Does Paired Kidney Exchange Reduce Demographic Disparities in Transplant Outcomes?*

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Abstract

Paired kidney exchange programs increase living donor transplants by facilitating matches across immunologically incompatible patient-donor pairs. Given existing concerns about demographic disparities in transplant access and outcomes, we examine the extent to which exchange differentially impacts patients of different demographic groups. To estimate causal relationships, we leverage the importance of patient proximity to exchange-facilitating centers and plausibly exogenous spatial and temporal variation in exchange activity. We show that exchange increases the quantity of living donor transplants, improves transplant survival, and reduces waiting time overall. Patients who are Black, younger, more-educated, privately-insured, and women experience the largest living donor transplant gains in percentage terms. Patients who are Black, younger, less-educated, insured by Medicaid, and women experience the largest improvements in survival. Our findings paint a nuanced picture. Kidney exchange seems to narrow gender and racial/ethnic gaps in transplantation, exacerbate disparities by age, and have mixed effects across education and insurance groups.

Keywords: organ donation, transplantation, kidney paired donation, exchange, matching, health disparities, transplant outcomes

JEL Classifications: D47, I11, I12, I18

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1 Introduction

Medical innovation has the potential to not only save money and lives, but also generate benefits beyond those that have traditionally been studied. For example, although many studies find that medical innovations can improve cost-effectiveness (Cutler & McClellan, 2001, Dranove *et al.*, 2022, Dunn *et al.*, 2023, Hall & Jones, 2007), recent work suggests that the benefits to innovation can be even larger when we consider positive externalities resulting from innovation (Callison *et al.*, Forthcoming). That said, disadvantaged groups may face more challenges in accessing innovative medical care, and thus, the benefits of innovation can be unequally distributed across groups (Alsan *et al.*, 2023, Cutler *et al.*, 2012, Glied & Lleras-Muney, 2008, Hoagland, 2024, Koning *et al.*, 2021). Factors such as education, race, gender, insurance coverage, and age can shape individuals' access to and quality of care, their preferences for care, and the trade-offs they face when considering competing treatment options (Adler & Rehkopf, 2008, Arcaya & Figueroa, 2017, Chandra *et al.*, 2024, Hamilton *et al.*, 2023). Understanding how innovation in policy and technology mitigates or exacerbates existing disparities can help policymakers and practitioners implement innovations in more careful and welfare-enhancing ways.

Efforts to reduce health disparities are particularly critical in the context of organ transplantation, where shortages of life-saving organs are widespread and so are demographic disparities in allocation.[1] As of October 2024, nearly 105,000 individuals await a transplant and 40% of those individuals have been waiting more than 2 years.[2] To address shortages, policymakers and researchers have primarily focused on increasing the supply of deceased donors, but living donor transplantation also plays a crucial role in meeting demand and is

[1]This phenomenon is not unique to transplantation. For example, in their analyses of a large U.S. health system, Singh & Venkataramani (2024) find that Black patients face longer wait times than White patients, and that in-hospital mortality rates increase for Black patients (but not White patients) as hospitals approach capacity limits.

[2]See: `https://optn.transplant.hrsa.gov/data/view-data-reports/build-advanced/`.

rife with demographic disparities.[3] For example, in 2019, only 11% of living donor kidney recipients were Black despite representing 25% of all End Stage Renal Diagnoses [ESRD] in the U.S. in that same year.[4] Disparities in living donor transplantation exist for other demographic groups as well. Figure 1, Panel A plots counts of living donor transplants against count of ESRD diagnoses for people of different demographic categories to highlight the existing disparities. Notably, privately insured patients receive proportionally more living donor transplants per ESRD diagnosis compared to those insured through Medicaid or Medicare. Patients younger than 50 and White patients are also advantaged in this respect. Although these same demographic groups have similar advantages in deceased donor transplants (Figure 1, Panel B) or likelihood of being removed from the waitlist due to sickness or death (Figure 1, Panel C), these disparities are not as striking as the ones found in living donor transplants. The figure highlights that reducing disparities in living donor access remains a particularly pressing challenge in this space.

In this paper, we study the extent to which paired kidney exchange programs increase living donation while also improving equity in transplant outcomes. Kidney exchanges allow patients with willing living donors to "exchange" donors if doing so would result in improved immunological compatibility between patient-donor pairs. Economists have contributed substantially to the development of modern paired kidney donation practice by applying mechanism design techniques to the patient-donor matching problem, simulating and comparing alternative mechanisms' effectiveness, and aiding in real-world implementation (e.g., Roth *et al.*, 2004, 2005a,b, 2007). Determining how many additional living donor transplants are generated by kidney exchange programs is a non-trivial exercise. For example, patients re-

[3]Examples from the literature that analyze and discuss the effects of various policy changes, supply shocks, and proposed reforms follow: Abadie & Gay (2006); Ausubel & Morrill (2014); Becker & Elias (2007); Bilgel (2012); Callison & Levin (2016); Cameron *et al.* (2013); Dickert-Conlin *et al.* (2019); Dickert-Conlin *et al.* (2024); Flavin (2016); Kessler & Roth (2012); Kessler & Roth (2014); Lacetera *et al.* (2014); Lemont (2024); Li *et al.* (2013); Rodrigue *et al.* (2007); Schnier *et al.* (2018); Siminoff *et al.* (2009); and Wellington & Sayre (2011).

[4]Source: Authors' calculations from USRDS and OPTN data available at the following websites: `https://usrds.org/data-query-tools/esrd-incident-count/` and `https://optn.transplant.hrsa.gov/data/view-data-reports/build-advanced/`.

ceiving transplants via exchange might have received a kidney from a directly-compatible living donor in the absence of exchange. Recent research finds that roughly 64% of transplants via exchange represent living donor transplants that would not have occurred in the absence of exchange (Teltser, 2019), while also improving patients' health outcomes (Chipman *et al.*, 2022, Ghanbariamin & Chung, 2020, Teltser, 2019). However, the distribution of these improvements across demographic subgroups has yet to be studied. If existing demographic disparities in living kidney donation are primarily attributable to differential access to immunologically compatible donors, then we might expect the introduction and expansion of kidney exchange to reduce such disparities. However, if the existing disparities are driven by a lack of willing and suitable donors (e.g., those who are in sufficient mental and physical health, those who can bear the costs associated with donating such as travel and time away from work), then paired exchange may exacerbate those disparities.

To quantify the demographic distribution of transplant outcome improvements attributable to kidney exchange, we start with the Scientific Registry of Transplant Recipients (SRTR) Standard Analysis Files (SAFs), which contain the universe of waiting list registrations, transplants, and donors in the United States. We then use these data to estimate the heterogeneous effects of kidney exchange on transplant quantity and quality across various demographic subgroups. To obtain causal estimates, we exploit plausibly exogenous variation in kidney exchange activity across time and place by constructing a measure of local exchange prevalence from data on patients' zip codes of residence, transplant center zip codes, and timing of outcomes. Our results suggest that some disadvantaged subgroups experience relatively large benefits from kidney exchange, while other disadvantaged groups benefit relatively little. Specifically, we find that kidney exchange generates larger increases in living donor transplants among patients who are Black or Hispanic, younger, more-educated, privately-insured, and women. In terms of survival, we find larger improvements among transplant recipients who are Black or Hispanic, younger, less-educated, insured by Medicaid, and women. Meanwhile, older patients and those with Medicare as their primary payer

experience little to no gains in number of living donor transplants and survival.

Our work contributes to the medical innovation literature and also to the organ transplantation and kidney exchange literature discussed above. Our work also contributes to the literature that specifically looks at the intersection of medical innovation and health disparities. For example, one strand of such research examines disparities in access to cancer-related innovation (Glied & Lleras-Muney, 2008, Jeon & Pohl, 2019, Lee *et al.*, 2021), and focuses on disparities by education and race. Jeon & Pohl (2019) and Glied & Lleras-Muney (2008) find that innovative health technology primarily benefits higher-educated patients, while Lee *et al.* (2021) find that racial and socioeconomic minority patients are slower to start to use digital breast tomosynthesis after the technology is introduced, even compared to women using the same facility. Our work similarly examines the effects of innovation on racial and educational disparities, but with respect to a different form of life-saving medical treatment, while also examining additional dimensions of heterogeneity including gender, age, and insurance coverage.

