

e-companion to

Hybrid Kidney Allocation: Improving Equity by Fair Integration of Deceased Donor-Initiated Chains in Kidney Exchange

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EC.1. Additional Model and Implementation Details

This section presents additional implementation details for the optimization frameworks. It includes the detailed construction of arc-position sets $\mathcal{K}_t(i, j)$ that determine admissible cycle and chain structures, the post-match-run allocation strategy used in the forward-looking static models, and the complete Sample Average Approximation (SAA) formulation.

EC.1.1. Arc-position sets for chains

We define the arc-position sets $\mathcal{K}_t(i, j)$ that determine the admissible positions of arcs within chains. We first give the definition for the static model and after that for the enhanced static model, with differences arising from how deceased-donor initiation and chain-length restrictions are handled.

Static model. Define the epoch-specific chain-length limit L_t that equals L if $t \in \mathcal{M}$ (i.e., t is a match run) and 1 otherwise (in accordance with Definition 2 from Section 2.2). We define $\mathcal{K}_t(i, j)$ as follows: for $(i, j) \in A_t^+$,

$$\mathcal{K}_t(i, j) := \begin{cases} \{1\}, & i \in N_t^d, j \in N_t^+ \\ \{d_t(i) + 1, \dots, L_t\}, & i, j \in N_t^p, d_t(i) < L_t, \\ \{d_t(i) + 1, \dots, L_t + 1\}, & i \in N_t^p, j \in N_t^r, d_t(i) < L_t + 1, \\ \emptyset, & \text{otherwise,} \end{cases}$$

where $d_t(i)$ is the length of the shortest directed path from any node in N_t^d to i ; by convention $d_t(i) = 0$ for $i \in N_t^d$ and $d_t(i) = \infty$ if i is not reachable from any node in N_t^d .

Enhanced static model. Under the enhanced static model, we permit deceased donor-initiated chains (DDICs) up to length $L + 1$ instead of length 1 to create more flexibility in using DDICs under

fairness constraints. Arcs from deceased donors (DDs) are restricted to position 0. The feasible positions for $(i, j) \in A_t^+$ are given by

$$\mathcal{K}_t(i, j) = \begin{cases} \{0\} & \text{if } i \in N_t^{DD}, j \in N_t^+, \\ \{1\} & \text{if } i \in N_t^{LD}, j \in N_t^+, \\ \{d_t(i) + 1, \dots, L\} & \text{if } i, j \in N_t^P, d_t(i) < L, \\ \{d_t(i) + 1, \dots, L + 1\} & \text{if } i \in N_t^P, j = \tau, d_t(i) < L + 1. \\ \emptyset & \text{otherwise.} \end{cases}$$

EC.1.2. Post-match run strategy for allocating chain-ending kidneys for the static models

After solving the enhanced or safe static model for a match run, we decide whether chain-ending donors become bridge donors (BDs) or donate to the waitlist using a simple deterministic rule. Any node $i \in N_t^d$ included in a single-node chain (i, τ) donates directly to the waitlist. Remaining chain-ending donors are sorted by arrival time of the patient-donor pair (PDP) to the kidney exchange program (KEP), earliest to latest. For each $x \in \{O, A, B, AB\}$, donors of type x are allocated to the waitlist in this order until the requirement for that blood type is met or no such donors remain. If shortages exist for types A or B, we use available O-type donors. Similarly, for shortages of type AB, we first use A- and B-type donors and, if needed, available O-type donors. Any remaining chain-ending donors become BDs for the next match run. When solving without fairness constraints, we ignore blood type and assign waitlist donations solely based on PDP arrival order.

Identifying an optimal assignment of chain-ending donors is difficult, as seemingly obvious proxies for future value, such as the number of outgoing arcs, can be misleading. A donor with few compatibility options may still enable valuable future exchanges, while a donor with many options may match patients who have alternatives. We therefore adopt a simple transparent rule. This also highlights an advantage of SAA, which can strategically plan the allocation of chain-ending donors.

