "secondary payer" that only covers costs that the group health plan does not cover due to coverage limits. After the 30th month of eligibility, Medicare becomes the primary payer of benefits.

11. Appendix Figure A.1b is a map of transplant centers in the U.S.

12. This occurs among 4 percent of candidates per transplant center (Ardekani and Orlowski 2010).

2.3 Allocation System for Deceased Donor Kidneys

There are no other channels for obtaining deceased donor organs outside of the allocation system. Two major pieces of legislation – the Uniform Anatomical Gift Act of 1968 (UAGA) and the National Organ Transplantation Act of 1984 (NOTA) – created much of the regulations governing the organ allocation system that exist in the United States today. The UAGA specifies the circumstances through which an individual can become an organ donor, either through their own choices or post-mortem by their relatives. The NOTA of 1984 prohibited commercial transactions of human organs nationwide and established the Organ Procurement and Transplantation Network (OPTN). OPTN administers organ recovery, maintains a national organ matching registry, and develops organ allocation policies.

In addition, the NOTA of 1984 introduced the concept of a "service area," which is a geographical boundary within which donor hospitals are matched to transplant centers and later referred to as donor service area (DSA). DSAs consist of sets of counties defined to ensure an adequate supply of organs to registered candidates while limiting the distance organs must travel. There were 57 DSAs across the nation in 2022. Figure 1 shows a map of DSA in the U.S.

If the donor's organ is eligible for transplant, the donor hospital notifies the local Organ Procurement Organization (OPO). The OPO oversees the allocation of the organs recovered within the DSA. Next, the donated kidney is evaluated for quality based on donor health and demographic information. The system calculates a Kidney Donor Profile Index (KDPI) score calculated based on the following ten donor characteristics to evaluate the expected life span of kidneys: age, height, weight, ethnicity, hypertension history, diabetes, cerebrovascular accident death, serum creatinine, Hepatitis C virus, and circulatory death. A higher index means a kidney has a lower expected likelihood of graft failure compared to other kidneys recovered in the last year. The allocation system classifies them into four subgroups: (1) 0–20%, (b) 21–34%, (c) 35–85%, and (d) 86–100%.

Finally, a computer system called DonorNet generates an ordered list of transplant candi-

dates – candidates are restricted to those with compatible blood types.[13] Candidates are also assessed on the similarity of tissue typing with a prospective donor based on HLA-ABDR typing. Fewer type mismatches are linked to a decreased likelihood of triggering an immune response and better post-transplant outcomes, including lower chances of graft rejection and graft failure (Held et al. 1994; Opelz and Döhler 2012).[14] Except for cases in which candidates have the same tissue typing as the donor[15], priority is given to those who are registered at a transplant center within the same service area as the donor hospital. That is, candidates in the same DSA as the donor hospital are prioritized for a kidney offer over those enrolled in transplant centers outside the DSA but within the same OPTN region[16] and those who are outside the OPTN region (that is, elsewhere in the nation). Appendix Table A.1 provides a table for kidney allocation point calculation used to rank each candidate within candidate category.[17]

After receiving an offer, candidates are given a specific amount of time to accept or reject the offer, given that kidneys lose viability within 72 hours after the donor's death. Non-utilization rate and pre-transplant mortality deaths are two measures often used to evaluate the efficiency of the allocation system. First, to evaluate the use of donated kidneys, non-utilization rate (often called the discard rate) is the share of kidneys recovered for transplant but not utilized (Israni et al. 2020; Organ Procurement and Transplantation Network 2023). Second, pre-transplant mortality is the number of transplant candidates that die on the

13. Kidneys from donors with blood types of AB, B, and O are offered to transplant candidates with the same blood types. Exceptions include 1) kidneys with blood types O or B can be transplanted to candidates with different blood types for offers with zero HLA mismatch and 2) kidneys with blood type A are offered for transplant candidates with blood type AB.

14. The number of mismatches ranges from zero ("zero mismatch") to six, and a lower number indicates that donors and transplant recipients share similar tissue type.

15. Candidates with "zero mismatch" with the donor are prioritized over candidates within the same DSA as the donor hospital, regardless of the location of their transplant centers.

16. Each OPTN region consists of a group of DSAs. There have been 11 OPTN regions in the U.S. since 1984. Appendix Figure A.3 shows the map of OPTN regions in the country.

17. In Appendix Table A.2, calculation of the kidney points considers the distance between donor hospital and transplant center (0-2 points) starting from March 21, 2021. If candidates have same points within the category, they are ranked based on the duration of registration. Appendix Figure A.2 describes how candidates are ranked in the national waitlist based on their health and demographic characteristics when kidney(s) becomes available from a deceased donor.

waitlist prior to getting a kidney transplant and is often used to assess performance of service areas and transplant centers.[18]

2.4 Donor Service Areas and the 2021 Reform

Although the DSA boundaries were originally defined to ensure equal access to kidney transplant candidates, in recent decades, supply and demand for deceased donor kidney transplants vary greatly across different geographical areas (Adler et al. 2016). Figure 2 illustrates geographical variation in use of donated kidneys (Panel A) and access to kidney transplants (Panel B) in years prior to the reform. To examine the relationship between kidney access and the use of donated kidneys, Appendix Figure A.4 provides a scatterplot illustrating the relationship between the number of available kidneys per candidate and the discard rate during the pre-period by "pre-reform" service area. The scatterplot shows a positive correlation (p-value=0.016) between these two measures, suggesting that the discard rate tended to be lower in places with lower kidney access during the pre-reform period.

A new policy was introduced on March 15, 2021, with the goal of addressing efficiency and equity in access to kidney transplants by providing more equal access to donated organs across geographical areas.[19] Under this reform, the allocation of deceased donor kidneys is based on the proximity between donor hospitals and transplant candidates rather than county-based service areas. Transplant candidates registered in transplant centers located within 250 nautical miles (i.e., 287.695 miles) from the donor hospital are prioritized for kidney offers, regardless of whether they are located within the same DSA as the donor hospital.[20] The average size of a proximity-based service area for a donor hospital is 260,024.64 square miles, which is 2.89 times larger than the average county-based service

18. For instance, the SRTR publishes pre-transplant mortality rates for the last two years for each transplant center in their annual program-specific reports.

19. The reform also took place in the pancreas allocation system. However, the size of the system is considerably smaller in scale compared to that of kidneys, with 19,762 kidney transplants in contrast to just 964 pancreas transplants in 2021.

20. The only exception was kidneys recovered from donor hospitals in Alaska (which takes less than 0.3% of kidneys recovered for transplant from 2021-2022) for which the concentric circle is drawn around Seattle-Tacoma International Airport. This measure ensures that kidneys recovered in Alaska can find suitable recipients promptly, given that there are no transplant centers located within the state.

area of 66,809.57 square miles.[21]

Using the pre-reform data, I assess whether the policy change is expected to reduce disparities in access to kidneys across geographic areas. Appendix Figure A.5 provides the distribution of the monthly number of recovered kidneys per candidate across transplant centers before and after the reform. This figure illustrates that the dispersion in kidney access is predicted to be smaller after the reform, suggesting that the reform may have contributed to equalizing kidney access across different areas.

The timing of policy implementation was hard to predict as it was originally planned to be implemented on December 15, 2020, but was pushed back due to concerns about the increased role of socioeconomic factors on transplant access and the COVID-19 pandemic. The OPTN announced in late February that the policy would be implemented on March 15, 2021 barring any further court intervention. The OPTN website posted an announcement on March 6, 2021, that the policy would go into effect on March 15, 2021.

While the change in geographic boundaries was the main policy change, three additional policy measures were introduced on March 15, 2021. These policies change the priority ranking of three rare types of candidates that comprise a small share of transplant recipients (<2% in both pre- and post-policy period) and they that had been prioritized over most other candidates prior to the reform (Appendix Figure A.2). Specifically, these categories are: (1) candidates with exhausted and imminent failure of access to dialysis ("medical urgency")[22]; (2) candidates who are prior living donors; and (3) pediatric candidates with kidney offers with non-zero HLA mismatch and KDPI below 35%. In robustness exercises, I show that my results are highly similar in a subsample of candidates whose ranking would not have been

21. 2021 Census U.S. Gazetteer Files is used to calculate total area in square miles, including both land and water, for each county. I merge this to a list of counties with their OPO affiliation information to calculate the total area size in square miles for each donor service area that existed as of February 2021. Following the policy change, the area for each proximity-based service area drawn around a donor hospital is 66809.57 square miles ($= \pi \times (287.6952 \text{ mi})^2$ or $\pi \times (250 \text{ nm})^2$).

22. Transplant candidates ever reported with medical urgency are rare – only 14 registrations were ever waiting in medical urgency status and 4 received a deceased donor transplant between the policy implementation date and June 30, 2021 (OPTN Report 2022).

affected.[23]

3 Data

My source of data is the restricted Scientific Registry of Transplant Recipients (SRTR), which stores information on the universe of deceased and living transplant donors, transplant candidates, and transplant recipients in the U.S. I combine detailed demographics and health conditions of all transplant donors, candidates, and recipients; comprehensive information on all offers made for a given kidney; precise geographical information on donor hospitals and transplant centers; and mortality outcomes from Social Security records for all recipients. Using these data, I construct two analysis samples – one that includes all donated kidneys and the other one spans January 2019–April 2023, and a monthly panel of transplant centers that spans the same time period.

3.1 Donated Kidney Sample

I construct a dataset covering all kidneys offered to transplant recipients from January 2019 to April 2023. Each observation is a donated kidney. To create these data, I first link together four datasets on donated kidneys using a unique ID for the donor. The first includes donor health measures, which are used to assess kidney quality. The second, called the Potential Transplant Recipient (PTR) dataset, contains the initial offer date for each kidney (approximately, the donor's date of death). The data also include information on any subsequent offers and the results of each offer (i.e., whether it was accepted or refused and the reasons for any refusals).

Third, I use data on the outcome ("disposition") for each kidney, including whether it was ultimately transplanted or discarded and the reasons for these outcomes. In particular, kidneys may be discarded for three reasons: (a) waited too long on the waitlist[24], (b) low quality[25], or (c) other factors.

23. This is consistent with Rausch, Niederhaus, and Forbes (2022), which discusses that the reform is unlikely affected access to kidney transplants for pediatric candidates.

24. Too old on pump; too old on ice; warm ischemic time too long; no recipient located – list exhausted.

25. Donor medical history; positive CMV; positive HIV; positive Hepatitis; biopsy findings; diseased organ;

Fourth, I link the donor hospital that oversaw organ recovery with detailed geographic information (GPS coordinates, zip code, and institution name, OPO affiliation).[26] During the period between January 2019 and April 2023, a total of 2,220 donor hospitals recovered at least one deceased donor kidney for transplant. As the distance between donor hospital and transplant center determines allocation after the policy implementation, I calculate the distance for all possible pairs of donor hospitals and transplant centers using their GPS coordinates.[27] To do so, I extract longitude and latitude information based on the addresses of transplant centers from Google Maps as the SRTR data does not provide information on their GPS coordinates.[28]

Finally, for the subset of kidneys that are transplanted, I merge in detailed information on each transplant recipient. I use this information to shed light on changes in access to kidney transplants across subgroups as a response to the policy change. Specifically, the information includes demographics (age, race, ethnicity, education attainment, insurance coverage) and health conditions (history of dialysis, diabetes, prior organ transplant).

To examine whether the reform changes access to kidneys among sociodemographic groups, I merge recipients' county of residence with the CDC Social Vulnerability Index (SVI). SVI is a composite measure of social determinants of health, which ranks counties based on 15 sociodemographic factors.[29] It is used to assess the area's relative vulnerability to public health emergencies and is known to be associated with disparities in access to health care and health outcomes among residents (Khazanchi et al. 2020; Phelos, Deeb, and Brown 2021; Bauer et al. 2022). I use the SVI 2018 for the analysis (Centers for Disease Control and Prevention/ Agency for Toxic Substances and Disease Registry/ Geospatial Research,

poor organ function; organ trauma; diseased organ; anatomical abnormalities; inadequate urine output.

26. I obtain a restricted version of data that includes GPS coordinates and unique IDs of each donor hospital.

27. I use the "geosphere" package in R, which includes the "distm" function to compute the shortest distance between two locations.

28. I use the "ggmap" package in R to extract GPS coordinates based on the addresses.

29. These factors include poverty rate, unemployment rate, educational attainment, elderly and child population, disability status, single-parent households, ethnic diversity, English proficiency, housing type, and vehicle ownership. CDC obtains these variables from the American Community Survey (ACS).

Analysis, and Services Program 2020).

My analytic sample includes adult deceased donors whose kidneys were recovered for transplant[30] with non-missing information for donor characteristics, including information used to calculate KDPI score for each kidney. The sample is further limited to deceased donor kidneys recovered from donor hospitals outside Alaska and recovered in DSAs that did not experience any change in OPO affiliation through the sample period. Two OPOs, LifeChoice Donor Services (CTOP) and New England Donor Bank (MAOB), merged on January 1, 2021. The sample includes 23,466 kidneys recovered for transplant within 28 weeks of the policy change from 1,749 donor hospitals.

Panels A-B of Table 1 present descriptive statistics for the kidney-level data. In Panel A, 23 percent of kidneys recovered for transplant are discarded (henceforth, "discard rate"). Of kidneys that were discarded, 60.9 percent of them were not used for transplant as they waited too long the waitlist, 7 percent of them were discarded due to organ or donor health concerns, and 2.4 percent were discarded due to other reasons. 17 percent of kidneys have KDPI above 85%, which are considered marginal kidneys. Panel B provides descriptive statistics of transplant recipients. Average distance between donor hospital and transplant recipient is 195 miles and average length of pre-transplant dialysis per transplant recipient is 4.4 years.

3.2 Transplant Center Sample

My second analysis dataset is a monthly panel of transplant centers that includes measures of health for all candidates registered at a given center, including those that do not receive a transplant. To create this sample, I use microdata on candidates that include health conditions (e.g., history of dialysis, diabetes, previous transplant records), transplant registration records, and transplant records (e.g., date of transplant, type of donor, characteristics of transplanted kidney). In addition, the data provide the exact date of death of all transplant

30. Categories of deceased donor organs not recovered are (a) authorization was not requested, (b) authorization not obtained, (c) not recovered, (d) recovered not for transplant (e.g., education/research purposes). Deceased donor kidneys with one of these disposition decision codes rarely enter the allocation system– a total of 248 non-recovered kidneys appeared in the PTR dataset within 26 weeks of the policy implementation date.

candidates from the Social Security Death Master File.

My sample consists of transplant centers with active transplant candidates prior to the policy change. To proxy for the size of each center, I calculate the average waitlist enrollment per month during 1-15 months prior to the reform. I exclude transplant centers located in DSAs that experienced any change in OPO affiliation through the sample period. Panel C of Table 1 presents descriptive statistics for transplant centers. The sample covers 222 transplant centers, with 423 candidates on the waitlist on average prior to the reform.

I consider two measures of candidate mortality: whether the candidate died while waiting for a transplant and whether the candidate died within 5 years after registering, regardless of whether they received a transplant. While the first measures deaths that may have been avoidable with a kidney transplant, the latter encompasses deaths that occur after waitlist removal due to deteriorated health and after transplants. For each outcome, I calculate total death counts by transplant center and month. To examine whether the policy change affected candidates' choice of transplant centers, I calculate the monthly number of newly added transplant candidates per transplant center.

Finally, I consider a few outcomes that are observed only for the subset of candidates that receive a transplant. These include whether the candidate experienced death or graft failure, or went back to dialysis within 3, 6, 9, and 12 months after their transplant. 3,125 candidates who received transplants experienced these outcomes within 12 months of kidney transplant.

3.2.1 Treatment Intensity

While all transplant candidates are subject to the policy change, the extent of its impact varies across transplant centers depending on changes in the number of available kidneys. I develop a measure of the *predicted* change in available kidneys at each transplant center, based on pre-reform data on kidney supply and demand at that center. I then use this proxy for treatment intensity in a differences-in-differences identification strategy, described in the next section.

Changes in kidney availability for a given transplant center can vary based on the number of donor hospitals for which it lies in the service area, as well as the size of other transplant centers in the same service area. For example, consider a scenario in the pre-reform era in which a DSA includes only one donor hospital and one transplant center. Suppose that there are several nearby donor hospitals within 250 nautical miles of this transplant center but positioned across the DSA border. Then, the transplant center would experience an increase in the number of available kidneys. This increase occurs assuming no changes in the set of transplant centers also receiving kidneys from these donor hospitals.

In Eq. 1, $\Delta Access_h$ is the predicted change in the number of available deceased donor kidneys for transplant center h, which is calculated as follows:

$$\underbrace{\Delta Access_h}_{\text{predicted change in kidney availability}} = \underbrace{\sum_{d \in circle(h)} k_d * \frac{n_h}{n_d}}_{\substack{\textit{predicted} \text{ kidney availability} \\ \text{within } r \text{ nautical miles (post-reform)}}} - \underbrace{\sum_{d \in DSA(h)} k_d * \frac{n_h}{n_{DSA(h)}}}_{\substack{\text{kidney availability} \\ \text{within DSA (pre-reform)}}} \quad (1)$$

where *DSA(h)* is a set of donor hospitals located in the same DSA as transplant center h. *circle(h)* is a set of donor hospitals located within r nautical miles of transplant center h. Since each service area is defined as a concentric circle with a radius of 250 nautical miles after the reform, r is set to 250. n_h denotes the average waitlist enrollment per month in transplant center h during the 26 months prior to the policy change (i.e., January 2019-February 2021). Then I calculate average monthly kidneys recovered within the same timeframe as a proxy for kidney supply at donor hospital d, k_d. Next, I calculate (1) total transplant candidates registered at centers within the same DSA as transplant center h, $n_{DSA(h)}$, and (2) total transplant candidates within 250 nautical miles of donor hospital d, n_d.

Based on this information, I calculate the predicted number of available kidneys to transplant center h in the pre-period by summing the average number of deceased donor kidneys recovered from donor hospitals within the same DSA as transplant center h, weighted by the share of transplant candidates registered in h in the DSA. For the predicted number of

available kidneys in the post-period, I sum the monthly number of kidneys recovered from all donor hospitals located within the 250 nautical miles of transplant center h, weighted by the share of transplant candidates in h among transplant candidates within 250 nautical miles from donor hospital d.[31]

Of 222 transplant centers included in the sample, 46 percent of them are predicted to have an increase in the number of available kidneys after the policy change (Panel C of Table 1).[32] To examine whether the treatment intensity is a strong proxy for changes in access to kidney transplants, I calculate a correlation between the predicted and actual changes in the monthly number of kidneys per transplant center before and after the reform.[33] The correlation between the predicted and actual changes, weighted by the size of the transplant center, is 0.385 (p-value<0.001), providing a suggestive evidence that the predicted treatment intensity is a good proxy for the actual changes. In addition, Appendix Figure A.8 plots the predicted changes in access to kidneys against the number of available kidneys by transplant center during the pre-reform period. The scatterplot shows a negative correlation (-0.23 with p-value<0.001) between these two measures, indicating that the reform may mitigate disparities in access to kidneys by reallocating donated kidneys to places with lower access during the pre-reform period.

Furthermore, I use this measure to calculate the predicted treatment intensity for transplant centers to examine how use of kidneys depends on overall changes in access to kidneys among nearby transplant centers. For instance, the decrease in the discard rate at the cut-off is likely to come from kidneys recovered from donor hospitals whose transplant centers within 250 nautical miles are predicted to experience lowered access to kidneys after the policy change. In Eq. 2, $\overline{\Delta Access}_d$ is calculated as the average treatment intensity measure for transplant centers located within 250 nautical miles from a donor hospital d, weighted

31. Appendix Figure A.6 presents a numerical example of how the predicted changes in the number of available kidneys for each transplant center are calculated.

32. Appendix Figure A.7 presents a histogram of $\Delta Access_h$, and Appendix Figure A.9 illustrates the average treatment intensity mapped by DSA.