Our findings inform kidney exchange programs and the broader transplant community about existing disparities in living donor transplantation, and how kidney exchange can both exacerbate and mitigate disparities. Understanding how kidney exchanges differentially benefit patients across groups provides insight on who might be most impacted by increased exposure to kidney exchange, and can guide policy and practice moving forward. For example, kidney exchange programs and consortia could change match prioritization rules to enhance equity, transplant centers could encourage disadvantaged compatible disadvantaged pairs to join exchange registries as a way to improve equity in transplant outcomes, and the overall transplant community could devote more resources to helping disadvantaged patients recruit willing and able living donors. Given that the United Network for Organ Sharing (UNOS) frequently revises deceased donor allocation policy in the interest of increasing equitable access to transplantation, it may also be desirable for UNOS to consider how kidney exchange affects equity, and shape allocation policy accordingly.

2 Potential Heterogeneous Effects of Kidney Exchange

In order to receive a living donor transplant, a patient first needs to find someone who is willing to donate a kidney to them. These living donors are usually friends or family of the transplant patient. However, not every willing donor is eligible to donate. Living donors need to be physically and mentally healthy enough to donate, and they also need to be immunologically compatible with the intended recipient. Immunological compatibility consists of two components, the first of which is blood type compatibility. For example, patients with blood type O can only receive an organ from a donor who also has blood type O, but any other blood type (A, B, AB) can also accept an organ from a type O donor. In addition to this, patients also need to have relatively few Human Leukocyte Antigen (HLA) mismatches with their potential donor. The number of HLA mismatches can range from 0 up to 6 and higher numbers represent a higher likelihood of a patient's immune system recognizing that a particular donated organ is foreign to the body and should be attacked (Lim *et al.*, 2012). When a patient's immune system attacks a donated kidney, this often leads to graft failure, where the donated kidney stops functioning.

Kidney exchange was introduced to allow patients with an immunologically incompatible potential donor to exchange potential living donors with another incompatible patient-donor pair if doing so results in immunologic compatibility. Exchanges also enable compatible patient-donor pairs to enter an exchange in search of an improved immunologic match. Although the most basic type of exchange is a two-way paired exchange cycle, where two patients exchange willing living donors, paired kidney exchanges can be expanded to cycles of three or more pairs. There can even be donor chains where a non-directed altruistic donor starts a series of paired exchanges that culminates in a donation to the deceased donor waiting list. List exchange is another approach, where the willing donor gives their kidney to someone on the deceased donor waiting list in exchange for elevated waiting list priority for their loved one in need.

Kidney exchanges have been shown to not only increase the number of transplants that

are able to take place, but they also reduce the risk of graft failure within 1 and 2 years (Teltser, 2019). As a result, patients who participate in exchange may benefit both by increasing their chance of receiving a living donor kidney transplant and by improving their expected transplant survival. However, because kidney exchange match prioritization rules incorporate some biological characteristics that are correlated with race and age, some racial or age subgroups may be at an advantage over others in receiving a match.[5]

In addition to differences brought about by the match prioritization rules, kidney exchange could potentially be more beneficial for patients who have historically had a harder time finding a living donor who is an immunological match because it relaxes the immunological constraints needed for a living donor transplant. One of these potential groups is patients who are Black. Black potential living donors have been found to be more likely to be ineligible to donate due to immunologic incompatibilities with their intended recipient than White potential donors (Lunsford *et al.*, 2006).[6] Therefore, kidney exchange programs might provide a relatively larger benefit to Black patients than White patients. Women may experience larger benefits because patients who have been pregnant may become sensitized to the HLA antigens of the fathers of their pregnancy and also to the HLA antigens of any resulting children (Bromberger *et al.*, 2017, Porrett, 2018). This sensitization may rule out partners or children as potential living donors, which in turn would lead to them having a smaller pool of potential donors. If kidney exchange allows women who have been pregnant to regain the use of these family members as potential donors, we may see larger benefits of

[5]Although the Organ Procurement and Transplantation Network (OPTN) arranges all deceased donor kidney and recipient matches in the US, most kidney exchanges are not facilitated by OPTN. Instead, most kidney exchanges are facilitated by nonprofit organizations like the National Kidney Registry (NKR) or the Alliance for Paired Kidney Donation (APKD), or by individual (or groups of) transplant centers. Each program has their own rules for prioritizing certain patients in matches over others. For example, NKR's top priority is facilitating as many matches as possible, with additional priority given to patients who are harder to match. Current OPTN policy prioritizes long chains of exchange matches made with patients who have a harder to match blood type, are highly sensitized due to high levels of HLA antibodies, are less than 18 years old, or have a willing living donor who has a less easily matched blood type. NKR's full policy may be viewed at `https://www.kidneyregistry.org/for-centers/medical-board-policies/` and OPTN's full policy may be viewed at `https://optn.transplant.hrsa.gov/policies-bylaws/policies/`.

[6]Black patients are more likely to have Black potential living donors because living donors are usually family or friends of the transplant patient. This implies that Black patients have a harder time achieving immunologic compatibility with their potential donors.

kidney exchange for women than for men.

On the other hand, immunologic incompatibility is not the only disqualifying factor for potential living donors; living donors also need to meet other medical and financial requirements. Because transplant patients of disadvantaged groups likely have potential living donors that are from the same disadvantaged groups as the patient due to homophily, existing health disparities likely result in disadvantaged groups being less likely to have potential donors that are eligible to be a living donor. For example, disadvantaged potential donors might be unable to donate due to being uninsured or unable to take time off of work or from caregiving responsibilities to go through the donation process. In addition to these factors, Black patients may be less likely to ask friends and relatives to be donors due to differences in perceived medical urgency and a general distrust of the medical system (Gore *et al.*, 2009). As a result, the introduction of kidney exchange may benefit disadvantaged patients much less than it benefits more advantaged patients. One final factor required to utilize kidney exchange is savviness in navigating the transplantation system, including finding out about and pursuing kidney exchanges. This savviness could be negatively correlated with a lower level of education, and in line with this, less educated patients have been found to be less likely to use a living donor (Gore *et al.*, 2009).[7] Therefore, the introduction of kidney exchange may maintain or further increase inequality in living donor transplantation across patients of different education levels.

3 Data

This study uses data from the Scientific Registry of Transplant Recipients (SRTR). The SRTR data system includes data on all donor, wait-listed candidates, and transplant recipients in the US, submitted by the members of the Organ Procurement and Transplantation Network (OPTN). The Health Resources and Services Administration (HRSA), U.S. Depart-

[7] Additionally, Segev *et al.* (2009) find that, among elderly patients, patients with a college education have higher access to transplantation.

ment of Health and Human Services provides oversight to the activities of the OPTN and SRTR contractors. Our SRTR data extract covers all kidney waitlist registrations and transplants that occurred from 1988 to 2018. These data contain individual level information for every registered patient and transplant recipient, including demographic information such as race, education, primary payer, age, and gender. These data also contain extensive individual level medical information such as the patient's blood type, previous transplant status, registration date, transplant date, HLA mismatches, donor characteristics, and transplant follow-up information (from which graft failure is calculated).[8] Additionally, through a special request, we obtained zip code information for patients and transplant centers.[9] These data also contain information on the outcome of each registration including: transplant, death, transfer to a different center, or still waiting as of December 31, 2018. We restrict our analysis to observations that resulted in either a transplant or death, as these encompass the clear and well-defined registration outcomes.[10] We restrict our sample to January 2000 (due to data quality issues before 2000) through December 2018 (our last full year of data).

Table 1 presents the distribution of the well-defined waitlist outcomes for each subgroup of interest. The first three of rows of the table show the differences in outcomes by race.[11] As seen in the table, Non-Hispanic White patients have a larger proportion of their registrations result in some form of living donor transplant (either a paired or list exchange, anonymous

[8]Roughly 17% of living donor kidney recipients never register for the deceased donor waiting list. These observations are entered as a transplant record and lack the information that is only relevant when a patient registers on the waiting list. This limitation makes the use of duration models unattractive in this setting.

[9]We use the "Donor relation" variable to determine whether a transplant is a direct living, deceased, anonymous, or exchange transplant. Kidney transplants are coded with one of the following donor relationships: sibling, twin, child, parent, other relative, significant other, miscellaneous unrelated donor, paired exchange, list exchange, anonymous, or deceased. Note that we can only connect donors to their actual recipients. Therefore, with respect to exchanges, we cannot connect donors to the loved one on whose behalf they are donating. Also, we cannot observe whether an anonymous donor's kidney is used to start a donor chain.