EC.1.3. Full Sample Average Approximation model

This section presents the full formulation of the SAA model described in Section 3.2. The model extends the static formulation (2) by incorporating multiple stochastic scenarios that represent future realizations of PDP and living nondirected donor (LNDD) arrivals and their compatibilities, and PDP departures. The objective is to maximize the expected number of transplants across all scenarios, accounting for both immediate and future match opportunities. Constraints ensure feasibility within each scenario and link decisions across periods, for instance by ensuring that

bridge donors can only initiate a chain if their paired patient has previously received a transplant. The complete mathematical formulation is

$$\begin{aligned} \max \quad & \sum_{(i,j) \in A_t} \sum_{k \in \mathcal{K}_t(i,j)} f_{ijk} + \sum_{c \in C_t} |c| y_c \\ & + \sum_{s \in \mathcal{S}} \left[\sum_{t' \in \mathcal{T}^s} \frac{\gamma_{t'}^s}{|\mathcal{S}|} \left(\sum_{(i,j) \in A_{t'}^s} \sum_{k \in \mathcal{K}_{t'}^s(i,j)} f_{ijk}^s + \sum_{c \in C_{t'}^s} |c| y_c^s \right) \right] \end{aligned} \quad (3a)$$

$$\begin{aligned} \text{s.t.} \quad & \sum_{c \in C_t: j \in c} y_c + \sum_{i: (j,i) \in A_t^+} \sum_{k \in \mathcal{K}_t(j,i)} f_{jik} + \sum_{c \in C^s: j \in c} y_c^s \\ & + \sum_{t' \in \mathcal{T}^s} \sum_{i: (j,i) \in A_{t'}^{s,+}} \sum_{k \in \mathcal{K}_{t'}^s(j,i): k \neq 1 \vee j \in N_{t'}^{s,d}} f_{jik}^s \leq 1 \quad \forall j \in N^s, s \in \mathcal{S} \end{aligned} \quad (3b)$$

$$\begin{aligned} & \sum_{i: (j,i) \in A_t^{s,+}, 1 \in \mathcal{K}_t^s(j,i)} f_{ji1}^s - \mathbf{1}_{\{\tilde{t}^- \leq t\}} \sum_{k \in \mathcal{K}_t(j, \tau^B)} f_{j \tau^B k} \\ & - \sum_{t' = \max\{t+1, \tilde{t}^-\}}^{\tilde{t}-1} \sum_{k \in \mathcal{K}_{t'}(j, \tau^B)} f_{j \tau^B k}^s \leq 0 \quad \forall s \in \mathcal{S}, j \in N^{s,p}, \tilde{t} \in \mathcal{M}^s \end{aligned} \quad (3b')$$

$$\sum_{i: (i,j) \in A_t, k \in \mathcal{K}_t(i,j)} f_{ijk} = \sum_{i: (j,i) \in A_t^+, k+1 \in \mathcal{K}_t(j,i)} f_{ji k+1} \quad \forall j \in N_t^p, k \in \bar{L}_t \quad (3c)$$

$$\sum_{i: (i,j) \in A_{t'}^s, k \in \mathcal{K}_{t'}^s(i,j)} f_{ijk}^s = \sum_{i: (j,i) \in A_{t'}^{s,+}, k+1 \in \mathcal{K}_{t'}^s(j,i)} f_{ji k+1}^s \quad \forall s \in \mathcal{S}, t' \in \mathcal{T}^s, j \in N_{t'}^{s,p}, k \in \bar{L}_{t'} \quad (3c')$$

$$f_{jik} \in \mathbb{B} \quad \forall (j,i) \in A_t^+, k \in \mathcal{K}_t^s(j,i) \quad (3d)$$

$$\begin{aligned} f_{jik}^s \in \mathbb{B} \quad & \forall s \in \mathcal{S}, t' \in \mathcal{T}^s, (j,i) \in A_{t'}^s, \\ & k \in \mathcal{K}_{t'}^s(j,i) \end{aligned} \quad (3d')$$

$$y_c \in \mathbb{B} \quad \forall c \in C_t \quad (3e)$$

$$y_c^s \in \mathbb{B} \quad \forall s \in \mathcal{S}, c \in C^s \quad (3e')$$

$$r_x^{s,\tilde{t}} \geq \tilde{Q}_x + q_x^{s,\tilde{t}^-} \quad \forall x \in \mathcal{X}, s \in \mathcal{S}, \tilde{t} \in \mathcal{M}^s, \quad (3f)$$