33. Appendix Figure A.10 provides a scatterplot that compares the proxy for treatment intensity with the actual shifts in average recipients of deceased donor kidneys within 15 months of the reform.

by their relative size to all transplant centers within the concentric circle drawn from the donor hospital.

$$\overline{\Delta Access}_d = \sum_{h \in circle(d)} \Delta Access_h * \frac{n_h}{n_d} \tag{2}$$

4 Empirical Strategies

My empirical strategies are (1) a regression discontinuity (RD) design with the initial offer date as a running variable and (2) a difference-in-differences (DD) design exploiting variation in the timing of policy change and treatment intensity across transplant centers. I use the kidney-level data to estimate the RD design and the transplant-center dataset for the DD design.[34]

4.1 Regression Discontinuity Design

My RD design leverages the sharp timing of the reform with respect to donated kidneys first entering the allocation system. Using this design, I investigate how the use of kidneys and the composition of transplant recipients respond when the service areas used for kidney allocation were changed from county-based geographical boundaries to concentric circles. My analysis sample includes deceased donor kidneys recovered for transplant and first offered to transplant candidates within 28 weeks from the policy implementation date, March 15th, 2021.[35] Eq. 3 presents the estimating equation for my RD specification:

$$Y_i = \alpha + \beta 1(\mathrm{D}_i \geq c) + 1(\mathrm{D}_i \geq c) f(\mathrm{D}_i - c) + f(\mathrm{D}_i - c) + X_i \rho + \epsilon_i \tag{3}$$

where f() is a control function based on the initial offer date. D_i denotes the initial date which deceased donor kidney i first appeared in the allocation system. $1(\mathrm{D}_i \geq c)$ is an

34. This study used data from the SRTR. The SRTR data system includes data on all donor, wait-listed candidates, and transplant recipients in the US, submitted by the members of the 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.

35. I employ the method developed by Calonico, Cattaneo, and Titiunik (2014) to calculate the data-driven bandwidth for my main outcome variable, an indicator of whether kidneys were discarded. The optimal bandwidth is 196 days (28 weeks).

indicator for deceased donor kidneys offered to kidney transplant candidates for the first time on or after March 15, 2021, which serves as the cut-off value c. Triangular weights are used to linearly weigh each observation based on distance from the cut-off. Standard errors are clustered at the level of initial offer date. X_i denotes control variables, which include a set of donor characteristics (gender, race/ethnicity, blood type, history of hypertension). Triangular weights are used to linearly weight each observation based on distance from the cut-off. Standard errors are clustered at the level of initial offer date.

The identifying assumption is that the assignment of kidneys into the allocation system on either side of the cut-off date is as good as random so that the outcomes of interests would have evolved smoothly in the absence of the policy change (Lee 2008). Under this assumption, β captures the effects on use of deceased donor kidneys and the composition of transplant recipients.

I employ two tests of the identifying assumption. First, I check the smoothness of the distribution of the initial offer date using the McCrary density test. This test helps examine possible manipulation or deliberate delay in registering certain kidneys in the allocation system under the new system. The results of the McCrary density test do not reject the null hypothesis that the density of my running variable is smooth around the cut-off point (p-value=0.16).[36]

Second, I examine whether deceased donor kidneys on either side of the cut-off have similar observable characteristics. Table 2 and Appendix Tables A.3-A.6 provide the RD estimates when Eq. 3 is estimated by setting each of the following kidney (i.e., donor) characteristics as the the dependent variable: a) demographics, b) health conditions, c) donor consent mechanisms, and d) circumstances of death. provide the RD estimates when these characteristics are used as the dependent variable to estimate Eq. 3. There are no significant systematic differences in these observable characteristics around the cut-off, which supports the validity of my RD design.

36. Appendix Figure A.11 presents the density of deceased donor kidneys based on their initial offer date.

For robustness exercises, I estimate Eq. 3 using a number of alternatives to my baseline specification: (1) excluding triangular weights, (2) excluding X_i, (3) setting f() as a local linear function form, and (4) using alternative choices of bandwidth length.

Furthermore, I perform placebo exercises by estimating Eq. 3 with two samples on livers and hearts recovered from deceased donors in the kidney-level data. As there are separate allocation systems based on organ type, the reform should not affect the allocation of deceased-donor organs that have not been affected by the policy change. Livers and hearts are two most commonly transplanted organs other than kidney.[37] Similarly to the kidney-level data, I restrict the sample to nonkidney organs that were recovered for transplant and were recovered as a single organ (that is, I drop double-lung from the sample) to keep the unit of the observation at the organ level.

4.2 Difference-in-Differences Design

Next, I use the monthly panel of transplant centers to examine how the reform affected access to transplant and health outcomes of transplant candidates. With these data, I employ a difference-in-differences design leveraging within-transplant center variation in predicted access to deceased donor kidney transplants over time. A fixed-effect Poisson model is used to estimate Eq. 4 to address the existence of zero pre-transplant deaths in certain transplant centers during specific months:

$$Y_{ht} = exp(\gamma \Delta Access_h * Post_t + \theta_h + \lambda_t)\epsilon_{ht} \tag{4}$$

where Y_{ht} denotes an outcome for transplant center h in month t. $Post_t$ is an indicator for months on or after March 2021. $\Delta Access_h$ is the predicted change in the available deceased donor kidneys for h, as defined in Eq. 1. θ_h is a transplant center fixed effects to take unobserved time-invariant transplant center characteristics into account. λ_t is a year-month fixed effect to capture aggregate time trends affecting all transplant centers in the U.S.

37. In 2021, 3,861 hearts, 2,443 lungs, and 8,595 livers from deceased donors were used for transplant.

I control for the natural log of the average number of candidates on the waitlist during the pre-period for each transplant center and constrain the coefficient to be one. γ is the key parameter of interest, capturing the effect of changing the service area boundaries on transplant center outcomes. Standard errors are clustered by transplant center.

To interpret γ as the causal effect of the policy change, the transplant centers predicted with higher treatment intensity would have had to have otherwise evolved on the same trajectory during the post-period compared to those with lower treatment intensity (Callaway, Goodman-Bacon, and Sant'Anna 2021). I estimate the following event-study specification to test for differential pre-trends in outcomes across transplant centers and to illustrate dynamic treatment effects:

$$Y_{ht} = exp(\sum_{\tau=-15(\neq -1)}^{14} \delta_\tau 1(t=\tau) * \Delta Access_h + \theta_h + \lambda_t)\epsilon_{ht} \tag{5}$$

where event-time τ is the difference in months between a given month t and March 2021. For pre-transplant mortality, the event time is defined by date of death. For post-transplant adverse health outcomes, event time is measured from the transplant date to capture health events occurring within a specific timeframe following the transplant. δ_τ captures changes in transplant center outcomes in month τ, relative to February 2021 ($\tau = -1$).

5 Results

I estimate the RD specification using the kidney-level data to study the effect of the reform of service areas on the use of deceased-donor kidneys and the demographics of transplant recipients. Then, I estimate the difference-in-differences strategy using the transplant-center-level data to examine the policy's impact on health outcomes of transplant candidates.

5.1 Kidney Outcomes: Utilization and Characteristics of Transplant Recipients

5.1.1 Use of Deceased Donor Kidneys

I first assess whether the reform shifts the geographic allocation of kidneys—in particular, whether kidneys are less likely to find the recipients at centers in the same DSA as the donor hospital, as would be expected. Figure 3 plots the share of kidneys transplanted within the DSA by initial offer date. Table 3 reports estimates and standard errors corresponding to Y_i from Eq. 3. In Column 1, the likelihood of kidneys finding the recipients within the DSA drops by 23.4 percentage points (43 percent) at the cut-off, suggesting that the policy change has an immediate and important effect on where kidneys are allocated.[38]

Next, I explore how the policy change affects the use of these kidneys. Figure 4 plots the overall discard rate against the initial offer date. In Column 2 of Table 3, the likelihood of kidneys being discarded drops by 3.8 percentage points (17 percent) at the cut-off. In particular, the likelihood of kidneys being discarded because they are on the waitlist too long discontinuously drops by 3.3 percentage point (26 percent; Column 3). In contrast, there are no discontinuous changes in the likelihood of kidneys being discarded because of organ-quality issues and other reasons at the cut-off (Columns 4–5). Thus, these results suggest that the reform increased the usage of donated kidneys and did so through an improvement in allocative efficiency, rather than a change in the composition of donors or other factors.

Robustness and Placebo Checks To assess the robustness of my findings, I estimate Eq. 3 using the dependent variables in Table 3 but with a number of different specifications: (1) dropping the control variables, (2) excluding weights, (3) setting f() as a local linear function form, and (4) using different bandwidth choices. In Appendix Table A.11, the RD estimates remain very similar across different specifications, which suggests that my findings are not sensitive to changes to my baseline specification.

38. Similarly, in Column 2 of Appendix Table A.7, the share of kidneys transplanted within the OPTN region drops by 11.9 percentage points (18 percent). Appendix Figure A.12 plots the share of kidneys transplanted within the OPTN region by initial offer date.

Moreover, I perform placebo tests by using samples on hearts and livers. Table 4 provides the RD estimates when dependent variables for Eq. 3 are an indicator of discarded organs and indicators of three organ-discard reasons.[39] All estimates in Table 4 are statistically indistinguishable from 0, supporting the validity of my study design.

Heterogeneity Analysis and Mechanisms

(a) Kidney Quality: To explore whether certain types of kidneys are more likely to be allocated after the reform, I examine how the effects on the discard rate vary by kidney quality.[40] In Panel A-(i) of Figure 5, the discard rate for kidneys with KDPIs above 85 percent decreases by 7.7 percentage points (12 percent) at the cut-off. In contrast, the coefficients for kidneys with KDPI below 85 percent are not statistically different from zero at 10 percent. These lower-quality kidneys must be used in a shorter period and can only be matched to transplant recipients who gave informed consent in advance to express their interest in these kidney offers. Reassuringly, the findings are similar when an alternative measure of kidney quality is used to estimate Eq. 3 (Panel A-(ii) of Figure 5).[41] These findings indicate that the policy particularly increases the use of marginal kidneys.

(b) Donor Hospital Characteristics: Next, I turn to explore heterogeneous effects by donor hospitals. First, Panel B of Figure 5 explores how the effects on use of donated kidneys vary by the location of donor hospital. Kidneys recovered from donor hospitals located in core metropolitan areas are less likely to be discarded by 5.8 percentage points (25 percent) at the cut-off. By comparison, the decrease in the discard rate from kidneys with donor hospitals

39. Appendix Figure A.14 provides the share of non-kidney organs that are being discarded by initial offer date.

40. As explained earlier, kidney quality decreases (equivalently, health risk increases) with KDPI and these four subgroups are (a) 0–20 percent, (b) 21–35 percent, (c) 35–85 percent, and (d) 86–100 percent. Appendix Figure A.13 plots the discard rate by four subgroups based on the KDPI score used by the allocation system.

41. Prior to 2014, kidneys were classified into one of two categories: expanded criteria donor (ECD) or standard criteria donor (SCD) kidneys, with the latter indicating higher quality than the former. ECD kidneys are those recovered from donors (1) aged 60 or older or (2) aged 50–59 with two or three of the following health conditions: high blood pressure, creatinine levels of 1.5 or higher, or death due to stroke (Ojo 2005). Similar to donated kidneys with KDPI above 85 percent, ECD kidneys were only offered to candidates who showed interest in them in advance. In Columns 5–6 of Appendix Table A.8, ECD kidneys show a 7.9 percentage point (13.9 percent) decrease in the discard rate at the cut-off.

located in less urbanized/populated areas is somewhat smaller (1.1 percentage points or 5 percent; Appendix Table A.9).

Next, Panel C of Figure 5 examines how use of kidneys varies by pre-reform kidney access of donated hospitals are located in. As higher kidney availability is positively associated with a higher discard rate, redistributing kidney access from high- to low-access regions through the reform can enhance the utilization of donated kidneys, particularly those recovered from areas with high access in the pre-reform period. The discard rate drops by 4.8 percentage points (22 percent) for donor hospitals with above-median access in the pre-period whereas 2.3 percentage point (10 percent) drops for those with below-median access cut-off.

Lastly, Panel D of Figure 5 explores how use of kidneys depends on overall changes in access to kidneys among nearby transplant centers.[42] The discard rate for kidneys recovered from donor hospitals where nearby transplant centers are predicted to experience lower kidney access on average drops by 5.4 percentage points (24 percent) at the cut-off. In comparison, the discard rate for kidneys from donor hospitals where nearby transplant centers are predicted to have higher kidney access on average is 3.1 percentage points (14 percent; Appendix Table A.10). Still, this comparison is suggestive as the coefficients are not statistically distinguishable.

5.1.2 Characteristics of Transplanted Kidneys

Next, I examine how the policy change affects travel distance, match quality, and the time it takes for kidneys to reach transplant centers where their recipients are enrolled. To do so, I limit the kidney-level data to kidneys used for transplant.

Table 5 reports the RD estimates when the dependent variables are the distance between donor hospitals and transplant centers. In Column 1, the travel distance increases by 19.8 nautical miles at the cut-off, but the estimate is not statistically distinguishable from zero. This could be attributable to the distributional effects – the likelihood of kidneys finding the recipients within 250 nautical miles of donor hospitals increases by 3.5 percentage points (4

42. As mentioned earlier, it is based on donor hospital's predicted treatment intensity in Eq. 2.

percent; Column 3) but the likelihood of kidneys finding the recipients within 50 nautical miles decreases by 18.2 percentage points (40 percent; Column 2).[43] Similar to the effects on travel distance, the number of hours kidneys are in cold storage (i.e. cold ischemia hours) increases by 1.6 hours (9 percent; Column 4) at the cut-off.

To examine the impact on match quality, I estimate Eq. 3 by setting the dependent variable equal to outcomes related to the number of HLA mismatches. In Appendix Table A.12, all RD estimates in the table are close to zero and are statistically insignificant at the 10 percent level. These results indicate that the policy change does not change the match quality but increases the efficiency of the allocation system by allowing kidneys to find a recipient more flexibly and within a timely manner.

5.1.3 Characteristics of Transplant Recipients

I shift my focus to examining how the reform changes who receives a kidney transplant. Limiting the sample to kidneys used for transplants, I estimate the RD model in Eq. 3 using the dependent variable as an indicator of candidate subgroups to test whether the composition of transplant recipients changes at the cut-off. Figure 6 plots the RD estimates.[44]

(a) Recipient Health Status: I examine whether the reform affects access to transplants for transplant candidates with higher health risks. I focus on three factors used to calculate the Estimated Post Transplant Survival score: number of years on dialysis, previous transplant history, and diabetes history.[45] To assess any distributional effects, I estimate Eq. 3 using the dependent variable as an indicator of four subgroups categorized by dialysis duration of the transplant candidate prior to the transplant: (1) zero years, (2) one to two years,

43. These results are consistent with an increased likelihood of kidneys finding the recipients *outside* the DSA (Column 1 of Table 5) but *within* 250 nautical miles after the reform (Column 3 of Table 5).

44. These RD estimates are reported in Appendix Tables A.13-A.15. To explore how the changes in kidney access associated with the reform map to changes in the composition of transplant recipients, Appendix Figure A.15 plots the average treatment intensity across transplant candidate subgroups. To do so, I use the data of transplant candidates on the waitlist prior to the reform. In Figure 6, candidate subgroups with higher average treatment intensity tend to have an improved access to kidney transplant after the reform.

45. As mentioned earlier, these factors are used to calculate EPTS score. As the life expectancy for transplant candidates on dialysis is 12.3 years (Held et al. 2016), those who undergo an extended period of dialysis face not only a shorter expected life span but an increased risk of being removed from the transplant waitlist because of factors such as mortality or other medical complications.

(3) three to four years, and (4) five years or more.

In Panel A of Figure 6, the likelihood of candidates with five or more years of dialysis history receiving kidney transplant increases by 5.8 percentage points (17 percent) at the cut-off. Meanwhile, the changes in the likelihood of recipient subgroups with less than five years of dialysis history at the cut-off are not statistically distinguishable from zero. But there are no discontinuous changes in the likelihood of candidates with previous transplant history or diabetes receiving kidney transplant at the cut-off.

(b) Sociodemographic Characteristics: Next, I examine whether the policy change has varying impacts on access to kidney transplants based on sociodemographic characteristics. I estimate Eq. 3 by setting dependent variables as indicators for quartile groups based on SVI of counties where candidates live at the time of the transplant. In Panel B of Figure 6, the likelihood of candidates living in counties with higher social vulnerability at time of the transplant increases discontinuously at the cut-off: a 3.2 percentage point (13 percent) increase for the fourth quartile, whereas a 4.7 percentage point (20 percent) decrease for the first quartile. Similarly, average SVI discontinuously increases by 5 percent at the cut-off.[46]

Given that SVI is a composite measure of social determinants of health, I check the robustness of results by re-estimating Eq. 3 by setting dependent variables as county poverty rates and indicators for racial/ethnic subgroups. Panel C of Figure 6 shows that the change in the likelihood of candidates from counties with higher poverty rates receiving kidney transplants at the cut-off. I observe a 3.5 percentage point increase (15 percent) for the candidates from the third quartile but a 3 percentage point decrease (12 percent) for the first quartile at the cut-off. In addition, Panel D of Figure 6 explores how changes in access to kidney transplants vary by racial/ethnic group.[47] The likelihood of having a Hispanic/Latino transplant recipient increases by 2.1 percentage points at the cut-off. In contrast, changes in the likelihood of non-Hispanic white, black, and AAPI recipients at the cut-off are close to

46. Column 1 of Appendix Table A.14 provides the corresponding RD estimates.

47. ESRD incidence rates are 3.8 times higher for Blacks and twice as high for Hispanics compared to non-Hispanic Whites (USRDS 2023).

zero and statistically indistinguishable at 10 percent, suggesting that the reform increases access to kidneys to marginalized populations.

5.2 Transplant Center Outcomes

Given that the results of the RD design suggest that the use of deceased donor kidneys increased as a response to the policy change, the policy change may have affected transplant candidates. In light of this, I turn to the transplant center-level identification strategy to examine the impact of the reform on health outcomes of transplant candidates. In addition, I explore its potential channels of change by examining the effects on monthly deceased kidney transplants, living donor kidney transplants, and candidates newly joining the waitlist.

5.2.1 Effects on Kidney Transplant Candidates

I estimate the event-study design in Eq. 5 to examine the effects on the deaths of transplant candidates. Figure 7a plots the event-study coefficients on the number of transplant candidates who passed away while on the waitlist in a month for a given transplant center. Figure 7a supports the claim that the transplant centers predicted to have higher treatment intensity evolved along the same trajectory in the number of transplant-candidate deaths during the pre-period as those predicted to have lower treatment intensity. Table 6 reports the estimated value for γ in Eq. 4, which captures the average effects of a one-unit increase in the number of kidneys available to transplant centers after the reform. In Column 1, monthly pre-transplant deaths decrease by 1.7 percent when access to deceased-donor kidneys increases by one unit.

Results are similar when an alternative death measure for transplant candidates is used. Figure 7b plots the event-study coefficients on the monthly transplant candidates' death counts within five years of waitlist registration per transplant center. This measure includes all deaths of transplant candidates who passed away on the waitlist and those who received kidney transplants but died within five years of entering the waitlist. The monthly death counts of candidates who passed away within five years of listing decreases by 1.6 percent

when access to kidneys increases by one unit after the reform (Column 2 of Table 6).

Consistent with the RD result that the use of deceased-donor kidneys increases at the cut-off, monthly deceased donor kidney transplant recipients increase by 1.4 percent when access to kidneys increases by one unit after the reform (Column 3 of Table 6). However, the decrease in monthly pre-transplant deaths is unlikely to be attributable to changes in living donor kidney transplants (Column 4 of Table 6). As transplant candidates need to look out for those willing to become living donors, these findings suggest that there is no crowding out in response to the reform. This may be linked to the relatively low substitutability between deceased and living donor kidneys, given that living donor kidney transplants are expected to last longer.[48]

Furthermore, the change in monthly pre-transplant deaths is also unlikely to be attributable to changes in the number of candidates newly joining the waitlist. Appendix Figure A.16b plots the coefficients from the event study when the outcome is monthly number of newly added candidates on the waitlist. The effect on the number of candidates joining the waitlist for deceased donor kidneys is close to zero and is statistically insignificant at the 10 percent level (Column 5 of Table 6).

To check the robustness of the findings, I estimate Eq. 3 with OLS specification. Appendix Table A.16 provides the results from the OLS model on the transplant candidate outcomes in Tables 4, respectively. Reassuringly, the results are similar to those from the Poisson model in Table 6.[49]

48. As most living donors for kidney transplant are family members or relatives of the recipients, a living donor kidney transplant is expected to have greater compatibility for the recipient compared to a deceased donor kidney transplant. The estimated graft failure for a living donor kidney was 19.2 years but 12.1 years for a deceased donor kidney transplant from 2014-2017 (Poggio et al. 2021).

49. For instance, Column 2 of Appendix Table A.16 shows that the number of pre-transplant deaths per 1,000 candidates decreases by 1.8 percent in the OLS model for one unit increase in available kidneys to transplant centers in the post-reform period, which is very similar to the 1.7 percent increase found in the Poisson model in Eq. 4.