[10]Note that patients may have multiple waiting list registrations. Patients with multiple registrations who died while waiting are only counted once, and we use their earliest listing coded as such. For the ending date of these observations, we use the earliest reported registration end date among those coded as removal due to death. For patients who receive a transplant, only one registration will show the transplant outcome, which is the observation we use.

[11]Although we would prefer to have finer racial categories, data limitations prevent this from being feasible due to the small number of patients who do not identify as White, Black, or Hispanic.

living donor, or direct living donor) than patients of other races. Additionally, they are less likely to die on the waitlist compared to other races. Moving down the table to the rows by age groups, we can see that patients older than 55 are the least likely to receive any form of transplant and are the most likely to die on the waitlist, compared to the other age categories. The next rows that split patients by their educational attainment show a similar disadvantage for patients on the waitlist who do not have any post-secondary schooling. Turning to payer type, first note that Private are those with private insurance as their primary payer, excluding any who have Medicaid as their secondary payer. Medicare are those who have Medicare as their primary payer, excluding any who have Medicaid as their secondary payer. Medicaid includes anyone with Medicaid as either their primary or secondary payer. Here we see that Private patients have an advantage and Medicaid and Medicare patients are more likely to receive deceased donor transplants or die on the waitlist compared to Private patients. Finally, the bottom rows show that women are slightly more likely to have their transplant involve a paired or list exchange than men, but slightly less likely to have a direct living donor transplant, and slightly more likely to die while waiting.

Table 2 presents the fraction of kidney grafts that fail within one, three, and five years; waiting list registration duration duration; and the number of HLA mismatches between donor and recipient. We see that graft failure rates are slightly lower among Hispanic recipients, younger recipients, higher educated recipients, and privately insured recipients.[12] We can also see that Non-Hispanic Black recipients have the highest number of HLA mismatches at 4.2, while Non-Hispanic White recipients have the lowest amount at 3.5. Non-Hispanic White recipients have the shortest waiting list registration durations on average, roughly 494

[12]Graft failure is defined for observations with a non-missing graft survival time in the SRTR data. It takes on a value of 1 if the patient died within X years ($X \in \{1, 3, 5\}$), or if there is a reported graft failure within X years. It takes on a value of 0 if the graft survival time exceeds X years, or if the patients' last known status is alive with the kidney still functioning after X years. The assumption is that these "lost" individuals would have returned to the system or they would have a death date reported through the Social Security Death Master File if their graft failed or they died. In order to ensure adequate time has passed for follow-up data, we restrict the analysis of one-year graft survival to transplants occurring on or before December 31, 2016, December 31, 2014 for three-year graft survival and December 31, 2012 for five-year graft survival.

days, while Non-Hispanic Black and Medicaid insured recipients have the longest waiting list durations.[13]

Note that there may be unaccounted-for systematic differences in the composition of patients, as well as the transplant environment, in areas with varying levels of exchange activity. For this reason, it will be particularly useful to control for relevant observable patient characteristics and for time-invariant heterogeneity across zip codes of residence. We discuss our estimation approach accounting for these concerns in the following section.

4 Estimation

Our first goal is to causally estimate the effect of nearby exchange activity on the number of transplants for different subgroups of patients, and then test whether such estimates differ from one another. For each subgroup, we estimate the effect of an increase in exposure to exchange activity on the number of transplants. After splitting our sample into subgroups, the following specification allows us to estimate the heterogeneous effects of interest directly:

$$Y_{zt} = \phi Activity_{zt} + \alpha_z + \gamma_q + \eta_z t + \zeta_{sy} + \epsilon_{zt}, \tag{1}$$

where Y represents the number of transplants received by patients residing in zip code z, in month-year t. Our central analyses focus on the counts of exchange transplants and overall living donor transplants. *Activity* is the number of exchanges that occur at transplant centers within 50 miles of zip code z in month-year t. We adjust this measure by excluding "own" exchange transplants: those received by patients of the relevant subgroup residing in zip code z at time t at a center within the 50 mile radius.[14] This measure reflects

[13]Note: roughly 17% of living donor kidney recipients never register for the waiting list. In these cases, registration duration is set to zero.

[14]We use GIS mapping software along with the zip codes of patients and transplant centers to determine which transplant centers are within 50 miles of the centroid of each observed patient zip code. We then aggregate over these nearby centers to determine how many transplants via kidney exchange occurred each month within the 50 mile radius.

both the potential of local transplant centers to perform exchanges and the realization of that potential. Since patients and donors must be able to travel to transplant centers for testing and eventual transplant procedures, *Activity* reflects patient access to exchange and, consequently, is correlated with the probability of a patient receiving an exchange transplant. We use 50 miles as the radius for *Activity* because approximately 71% of patients who receive transplants do so within 50 miles of their home zip code overall.[15]

In our specification above, we also include a zip code fixed effect, α_z, to control for any unobserved heterogeneity across zip codes where patients live, especially unobservables correlated with nearby exchange activity and transplant outcomes. These factors might include average affluence or quality of nearby health care institutions. We also include quarter-year fixed effects, γ_q, to control for nationwide transplantation trends and national-level policy shocks. Zip-code specific linear time trends, $\eta_z t$, account for local trends in transplant quantity and quality that could be correlated with local trends with kidney exchange activity such as demand for kidney transplants or quality of local medical facilities. State-year fixed effects, ζ_{sy}, control for state-level policy shocks that may affect the supply of living and deceased donor transplants, such as incentives for living donors or traffic safety laws. Finally, ϵ_{zt} is the idiosyncratic error term.

For the coefficient on *Activity* to represent a causal effect, *Activity* must be exogenous to the dependent variables of interest. Because the inclusion of zip code and quarter-year fixed effects control for national trends and time-invariant differences across locations, and zip code linear time trends and state-year fixed effects further control for any regional trends, this leaves two primary remaining potential threats to the exogeneity of *Activity*. The first is if transplant centers adopt and promote exchange as a transplant option in response to local demand for exchange and idiosyncratic pre-trends in the dependent variables of interest. The second is if transplant patients who are interested in receiving an exchange transplant move to areas with a higher concentration of exchange activity. Earlier work tests for evidence

[15]Note that Teltser (2019) tests the robustness of the analysis to the use of different radii and finds that the estimates are largely insensitive to the choice of mileage.

of both of these threats, and does not find evidence supporting either one (Teltser, 2019). That is, local shocks to the outcome variables of interest do not appear to predict future kidney exchange activity. In addition, Teltser (2019) shows that patients do not appear to relocate based on the level of exchange activity in their zip codes of residence at time of waitlist registration, nor is any observed relocation driven by activity differentials between zip code at time of waitlist registration versus time of transplant.

Finally, in addition to estimating how kidney exchange affects transplant quantities, we also estimate how an increase in the probability of receiving a transplant through kidney exchange affects the quality of transplant outcomes, conditional on receiving a transplant. We use a similar method to what was outlined above, except now we use individual level observations. The reduced form specification is now:

$$Y_{izt} = \phi Activity_{izt} + \alpha_z + \gamma_t + \eta_z t + \zeta_{sy} + \epsilon_{izt}, \tag{2}$$

where Y now represents a quality outcome for patient i in zip code z who receives a transplant in month-year t. While our central quality outcome is one-year graft failure, we also look at three-year and five-year graft failure, the number of HLA mismatches, and waiting list registration duration in the appendix. In this specification, an additional nearby exchange results in a change of ϕ in quality outcome Y. For graft failure, this coefficient reflects a percentage point change. For HLA mismatches, it reflects the change in the number of mismatches. For registration duration, it reflects the change in the elapsed number of days between time of waitlist registration and transplant.

5 Results

Before presenting our heterogeneity estimates, we first replicate the quantity and quality instrumental variable analyses from Teltser (2019) after including more than four additional years of data (i.e., January 2000 through December 2018, see Appendix Tables A1 and

A2). We find that 62.6% of exchange transplants represent new living donor transplants — those that would not have occurred in the absence of exchange. This is nearly identical to the previous estimate of 64%. We also find similar underlying substitution estimates: 42.7% of exchange transplant recipients would have received a direct living donor kidney in the absence of exchange (43% previously), while each additional exchange increases (i.e., "crowds-in") non-directed anonymous living donations by 0.054 (i.e., 5.4%, compared to 7% found previously). Moreover, we find similar overall quality effects. For example, a one percentage point increase in the probability of receiving an exchange transplant reduces one-year graft failure by 0.18 percentage points (compared to the earlier estimate of 0.21), and reduces time spent waiting for a transplant by 4 days (compared to 3.8). Thus, our findings reaffirm that, on average, kidney exchange substantially increases transplant quantity and quality overall. We now turn toward the results of our heterogeneity analyses, which provide insight into which subgroups of patients benefit most from exchanges.