where $\tilde{t}^- = \max\{t'' \in \mathcal{M}^s \cup \{0\} : t'' < \tilde{t}\}$ and $r_x^{s,\tilde{t}}$ and $q_x^{s,\tilde{t}}$ are defined as in Section 3.2. Objective (3a) is used to maximize the total discounted number of transplants. Constraints (3b) ensure that each patient and donor appear in at most one cycle or chain per scenario, except for pairs that are used as BDs, who may appear a second time to initiate a bridge chain. We exclude arcs at position 1 from nodes in $N^{s,p}$, as these correspond to bridge-chain initiations. Constraints (3b') ensure consistent use of BDs. In particular, they impose that a bridge chain starting at PDP j in match run $\tilde{t}$ is only allowed if j received a kidney at the end of a chain in or after the preceding match run $\tilde{t}^-$ and did not

donate to the waitlist. Next, (3c)-(3c') are the flow conservation: a paired donor may only donate in a chain if their patient receives a kidney in that same chain. Fairness constraints (3f) impose that, for each scenario s and match run $\tilde{t} \in \mathcal{M}^s$, the number of living donor (LD) kidneys allocated to patients of type $x \in \mathcal{X}$ on the waitlist by the end of that match run (left-hand side) should be at least the required number (right-hand side). This required number is effectively the number of arrived living and used deceased NDDs of type x up to the match run preceding $\tilde{t}$ minus the cumulative number of LDs allocated to patients of type x on the waitlist by the end of that match run. Finally, all decision variables are still binary, as enforced by (3d)-(3e').

EC.1.3.1. Additional chain-ending constraints We next present constraints on the blood type distribution of chain-ending kidneys. Like in Section 3.3.1, let $\mathcal{X} := \{\mathcal{X}' \subseteq \mathcal{X} | \mathcal{X}_x \subseteq \mathcal{X}', \forall x \in \mathcal{X}'\} = \{\{O\}, \{O, A\}, \{O, B\}, \{O, A, B\}, \mathcal{X}\}$ denote the nested family of compatibility sets. We impose:

$$\begin{aligned} & \mathbf{1}_{\{\tilde{t}=t\}} \sum_{j \in N_t: x_j \in X} \sum_{(j, \tau) \in A_t^\tau} \sum_{k \in \mathcal{K}_t(j, \tau)} f_{j\tau k} + \mathbf{1}_{\{\tilde{t} \neq t\}} \sum_{j \in N_{\tilde{t}}^s: x_j \in X} \sum_{(j, \tau) \in A_{\tilde{t}}^{s, \tau}} \sum_{k \in \mathcal{K}_{\tilde{t}}^s(j, \tau)} f_{j\tau k}^s \\ & = \sum_{x \in X} (\tilde{Q}_x + q_x^{s, t}) - \mathbf{1}_{\{\tilde{t} \neq t\}} \sum_{x \in X} F_{xt}^{WL} - \sum_{t'=t+1}^{\tilde{t}-1} F_{xt'}^{WL, s}, \quad \forall X \in \mathcal{X}, s \in \mathcal{S}, \tilde{t} \in \mathcal{M}^s. \end{aligned} \quad (3g)$$

Constraints (3g) ensure that the aggregate number of chain-ending kidneys compatible with each subset of blood types $X \in \mathcal{X}$ equals the required number for each match run in each scenario.

EC.2. Data Simulation Procedure

This section gives more details about our Kidney Exchange Program (KEP) simulator, including the computation of departure rates (Section EC.2.1), the generation of patient–donor pair (PDP) arrivals (Section EC.2.2), and the rationale for the warm-up period and number of simulation runs (Section EC.2.3 and Section EC.2.4).

EC.2.1. Computation of departure rates

We adjust observed departure rates from Holscher et al. (2018). The reported values are the percentage of pairs that left, but this is not equal to the departure rate. Namely, for patients who received a transplant within the first year, we lack data on what proportion would have otherwise departed within that period, suggesting that the true departure rate is higher than the observed proportion of pairs that left the program. Testing confirmed that using the observed rates as departure rates underestimated the actual number of departures.