5.2.2 Effects on Kidney Transplant Recipients

The results of the RD design suggest that the decrease in the discard rate is largely driven by increased use of marginal kidneys and that kidneys are remaining in cold storage longer before being transplanted to recipients than they were prior to the reform. As these types of kidneys are expected to have higher graft failure, I examine whether the policy change affects the health outcomes of transplant recipients in the short run. I define post-transplant adverse health outcomes as (1) deaths, (2) graft failure, and (3) resuming maintenance dialysis. Table 7 reports the estimates of γ in Eq. 4. Figure 8 plots the event-study coefficients on monthly number of transplant recipients who ever experience adverse health outcomes within 3, 6, 9, and 12 months of transplant.

In Figure 8, transplant centers predicted to have higher treatment intensity move on the same trajectory in terms of the number of transplant recipients experiencing adverse health outcomes during the pre-period compared to those predicted to have lower treatment intensity. All estimates in Table 7 are close to zero and statistically insignificant at the 10 percent level, which are also found in the OLS model.[50] The results indicate that it is unlikely that the reform affects the mortality of transplant recipients in the short run.

6 Conclusion

This paper studies the impact of redefining boundaries to allocate perishable goods across local catchment areas and its implications for efficiency and equity. I examine these questions in the context of kidney transplants, where the stakes of preventing inefficient allocation are particularly high. I employ detailed administrative microdata on organs, transplant candidates, and transplant centers to estimate two empirical designs that exploit the sharp timing of the reform and variation in treatment intensity across transplant centers based on their precise location.

Employing a regression discontinuity design, I find that the reform resulted in an imme-

50. Appendix Table A.17 provides the results from the OLS model on the post-transplant health outcomes.

diate decline in the role of pre-reform geographic boundaries in the kidney allocation system by 43 percent. In addition, the reform led to a 17 percent decrease in the kidney discard rate. I also document distributional effects – kidney recipients were more likely to have an extended dialysis history and live in counties with higher marginalized populations relative to pre-reform recipient characteristics. Using a difference-in-differences design, I find that monthly pre-transplant deaths decrease by 1.7 percent but observe no changes in adverse health outcomes of transplant recipients when access to deceased donor kidneys increases by one unit in response to the reform.

Using the estimates from the RD design, I conduct a back-of-the-envelope calculation to explore the extent of the reform on the allocation system as well as Medicare. First, the reform may have led to an additional 816 kidneys being used for transplant annually, which would otherwise have been discarded.[51] Considering 19,762 candidates received deceased donor kidney transplants in 2021 (Israni et al. 2023), this increase in successful matches implies that redefining the catchment area led to a noticeable increase in the number of kidneys used for transplant. Second, the reform may have saved 5,712 years of life.[52] Lastly, Medicare may have saved $119 million (816 transplant recipients $\times$ $146,000) that would have otherwise been spent subsidizing dialysis treatment, as the program covers significant dialysis costs even for patients under 65 (Held et al. 2016).

The findings of this paper indicate that the reform improves both the efficiency and equity of the kidney allocation system in the short run. In light of this, examining the long-term impacts of this policy change could provide valuable insights for future research, particularly regarding changes in transplant center behaviors and donor decision-making. For example, the willingness of deceased donors to sign up may be influenced by the perception that their

51. As 23,466 kidneys were recovered for transplant within 196 days of the reform, 1,822 kidneys were recovered for transplant each month on average. Given that the discard rate was 22 percent before the reform, 401 kidneys ($= 1,822$ kidneys$\times 0.22$) were discarded each month on average. As the results from the RD design show that the discard rate was decreased by 17 percent after the reform, additional 68 kidneys ($= 401 \times 0.17$) were used for transplant each month, which is 816 transplant recipients annually.

52. Transplant candidates are expected to have an additional 7 years compared to receiving dialysis while on the waiting list.

organs are less likely to be allocated to local or state residents. Given that the dispersion of kidney access across transplant centers is expected to decrease as the size of the boundaries increases (Appendix Figure A.17), understanding these long-term impacts could be valuable for facilitating discussions about the potential adoption of even broader service areas.[53]

53. I calculate predicted kidney availability for each transplant center by adjusting different radius r in Eq 1.

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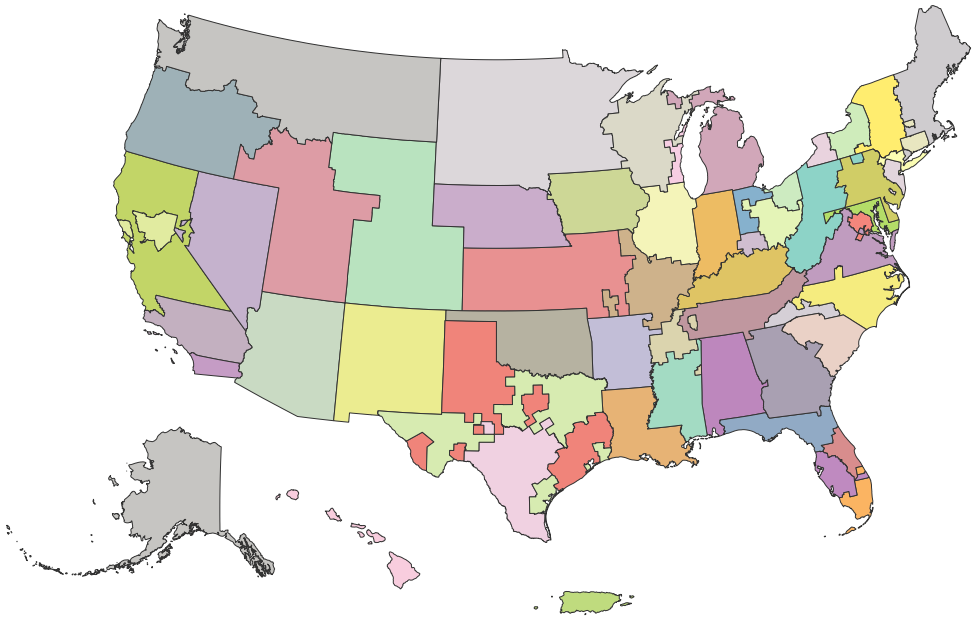
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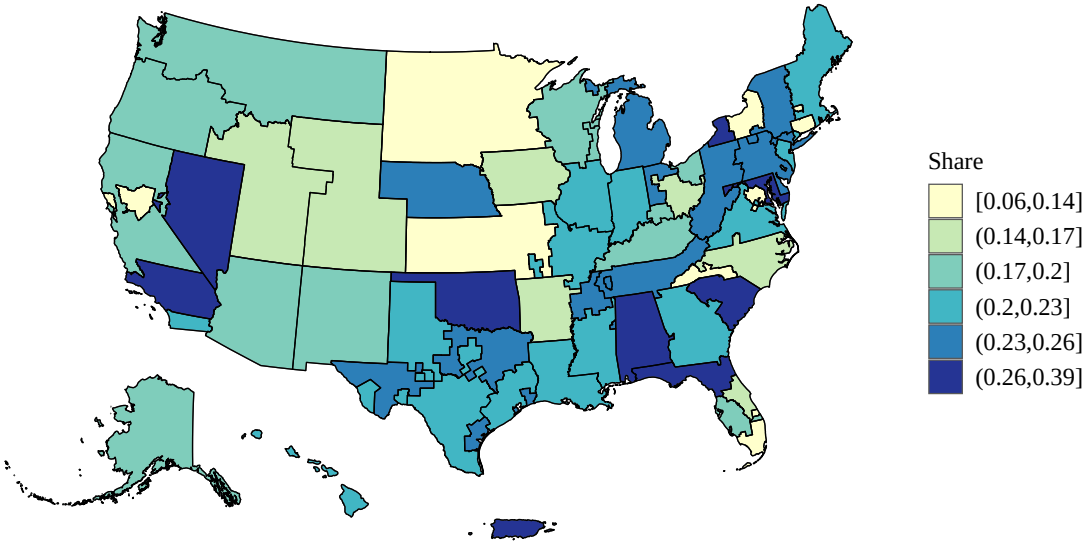
Figure 1: Map of Donor Service Area



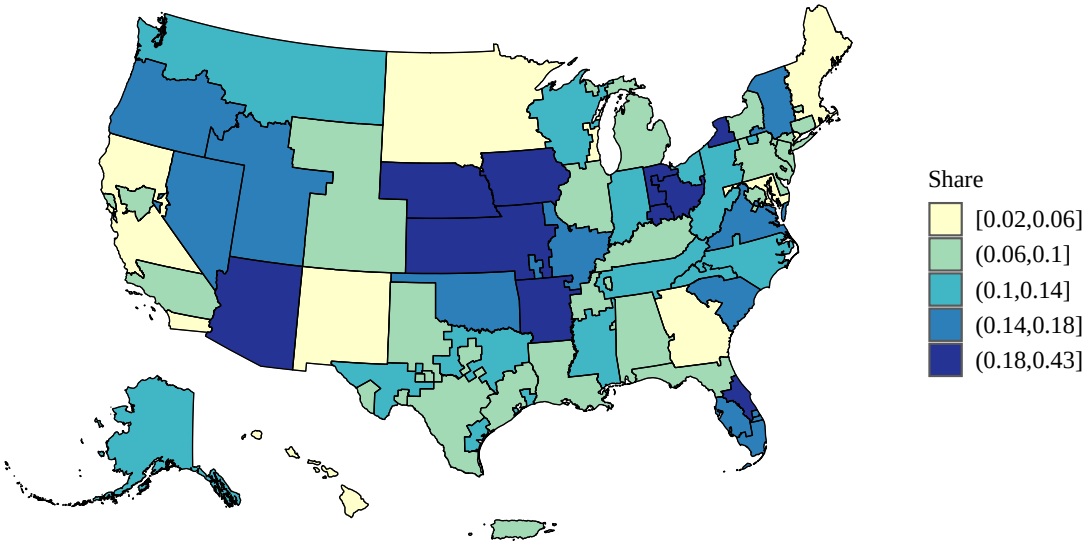
Notes: In 2022, there are 57 donor service areas (DSAs) across the United States (Panel A). Each DSA consists of a group of counties defined to ensure an adequate supply of organs to registered candidates while limiting the distance organs must travel. Under the 2021 reform, the allocation of deceased donor kidneys is based on the proximity between donor hospitals and transplant candidates rather than county-based service areas. For more information about DSAs, see section 2.

Figure 2: Geographic Disparities in Kidney Allocation Prior to the 2021 Reform

(a) Share by Kidneys Discarded by Donor Location

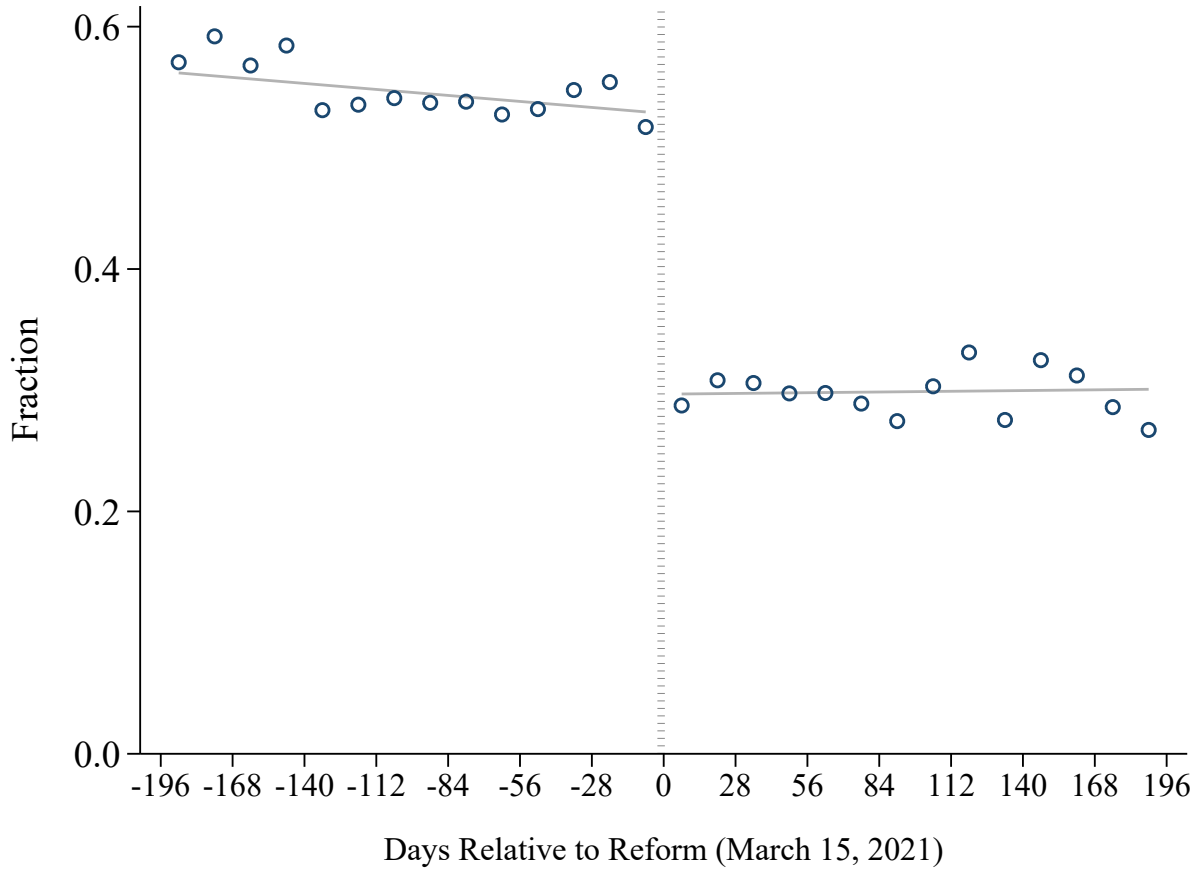


(b) Share of Candidates Receiving Kidney Transplants by Location



Notes: This figure illustrates the geographical variation in the use of donated kidneys (Panel A) and access to kidney transplants (Panel B) in the years prior to the reform. Panel A maps the share of deceased donor kidneys procured but discarded in a given donor service area (DSA). Panel B maps the share of transplant candidates who received kidneys from the donor registered in a given DSA. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets from January 2019 to February 2021, which include the universe of deceased donor kidneys and transplant candidates in the U.S.

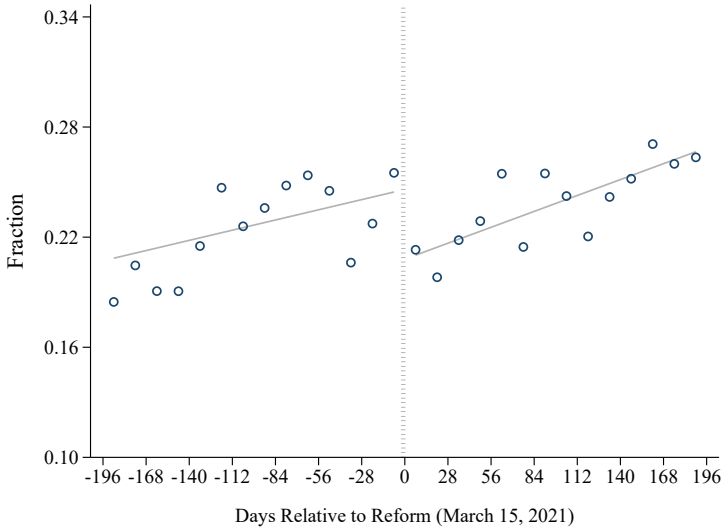
Figure 3: Share of Donated Kidneys Allocated Within "Pre-Reform Service Areas"



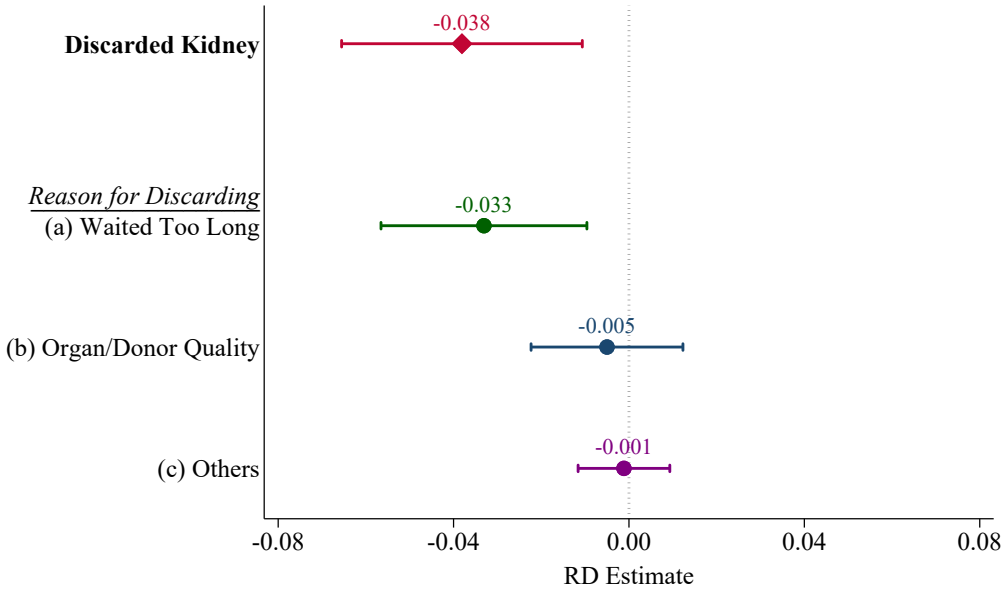
Notes: This figure shows the share of kidneys allocated to candidates at transplant centers within Donor Service Areas, which is the allocation boundaries in use prior to March 15, 2021. The date on the x-axis is the initial offer date. Each dot represents two weeks. Sample is drawn from the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys in the U.S. For more information on the sample, see the notes to Table 1.