5.1 Heterogeneity by Race

First, we estimate the heterogeneous effects of kidney exchange by race by estimating equations (1) and (2). Table 3 presents these estimates. As shown by the first stage coefficients in column 1, the increase in exchange transplants resulting from one additional local exchange transplant varies meaningfully by race. While Non-Hispanic White patients experience the largest raw increase in exchange transplants resulting from an additional nearby exchange transplant, they experience the smallest gain in percentage terms. That is, Non-Hispanic White patients see a 45% increase in exchange transplants when an additional nearby exchange is performed, compared to Non-Hispanic Black and Hispanic patients who experience an 87% and 85% increase in exchange transplant frequency. In the second column, we examine how an additional nearby exchange transplant increases the frequency of living donor transplants overall, and find again that the effect is largest for Non-Hispanic Black patients (3.7%), followed by Hispanic patients (2.9%), and smallest among Non-Hispanic White pa-

tients (2.3%). These estimates suggest that existing disadvantages in transplant access and outcomes among non-White patients are likely attributable to a relative lack of *compatible* willing donors, rather than a relative lack of access to willing living donors in general.

Additionally, we see that exchanges yield meaningful quality gains for Black and Hispanic patients in column 3. Specifically, we find that an additional nearby exchange transplant reduces the probability of graft failure within one year for Non-Hispanic Black patients by 0.26 percentage points, which translates to a 3% reduction. The corresponding figure for Hispanic patients is a 1.6% decrease in one-year graft failure, while Non-Hispanic White patients experience a (statistically insignificant) 1.4% increase in their one-year graft failure rate. Taken together, these quantity and quality estimates suggest that Black and Hispanic patients experience relatively larger benefits from the introduction and expansion of kidney exchange compared to Non-Hispanic White patients.

In Appendix Table A3, we present additional results where we examine additional measures of quality as well as some more detailed quantity/substitution estimates. In general, these estimates show similar patterns to our central outcomes of interest. Interestingly, the proportionally larger gain in living donor transplants that we saw that Non-Hispanic Black patients experience due to kidney exchange in Table 3 occurs despite these patients also experiencing the proportionally largest rate of offsetting substitution away from direct living donor transplants. At the same time, we find Non-Hispanic Black patients experience disproportionately large gains in anonymous (or non-directed) living donor transplants.

5.2 Heterogeneity by Age

Although patients who are of a racial minority benefit with respect to the quantity and quality of transplants with kidney exchange, younger patients are the primary beneficiaries of kidney exchange, as we discuss next. In Table 4, we present our estimates for the heterogeneous benefit of kidney exchange by age. Column 1 shows that the increase in exchange transplants for each subgroup resulting from an additional local exchange transplant declines

in magnitude as we move to older groups of patients: 18 to 35 year-olds have a 69% increase, 35 to 55 year-olds have a 59% increase, and patients older than 55 only have a 49% increase. The analogous reduced form estimates for these groups in the next column imply that the resulting increase in total living donor transplants from an increase in local exchange activity is 4%, 3%, and 1% for these groups from youngest to oldest respectively. These estimates show that older patients experience a relatively small increase in living donor transplants from kidney exchange.

Although they do not have large increases in their quantity of new living donor transplants from kidney exchange, older patients may still benefit from a large increase in the quality of the recipient-donor match due to kidney exchange. Column 3 displays our 1-year graft failure estimates and shows that this is not the case: patients who are older than 55 do not have any meaningful improvement in graft survival while patients who are 18-35 have a 4.4% improvement in 1 year graft failure and patients who are 35-55 have a 2.4% improvement. Overall, it appears that younger patients are the primary beneficiaries of kidney exchange both with respect to the number of living donor transplants gained and also with respect to improved graft survival.[16]

5.3 Heterogeneity by Educational Attainment

Table 5 shows our estimates for the heterogeneous effect of exchange by educational attainment. As seen by the coefficients in column 1, there does not appear to be a differential increase in exchange transplants from local exchange activity across patients with differing educational attainment. Patients with a high school education or less experience a 56% increase in exchange transplants from an increase in local exchange activity and patients with at least some post-secondary educational attainment experience a 57% increase in exchange transplants from a one transplant increase in local exchange activity. However, the resulting increase in total living donor transplants, shown in the next column, is 2.2% for patients

[16] Additional heterogeneity estimates by age presented in Appendix Table A4 show similar patterns as our central outcomes of interest.

with a high school degree or less and 3.3% for patients with more than a high school degree. This shows that higher educated patients experience a larger benefit from kidney exchange with respect to number of living donor transplants.

The final column in this table displays our estimates of the effect of kidney exchange on 1-year graft failure. Comparing the estimates in column 3, we can see that lower-educated individuals have a proportionally larger reduction in graft failure rate than higher-educated patients. Thus, overall, it appears the effect of kidney exchange on disparities by education is mixed. Although lower educated patients have proportionally larger reductions in graft failure from kidney exchange, kidney exchange appears to benefit patients with more education more when it comes to the quantity of living donor transplants.[17]

5.4 Heterogeneity by Payer

Moving to our results by source of insurance coverage presented in Table 6, we can see that Private and Medicaid patients have the proportionally largest increases in exchange transplants from one additional local exchange transplant from column 1.[18] Medicaid-insured patients have the largest increase with a 70% increase, Private patients have the next highest with a 60% increase, and finally, Medicare patients have the smallest with only a 47% increase. However, the reduced form estimates in column 2 imply that the resulting increase in total living donor transplants is the largest for Private patients. While Private patients have a 3.7% increase in living donor transplants from an increase in local exchange transplants, patients insured through Medicaid have a 1.3% increase and Medicare patients experience an even smaller and statistically insignificant 0.3% increase in living donor transplants.

When looking at the reduced form estimates for graft failure in Column 3 of Table 6 we see that Medicaid-insured patients have the proportionally largest reduction in 1-year graft

[17] Additional heterogeneity estimates by education presented in Appendix Table A5 show similar patterns as our central outcomes of interest.

[18] Recall that Private are those with private insurance as their primary payer, excluding any who have Medicaid as their secondary payer. Medicare are those with Medicare as their primary payer, excluding any who have Medicaid as their secondary payer. Medicaid includes anyone with Medicaid as either their primary or secondary payer.

failure from kidney exchange with a 4% reduction. In comparison, Private patients have a 1.2% reduction and Medicare patients have only a 0.7% reduction, and the underlying coefficients for these two groups are not statistically significantly different from zero. Overall, our results suggest that although Private patients experience the largest gains in the number of living donor transplants after kidney exchange is introduced, they experience slightly smaller quality improvements. The opposite is true for Medicaid-insured patients: they enjoy relatively large improvements in graft survival despite minimal increases in number of living donor transplants. Finally, in contrast to the other payer sources, Medicare patients appear to experience very small, if any, quantity and quality improvements from kidney exchange.[19]

5.5 Heterogeneity by Gender

Turning to heterogeneous effects by gender, we present our findings along this dimension in Table 7. From column 1, women appear to have a slightly larger increase in exchange transplants from an increase in local exchange activity with an increase of 61% compared to slightly smaller 56% increase for men. The reduced form estimates in column 2 imply that the resulting increase in total living donor transplants from a one transplant increase in local exchange activity is similar across genders. Specifically, there is a 2.9% increase for women and a 2.3% increase for men.

Despite having relatively similar gains in living donor transplants from kidney exchange, the 1-year graft failure estimates in the final column of Table 7 suggest that women experience slightly larger improvements in graft survival compared to men. Although this difference is not statistically significant, the implied increase for women of 2.3% is about twice as large as the 1.1% increase for men. In general, it appears that the gains in living donor transplants from kidney exchange are distributed similarly across genders but women experience a relatively larger improvement in graft survival from the proliferation of kidney

[19] Additional heterogeneity estimates by payer presented in Appendix Table A6 show similar patterns as our central outcomes of interest.

exchange.[20]

6 Conclusion

The creation and refinement of kidney exchange programs and algorithms has been a crucial innovation for maximizing the number of transplants that can occur given the growing shortage of donated kidneys. Given the widespread concern in the transplant community about disparities in transplant access and quality across dimensions such as race, age, and education, we analyze the differential effects of exchange on various demographic subgroups of patients.