To correct for this, we apply a multiplication factor calculated as follows: if $x\%$ of patients of a certain blood type received a transplant within the first year, we multiply the observed rate by

$$\frac{100}{100 - x \cdot \frac{2}{3}}$$

to obtain the departure rate for this blood type. This adjustment is intended to bring the implied one-year departure rates closer to those reported in Holscher et al. (2018), and can be interpreted as assuming that transplanted patients spent, on average, one-third of a year in the KEP.

EC.2.2. Generation of patient-donor pair arrivals

We generate PDP arrivals as follows. We first sample the total number of arrivals over the horizon based on the overall arrival rate. Next, we generate a set of patients and a set donors, both of size equal to the total number of arrivals.

- Each patient is assigned a blood type and calculated Panel Reactive Antibody (cPRA) level drawn independently from observed marginal distributions of patient blood types and cPRA levels (see Table 1 in Section 4). Patient blood type and cPRA are assumed to be independent. Each patient is also assigned an arrival time drawn uniformly over the horizon.
- Each donor is assigned a blood type based on the empirical paired donor blood type distribution (see Table 1 in Section 4).

Next, we assign donors to patients so as to maximize the number of incompatible pairs. For each blood-type compatible patient–donor combination, we draw a random number between 0 and 1. A pair is deemed incompatible if it is blood-type incompatible or if the random number is lower than the patient’s cPRA value. Using the resulting incompatibility edges, we solve a maximum matching problem to find the maximum number of incompatible pairs. This preserves correlations between patient and donor blood types. A random tie-breaking rule is used to ensure a realistic representation of the pool. This prevents high-cPRA patients from being systematically assigned only blood-type compatible donors. If a perfect matching does not exist, we iteratively generate additional pairs, only keeping them if they are incompatible, until the desired number of incompatible pairs is reached. Across all generated instances, this was required for at most 0.5% of pairs.

EC.2.3. Warm-up period

Here, we present the rationale for the warm-up period length of 6 years. Detailed results are presented only for the model based on sample average approximation (SAA) from Section 3.2 for one specific parameter configuration. However, observed patterns are consistent across all tested

settings and models. The setting we present corresponds to KEP-163, with maximum cycle and chain length $K = L = 3$, deceased donor factor $DDf = 1$, cPRA threshold $\theta_{cPRA} = 0.98$, and consent fraction $\theta_{cons} = 1$. This corresponds to a KEP with 163 annual PDP arrivals, where deceased donors (DDs) and living nondirected donors (LNDDs) arrive at equal rates and patients with $cPRA \geq 98\%$ are fully willing to accept compatible DD organs.

Figure EC.1 shows the blood type distribution of registered patients, and Figure EC.2 shows their cPRA distribution over time. Both figures demonstrate that the pool composition stabilizes within the first few years, even though the total pool size continues to grow for a longer period. By month 72, both the total pool size and its composition have stabilized with minimal variation thereafter. Based on these observations, we used a warm-up period of 72 months.

Figure EC.1 Average size and patient blood type composition of the KEP-163 pool, with a calculated Panel Reactive Antibody (cPRA) threshold of 98% and arrival rate of deceased donors equal to that of living nondirected donors, based on 25 replications. Error bars depict 95% confidence intervals.

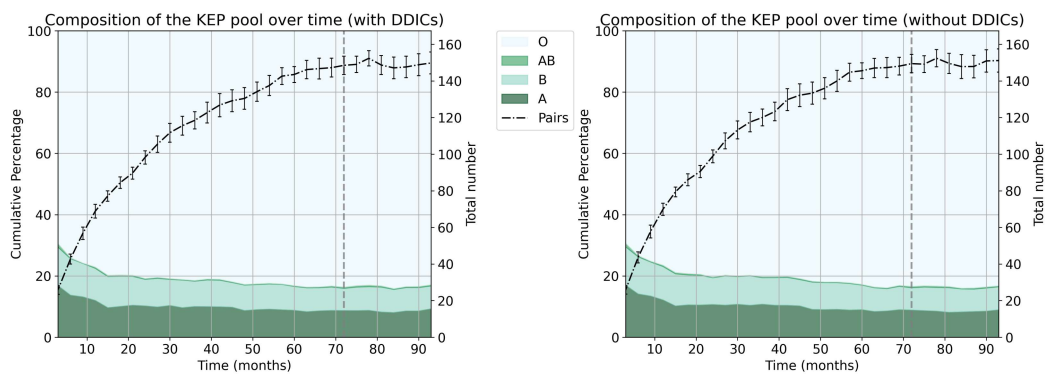


Figure EC.2 Average size and patient calculated Panel Reactive Antibody (cPRA) composition of the KEP-163 pool, with a cPRA threshold of 98% and arrival rate of deceased donors equal to that of living nondirected donors, based on 25 replications. Error bars depict 95% confidence intervals.