Figure 4: Share of Donated Kidneys that are Discarded

(a) Overall Discard Rate

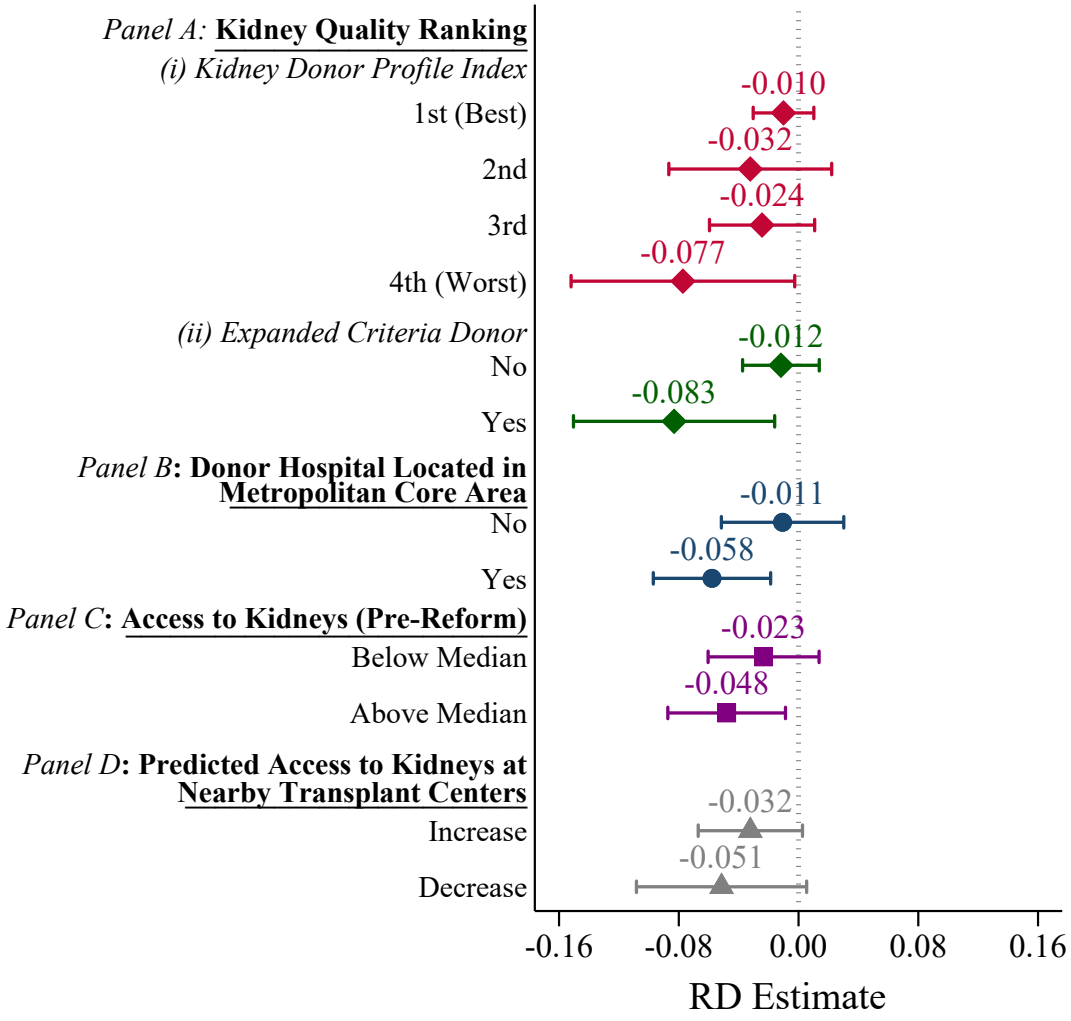


(b) By Reason for Discarding



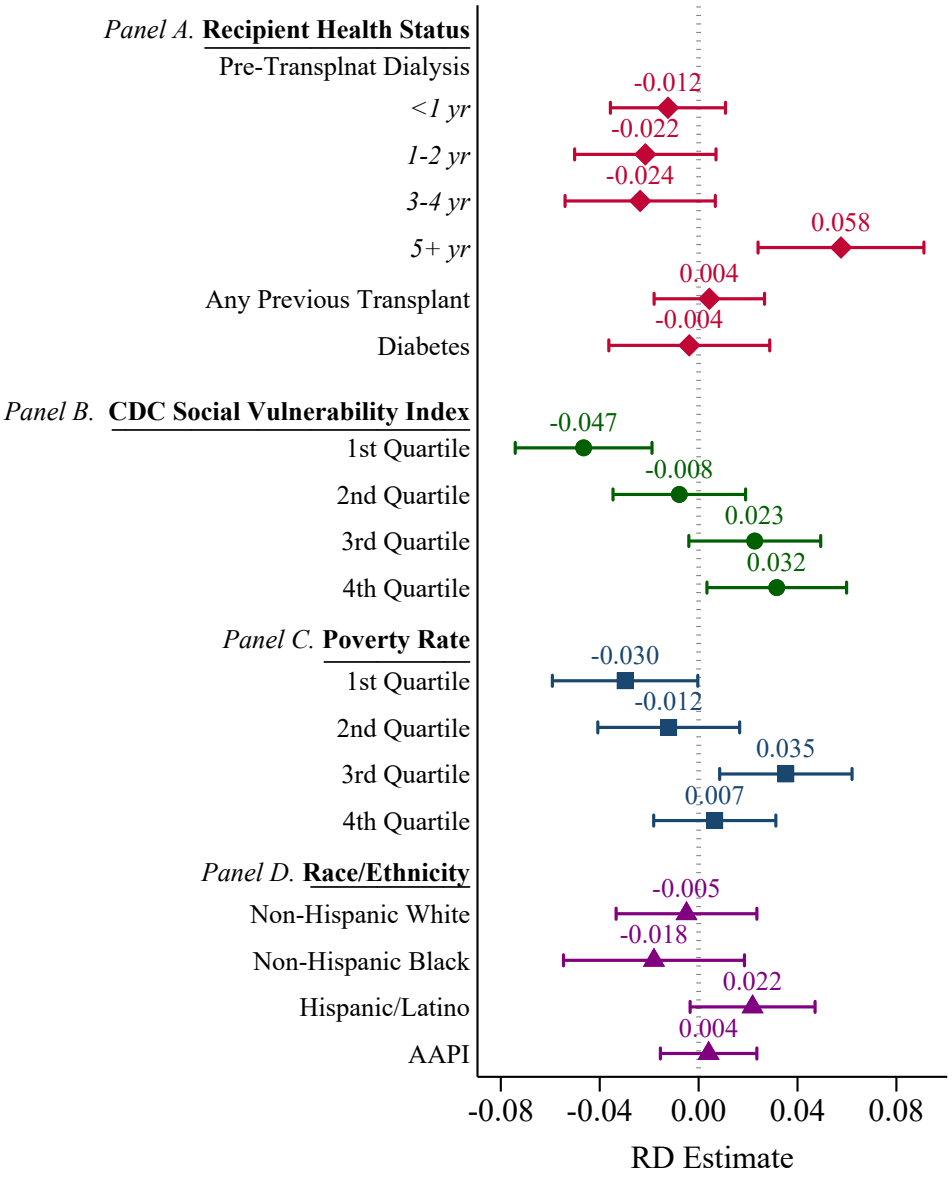
Notes: Figure 4 displays the share of deceased donor kidneys that are discarded by initial offer date relative to the allocation reform on March 15, 2021. Each dot represents two weeks. Figure 4b plots β from Eq. 3 and corresponding 95% confidence intervals. The outcomes are (1) an indicator of kidneys discarded and (2) indicators of kidneys discarded a) as they waited too long on the waitlist ("discarded due to list exhaustion"), b) due to organ quality concerns ("discarded due to donor quality"), and c) due to other factors ("others"). The date on the x-axis is the initial offer date. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys in the U.S. For more information on sample, see the notes to Table 1.

Figure 5: Heterogeneous Effects on the Likelihood a Kidney is Discarded



Notes: This figure plots β from Eq. 3 and corresponding 95% confidence intervals when an indicator of discarded kidneys is used as an outcome variable. Appendix Tables A.8-A.10 provide the corresponding RD estimates. Panel A illustrates how the effects on the discard rate vary by kidney quality. Panel B presents how the effects on use of donated kidneys vary by the location of donor hospital. Panel C illustrates how the change in discard rates following the reform varies between donor service areas with above-average and below-average kidney access prior to the reform. Panel D uses predicted changes in kidney access among nearby transplant centers from Eq. 2 to illustrate how the kidney discard rate varies with changes in access at these centers. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys in the U.S. For more information on sample, see the notes to Table 1.

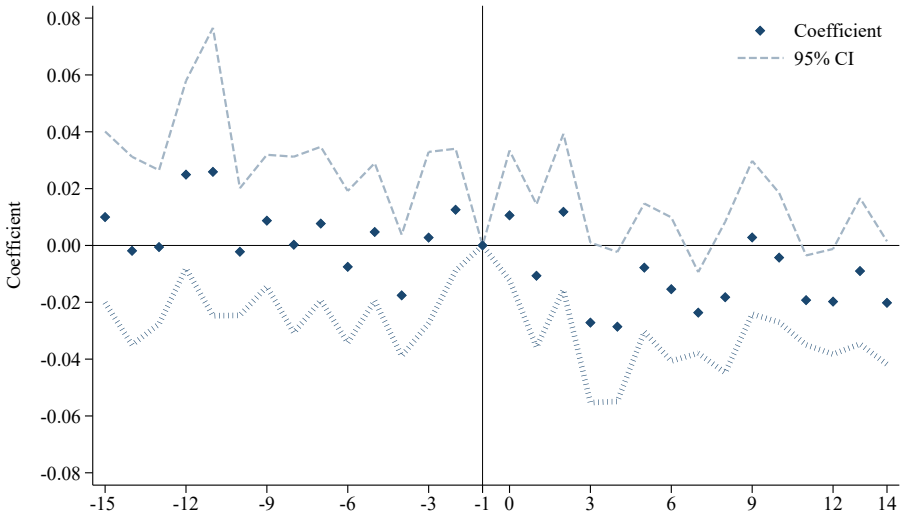
Figure 6: Effects on the Composition of Kidney Transplant Recipients



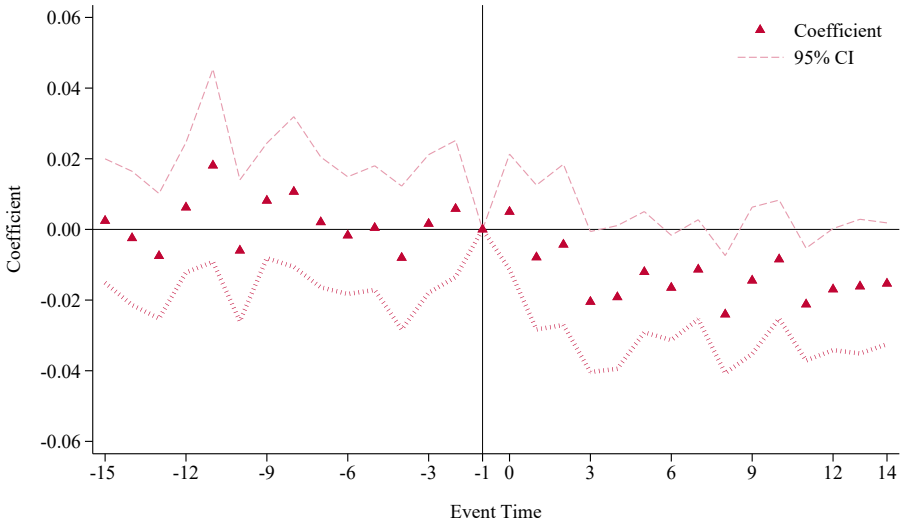
Notes: This figure presents β from Eq. 3 and corresponding 95% confidence intervals. Panel A presents the RD estimates when an indicator of four subgroups categorized by pre-transplant dialysis duration is used as the dependent variable: (1) zero years, (2) one to two years, (3) three to four years, and (4) five years or more. Panel B provides the RD estimates when an indicator for quartile groups based on the CDC social vulnerability index of counties where recipients live at the time of their transplant as the dependent variable. Panel C reports the RD estimates when an indicator for quartile groups based on the poverty rate of counties where recipients live at the time of their transplant as the dependent variable. Panel D provides the RD estimates when Eq. 3 is estimated by setting dependent variables as indicators for the race and ethnicity of transplant recipients. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys in the U.S. The sample consists of deceased donor kidneys in Table 3 used for transplant. Appendix Tables A.13-A.15 provide the corresponding regression tables.

Figure 7: Effects on Deaths Among Transplant Candidates

(a) Deaths Among Candidates on the Waitlist



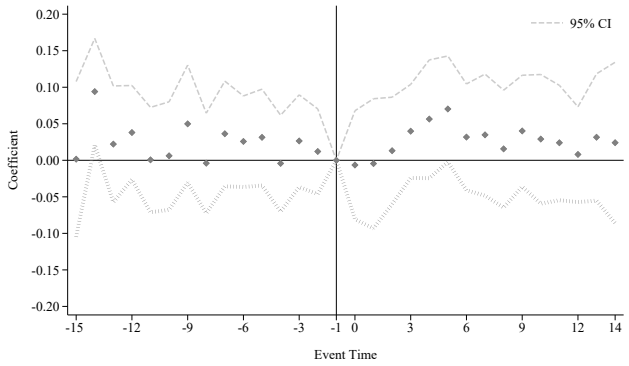
(b) All Candidate Deaths Within 5 Years of Entering Waitlist



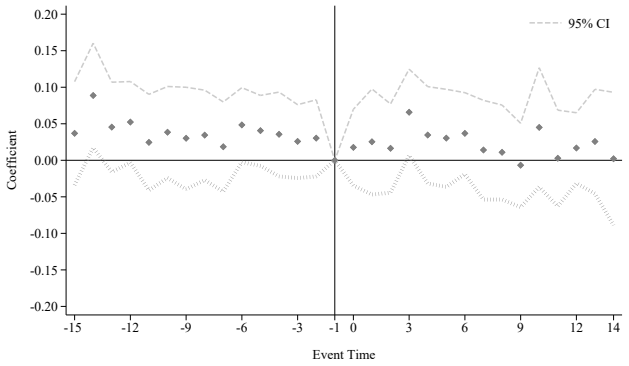
Notes: This figure displays the coefficients and their corresponding 95% confidence intervals obtained from the event-study design specified in Eq. 5. The outcomes are the monthly number of deaths on the waitlist (Panel A) and the number of transplant candidates' deaths within five years of waitlist registration per transplant center (Panel B). Event time is defined as the number of months since February 2021, a month before the policy change. The sample is limited to transplant centers with active transplant candidates prior to the policy change and not located in DSAs that did not experience any change in OPO affiliation through the sample period.

Figure 8: Event Study Figures on Post-Transplant Adverse Health Outcomes

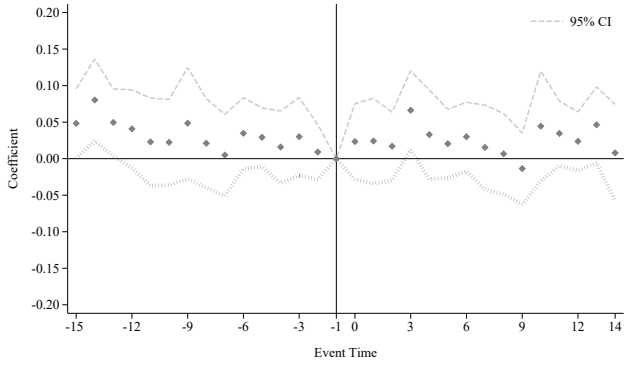
(a) within 3 months of transplant



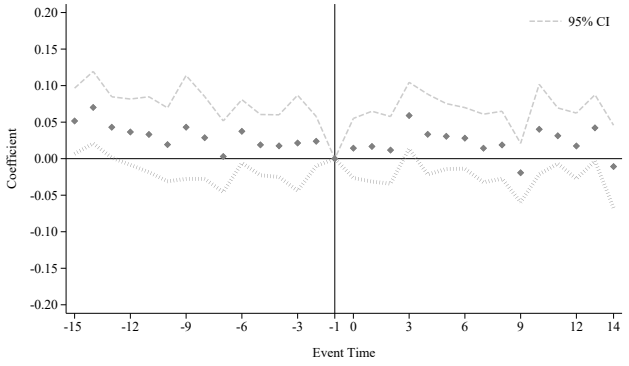
(b) within 6 months of transplant



(c) Within 9 months of transplant



(d) Within 12 months of transplant



Notes: This figure presents the coefficients and 95% confidence intervals from regressions estimation in Eq. 5. I define post-transplant adverse health outcomes as 1) deaths, 2) graft failure, and 3) resuming maintenance dialysis. The dependent variables used to construct each sub-figure are the number of transplant recipients ever experienced adverse health outcomes within 3, 6, 9, and 12 months of transplant, respectively. Event time refers to the number of months between transplant date and February 2021, a month prior to the policy change. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S.

Table 1: Descriptive Statistics

	(1) Mean
Panel A: Deceased Donor Kidneys *(N=23,466)*	
Share of discarded kidneys	0.230
a) Discarded due to list exhaustion	0.140
b) Discarded due to kidney/donor quality	0.065
c) Others	0.024
Blood O Type	0.480
KDPI 86-100%	0.165
Donor Hospital Characteristics	
Located in metropolitan core	0.576
Predicted decrease in access to kidneys at nearby transplant centers	0.451
Panel B: Transplant Recipients *(N=17,911)*	
Non-Hispanic white	0.375
Non-Hispanic black	0.344
Hispanic/Latino	0.197
Wait time (in days)	1580.372
County of residence	
CDC Social vulnerability index	0.561
Poverty rate	14.157
Panel C: Transplant Centers *(N=222)*	
Average active candidates per quarter	423.336
Centers with predicted increase in access to kidneys after the reform	0.478

Notes: The sample is drawn from the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys in the U.S. In Panel A, each observation is a donated kidney from a deceased donor. The sample is limited to (i) adult donors (18 or above), (ii) initial offer was made ± 196 days (28 weeks) from the cut-off, (iii) donors whose kidney biopsy information is complete, (iv) donor hospital located outside Alaska, (v) donor hospitals which did not experience any change in OPO affiliation through the sample period. "Share of kidneys discarded" is calculated by dividing the number of kidneys not used for transplant by the number of kidneys recovered for transplant. I use the reason for discard code for organ disposition to calculate the share of kidneys discarded: a) as they waited too long on the waitlist ("discarded due to list exhaustion"), b) due to organ quality concerns ("discarded due to donor quality"), and c) due to other factors ("others"). In Panel B, the sample covers 17,911 transplant recipients who (1) received transplants using kidneys included in the sample for Panel A (2) with non-missing candidate ID. In Panel C, descriptive statistics for transplant centers included in the transplant-center sample are provided. These transplant centers have at least one candidate waiting for a deceased donor kidney transplant prior to the policy change.

Table 2: Validity Test

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Kidney Quality Ranking (KDPI)				Donor Blood Type				Donor Hospital Characteristics	
	1st (Best)	2nd	3rd	4th (Worst)	A	B	AB	O	Metropolitan Core Area	Nearby Transplant Centers Reduced Access to Kidneys
1(OfferDate≥ c)	-0.0034	0.0183	-0.0043	-0.0106	0.0005	0.0102	0.0168	-0.0275	0.0074	-0.0119
	(0.0172)	(0.0135)	(0.0181)	(0.0153)	(0.0175)	(0.0073)	(0.0124)	(0.0207)	(0.0208)	(0.0212)
Mean, Pre-policy	0.186	0.134	0.519	0.161	0.378	0.031	0.104	0.486	0.571	0.478
Observations	23,466	23,466	23,466	23,466	23,466	23,466	23,466	23,466	23,466	23,466
Controls	No	No	No	No	No	No	No	No	No	No
Bandwidth	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days
Degree of polynomial	1	1	1	1	1	1	1	1	1	1
Weighting Scheme	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular
Std error	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster

Notes: This table provides the RD estimates of β in Eq. 3. Each column represents a separate regression in which the dependent variable is one of donor characteristics, as reported in the column headings. The sample includes deceased donor kidneys for which the initial offer was made ± 196 days (28 weeks) from the cut-off, March 15, 2021. The cut-off date is March 15, 2021. As the allocation system classifies kidneys into four subgroups based on Kidney Donor Profile Index (KDPI) to generate a nationwide waitlist, Columns 1-4 provide the RD estimates when the dependent variable is an indicator for (a) kidneys with KDPI 0-20% ("1st best"), (b) 21-34%, (c) 35-85%, and (d) 86-100% ("4th worst"). "Mean, Pre-policy" is the average of outcome variable between -1 and -196 days prior to the policy change. For more information on the sample, see the notes to Table 1. Standard errors are clustered at the initial offer date and are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Impact on Use of Deceased Donor Kidney

	(1)	(2)	(3)	(4)	(5)
	1(Transplanted	1(Discarded	Reason Code for Being Discarded		
	Within DSA)	Kidney)	1(Waited Too Long)	1(Organ quality)	1(Others)
1(OfferDate≥c)	-0.2341***	-0.0381***	-0.0331***	-0.0050	-0.0011
	(0.0157)	(0.0140)	(0.0119)	(0.0088)	(0.0053)
Mean, Pre-policy	0.548	0.223	0.126	0.070	0.025
Observations	23,466	23,466	23,466	23,466	23,466
Controls	Yes	Yes	Yes	Yes	Yes
Bandwidth	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days
Degree of polynomial	1	1	1	1	1
Weighting Scheme	Triangular	Triangular	Triangular	Triangular	Triangular
Std error	Cluster	Cluster	Cluster	Cluster	Cluster

Notes: This table provides the RD estimates of β in Eq. 3. Column (1) provides the impact on an indicator of kidneys finding recipient within the donor service area of donor hospital. Column (2) provides the impact on an indicator of discarded kidneys. Columns (3)-(5) report the impact on indicators of kidneys (a) discarded as they waited too long on the waitlist, (b) discarded due to organ quality concerns, and (c) discarded due to other factors, respectively. The sample includes deceased donor kidneys for which the initial offer was made ± 196 days (28 weeks) from the cut-off, March 15, 2021. The running variable is the initial offer date of kidneys. The cut-off date is March 15, 2021. Control variables include (a) gender of donor, (b) race/ethnicity of donor, (c) blood type of donor, and (d) donor's hypertension status. 'Mean, Pre-policy" is the average of outcome variable between -1 and -196 days prior to the policy change. For more information on the sample, see the notes to Table 1. Standard errors are clustered at the initial offer date and are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Placebo Test: Non-Kidney Samples

	(1)	(2)	(3)	(4)
	1(Discarded)	Reason Code for Being Discarded		
		1(Waited Too Long)	1(Organ quality)	1(Others)
Panel A. Non-Kidney Organs (Heart, Lung)				
1(OfferDate≥c)	0.0059	-0.0054	0.0072	0.0015
	(0.0104)	(0.0046)	(0.0078)	(0.0057)
Observations	11,615	11,615	11,615	11,615
Panel B. Heart				
1(OfferDate≥c)	0.0119	-0.0063	0.0133	0.0015
	(0.0142)	(0.0062)	(0.0107)	(0.0076)
Observations	8,258	8,258	8,258	8,258
Panel C. Lung				
1(OfferDate≥c)	-0.0097	-0.0035	-0.0082	0.0016
	(0.0103)	(0.0034)	(0.0058)	(0.0071)
Observations	3,357	3,357	3,357	3,357