Leveraging spatial and temporal variation in patients' exposure to kidney exchanges, we show that there are indeed differential effects of the introduction of exchange on patient outcomes across demographic patient subgroups. We find that the introduction of exchange appears to reduce racial quantity and quality disparities in living donation. However, while younger patients experience both quantity and quality improvements, exchanges appear to offer no improvements in quantity or quality for patients older than 55. The introduction of exchange, if anything may exacerbate disparities in living donor transplant quantity across the education distribution, though it does appear to provide larger graft survival improvements to less-educated patients. Patients with private insurance as their primary payer appear to be the main beneficiaries of quantity benefits from kidney exchange (thereby exacerbating existing disparities), but Medicaid-insured patients experience the largest quality improvements. Finally, although men and women experience similar quantity gains from kidney exchange, women experience larger quality improvements.

For transplant centers and exchange consortia operating with the goal of improving patient outcomes for all, as well as mitigating inequality between different patient subgroups, our results suggest that exchange programs may want to place greater emphasis on fa-

[20] Additional heterogeneity estimates by gender presented in Appendix Table A7 show similar patterns as our central outcomes of interest.

cilitating exchange participation among older patients and patients with public insurance. Additionally, our results highlight the importance of barriers other than immunological compatibility to living donation. For example, disadvantaged groups may fail to benefit from kidney exchange due to a lack of potential living donors that meet the general health requirements to donate. Future work could explore the extent to which these other barriers explain our findings of heterogeneity across multiple dimensions. Our findings may also be used to breathe new life into the practice of list exchange, since programs could use list exchange to more-directly allocate living donor kidneys to disadvantaged patients on deceased-donor waiting lists.

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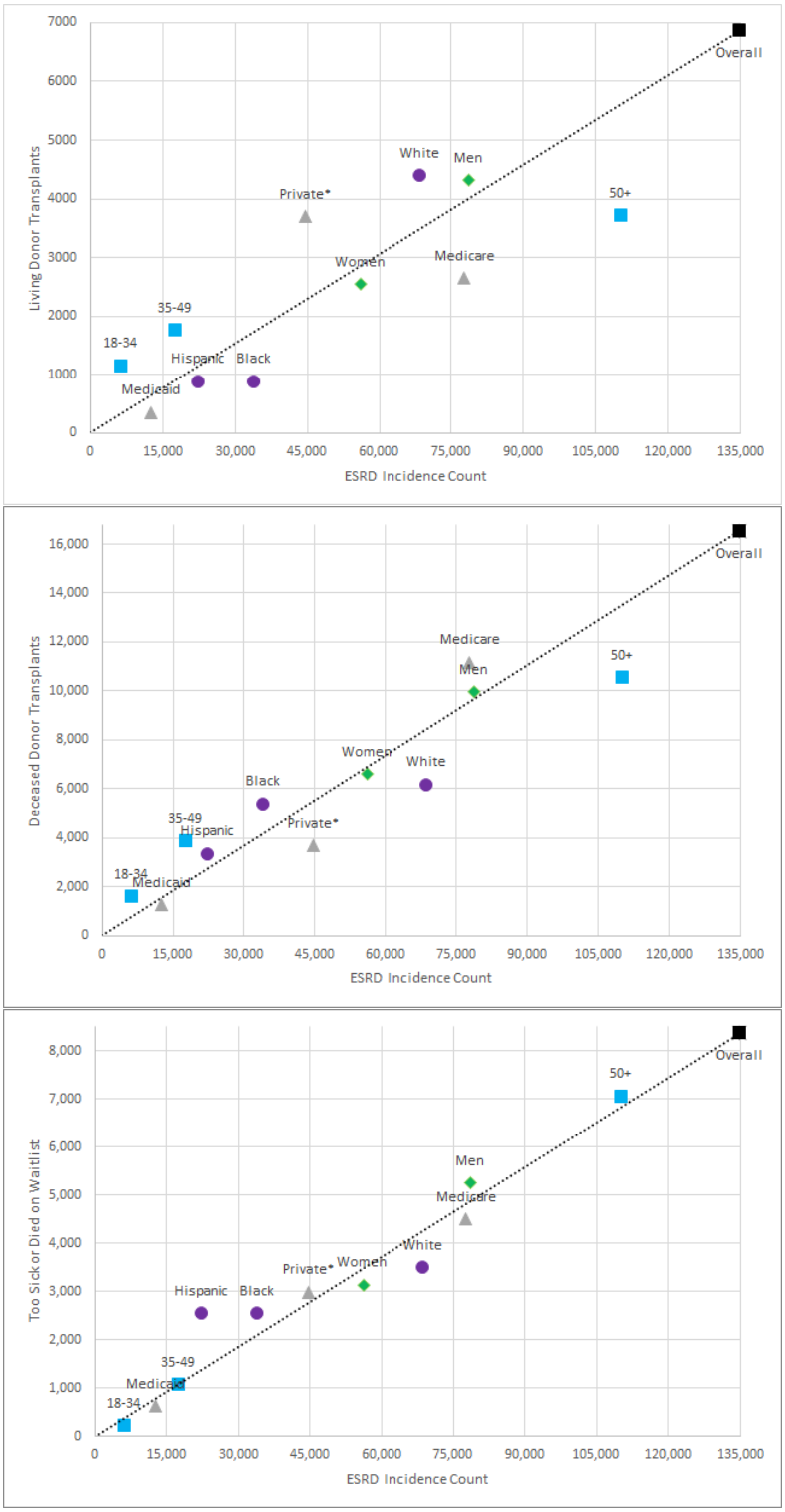
Figures and Tables

Figure 1: ESRD Incidence Compared to Wait List Outcomes by Demographic Groups



Notes: Privately insured ESRD count also include those listed a payer of "Other/Unknown". ESRD incidence counts for 2019 were obtained using the USRDS ESRD Incidence Count Data Query Tool and Table D.17 from the USRDS Annual Data Report for 2021. Living donor transplant, deceased donor transplant, and wait list removal counts for 2019 were obtained using the OPTN Build Advanced Data Report Tool.

Table 1: Summary Statistics, Heterogeneity in Quantity Outcomes

		Paired or List Exchange (%)	Anonymous Living Donor (%)	Direct Living Donor (%)	Deceased Donor (%)	Died on the Waitlist (%)	Number of Patients
Race	Non-Hisp White	2.3	0.7	30.8	48.6	17.6	194,693
	Non-Hisp Black	1.0	0.3	12.7	61.5	24.4	102,720
	Hispanic	1.7	0.4	23.2	54.2	20.5	51,964
Age	18-35	2.2	0.6	34.3	53.3	9.6	58,193
	36-55	1.9	0.6	24.1	55.3	18.1	169,411
	55+	1.7	0.5	19.9	51.5	26.4	146,801
Education	HS or below	1.4	0.4	20.0	56.7	21.5	162,731
	Some College or Above	2.7	0.7	28.4	51.3	16.9	167,776
Payer	Private	2.6	0.7	33.3	48.2	15.3	173,347
	Medicare	1.5	0.5	16.4	58.7	22.9	113,895
	Medicaid	0.9	0.4	14.8	57.9	26.0	77,562
Gender	Male	1.8	0.6	24.3	53.5	19.9	225,945
	Female	2.1	0.6	23.6	53.6	20.3	148,460

Notes: The sample for this table includes individual-level kidney transplants or deaths while waiting that occurred between January 2000 and December 2018. The private payer category includes those with private insurance as their primary payer, excluding any of those who have Medicaid as their secondary payer. Medicare includes those with Medicare as their primary payer, excluding any of those who have Medicaid as their secondary payer. Medicaid includes anyone with Medicaid as either their primary or secondary payer.

Table 2: Summary Statistics, Heterogeneity in Quality Outcomes

		Graft Failure <1 year	Graft Failure < 3 years	Graft Failure <5 years	Registration Duration (days)	HLA Mismatches	Number of Recipients
Race	Non-Hisp White	0.073	0.148	0.233	494	3.49	155,470
	Non-Hisp Black	0.088	0.195	0.306	826	4.20	74,419
	Hispanic	0.062	0.124	0.202	755	3.64	38,480
Age	18-35	0.063	0.151	0.238	679	3.58	47,881
	36-55	0.068	0.139	0.217	676	3.77	133,709
	55+	0.088	0.179	0.287	575	3.79	102,880
Education	HS or below	0.076	0.163	0.260	686	3.77	122,590
	Some College or Above	0.067	0.140	0.223	587	3.76	134,537
Payer	Private	0.061	0.126	0.202	602	3.66	141,910
	Medicare	0.090	0.187	0.297	579	3.84	82,695
	Medicaid	0.086	0.185	0.287	813	3.81	52,313
Gender	Male	0.075	0.157	0.250	632	3.82	175,939
	Female	0.074	0.153	0.237	648	3.62	113,317

Notes: The sample for this table includes individual-level data on kidney transplants that occurred between January 2000 and December 2018. Graft failure is defined as failure of the organ or death within the specified timeframe. Registration duration is the elapsed time from waitlist registration to transplant, or 0 when the recipient did not first register on a waitlist. HLA mismatches are human leukocyte antigen mismatches between patient and donor, and can range from 0 to 6. The private payer category includes those with private insurance as their primary payer, excluding any of those who have Medicaid as their secondary payer. Medicare includes those with Medicare as their primary payer, excluding any of those who have Medicaid as their secondary payer. Medicaid includes anyone with Medicaid as either their primary or secondary payer.