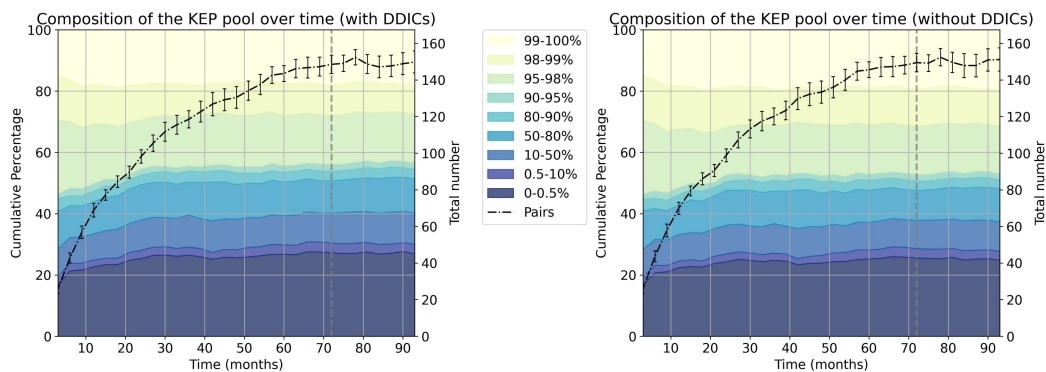
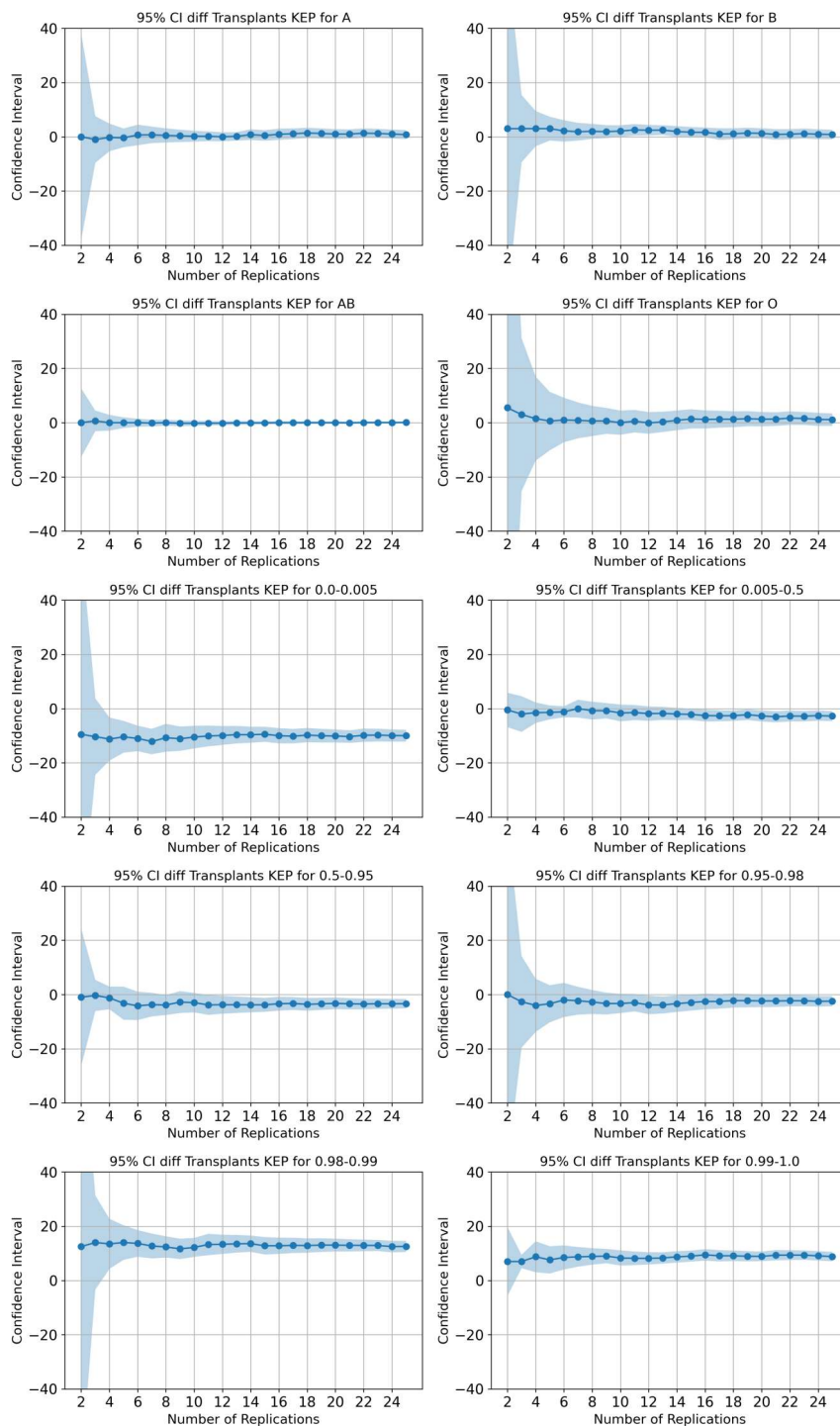