Notes: This table provides the RD estimates of β in Eq. 3 using the data on the placebo sample. The sample consists of livers, hearts, and lungs recovered for transplant from the donors included in the kidney-level data. The cut-off date is March 15, 2021. "Mean, Pre-policy" is the average of outcome variable between -1 and - 196 days (28 weeks) prior to the policy change. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S. For more information on sample, see the notes to Table 1. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: Average Transplanted Kidney Characteristics – Travel Distance/Hours

	(1)	(2)	(3)	(4)
	Distance Between Donor Hospital and Transplant Center			Cold Storage
	Travel Distance (nm)	1(Within < 50 nm)	1(Within < 250 nm)	Hours
1(OfferDate≥c)	19.8353	-0.1819***	0.0351***	1.5598***
	(12.2534)	(0.0183)	(0.0127)	(0.2838)
Mean, Pre-policy	195.166	0.468	0.820	17.624
Observations	17,911	17,911	17,911	17,911
Controls	Yes	Yes	Yes	Yes
Bandwidth	± 196 days	± 196 days	± 196 days	± 196 days
Degree of polynomial	1	1	1	1
Weighting Scheme	Triangular	Triangular	Triangular	Triangular
Std error	Cluster	Cluster	Cluster	Cluster

Notes: This table provides the RD estimates of β in Eq. 3. The sample consists of deceased donor kidneys in Table 3 used for transplant. The running variable is the initial offer date of kidneys. Column 1 shows the effect on travel distance in nautical miles (nm; 1 nm = 1.15078 miles) between donor hospital and transplant center. Columns 2-3 present the effects on whether the transplant center is located within 50 and 250 nm of donor hospital, respectively. Column 4 reports the impact on cold ischemic hours, which measures the number of hours the kidney was in cold or chilled status (i.e., between being removed from the donor and the cold storage solution). Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys in the U.S. The cut-off date is March 15, 2021. "Mean, Pre-policy" is the average of outcome variable between -1 and -196 days prior to the policy change. Standard errors are clustered at the initial offer date and are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6: Monthly Transplant Center Outcomes: Transplant Candidates

	(1)	(2)	(3)	(4)	(5)
	Monthly Number of Transplant Candidates				
	Received Deceased Donor Kidney Transplant	Died on Waitlist	All Deaths ($\leq$ 5 years Joining Waitlist)	Received Living Donor Kidney Transplant	Newly Joined Waitlist
$\Delta Access_h * Post_{ym}$	0.01468**	-0.01631***	-0.01595***	0.00213	0.00222
	(0.00661)	(0.00617)	(0.00322)	(0.00506)	(0.00395)
Mean of Dep. Var (Pre)	6.241	1.922	2.864	1.879	11.601
Observation	6,660	6,660	6,660	6,660	6,660

Notes: This table reports the estimates of γ in Eq. 4. The transplant center-month data includes transplant centers with active transplant candidates prior to the policy change, not located in donor service areas that did not experience any change DSA affiliation through the sample period. Column 1 presents the impact on the number of deceased kidney transplants. Columns 2 and 3 reports the impact on the number of transplant candidates died on the waitlist and transplant candidates died within 5 years of entering the waitlist, respectively. The first measures deaths that may have been avoidable with a kidney transplant and the latter encompasses deaths that occur after waitlist removal due to deteriorated health and after transplants. Column 4 reports the impact on the number of living donor transplants. Column 5 reports the impact on the number of newly added candidates. "Mean of Dep-Var" is the average of outcome variable between -1 and -15 months prior to the policy change. Standard errors clustered at transplant center level are in parentheses. * p $<$ 0.1, ** p $<$ 0.05, *** p $<$ 0.01.

Table 7: Monthly Transplant Center Outcomes: Transplant Recipients

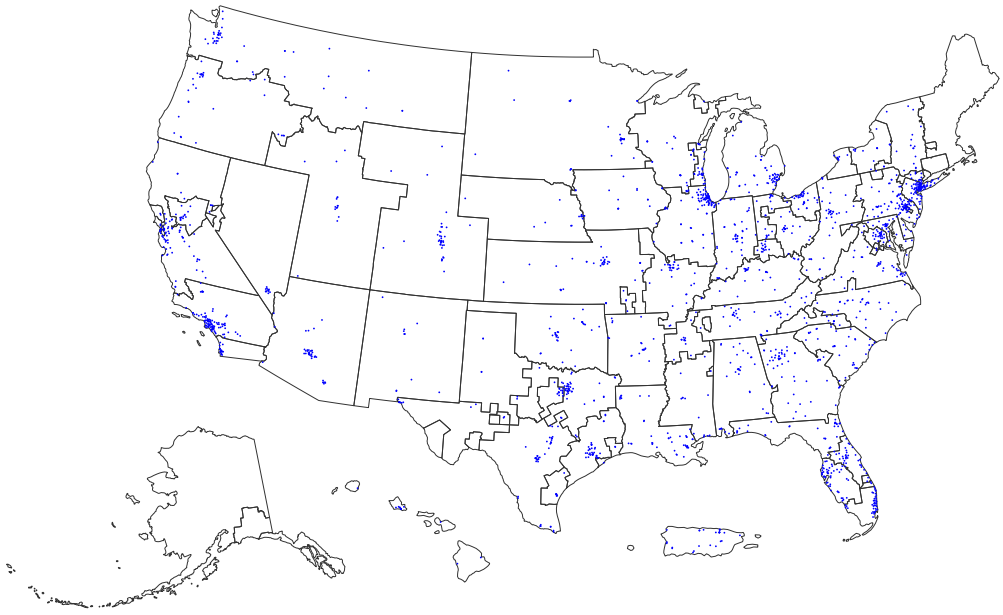
	(1)	(2)	(3)	(4)
	Monthly Number of Transplant Recipients Experiencing Adverse Health Outcomes after Kidney Transplant			
	≤3 months	≤6 months	≤9 months	≤12 months
$\Delta Access_h * Post_{ym}$	0.00260	-0.01319	-0.00428	-0.00712
	(0.01445)	(0.01102)	(0.00955)	(0.00782)
Mean of Dep. Var (Pre)	0.181	0.275	0.355	0.431
Observation	6,660	6,660	6,660	6,660

Notes: This table reports the estimates of γ in Eq. 4. I define post-transplant adverse health outcomes as 1) deaths, 2) graft failure, 3) resuming maintenance dialysis within 3, 6, 9, and 12 months of deceased donor kidney transplant. Columns 1-4 report the effects on the number of deaths of recipients within 3, 6, 9, 12 months of kidney transplant date. "Mean of Dep-Var" is the average of outcome variable between -1 and -15 months prior to the policy change. Figure 8 plots the estimates from Eq. 5 when monthly number of transplant recipients who experienced these adverse health outcomes within 3, 6, 9, and 12 months of transplant is used as a dependent variable in Eq. 5. Standard errors clustered at transplant center level are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

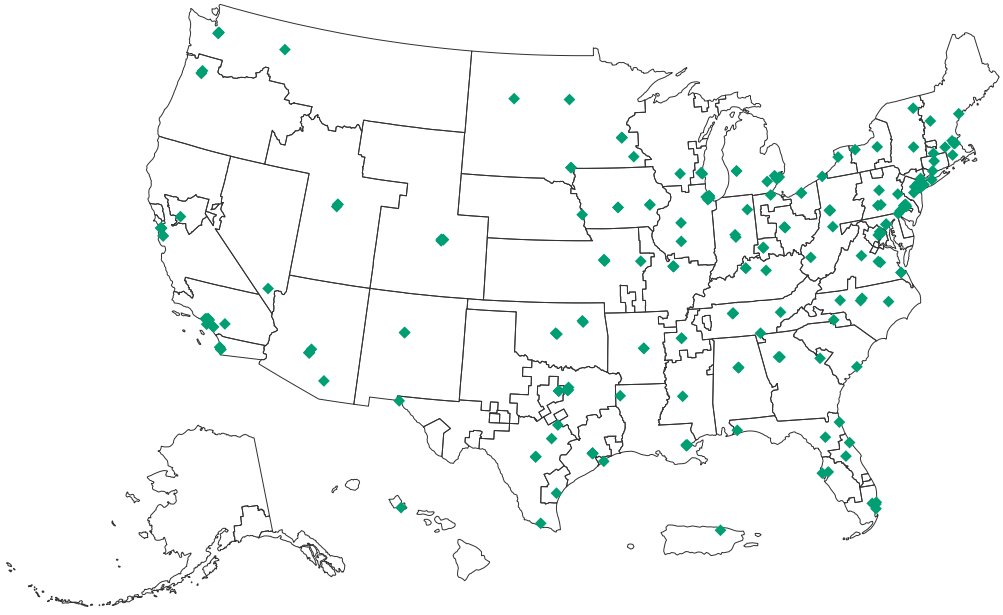
Appendix Figures and Tables

Figure A.1: Map of Donor Hospital and Transplant Center

(a) Donor Hospitals



(b) Transplant Centers



Notes: This figure shows geographic locations of 1,749 donor hospitals (Panel A) and 222 transplant centers (Panel B). Each dot shows the geographic coordinates of donor hospitals and transplant centers.

Figure A.2: Table 1 of Israni et al. (2014)

Table 1. Overview of the new kidney allocation policy, based on the KDPI[a] and EPTS[b]

Wait-Listed Candidates			
KDPI≤0.20	KDPI 0.21–0.34	KDPI 0.35–0.85	KDPI>0.85
Local CPRA 100%	Local CPRA 100%	Local CPRA 100%	Local CPRA 100%
Regional CPRA 100%	Regional CPRA 100%	Regional CPRA 100%	Regional CPRA 100%
National CPRA 100%	National CPRA 100%	National CPRA 100%	National CPRA 100%
Local CPRA 99%	Local CPRA 99%	Local CPRA 99%	Local CPRA 99%
Regional CPRA 99%	Regional CPRA 99%	Regional CPRA 99%	Regional CPRA 99%
Local CPRA 98%	Local CPRA 98%	Local CPRA 98%	Local CPRA 98%
0 HLA mm top 20	0 HLA mm	0 HLA mm	0 HLA mm
Prior living donors	Prior living donors	Prior living donors	Local, regional adult
Local pediatric	Local pediatric	Local	National adult
Local top 20	Local adult	Regional	
0 HLA mm bottom 80	Regional pediatric	National	
Local bottom 80	Regional adult		
Regional pediatric	National pediatric		
Regional top 20	National adult		
Regional bottom 80			
National pediatric			
National top 20			
National bottom 80			

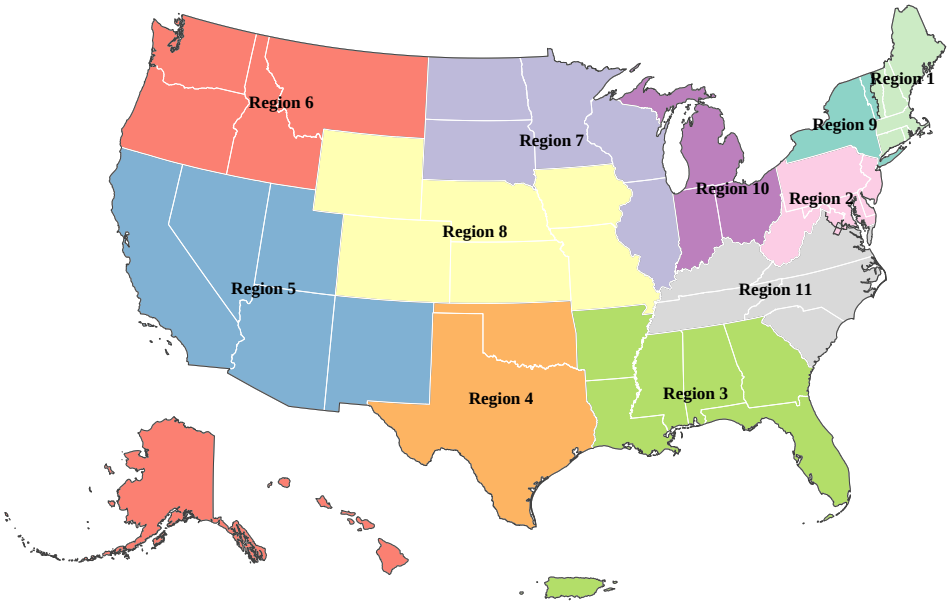
0 HLA mm designates candidates with zero HLA mismatch at A, B, and DR loci; top 20 designates candidates in the top 20th percentile of survival; bottom 80 designates candidates not in the top 20th percentile of survival. Both the new and the current allocation policies give priority to candidates listed for simultaneous kidney and non-kidney organ transplants, including kidney-pancreas, kidney-liver, and kidney-heart transplants. This is not shown in the table above and is not included in the KPSAM modeling. Prior living donors represent a small number of candidates who are not included in the KPSAM modeling. SCr, serum creatinine; CVA, cerebrovascular accident.

[a]KDPI is derived from the kidney donor risk index (KDRI) developed by Rao *et al.*[7] The KDPI includes only the donor-specific elements of the KDRI, and is mapped to a reference population from the previous year, in order to yield percentiles. For KDRI, the reference population is all kidneys recovered for transplant between January 1, 2007, and December 31, 2009. The calculation is as follows: KDRI=exp(−0.0194×I[age<18 yr]×[age−18 yr]+0.0128×[age−40 yr]+0.0107×I[age>50 yr] +0.179×I[race=African American]+0.126×I [hypertensive]+0.130×I[diabetic]+0.220×[SCr−1 mg/dl] −0.209×I[SCr>1.5 mg/dl]×[SCr−1.5 mg/dl]+0.0881×I[cause of death=CVA]−0.0464× [{height−170 cm}/10]−0.0199×I[weight<80 kg]×[{weight–80 kg}/5]+0.133×I[donation after cardiac death] +0.240×I[hepatitis C]−0.0766, where I is equal to 1 if the condition is true and I is equal to 0 if the condition is false.

[b]EPTS score=0.047×MAX (Age−25, 0)−0.015×Diabetes×MAX(Age–25,0)+0.398×Prior Organ Transplant −0.237×Diabetes×Prior Organ Transplant+0.315×log(Years on Dialysis+1)−0.099×Diabetes×log(Years on Dialysis+1)+0.130×(Years on Dialysis=0)−0.348×Diabetes×(Years on Dialysis=0)+1.262×Diabetes.

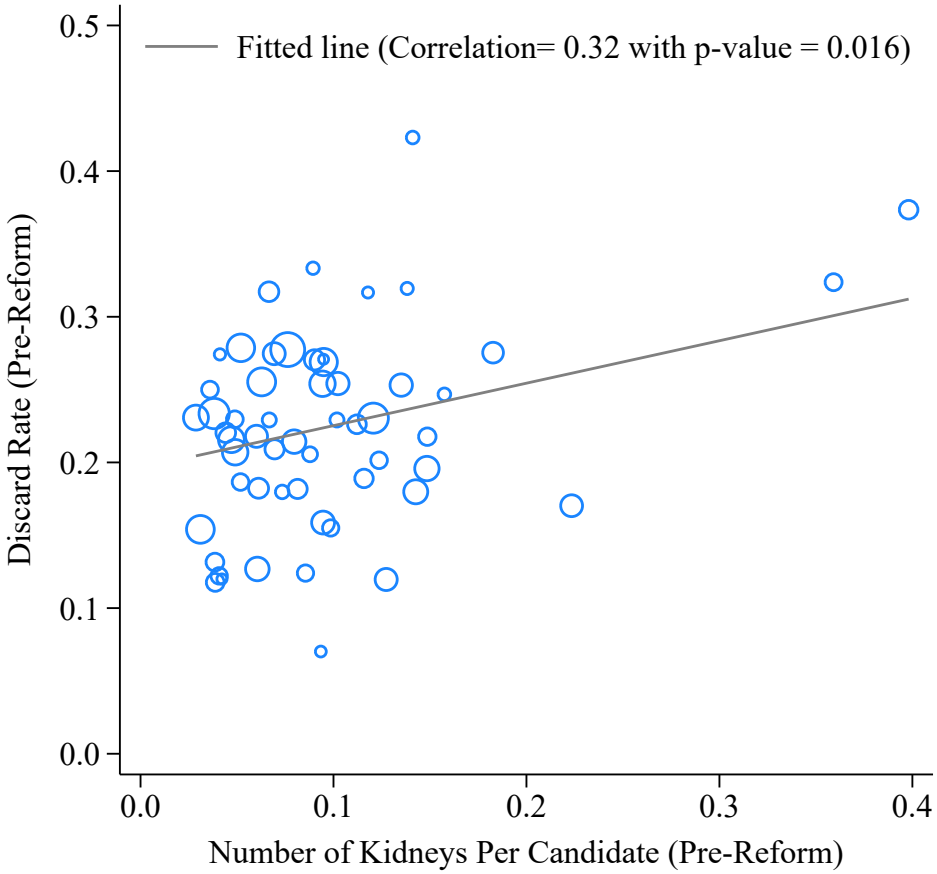
Notes: Appendix Figure A.2 describes how candidates are ranked in the national waitlist based on their health and demographic characteristics when kidney(s) becomes available from a deceased donor.

Figure A.3: Map of OPTN Region



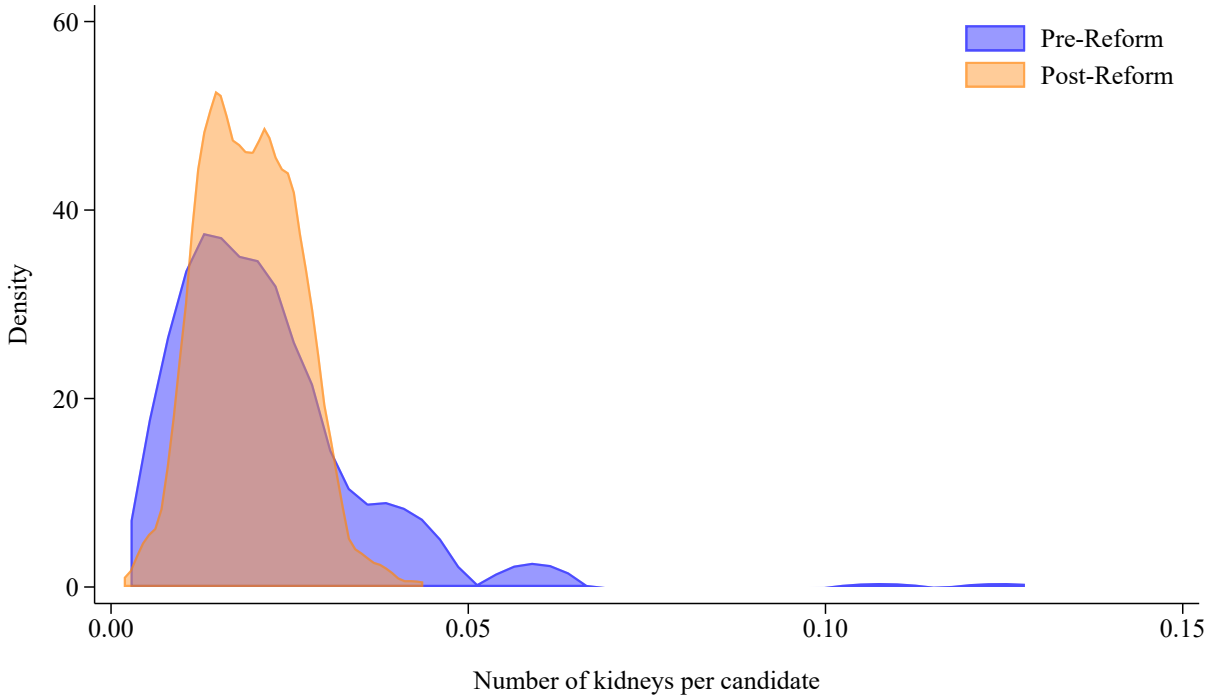
Notes: 11 OPTN regions were established in 1986 and there were no changes since then (Source: https://optn.transplant.hrsa.gov/about/regions/). For more information about OPTN regions, see section 2.

Figure A.4: Correlation between Discard Rate and Access to Kidneys prior to the Reform



Notes: This figure displays a scatterplot illustrating the relationship between the discard rate and average access to kidneys by "pre-reform" service area. Access to kidneys is defined as the quantity of available kidneys per candidate in a given "pre-reform" service area during the pre-reform period (i.e., January 2019-February 2021). Each data point on the scatterplot represents a "pre-reform" service area, with the size of the data point being proportionally weighted by the monthly number of kidneys recovered for transplant during the pre-reform period. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S.