Table 3: Main Quantity and Quality Outcomes by Race/Ethnicity

		Exchange (First Stage)	Any Living Transplant (Reduced Form)	One-Year Graft Failure (Reduced Form)
Nearby exchanges (Excluding Own)				
	Non-Hisp White	0.00038***	0.00028***	0.00103
		(0.00003)	(0.00007)	(0.00076)
		[0.00084]	[0.01222]	[0.07322]
		45.1%	2.3%	1.4%
	Non-Hisp Black	0.00017***	0.00010**	-0.00264***
		(0.00002)	(0.00004)	(0.00091)
		[0.00020]	[0.00269]	[0.08763]
		86.6%	3.7%	-3.0%
	Hispanic	0.00014***	0.00007	-0.00099
		(0.00002)	(0.00004)	(0.00109)
		[0.00016]	[0.00244]	[0.06155]
		85.3%	2.9%	-1.6%
P-values for tests of different coefficients:				
	Black and White	0.0000***	0.0316**	0.0021***
	Hispanic and White	0.0000***	0.0119**	0.1240
	Black and Hispanic	0.1929	0.5949	0.2429

Notes: The sample for this table includes kidney transplants that occurred between January 2000 and December 2018. The transplant count analyses in columns 1 and 2 use zip code-month-year level aggregates by group, while the graft failure analysis in column 3 uses individual-level data. Graft failure is defined as failure of the organ or death within the specified timeframe. To test for differences between coefficients, we estimate a fully-interacted regression specification for each outcome of interest, which yields coefficients and standard errors that are identical to those from the analogous individual subsample regressions. Standard errors are robust to clustering at the zip code level. *** p<0.01, ** p<0.05, * p<0.10

Table 4: Main Quantity and Quality Outcomes by Age

		Exchange (First Stage)	Any Living Transplant (Reduced Form)	One-Year Graft Failure (Reduced Form)
Nearby exchanges (Excluding Own)				
	18-35	0.00016***	0.00016***	-0.00278**
		(0.00002)	(0.00004)	(0.00132)
		[0.00023]	[0.00397]	[0.06284]
		68.6%	4.0%	-4.4%
	35-55	0.00036***	0.00025***	-0.00162**
		(0.00003)	(0.00006)	(0.00066)
		[0.00061]	[0.00831]	[0.06777]
		59.4%	3.0%	-2.4%
	55+	0.00022***	0.00006	0.00032
		(0.00002)	(0.00006)	(0.00091)
		[0.00045]	[0.00597]	[0.08820]
		48.9%	1.0%	0.4%
P-values for tests of different coefficients:				
	18-35 and 35-55	0.0000***	0.2767	0.4205
	18-35 and 55+	0.0360**	0.1321	0.0469**
	35-55 and 55+	0.0003***	0.0264**	0.0845*

Notes: The sample for this table includes kidney transplants that occurred between January 2000 and December 2018. The transplant count analyses in columns 1 and 2 use zip code-month-year level aggregates by group, while the graft failure analysis in column 3 uses individual-level data. Graft failure is defined as failure of the organ or death within the specified timeframe. To test for differences between coefficients, we estimate a fully-interacted regression specification for each outcome of interest, which yields coefficients and standard errors that are identical to those from the analogous individual subsample regressions. Standard errors are robust to clustering at the zip code level. *** p<0.01, ** p<0.05, * p<0.10

Table 5: Main Quantity and Quality Outcomes by Educational Attainment

		Exchange (First Stage)	Any Living Transplant (Reduced Form)	One-Year Graft Failure (Reduced Form)
Nearby exchanges (Excluding Own)				
	HS or Less	0.00024***	0.00015***	-0.00225***
		(0.00002)	(0.00006)	(0.00075)
		[0.00043]	[0.00673]	[0.07646]
		56.2%	2.2%	-2.9%
	Some Coll. or More	0.00048***	0.00033***	-0.00070
		(0.00003)	(0.00008)	(0.00069)
		[0.00084]	[0.01012]	[0.06742]
		57.0%	3.3%	-1.0%
P-values for tests of different coefficients:				
	HS and SC	0.0000***	0.0635**	0.1300

Notes: The sample for this table includes kidney transplants that occurred between January 2000 and December 2018. The transplant count analyses in columns 1 and 2 use zip code-month-year level aggregates by group, while the graft failure analysis in column 3 uses individual-level data. Graft failure is defined as failure of the organ or death within the specified timeframe. To test for differences between coefficients, we estimate a fully-interacted regression specification for each outcome of interest, which yields coefficients and standard errors that are identical to those from the analogous individual subsample regressions. Standard errors are robust to clustering at the zip code level. *** p<0.01, ** p<0.05, * p<0.10

Table 6: Main Quantity and Quality Outcomes by Payer

		Exchange (First Stage)	Any Living Transplant (Reduced Form)	One-Year Graft Failure (Reduced Form)
Nearby exchanges (Excluding Own)				
	Private	0.00049***	0.00043***	-0.00070
		(0.00003)	(0.00008)	(0.00062)
		[0.00082]	[0.01177]	[0.06060]
		59.5%	3.7%	-1.2%
	Medicare	0.00015***	0.00001	-0.00060
		(0.00002)	(0.00004)	(0.00122)
		[0.00032]	[0.00388]	[0.08964]
		46.5%	0.3%	-0.7%
	Medicaid	0.00009***	0.00003	-0.00342***
		(0.00001)	(0.00004)	(0.00122)
		[0.00013]	[0.00232]	[0.08558]
		69.7%	1.3%	-4.0%
P-values for tests of different coefficients:				
	Private and Medicare	0.0000***	0.0000***	0.9452
	Private and Medicaid	0.0000***	0.0000***	0.0442**
	Medicare and Medicaid	0.0054*	0.6229	0.0968*

Notes: The sample for this table includes kidney transplants that occurred between January 2000 and December 2018. The transplant count analyses in columns 1 and 2 use zip code-month-year level aggregates by group, while the graft failure analysis in column 3 uses individual-level data. Graft failure is defined as failure of the organ or death within the specified timeframe. The private payer category includes those with private insurance as their primary payer, excluding any of those who have Medicaid as their secondary payer. Medicare includes those with Medicare as their primary payer, excluding any of those who have Medicaid as their secondary payer. Medicaid includes anyone with Medicaid as either their primary or secondary payer. To test for differences between coefficients, we estimate a fully-interacted regression specification for each outcome of interest, which yields coefficients and standard errors that are identical to those from the analogous individual subsample regressions. Standard errors are robust to clustering at the zip code level. *** p<0.01, ** p<0.05, * p<0.10

Table 7: Main Quantity and Quality Outcomes by Gender

		Exchange (First Stage)	Any Living Transplant (Reduced Form)	One-Year Graft Failure (Reduced Form)
Nearby exchanges (Excluding Own)				
	Women	0.00034***	0.00021***	-0.00170**
		(0.00003)	(0.00006)	(0.00075)
		[0.00056]	[0.00716]	[0.07353]
		60.6%	2.9%	-2.3%
	Men	0.00041***	0.00025***	-0.00080
		(0.00003)	(0.00008)	(0.00061)
		[0.00073]	[0.01108]	[0.07460]
		56.2%	2.3%	-1.1%
P-values for tests of different coefficients:				
	Women and Men	0.0832*	0.6550	0.3507

Notes: The sample for this table includes kidney transplants that occurred between January 2000 and December 2018. The transplant count analyses in columns 1 and 2 use zip code-month-year level aggregates by group, while the graft failure analysis in column 3 uses individual-level data. Graft failure is defined as failure of the organ or death within the specified timeframe. To test for differences between coefficients, we estimate a fully-interacted regression specification for each outcome of interest, which yields coefficients and standard errors that are identical to those from the analogous individual subsample regressions. Standard errors are robust to clustering at the zip code level. *** p<0.01, ** p<0.05, * p<0.10