Figure EC.3 Impact of the number of replications on the 95% confidence intervals for the difference in the number of transplants between the cases with and without deceased donor-initiated chains. Results are based on the KEP-163 configuration, with an 8-year evaluation horizon, a cPRA threshold of 98%, and an arrival rate of deceased donors equal to that of living nondirected donors.



EC.2.4. Number of replications

To validate our choice of running 25 replications, we analyze the variance of key outcomes. While detailed results are presented for only the SAA model for one specific parameter configuration (KEP-163, $K = L = 3$, $DDf = 1$, $\theta_{cPRA} = 0.98$, and $\theta_{cons} = 1$), observed patterns are consistent across all tested settings and models. Figure EC.3 shows how the 95% confidence intervals for differences in transplant numbers change with the number of replications.

Although small fluctuations occur early on, the variance stabilizes rapidly. Both figures indicate that confidence intervals converge and remain stable after around 25 replications, confirming that this number of runs is sufficient for reliable estimation.

EC.3. Additional Model Comparison and Sensitivity Analysis Results

This section presents supplementary results, on the O-only fairness specification (Section EC.3.1), a comparison with a variant of the Sample Average Approximation (SAA)-based model that maximizes immediate transplants in every match run (Section EC.3.2), and sensitivity to deceased donor (DD) availability (Section EC.3.3), to maximum cycle and chain lengths (Section EC.3.4), and to bridge donor departures and the timing of waitlist donation requirements (Section EC.3.5).

EC.3.1. Results for the O-only fairness specification

Table EC.1 reports outcomes for the O-only fairness specification, in which fairness constraints ((3f) for the SAA-based model and (4) for enhanced static) are applied exclusively to O-type kidneys. The results show that when fairness is enforced only for O-type donations, fairness violations persist for blood types A and B, with a surplus of AB. These results confirm that fairness enforcement for only blood type O donations still leads to a disturbance of blood-type balance. The partial relaxation of fairness constraints does lead to a 3.7% increase in transplants, but roughly 80% of these additional transplants go to patients with calculated Panel Reactive Antibody (cPRA) below 95%.

Table EC.1 Outcomes of a KEP with deceased donor-initiated chains (DDICs) for the O-only fairness specification, showing average transplant counts, donor use, and donations to the waitlist over an 8-year evaluation horizon across 25 simulations.