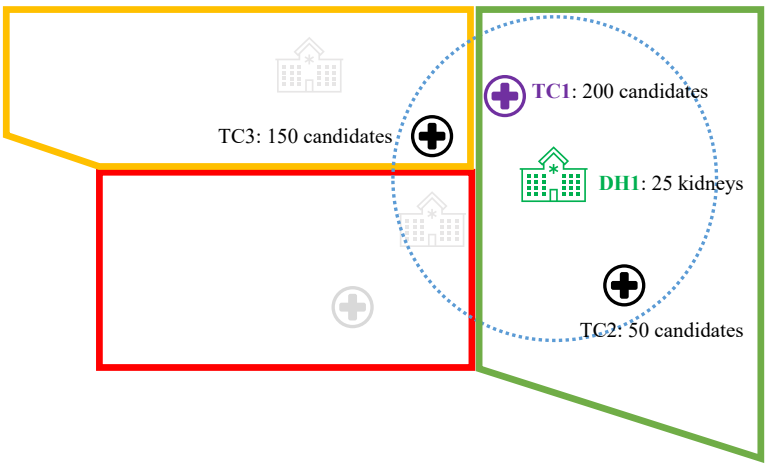
Figure A.5: Distribution of Predicted Access to Kidneys



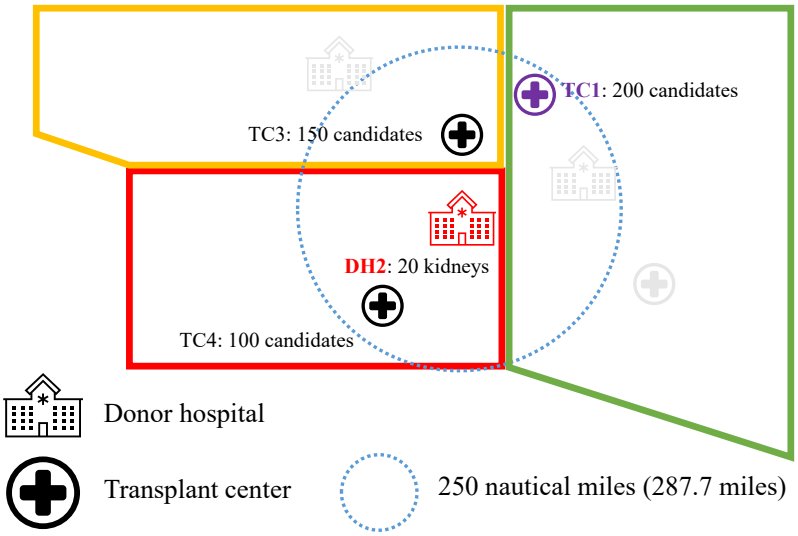
Notes: The figure presents the kernel density of predicted access to kidneys across transplant centers before and after the reform. Predicted access to kidneys is defined as the quantity of available kidneys per candidate in a given transplant center during the pre-reform period (i.e., January 2019-February 2021). Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S.

Figure A.6: Treatment Intensity: Numerical Example

(a) Panel A: Donor Hospital in Green DSA

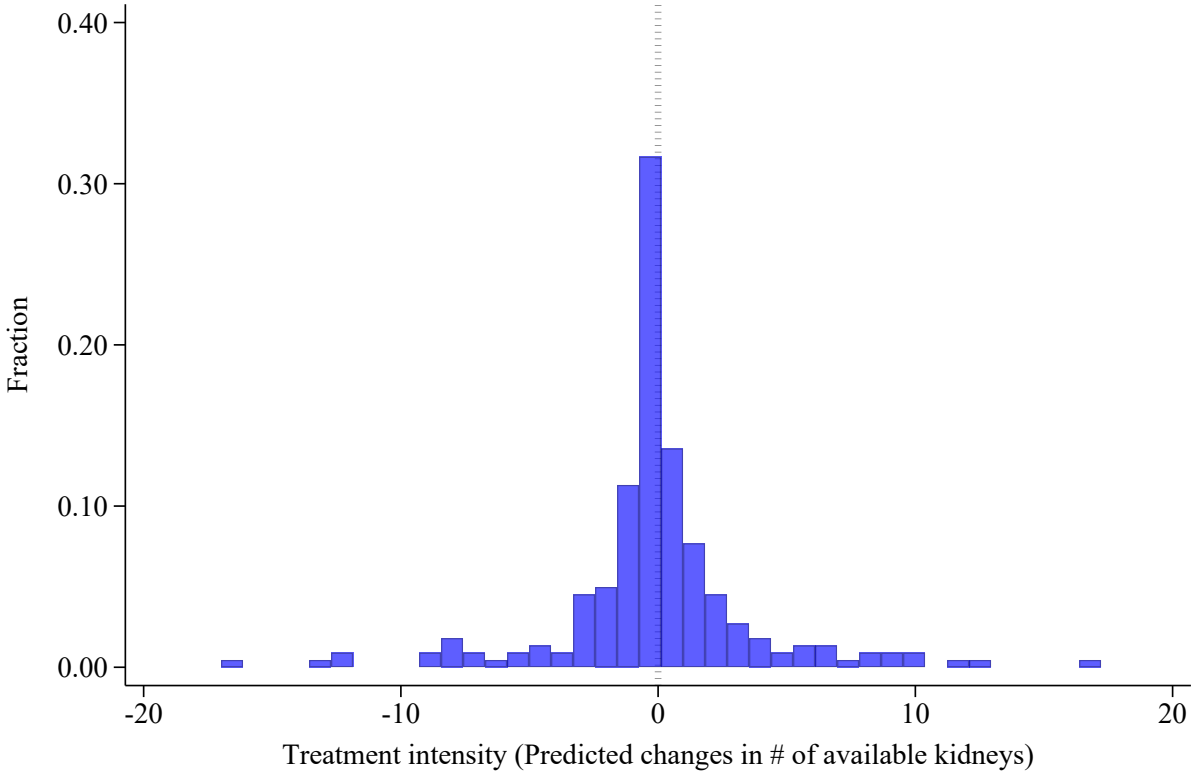


(b) Panel B: Donor Hospital in Red DSA



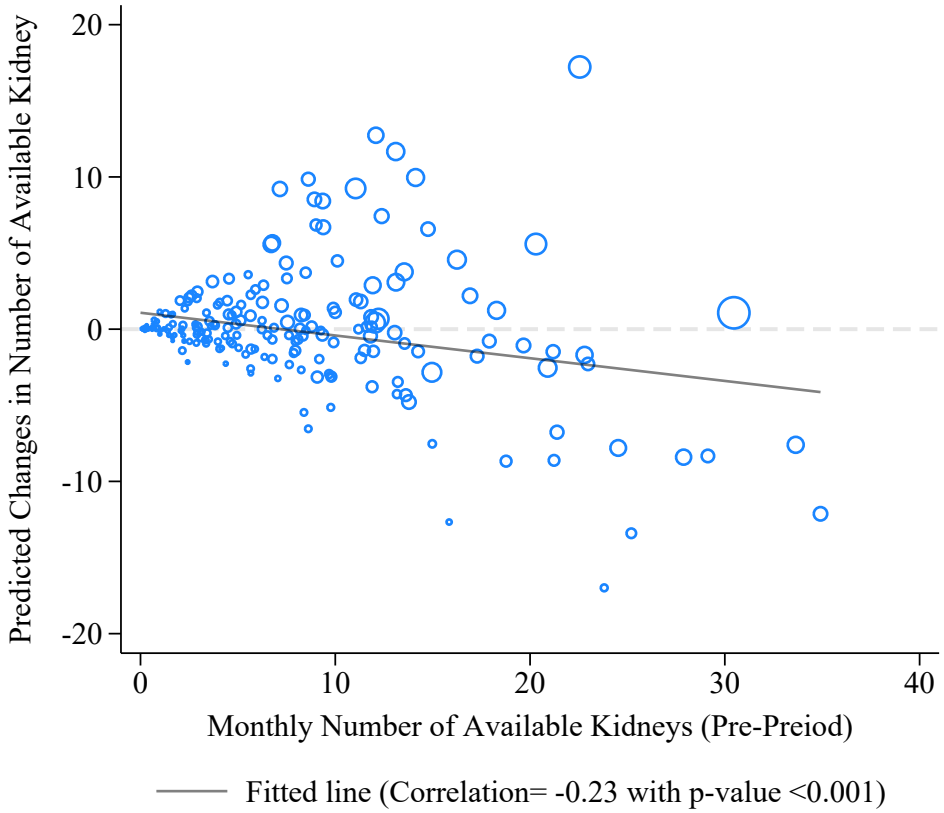
Notes: Consider an example where there are three DSA areas in a county that consists of three DSAs and there are two transplant centers in the green DSA, TC1 and TC2. Within this green DSA, a single donor hospital named DH1 recovers an average of 25 deceased donor kidneys per month. TC1 has approximately 200 active transplant candidates, while TC2 has around 50 active candidates. Given that there is only one donor hospital in the green DSA, transplant candidates listed at TC1 or TC2 receive priority access to kidneys recovered from DH1 compared to candidates listed at transplant centers outside the green DSA. Prior to the policy change, TC1 has access to 20 kidneys from DH1, which was calculated as $(= 25 * (200/(200 + 50)))$. In the post-period, TC1 now belongs to the initial offer group of two donor hospitals: DHI, located within the same DSA, and DH2, located in the red DSA, which recovers 20 kidneys monthly. In Panel A, DH1 is located within a 250nm radius of three transplant centers (TC1, TC2, TC3), with a total of 400 registered candidates across these centers. Similarly, DH2 is located within 250nm of three transplant centers (TC1, TC3, TC4), with a total of 450 registered candidates across these centers, in Panel B. As a result, TC1 is predicted to receive 12.5 $(=25 * (200/400))$ kidneys from DH1 and 8.9 $(\approx 20 * (200/450))$ kidneys from DH2 in the post-period. Therefore, the predicted change in available deceased donor kidneys for TC1 is 1.4 kidneys.

Figure A.7: Histogram of Predicted Changes in Number of Kidneys by Transplant Center



Notes: This figure provides a histogram of treatment intensity measure with a bin size 40. Eq. 1 is used to calculate this measure. Appendix Figure A.6 presents a numerical example of calculating the predicted changes in available deceased donor kidneys for each transplant center. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S.

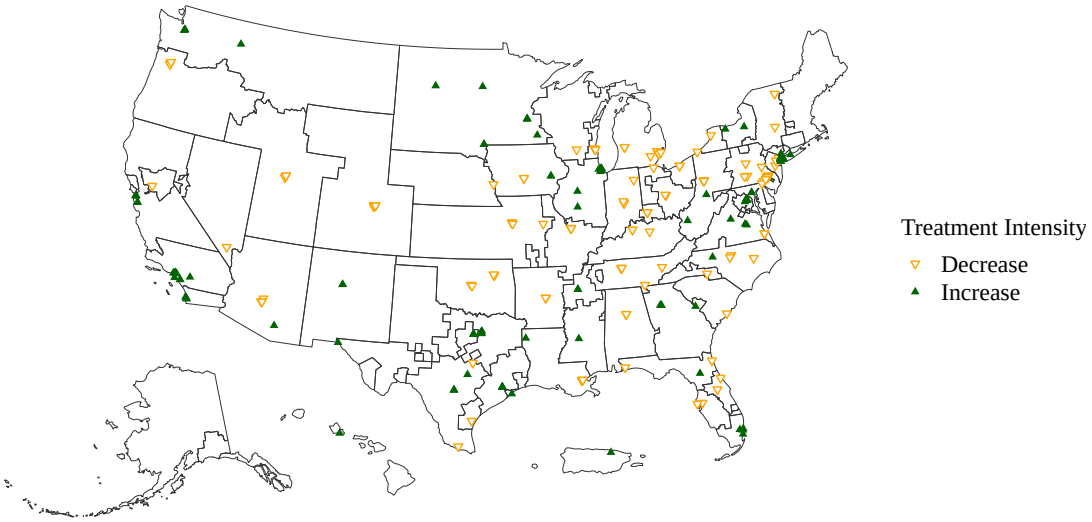
Figure A.8: Predicted Changes in Kidney Access and Pre-Reform Kidney Access



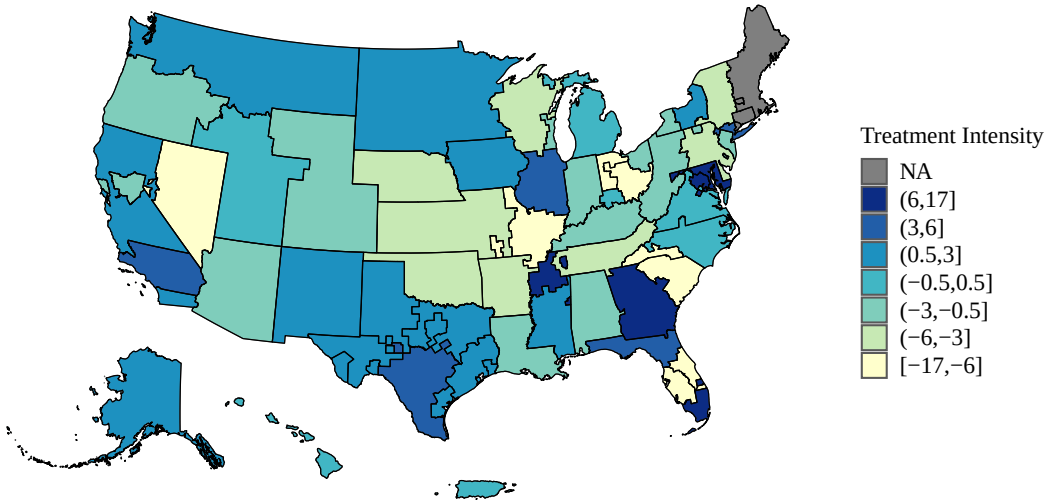
Notes: This figure displays a scatterplot illustrating the relationship between the monthly number of avaiable kidneys during pre-reform period and the predicted changes in kidney access by transplant center. Each data point on the scatterplot represents a transplant center. The correlation between these two measures, weighted by the size of the transplant center, is - 0.23 (p-value<0.001). Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S.

Figure A.9: Map of Treatment Intensity

(a) By Transplant Center

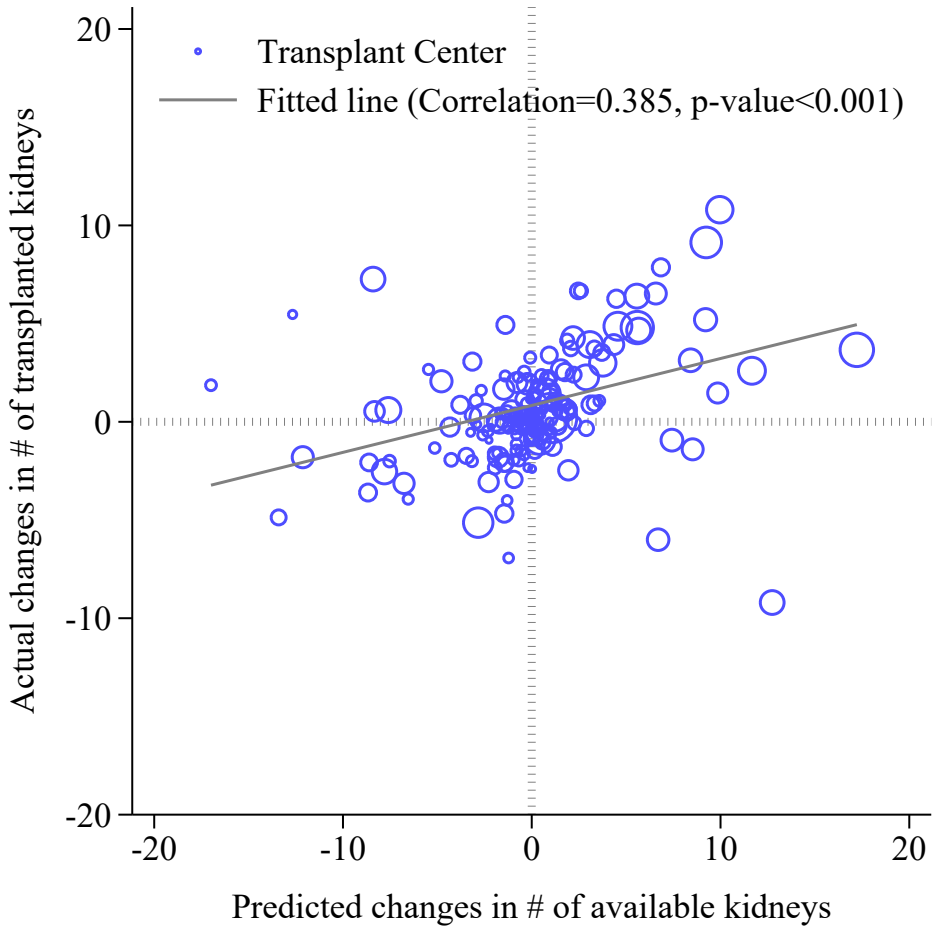


(b) By "Pre-Reform Service Area"



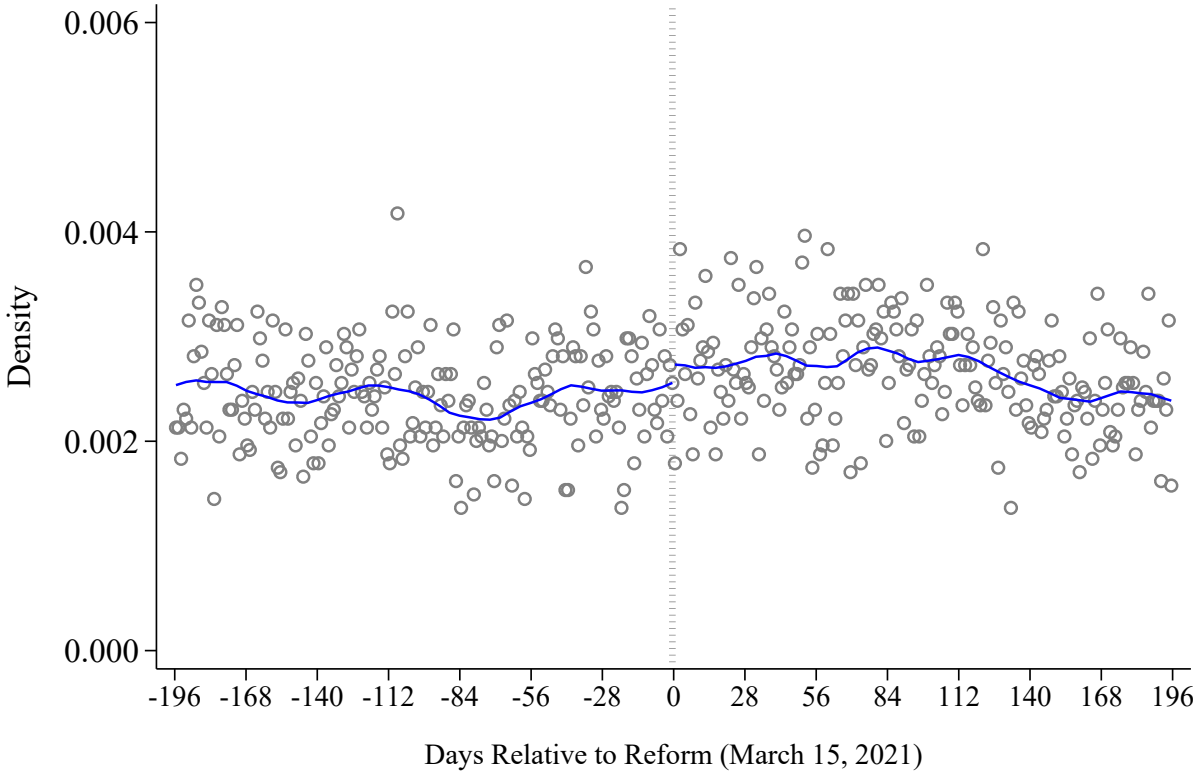
Notes: Eq. 1 calculates the predicted change in the number of available deceased donor kidneys for each transplant center based on pre-reform data. Appendix Figure A.9a illustrates the average treatment intensity mapped by transplant center. Appendix Figure A.9b depicts the average treatment intensity by Donor Service Area (DSA). Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys, transplant candidates, and transplant centers in the U.S.