Appendix A Additional Tables and Figures

Table A1: Replication of Teltser (2019), Quantity Outcomes

	Exchange (first stage)	Direct Living	Anonymous	Deceased	Died on wait list
Panel A: OLS quantity estimates					
Exchange (count)	-	-0.00394	0.00007	-0.00150	-0.00155
	-	(0.00252)	(0.00050)	(0.00393)	(0.00243)
Panel B: Reduced form and IV quantity estimates using Activity					
Nearby Exchanges (excluding own)	0.00074***	-0.00032***	0.00004**	-0.00005	-0.00003
	(0.00004)	(0.00009)	(0.00002)	(0.00013)	(0.00009)
IV Estimates	-	-0.42743***	0.05392**	-0.07235	-0.03883
	-	(0.11719)	(0.02460)	(0.17230)	(0.11863)
Observations	5,424,576	5,424,576	5,424,576	5,424,576	5,424,576
Number of Zip Codes	23,792	23,792	23,792	23,792	23,792

Notes: The sample for this table includes kidney transplants or deaths while waiting that occurred between January 2000 and December 2018. These transplant count analyses use data aggregated to the zip code-month-year level. Standard errors are robust to clustering at the zip code level. *** p<0.01, ** p<0.05, * p<0.10

Table A2: Replication of Teltser (2019), Quality Outcomes

	Graft Failure <1 year	Graft Failure <2 years	HLA Mismatches	Registration Duration (Days)
Panel A: OLS quality estimates				
Exchange (count)	-0.03336***	-0.04283***	0.54174***	-172.87343***
	(0.00286)	(0.00413)	(0.01770)	(8.15457)
Panel B: Reduced form and IV quality estimates using Activity				
Nearby Exchanges (excluding own)	-0.00117***	-0.00086	0.00099	-2.34199*
	(0.00044)	(0.00058)	(0.00258)	(1.30719)
IV Estimates	-0.18498***	-0.13140	0.16887	-400.37930*
	(0.06973)	(0.08854)	(0.43788)	(223.87465)
Observations	245,708	228,593	288,541	294,425
Number of Zip Codes	16991	16657	17763	17876

Notes: The sample for this table includes individual-level data on kidney transplants that occurred between January 2000 and December 2018. Graft failure is defined as failure of the organ or death within the specified timeframe. Registration duration is the elapsed time from waitlist registration to transplant, or 0 when the recipient did not first register on a waitlist. HLA mismatches are human leukocyte antigen mismatches between patient and donor, and can range from 0 to 6. Standard errors are robust to clustering at the zip code level. *** p<0.01, ** p<0.05, * p<0.10

Table A3: Additional Quantity and Quality Outcomes by Race/Ethnicity

		Any TX	Direct Living	Anon	Dec. Don.	Graft Failure <3 years	Graft Failure <5 years	Registration Duration (Days)	HLA Mismatches
Nearby exchanges (Excluding Own)									
	Non-Hisp White	0.00027***	-0.00011*	0.00001	-0.00001	0.00059	-0.00099	-0.79779	0.01242***
		(0.00010)	(0.00006)	(0.00001)	(0.00007)	(0.00121)	(0.00179)	(1.87902)	(0.00467)
		[0.02979]	[0.01112]	[0.00026]	[0.01757]	[0.14827]	[0.23341]	[493.87]	[3.49419]
		0.9%	-1.0%	3.9%	-0.1%	0.4%	-0.4%	-0.2%	0.4%
	Non-Hisp Black	0.00013	-0.00009**	0.00002***	0.00003	-0.00339**	-0.00354	-2.44783	-0.00353
		(0.00009)	(0.00004)	(0.00001)	(0.00008)	(0.00154)	(0.00226)	(2.67479)	(0.00453)
		[0.01442]	[0.00243]	[0.00006]	[0.01173]	[0.19492]	[0.30628]	[826.08]	[4.19908]
		0.9%	-3.7%	31.2%	0.3%	-1.7%	-1.2%	-0.3%	-0.1%
	Hispanic	-0.00003	-0.00007*	0.000002	-0.00010*	0.00283	0.00308	-6.72951*	-0.00472
		(0.00007)	(0.00004)	0.000005	(0.00006)	(0.00200)	(0.00270)	(3.69487)	(0.00669)
		[0.00767]	[0.00224]	[0.00004]	[0.00523]	[0.12444]	[0.20217]	[755.34]	[3.64241]
		-0.4%	-3.1%	5.6%	-1.3%	2.3%	1.5%	-0.9%	-0.1%
P-values for tests of different coefficients:									
	Black and White	0.2940	0.7366	0.5271	0.7365	0.0430**	0.3790	0.6146	0.0145**
	Hispanic and White	0.0131**	0.5197	0.5712	0.3045	0.3353	0.2058	0.1493	0.0344**
	Black and Hispanic	0.1450	0.6762	0.0384**	0.1754	0.0134**	0.0593*	0.3453	0.8824

Notes: The sample for this table includes kidney transplants that occurred between January 2000 and December 2018. The transplant count analyses use zip code-month-year level aggregates by group, while the graft failure, registration duration, and HLA mismatch analyses use individual-level data. "Anon" represents anonymous (or non-directed) living donor transplants. Graft failure is defined as failure of the organ or death within the specified timeframe. Registration duration is the elapsed time from waitlist registration to transplant, or 0 when the recipient did not first register on a waitlist. HLA mismatches are human leukocyte antigen mismatches between patient and donor, and can range from 0 to 6. To test for differences between coefficients, we estimate a fully-interacted regression specification for each outcome of interest, which yields coefficients and standard errors that are identical to those from the analogous individual subsample regressions. Standard errors are robust to clustering at the zip code level. *** p<0.01, ** p<0.05, * p<0.10

Table A4: Additional Quantity and Quality Outcomes by Age

		Any TX	Direct Living	Anon	Dec. Don.	Graft Failure <3 years	Graft Failure <5 years	Registration Duration (Days)	HLA Mismatches
Nearby exchanges (Excluding Own)									
	18-35	0.00019***	-0.00002	0.00002**	0.00002	-0.00243	-0.00220	-5.69528	-0.00492
		(0.00006)	(0.00004)	(0.00001)	(0.00005)	(0.00255)	(0.00374)	(4.41049)	(0.00849)
		[0.00970]	[0.00367]	[0.00007]	[0.00572]	[0.15066]	[0.23774]	[679.11]	[3.58266]
		2.0%	-0.5%	29.7%	0.3%	-1.6%	-0.9%	-0.8%	-0.1%
	35-55	0.00036***	-0.00013**	0.00002	0.00012	-0.00121	-0.00139	-3.55242*	0.00014
		(0.00010)	(0.00006)	(0.00001)	(0.00008)	(0.00111)	(0.00162)	(2.12521)	(0.00413)
		[0.02558]	[0.00752]	[0.00018]	[0.01728]	[0.13921]	[0.21749]	[675.90]	[3.77322]
		1.4%	-1.7%	11.0%	0.7%	-0.9%	-0.6%	-0.5%	0.0%
	55+	-0.00014	-0.00017***	0.00001	-0.00020**	0.00122	0.00102	-2.07590	0.00139
		(0.00010)	(0.00005)	(0.00001)	(0.00008)	(0.00146)	(0.00218)	(1.92685)	(0.00451)
		[0.01991]	[0.00538]	[0.00014]	[0.01395]	[0.17852]	[0.28717]	[574.65]	[3.79146]
		-0.7%	-3.2%	7.3%	-1.4%	0.7%	0.4%	-0.4%	0.0%
P-values for tests of different coefficients:									
	18-35 and 35-55	0.1502	0.0847*	0.8919	0.3343	0.6499	0.8365	0.6522	0.5810
	18-35 and 55+	0.0053***	0.0113**	0.4467	0.0207**	0.1982	0.4407	0.4370	0.4984
	35-55 and 55+	0.0005***	0.5921	0.4559	0.0082***	0.1869	0.3762	0.6095	0.8389