Model	SAA	Enhanced static
Number of transplants in the KEP		
Total	771.0	767.2
O	308.1	302.5
A	279.7	280.1
B	159.7	161.3
AB	23.5	23.3
0–95%	486.2	494.4
95–98%	140.0	136.4
98–99%	90.2	85.4
≥99%	54.5	51.0
Living donor donations to the waitlist (available NDDs)		
Total	273.2 (273.0)	272.5 (272.2)
O	132.0 (131.3)	130.7 (130.0)
A	74.8 (100.7)	77.8 (101.1)
B	30.6 (35.6)	29.8 (35.7)
AB	35.9 (5.4)	34.2 (5.4)

Note. “NDDs” are available living and used deceased nondirected donors. Letters (O, A, B, AB) indicate blood types and percentages refer to cPRA levels. Fairness constraints ((3f) for SAA and (4) for the enhanced static model) are applied only for blood type $x \in \{O\}$. Available living NDDs: 244.2 in total (O: 106.9, A: 97.4, B: 34.5, AB: 5.4). Higher reported numbers of NDDs (in brackets) indicate additional deceased donors used in the KEP. In **bold** we highlight shortages of at least one waitlist donation for that blood type.

EC.3.2. Results for an SAA-based model that maximizes immediate transplants

We additionally evaluated a hierarchical variant of the SAA model in which we first maximize the number of immediate transplants and, among all such solutions, maximize the expected discounted number of future transplants. This variant removes the possibility of intentionally postponing currently feasible transplants, while still allowing the model to exploit future information in two important ways. First, it can make future-aware decisions regarding bridge donors, for example by preferring bridge donors with stronger expected future matching potential. Second, among solutions with the same number of immediate transplants, it can favor exchanges involving more difficult-to-match patients based on expected future transplantation opportunities. This variant of the SAA model was motivated by the fact that, in the unrestricted SAA model, on average approximately 20% of currently feasible transplants are postponed to future match runs.

The results in Table EC.2 show that both SAA variants achieve very similar total transplant counts (difference below 0.1%), while the hierarchical variant uses 21% more DDs to initiate

chains (39.3 versus 32.5). The unrestricted SAA model yields slightly more transplants for highly sensitized patients (approximately 2% more for patients with cPRA above 99%), suggesting that postponement of feasible transplants can provide additional benefits for difficult-to-match patients. The hierarchical variant results in somewhat more fairness-constraint violations, although these remain limited overall. Hence, even when immediate transplant maximization is imposed in every match run, most advantages of the forward-looking approach remain intact, even though the full SAA model provides some additional benefits.

Table EC.2 Outcomes of a KEP with deceased donor-initiated chains (DDICs) for different model formulations, showing average transplant counts, donor use, and donations to the waitlist over an 8-year evaluation horizon across 25 simulations.

Model	SAA		Enhanced static
	No	Yes	Yes
Maximize immediate transplants			
Number of transplants in the KEP			
Total	743.3	744.2	739.9
O	305.0	303.1	301.7
A	261.3	262.6	259.7
B	154.0	155.5	155.7
AB	23.0	23.0	22.8
0-95%	464.6	468.2	472.2
95-98%	135.5	133.2	133.4
98-99%	88.5	89.2	84.4
≥99%	54.7	53.5	50.0
Living donor donations to the waitlist (available NDDs)			
Total	277.6 (276.7)	284.3 (283.5)	273.2 (272.8)
O	133.5 (134.3)	137.9 (141.1)	131.4 (131.0)
A	101.4 (101.4)	101.0 (101.4)	101.1 (100.9)
B	35.4 (35.6)	35.4 (35.6)	35.4 (35.4)
AB	7.2 (5.4)	10.0 (5.4)	5.4 (5.4)

Note. “NDDs” are available living and used deceased nondirected donors. Letters (O, A, B, AB) indicate blood types and percentages refer to cPRA levels. Available living NDDs: 244.2 in total (O: 106.9, A: 97.4, B: 34.5, AB: 5.4). Higher reported numbers of NDDs (in brackets) indicate additional deceased donors used in the KEP. In **bold** we highlight shortages of at least one waitlist donation for that blood type.

EC.3.3. Sensitivity of deceased donor availability

Table EC.3 provides the outcomes underlying Figure 4 from Section 5.4. The results confirm that as DD availability increases, the relative benefit of deceased donor-initiated chains (DDICs) grows, particularly for highly sensitized patients, while the fraction of DDs redirected to the KEP decreases.