Figure A.10: Correlation Between Predicted and Actual Changes in Kidney Access



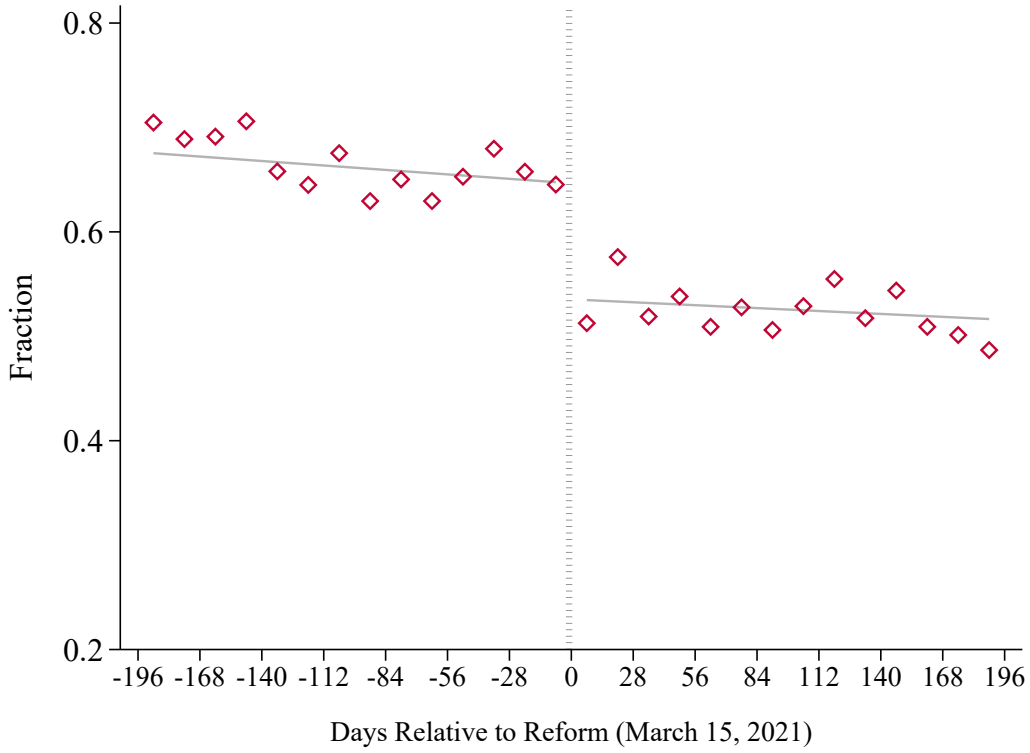
Notes: A scatterplot compares the predicted changes in available kidneys ("treatment intensity") against the actual changes in average deceased donor kidney transplant recipients within 15 months of the policy change. Predicted changes in the number of available deceased donor kidneys for transplant center h is calculated based on Eq. 1. Appendix Figure A.6 presents a numerical example of calculating the predicted changes in available deceased donor kidneys for each transplant center. The correlation between the predicted and actual changes, weighted by the size of the transplant center, is 0.385 (p-value<0.001).

Figure A.11: McCrary Density Test



Notes: The figure presents the density of deceased donor kidneys by their initial offer date. Each dot represents a single day. I use DCDensity.ado, which was written by Justin McCrary and Brian Kovak, to estimate a McCrary density test in Stata. The p-value of the McCrary density test is 0.1603. For more information on the sample, see the notes to Table 1.

Figure A.12: Share of kidneys finding the recipients within the same OPTN region



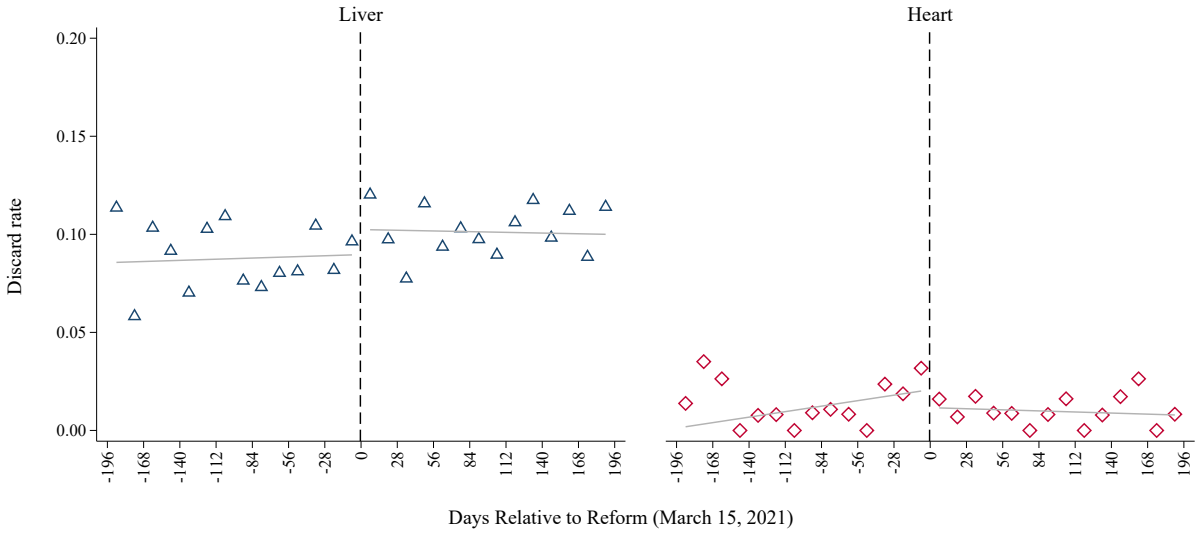
Notes: This figure shows the share of kidneys finding to the recipients within OPTN region by initial offer date relative to the allocation reform on March 15, 2021. Each dot represents two weeks. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys in the U.S. For more information on sample, see the notes to Table 1.

Figure A.13: Discard Rate by KDPI Score



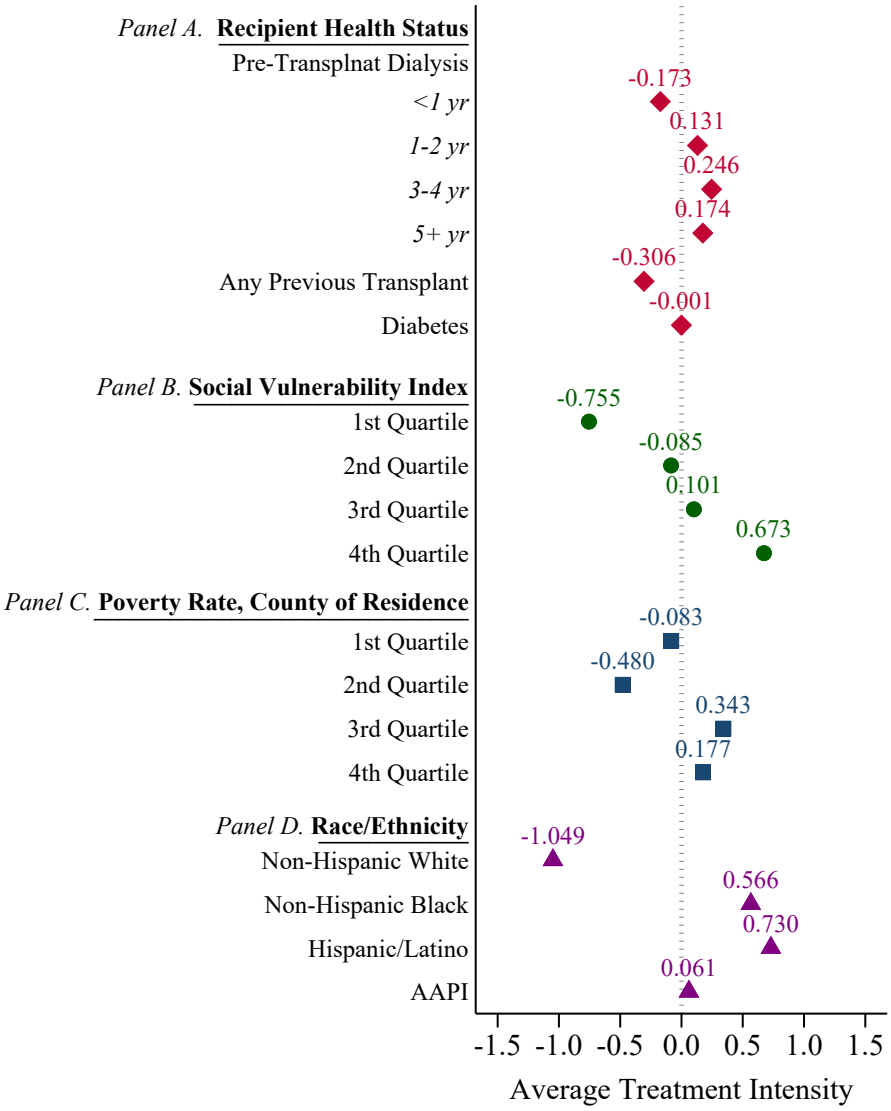
Notes: This figure shows the share of deceased donor kidneys that are discarded by initial offer date relative to the allocation reform on March 15, 2021 by kidney quality measure. Kidney Donor Profile Index (KDPI) is a kidney quality measure used to evaluate the expected likelihood of graft failure for a given for deceased donor kidney relative to other kidneys recovered in the last year. The sample is divided into four based on four KDPI categories used in the allocation system. Each dot represents two weeks. The date on the x-axis is the initial offer date. Each dot represents two weeks. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys in the U.S. For more information on sample, see the notes to Table 1.

Figure A.14: Placebo Test: Discard Rates for Liver and Heart



Notes: This table provides the RD estimates of β in Eq. 3 using the data on the placebo sample. The sample consists of livers, hearts, and lungs recovered for transplant from the donors included in the kidney-level data. The cut-off date is March 15, 2021. "Mean, Pre-policy" is the average of outcome variable between -1 and - 196 days (28 weeks) prior to the policy change. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S.

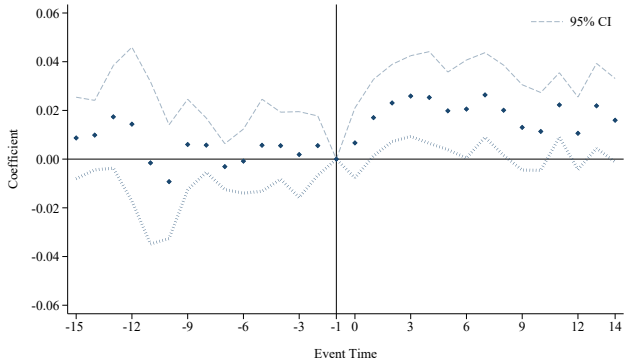
Figure A.15: Average Treatment Intensity across Transplant Candidate Subgroups



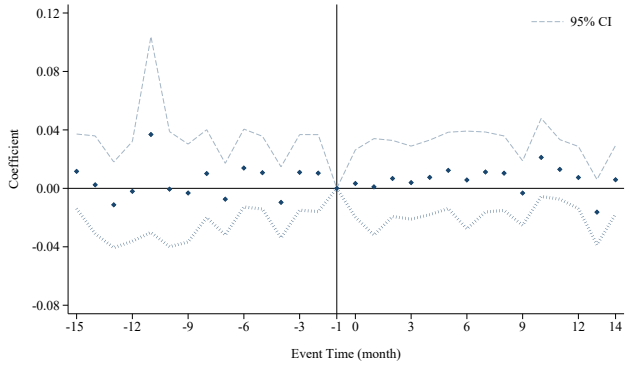
Notes: This figure presents the average treatment intensity for different transplant candidate subgroups: pre-dialysis duration/pre-transplant history/diabetes status (Panel A), CDC social vulnerability index (Panel B), poverty rate in 2019 (Panel C), and racial/ethnic groups of candidates (Panel D). The average treatment intensity for different subgroups is calculated based on transplant candidates who remain on the waitlist prior to the policy implantation date, March 15, 2021. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S.

Figure A.16: Event Study Figures on Outcomes of Transplant Centers

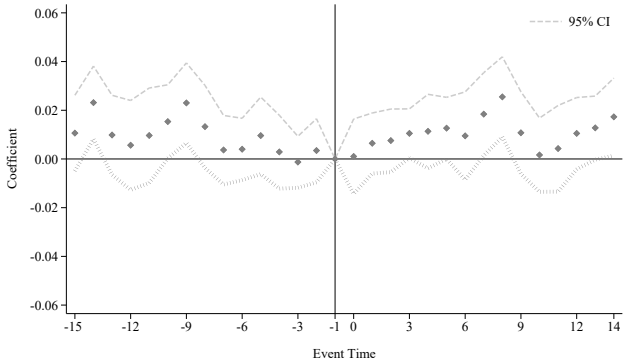
(a) Deceased Donor Kidney Transplant



(b) Living Donor Transplant

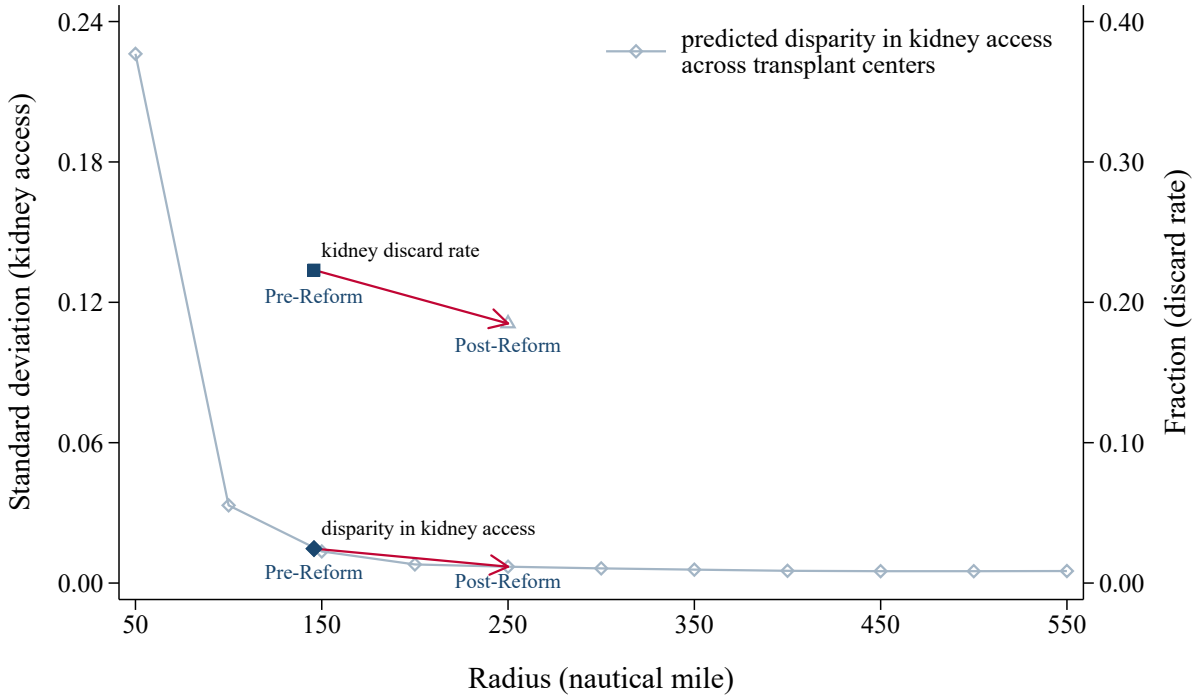


(c) Newly Joined to Waitlist



Notes: Figures A.16a-A.16c display the coefficients and 95% confidence intervals from regressions estimation in Eq. 5. Event time refers to the number of months from February 2021, a month before the policy change. The sample is limited to transplant centers with active transplant candidates at least 19 months prior to the policy change and not located in DSAs that did not experience any change in OPO affiliation through the sample period. Figure A.16a plots the event study coefficients and 95% confidence intervals when the outcome is the number of decease donor kidney transplant recipients. Figure A.16b plots the event study coefficients when the number of living donor kidney transplant recipients is used as a dependent variable in Eq. 5. Figures 7a plots the estimates when the number of transplant candidate deaths who died on the waitlist is used as a dependent variable in Eq. 5. Figure A.16c plots the event study estimates when the number of newly added candidates on the waitlist is used as a dependent variable in Eq. 5. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S.

Figure A.17: Use of Kidney and Predicted Dispersion in Kidney Access by Service Area Size



Notes: This figure shows how the dispersion of kidney access across transplant centers varies with the size of circular boundaries. Access to kidneys is defined as the number of available kidneys per candidate in a give transplant center. I use data from the pre-reform periods (i.e., January 2019-February 2021) to calculate the predicted number of available kidneys to transplant center to calculate the predicted number of available kidneys in the post-period. I calculate predicted kidney availability for each transplant center by adjusting different radius $r \in \{50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550\}$ in Equation 1. Y-axis on the left shows standard deviation of predicted access to kidneys across transplant centers. Y-axis on the right presents the share of donated kidneys recovered for transplant but discarded in the end. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S.

Table A.1: Kidney Allocation Point Calculation

(a) Before March 15, 2021

Transplant Candidate	Points Awarded
1) Waiting Time (in days)	$\frac{1}{365}$ points
2) Age 0-10, zero-HLA mismatch	4 points
3) Age 11-17, zero-HLA mismatch	3 points
4) Age 0-10, KDPI 0-35% kidney	1 point
5) Prior living donor	4 points
6) CPRA 20-100%	Table A.2
7) Single HLA-DR mismatch	1 point
8) Zero HLA-DR mismatch	2 points

(b) On/After March 15, 2021

Transplant Candidate	Points Awarded
1) Waiting Time (in days)	$\frac{1}{365}$ points
2) Age 0-10, zero-HLA mismatch	4 points
3) Age 11-17, zero-HLA mismatch	3 points
4) Age 0-10, KDPI 0-35% kidney	1 point
5) Prior living donor	4 points
6) CPRA 20-100%	Table A.2
7) Single HLA-DR mismatch	1 point
8) Zero HLA-DR mismatch	2 points
9) Distance between donor hospital and transplant center	
(i) $<$ 250nm	$2 - \left(\frac{2}{250} \times \text{distance}\right)$
(ii) 250nm -2499 nm	$4 - \left(\frac{4}{2500-250} \times (\text{distance} - 250)\right)$

Table A.2: Kidney Points Based on Transplant Candidate's CPRA Score

CPRA Score of Transplant Candidate	Points Awarded
0-19	0
20-29	0.08
30-39	0.21
40-49	0.34
50-59	0.48
60-69	0.81
70-74	1.09
75-79	1.58
80-84	2.46
85-89	4.05
90-94	6.71
95	10.82
96	12.17
97	17.3
98	24.4
99	50.09
100	202.1

Notes: This table shows the kidney allocation point calculation used to rank each candidate within the candidate category before and after the policy change. In Appendix Table A.2, the calculation of the kidney points considers the distance between the donor hospital and transplant center entered the kidney points (0-2 points) starting from March 21, 2021.

Table A.3: Validity Test: (1) Donor Demographics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Female	Age	Non-Hispanic White	Non-Hispanic Black	Hispanic /Latino	Body Mass Index	Recovered in Different State
1(OfferDate≥ c)	0.0153	-0.8364	0.0100	-0.0080	-0.0006	-0.2623	-0.0065
	(0.0210)	(0.6239)	(0.0158)	(0.0142)	(0.0143)	(0.2987)	(0.0100)
Mean, Pre-policy	0.389	43.352	0.726	0.143	0.132	28.892	0.082
Observations	23,466	23,466	23,466	23,466	23,466	23,466	23,466
Controls	No	No	No	No	No	No	No
Bandwidth	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days
Degree of polynomial	1	1	1	1	1	1	1
Weighting Scheme	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular
Std error	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster

Notes: This table provides the RD estimates of β in Eq. 3. Each column represents a separate regression in which the dependent variable is one of donor characteristics, as reported in the column headings. The sample includes deceased donor kidneys for which the initial offer was made ± 196 days (28 weeks) from the cut-off, March 15, 2021. The cut-off date is March 15, 2021. "Mean, Pre-policy" is the average of outcome variable between -1 and -196 days prior to the policy change. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S. For more information on sample, see the notes to Table 1. Standard errors are clustered at the initial offer date and are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A.4: Validity Test: (2) Donor's Consent Mechanism

	(1)	(2)	(3)
	Written Consent	Driver license	Donor Registry
1(OfferDate≥ c)	-0.0074	0.0044	-0.0072
	(0.0211)	(0.0161)	(0.0215)
Mean, Pre-policy	0.600	0.191	0.497
Observations	23,466	23,466	23,466
Controls	No	No	No
Bandwidth	± 196 days	± 196 days	± 196 days
Degree of polynomial	1	1	1
Weighting Scheme	Triangular	Triangular	Triangular
Std error	Cluster	Cluster	Cluster

Notes: This table provides the RD estimates of β in Eq. 3. Each column represents a separate regression in which the dependent variable is one of donor characteristics, as reported in the column headings. The sample includes deceased donor kidneys for which the initial offer was made ± 196 days (28 weeks) from the cut-off, March 15, 2021. The cut-off date is March 15, 2021. "Mean, Pre-policy" is the average of outcome variable between -1 and -196 days prior to the policy change. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S. For more information on sample, see the notes to Table 1. Standard errors are clustered at the initial offer date and are in parentheses. * p < 0.1, ** p < 0.05, *** p < 0.01.