Notes: The sample for this table includes kidney transplants that occurred between January 2000 and December 2018. The transplant count analyses use zip code-month-year level aggregates by group, while the graft failure, registration duration, and HLA mismatch analyses use individual-level data. "Anon" represents anonymous (or non-directed) living donor transplants. Graft failure is defined as failure of the organ or death within the specified timeframe. Registration duration is the elapsed time from waitlist registration to transplant, or 0 when the recipient did not first register on a waitlist. HLA mismatches are human leukocyte antigen mismatches between patient and donor, and can range from 0 to 6. To test for differences between coefficients, we estimate a fully-interacted regression specification for each outcome of interest, which yields coefficients and standard errors that are identical to those from the analogous individual subsample regressions. Standard errors are robust to clustering at the zip code level. *** p<0.01, ** p<0.05, * p<0.10

Table A5: Additional Quantity and Quality Outcomes by Educational Attainment

		Any TX	Direct Living	Anon	Dec. Don.	Graft Failure <3 years	Graft Failure <5 years	Registration Duration (Days)	HLA Mismatches
Nearby exchanges (Excluding Own)									
	HS or Less	0.00008	-0.00010*	0.00002	-0.00007	-0.00059	-0.00034	-3.11657	0.00257
		(0.00010)	(0.00005)	(0.00001)	(0.00009)	(0.00131)	(0.00193)	(2.16705)	(0.00437)
		[0.02424]	[0.00617]	[0.00013]	[0.01751]	[0.16288]	[0.26025]	[686.27]	[3.76587]
		0.3%	-1.6%	15.1%	-0.4%	-0.4%	-0.1%	-0.5%	0.1%
	Some Coll. or More	0.00040***	-0.00017**	0.00002	0.00007	-0.00054	-0.00157	-1.11617	0.00066
		(0.00012)	(0.00007)	(0.00002)	(0.00009)	(0.00110)	(0.00168)	(1.74814)	(0.00375)
		[0.02646]	[0.00905]	[0.00023]	[0.01634]	[0.14026]	[0.22259]	[586.86]	[3.75834]
		1.5%	-1.9%	8.6%	0.4%	-0.4%	-0.7%	-0.2%	0.0%
P-values for tests of different coefficients:									
	HS and SC	0.0461**	0.4120	0.6532	0.2688	0.9752	0.6307	0.4720	0.7397

Notes: The sample for this table includes kidney transplants that occurred between January 2000 and December 2018. The transplant count analyses use zip code-month-year level aggregates by group, while the graft failure, registration duration, and HLA mismatch analyses use individual-level data. "Anon" represents anonymous (or non-directed) living donor transplants. Graft failure is defined as failure of the organ or death within the specified timeframe. Registration duration is the elapsed time from waitlist registration to transplant, or 0 when the recipient did not first register on a waitlist. HLA mismatches are human leukocyte antigen mismatches between patient and donor, and can range from 0 to 6. To test for differences between coefficients, we estimate a fully-interacted regression specification for each outcome of interest, which yields coefficients and standard errors that are identical to those from the analogous individual subsample regressions. Standard errors are robust to clustering at the zip code level. *** p<0.01, ** p<0.05, * p<0.10

Table A6: Additional Quantity and Quality Outcomes by Payer

						Graft Failure		Registration	HLA
		Any TX	Direct Living	Anon	Dec. Don.	<3 years	<5 years	Duration (Days)	Mismatches
Nearby exchanges (Excluding Own)									
	Private	0.00045***	-0.00008	0.00002	0.00002	-0.00019	-0.00014	-2.74798	0.00263
		(0.00011)	(0.00007)	(0.00001)	(0.00008)	(0.00101)	(0.00151)	(1.86055)	(0.00401)
		[0.02726]	[0.01071]	[0.00023]	[0.01549]	[0.12623]	[0.20155]	[602.08]	[3.66346]
		1.7%	-0.7%	8.8%	0.1%	-0.2%	-0.1%	-0.5%	0.1%
	Medicare	-0.00008	-0.00015***	0.00000	-0.00009	0.00068	-0.00003	-2.95389	0.00676
		(0.00009)	(0.00004)	(0.00001)	(0.00007)	(0.00211)	(0.00302)	(2.62629)	(0.00551)
		[0.01629]	[0.00347]	[0.00010]	[0.01241]	[0.18697]	[0.29703]	[579.45]	[3.84428]
		-0.5%	-4.3%	0.0%	-0.7%	0.4%	0.0%	-0.5%	0.2%
	Medicaid	0.00004	-0.00007**	0.00001**	0.00000	-0.00049	-0.00051	1.17590	0.00020
		(0.00007)	(0.00003)	(0.00001)	(0.00006)	(0.00211)	(0.00304)	(3.60377)	(0.00674)
		[0.01065]	[0.00213]	[0.00006]	[0.00833]	[0.18467]	[0.28731]	[813.48]	[3.81382]
		0.4%	-3.3%	17.5%	0.0%	-0.3%	-0.2%	0.1%	0.0%
P-values for tests of different coefficients:									
	Private and Medicare	0.0002***	0.3908	0.4210	0.3420	0.7051	0.9750	0.9488	0.5438
	Private and Medicaid	0.0023***	0.8330	0.7603	0.8778	0.8949	0.9129	0.3268	0.7538
	Medicare and Medicaid	0.2946	0.0847*	0.4407	0.3496	0.6873	0.9104	0.3455	0.4430

Notes: The sample for this table includes kidney transplants that occurred between January 2000 and December 2018. The transplant count analyses use zip code-month-year level aggregates by group, while the graft failure, registration duration, and HLA mismatch analyses use individual-level data. "Anon" represents anonymous (or non-directed) living donor transplants. Graft failure is defined as failure of the organ or death within the specified timeframe. Registration duration is the elapsed time from waitlist registration to transplant, or 0 when the recipient did not first register on a waitlist. HLA mismatches are human leukocyte antigen mismatches between patient and donor, and can range from 0 to 6. The private payer category includes those with private insurance as their primary payer, excluding any of those who have Medicaid as their secondary payer. Medicare includes those with Medicare as their primary payer, excluding any of those who have Medicaid as their secondary payer. Medicaid includes anyone with Medicaid as either their primary or secondary payer. To test for differences between coefficients, we estimate a fully-interacted regression specification for each outcome of interest, which yields coefficients and standard errors that are identical to those from the analogous individual subsample regressions. Standard errors are robust to clustering at the zip code level. *** p<0.01, ** p<0.05, * p<0.10

Table A7: Additional Quantity and Quality Outcomes by Gender

		Any TX	Direct Living	Anon	Dec. Don.	Graft Failure <3 years	Graft Failure <5 years	Registration Duration (Days)	HLA Mismatches
Nearby exchanges (Excluding Own)									
	Women	0.00017*	-0.00015***	0.00002**	-0.00004	-0.00163	-0.00384**	-4.45900*	0.00508
		(0.00010)	(0.00005)	(0.00001)	(0.00008)	(0.00127)	(0.00184)	(2.31891)	(0.00464)
		[0.02182]	[0.00645]	[0.00016]	[0.01466]	[0.15292]	[0.23679]	[648.40]	[3.62444]
		0.8%	-2.3%	12.8%	-0.3%	-1.1%	-1.6%	-0.7%	0.1%
	Men	0.00024**	-0.00017**	0.00002	-0.00001	0.00035	-0.00062	-0.60737	-0.00174
		(0.00012)	(0.00007)	(0.00001)	(0.00010)	(0.00102)	(0.00147)	(1.69735)	(0.00342)
		[0.03337]	[0.01013]	[0.00023]	[0.02229]	[0.15654]	[0.25025]	[631.65]	[3.82173]
		0.7%	-1.7%	8.7%	0.0%	0.2%	-0.2%	-0.1%	0.0%
P-values for tests of different coefficients:									
	Women and Men	0.6539	0.8147	0.6205	0.8255	0.2242	0.1691	0.1783	0.2351

Notes: The sample for this table includes kidney transplants that occurred between January 2000 and December 2018. The transplant count analyses use zip code-month-year level aggregates by group, while the graft failure, registration duration, and HLA mismatch analyses use individual-level data. "Anon" represents anonymous (or non-directed) living donor transplants. Graft failure is defined as failure of the organ or death within the specified timeframe. Registration duration is the elapsed time from waitlist registration to transplant, or 0 when the recipient did not first register on a waitlist. HLA mismatches are human leukocyte antigen mismatches between patient and donor, and can range from 0 to 6. To test for differences between coefficients, we estimate a fully-interacted regression specification for each outcome of interest, which yields coefficients and standard errors that are identical to those from the analogous individual subsample regressions. Standard errors are robust to clustering at the zip code level. *** p<0.01, ** p<0.05, * p<0.10