Table A.5: Validity Test: (3) Donor's Cause of Death

	(1)	(2)	(3)	(4)	(5)
	Brain	Circumstances of Death			
	Death	Natural Causes	MVA	Suicide/Homicide	Non-MVA/Others
1(OfferDate≥ c)	0.0022	-0.0269	0.0172	-0.0120	0.0217
	(0.0154)	(0.0211)	(0.0122)	(0.0131)	(0.0167)
Mean, Pre-policy	0.715	0.464	0.114	0.137	0.285
Observations	23,466	23,466	23,466	23,466	23,466
Controls	No	No	No	No	No
Bandwidth	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days
Degree of polynomial	1	1	1	1	1
Weighting Scheme	Triangular	Triangular	Triangular	Triangular	Triangular
Std error	Cluster	Cluster	Cluster	Cluster	Cluster

Notes: This table provides the RD estimates of β in Eq. 3. Each column represents a separate regression in which the dependent variable is one of donor characteristics, as reported in the column headings. The sample includes deceased donor kidneys for which the initial offer was made ± 196 days (28 weeks) from the cut-off, March 15, 2021. The cut-off date is March 15, 2021. "Mean, Pre-policy" is the average of outcome variable between -1 and -196 days prior to the policy change. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S. For more information on sample, see the notes to Table 1. Standard errors are clustered at the initial offer date and are in parentheses. * p < 0.1, ** p < 0.05, *** p < 0.01.

Table A.6: Validity Test: (4) Donor's Health Status

	(1)	(2)	(3)	(4)	(5)
	Donation after Circulatory Death	Kidney Donor Risk Index	Expanded Criteria Donor Kidney	Cancer History	HCV Positive
1(OfferDate≥ c)	-0.0102	-0.0224	-0.0225	0.0089	0.0054
	(0.0166)	(0.0167)	(0.0166)	(0.0074)	(0.0127)
Mean, Pre-policy	0.337	1.100	0.235	0.033	0.114
Observations	23,466	23,466	23,466	23,466	23,466
Controls	No	No	No	No	No
Bandwidth	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days
Degree of polynomial	1	1	1	1	1
Weighting Scheme	Triangular	Triangular	Triangular	Triangular	Triangular
Std error	Cluster	Cluster	Cluster	Cluster	Cluster

Notes: This table provides the RD estimates of β in Eq. 3. Each column represents a separate regression in which the dependent variable is one of donor characteristics, as reported in the column headings. The sample includes deceased donor kidneys for which the initial offer was made ± 196 days (28 weeks) from the cut-off, March 15, 2021. Standard errors are clustered at the running variable The cut-off date is March 15, 2021. "Mean, Pre-policy" is the average of outcome variable between -1 and -196 days prior to the policy change. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S. For more information on sample, see the notes to Table 1. Standard errors are clustered at the initial offer date and are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A.7: Results on the Likelihood a Kidney finds a Recipient within OPTN Region and State

	(1)	(2)
	Kidney Found Transplant Recipient	
	Within OPTN Region	Within State
1(OfferDate≥c)	-0.1195***	-0.1437***
	(0.0147)	(0.0145)
Mean, Pre-policy	0.666	0.517
Observations	23,466	23,466
Controls	Yes	Yes
Bandwidth	± 196 days	± 196 days
Degree of polynomial	1	1
Weighting Scheme	Triangular	Triangular
Std error	Cluster	Cluster

Notes: This table provides the RD estimates of β in Eq. 3. Column (1) reports the impact on an indicator of kidneys finding recipient within the OPTN region of donor hospital. Column (2) reports the impact on an indicator of kidneys finding recipient within the state of donor hospital. The running variable is the initial offer date of kidneys. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S. The cut-off date is March 15, 2021. For more information on sample, see the notes to Table 1. "Mean, Pre-policy" is the average of outcome variable between -1 and -196 days prior to the policy change. Standard errors are clustered at the initial offer date and are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A.8: Results on the Likelihood a Kidney is Discarded by Kidney Quality

	(1)	(2)	(3)	(4)	(5)	(6)
	Kidney Donor Profile Index (KDPI)				Expanded Criteria Donor	
	0-20	21-34	35-85	86-100	No (SCD)	Yes (ECD)
1(OfferDate≥c)	-0.0100	-0.0322	-0.0244	-0.0773**	-0.0118	-0.0832**
	(0.0103)	(0.0277)	(0.0179)	(0.0380)	(0.0130)	(0.0342)
Mean, Pre-policy	0.030	0.066	0.202	0.646	0.128	0.531
Share, Subgroup	0.179	0.135	0.521	0.165	0.768	0.232
Observations	4,209	3,161	12,231	3,865	18,033	5,433
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Bandwidth	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days
Degree of polynomial	1	1	1	1	1	1
Weighting Scheme	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular
Std error	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster

Notes: This table provides the RD estimates of β in Eq. 3, when the outcome is an indicator of discarded deceased donor kidneys. The cut-off date is March 15, 2021. Columns (1)-(4) use the sample of kidneys with KDPI (1) 0-20%, (2) 21-34%, (3) 35-85%, and (4) 86-100%, respectively. Columns (5)-(6) use the sample of kidneys classified as "standard criteria donor" (SCD) and "expanded criteria donor" (ECD), respectively. Prior to 2014, the kidney allocation system classified kidneys into two types: ECD or SCD kidneys. ECD kidneys are those recovered from donors (1) 60 or older or (2) aged 50–59 with two or three of the following conditions: high blood pressure, creatinine levels of 1.5 or higher, or death due to stroke. SCD kidneys refer to kidneys that are not categorized as ECD kidneys. The running variable is the initial offer date of kidneys. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S. For more information on sample, see the notes to Table 1. "Mean, Pre-policy" is the average of outcome variable between -1 and -196 days prior to the policy change. Standard errors are clustered at the initial offer date and are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A.9: Results on the Likelihood a Kidney is Discarded by Donor Hospital Location

	(1)	(2)
	Donor Hospital Location: Metropolitan, Core	
	Yes	No
1(OfferDate≥c)	-0.0578***	-0.0107
	(0.0199)	(0.0208)
Mean, Pre-policy	0.229	0.215
Observations	13,510	9,956
Controls	Yes	Yes
Bandwidth	± 196 days	± 196 days
Degree of polynomial	1	1
Weighting Scheme	Triangular	Triangular
Std error	Cluster	Cluster

Notes: This table provides the RD estimates of β in Eq. 3, when the outcome is an indicator of discarded deceased donor kidneys. "Mean, Pre-policy" is the average of outcome variable between -1 and -196 days prior to the policy change. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S. For more information on sample, see the notes to Table 1. Standard errors are clustered at the initial offer date and are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A.10: Results on the Likelihood a Kidney is Discarded by Donor Hospital

	(1)	(2)
	Donor Hospital Characteristics: Nearby Transplant Centers Predicted to Increase in Kidney Access after the Reform	
	No	Yes
1(OfferDate≥c)	-0.0539*	-0.0310*
	(0.0280)	(0.0177)
Mean, Pre-policy	0.226	0.221
Share, Subgroup	0.346	0.654
Observations	8,115	15,351
Controls	Yes	Yes
Bandwidth	± 196 days	± 196 days
Degree of polynomial	1	1
Weighting Scheme	Triangular	Triangular
Std error	Cluster	Cluster

Notes: This table provides the RD estimates of β in Eq. 3, when the outcome is an indicator of deceased donor kidneys that are discarded. Column (1) reports the impact on the share of discarded kidneys from donor hospitals whose nearby transplant centers are predicted to decrease on average after the policy change. Column (2) provides the impact on the share of discarded kidneys from donor hospitals whose nearby transplant centers are predicted to increase on average after the reform. The running variable is the initial offer date of kidneys. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S. The cut-off date is March 15, 2021. For more information on the sample, see the notes to Table 1."Mean, Pre-policy" is the average of outcome variable between -1 and -196 days prior to the policy change. Standard errors are clustered at the initial offer date and are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A.11: Robustness Check

	(1)	(2)	(3)	(4)	(5)	(6)
	1(Transplanted	1(Transplanted	1(Discarded	Reason Code for Being Discarded		
	Within DSA)	Within OPTN Region)	Kidney)	1(Waited Too Long)	1(Organ quality)	1(Others)
Panel A. Main Specification						
1(OfferDate≥c)	-0.2349***	-0.1157***	-0.0384***	-0.0334***	-0.0051	-0.0011
	(0.0156)	(0.0151)	(0.0140)	(0.0120)	(0.0089)	(0.0053)
Panel B. No Covariates						
1(OfferDate≥c)	-0.2351***	-0.1154***	-0.0379***	-0.0325***	-0.0054	-0.0011
	(0.0154)	(0.0153)	(0.0144)	(0.0120)	(0.0090)	(0.0053)
Panel C. No Weighting						
1(OfferDate≥c)	-0.2245***	-0.1028***	-0.0409***	-0.0284**	-0.0113	-0.0021
	(0.0145)	(0.0145)	(0.0131)	(0.0111)	(0.0080)	(0.0050)
Panel D. Local Linear Specification						
1(OfferDate≥c)	-0.2371***	-0.1184***	-0.0378***	-0.0343***	-0.0039	-0.0009
	(0.0163)	(0.0156)	(0.0145)	(0.0124)	(0.0092)	(0.0055)
Panel E. Bandwith ± 22 weeks						
1(OfferDate≥c)	-0.2386***	-0.1223***	-0.0357**	-0.0358***	-0.0014	-0.0001
	(0.0174)	(0.0165)	(0.0156)	(0.0134)	(0.0099)	(0.0059)
Panel F. Bandwith ± 24 weeks						
1(OfferDate≥c)	-0.2378***	-0.1201***	-0.0369**	-0.0348***	-0.0029	-0.0007
	(0.0168)	(0.0160)	(0.0150)	(0.0129)	(0.0095)	(0.0057)
Panel G. Bandwith ± 26 weeks						
1(OfferDate≥c)	-0.2369***	-0.1183***	-0.0379***	-0.0343***	-0.0040	-0.0009
	(0.0162)	(0.0155)	(0.0145)	(0.0124)	(0.0092)	(0.0055)
Panel G. Bandwith ± 30 weeks						
1(OfferDate≥c)	-0.2329***	-0.1130***	-0.0390***	-0.0326***	-0.0063	-0.0012
	(0.0151)	(0.0147)	(0.0135)	(0.0116)	(0.0086)	(0.0052)
Panel H. Bandwith ± 32 weeks						
1(OfferDate≥c)	-0.2306***	-0.1108***	-0.0397***	-0.0323***	-0.0069	-0.0014
	(0.0147)	(0.0143)	(0.0131)	(0.0112)	(0.0083)	(0.0050)
Panel I. Bandwith ± 34 weeks						
1(OfferDate≥c)	-0.2298***	-0.1097***	-0.0398***	-0.0312***	-0.0076	-0.0017
	(0.0143)	(0.0140)	(0.0128)	(0.0109)	(0.0081)	(0.0049)

Notes: This table provides the RD estimates of β in Eq. 3 using a number of alternatives to my baseline specification (Panel A): 1) excluding X_i (Panel B), 2) without the triangular weights (Panel C), 3) setting f() as a local linear function form (Panel D), and 4) using alternative choices of bandwidth length (Panels E-I). The sample consists of deceased donor kidneys recovered for transplant. The cut-off date is March 15, 2021. "Mean, Pre-policy" is the average of outcome variable between -1 and -196 days prior to the policy change. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S. For more information on the sample, see the notes to Table 1. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A.12: Average Transplant Recipient Characteristics – Number of HLA Typing Mismatch

	(1)	(2)	(3)	(4)	(5)
	Number of HLA Typing Mismatchs				
	Raw count	0	1 or 2	3 or 4	5 or 6
1(OfferDate≥c)	-0.0380	-0.0002	0.0113	-0.0026	-0.0085
	(0.0498)	(0.0071)	(0.0074)	(0.0160)	(0.0173)
Mean, Pre-policy	4.209	0.044	0.056	0.410	0.489
Observations	17,878	17,878	17,878	17,878	17,878
Controls	Yes	Yes	Yes	Yes	Yes
Bandwidth	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days
Degree of polynomial	1	1	1	1	1
Weighting Scheme	Triangular	Triangular	Triangular	Triangular	Triangular
Std error	Cluster	Cluster	Cluster	Cluster	Cluster

Notes: This table provides the RD estimates of β in Eq. 3 using the sample of deceased donor kidney transplant recipients. Column (1) reports the impact on average number of HLA mismatches. Columns 2-5 report the RD estimated when the dependent variable is an indicator of zero HLA mismatch (Column 2), one or two HLA mismatches (Column 3), three or four HLA mismatches (Column 4), and five or six HLA mismatches(Column 5), respectively. The sample consists of deceased donor kidneys in Table 3 used for transplant. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys in the U.S. The cut-off date is March 15, 2021. For more information on the sample, see the notes to Table 1. "Mean, Pre-policy" is the average outcome variable between -1 and -196 days before the policy change. Standard errors are clustered at the running variable and in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A.13: Average Transplant Recipient Characteristics – Recipient Health Status

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Number of Years	By Number of Years				Previous	Diabetes
	on Dialysis	< 1	1-2	3-4	5+	Transplant	History
1(OfferDate$\geq$c)	0.3526***	-0.0124	-0.0216	-0.0236	0.0576***	0.0043	-0.0038
	(0.1259)	(0.0118)	(0.0145)	(0.0155)	(0.0171)	(0.0114)	(0.0166)
Mean, Pre-policy	3.683	0.207	0.226	0.218	0.349	0.125	0.411
Observations	17,911	17,911	17,911	17,911	17,911	17,911	17,911
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bandwidth	$\pm$ 196 days	$\pm$ 196 days	$\pm$ 196 days	$\pm$ 196 days	$\pm$ 196 days	$\pm$ 196 days	$\pm$ 196 days
Degree of polynomial	1	1	1	1	1	1	1
Weighting Scheme	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular
Std error	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster

Notes: This table provides the RD estimates of β in Eq. 3. The sample consists of deceased donor kidneys in Table 3 used for transplant. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys in the U.S. The cut-off date is March 15, 2021. "Mean, Pre-policy" is the average of outcome variable between -1 and -196 days prior to the policy change.Standard errors are clustered at the running variable and in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A.14: Average Transplant Recipient Characteristics – SVI and Poverty Rate

	(1)	(2)	(3)	(4)	(5)
	All	By Quartile			
	(Raw value)	1st	2nd	3rd	4th
Panel A. CDC Social Vulnerability Index					
1(OfferDate≥c)	0.0255***	-0.0465***	-0.0078	0.0227*	0.0316**
	(0.0079)	(0.0141)	(0.0136)	(0.0136)	(0.0144)
Mean, Pre-policy	0.555	0.260	0.253	0.244	0.242
Average Social Vulnerability Index		0.226	0.487	0.677	0.859
Panel B. Poverty Rate					
1(OfferDate≥c)	0.1717	-0.0303**	-0.0122	0.0356***	0.0068
	(0.1776)	(0.0150)	(0.0145)	(0.0135)	(0.0126)
Mean, Pre-policy	14.040	0.254	0.257	0.238	0.251
Average Poverty Rate		8.053	12.424	15.093	20.765
Controls	Yes	Yes	Yes	Yes	Yes
Bandwidth	± 196 days	± 196 days	± 196 days	± 196 days	± 196 days
Degree of polynomial	1	1	1	1	1
Weighting Scheme	Triangular	Triangular	Triangular	Triangular	Triangular
Std error	Cluster	Cluster	Cluster	Cluster	Cluster

Notes: This table provides the RD estimates of β in Eq. 3. The sample consists of deceased donor kidneys in Table 3 used for transplant. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys in the U.S. Poverty rate refers to the percentage of county residents living under the federal poverty line in 2019. Column (1) reports the impact on average county characteristics that recipient lived at the time of transplant. Columns (2)-(5) report the RD estimates when the dependent variable is an indicator of transplant recipient living in counties with in the first, second, third, or forth quartile group, respectively. "Mean, Pre-policy" is the average of outcome variable between -1 and -196 days prior to the policy change. Standard errors are clustered at the running variable and in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A.15: Average Transplant Recipient Characteristics – Race/Ethnicity

	(1)	(2)	(3)	(4)
	Transplant Recipient			
	Non-Hispanic White	Non-Hispanic Black	Hispanic/Latino	Non-Hispanic AAPI
1(OfferDate≥c)	-0.0049	-0.0181	0.0218*	0.0040
	(0.0145)	(0.0186)	(0.0129)	(0.0099)
Mean, Pre-policy	0.392	0.341	0.185	0.091
Observations	17,911	17,911	17,911	17,911
Controls	Yes	Yes	Yes	Yes
Bandwidth	± 196 days	± 196 days	± 196 days	± 196 days
Degree of polynomial	1	1	1	1
Weighting Scheme	Triangular	Triangular	Triangular	Triangular
Std error	Cluster	Cluster	Cluster	Cluster

Notes: This table provides the RD estimates of β in Eq. 3 using the sample that consists of deceased donor kidneys used for transplant. The cut-off date is March 15, 2021. "Mean, Pre-policy" is the average of outcome variable between -1 and -196 days prior to the policy change. Source of data is the restricted Scientific Registry of Transplant Recipients (SRTR) datasets, which include the universe of deceased donor kidneys and transplant candidates in the U.S. Standard errors are clustered at the running variable and in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A.16: Robustness Check – Monthly Transplant Center Outcomes: Candidates (OLS)

	(1)	(2)	(3)	(4)	(5)
	Number of Transplant Candidates per 1,000 Candidates				
	Received Deceased Donor Kidney Transplant	Died on Waitlist	All Deaths Within 5 years Joining Waitlist	Received Living Donor Kidney Transplant	Newly Joined Waitlist
$\Delta Access_h * Post_{ym}$	0.20822**	-0.07948***	-0.12304***	0.00071	-0.06299
	(0.09901)	(0.02621)	(0.02568)	(0.02162)	(0.12371)
Mean of Dep. Var (Pre)	14.743	4.539	6.765	4.439	27.404
Observation	6,660	6,660	6,660	6,660	6,660

Notes: This table reports the estimates of γ in Eq. 4 but with the OLS specification. The transplant center-month data includes transplant centers with active transplant candidates prior to the policy change, not located in donor service areas that did not experience any change DSA affiliation through the sample period. Results in Columns 1–5 are weighted by the monthly average waitlist enrollment during the pre-preiod. Column 1 presents the impact on the number of deceased kidney transplants per 1,000 candidate. Columns 2 and 3 reports the impact on the number of transplant candidates died on the waitlist per 1,000 candidate and transplant candidates died within 5 years of entering the waitlist per 1,000 candidate, respectively. Column 4 reports the impact on the number of living donor transplants per 1,000 candidate. Column 5 reports the impact on the number of newly added candidates per 1,000 candidate. "Mean of Dep-Var" is the average of outcome variable between -1 and -15 months prior to the policy change, weighted by the average number of transplant candidates on the waitlist. Standard errors clustered at transplant center level are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A.17: Robustness Check – Monthly Transplant Center Outcomes: Recipients

	(1)	(2)	(3)	(4)
	Transplant Recipient Adverse Health Outcomes per 1,000 Candidates			
	≤3 months	≤6 months	≤9 months	≤12 months
$\Delta Access_h * Post_{ym}$	0.00077	-0.01029	-0.00440	-0.00790
	(0.00677)	(0.00902)	(0.00954)	(0.00987)
Mean of Dep. Var (Pre)	0.428	0.649	0.838	1.017
Observation	6,660	6,660	6,660	6,660

Notes: This table reports the estimates of γ in Eq. 4. I define post-transplant adverse health outcomes as 1) deaths, 2) graft failure, 3) resuming maintenance dialysis within 3, 6, 9, and 12 months of deceased donor kidney transplant. Columns (1)-(4) report the effects on the number of deaths of recipients within 3, 6, 9, 12 months of transplant date per 1000 candidate. Results in Columns 1–5 are weighted by the average number of transplant candidates on the waitlist per transplant center during the pre-preiod. "Mean of Dep-Var" is the average of outcome variable between -1 and -15 months prior to the policy change, weighted by the average number of transplant candidates on the waitlist. Standard errors clustered at transplant center level are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.