Table EC.3 Difference (absolute and percentage) in transplants between cases with and without deceased donor-initiated chains for different deceased donor factors (DDfs): total transplants and transplants for different cPRA levels. DDf refers to the ratio of the expected number of deceased donor (DD) to the expected number of living nondirected donor arrivals. Also shows the number and percentage of DDs redirected to the KEP and the average increase in transplants per DD used.

DDf	Δ Total	Δ 0–98%	$\Delta \geq 98\%$	DDs Used	Δ /DD Used Total	Δ /DD Used $\geq 98\%$
$1/2$	4.4*	-3.4	7.8*	14.5	0.31	0.54
	0.6%	-0.5%	6.6%	11.9%		
1.0	8.0*	-7.4*	15.4*	28.7	0.28	0.54
	1.1%	-1.2%	13.0%	11.6%		
2.0	15.5*	-12.2*	27.8*	49.2	0.32	0.56
	2.1%	-2.0%	23.3%	9.8%		
5.0	26.3*	-26.8*	53.1*	92.5	0.28	0.57
	3.6%	-4.4%	44.6%	7.4%		
10.0	35.4*	-35.4*	70.8*	126.6	0.28	0.56
	4.8%	-5.8%	59.5%	5.1%		

Note: Absolute difference shown on the first row for each combination; percentage difference shown on the second row. The results are based on 25 simulations that were evaluated over an 8-year horizon. * indicates the difference is significant at the 95% level (two-sided paired t-test, $n = 25$).

EC.3.4. Sensitivity of maximum cycle and chain lengths

To assess the robustness of our results with respect to the maximum cycle and chain lengths, we perform a sensitivity analysis on (K, L) . Table EC.4 reports the total number of transplants, the absolute and percentage differences between the policies with and without DDICs, and the number of DDs redirected to the KEP. The results show that changes in (K, L) have only minor effects on outcomes. While longer cycles and chains occasionally appear when K and L are increased, they have only a minor impact on the number of transplants over time. Also the proportion of DDs used

Table EC.4 Difference (absolute and percentage) in transplants between cases with and without deceased donor-initiated chains (DDICs) for different maximum cycle and chain lengths (K, L) : total transplants and transplants for different cPRA levels. Also shows how many deceased donors (DDs) are redirected to the KEP in the case with DDICs.

(K, L)	Total (with DDICs)	Δ Total	Δ 0–98%	$\Delta \geq 98\%$	DDs Used
(3,3)	739.9	8.0*	-7.4*	15.4*	28.7
		1.1%	-1.2%	13.0%	11.6%
(3,4)	743.4	7.4*	-7.3*	14.8*	28.1
		1.0%	-1.2%	12.1%	11.3%
(3,5)	743.9	6.7*	-7.4*	14.1*	27.8
		0.9%	-1.2%	11.5%	11.2%
(3,6)	744.6	7.0*	-6.7*	13.7*	27.3
		0.9%	-1.1%	11.1%	11.0%
(4,4)	743.5	7.8*	-7.1*	14.8*	28.0
		1.1%	-1.2%	12.2%	11.3%
(4,5)	744.1	6.6*	-7.3*	13.9*	27.8
		0.9%	-1.2%	11.3%	11.2%
(4,6)	744.8	7.1*	-6.6*	13.8*	27.5
		1.0%	-1.1%	11.1%	11.1%

Note: Absolute difference shown on the first row for each combination; percentage difference shown on the second row. The results are based on 25 simulations that were evaluated over an 8-year horizon. * indicates the difference is significant at the 95% level (two-sided paired t-test, $n = 25$).

to initiate chains and corresponding gains in transplant numbers remain largely stable, indicating that the impact of DDICs does not depend materially on the chosen maximum cycle or chain length.

EC.3.5. Sensitivity of bridge donor departures and timing of waitlist donation requirements

Throughout the paper, we assume that bridge donors (BDs) remain available only during a single match run, but do not depart stochastically. If they are not matched to anyone in the single match run in which they are available, they are assumed to donate to the waitlist. In addition, a nondirected donor used to initiate a chain must lead to a waitlist donation by a living donor (LD) of compatible blood type by the end of the next match interval, corresponding to a return period of two match runs. These assumptions are simplifying modeling choices. In practice, BDs may become unavailable before donating, for example due to renegeing, illness, or death, and the time allowed for return of kidneys to the waitlist could be shorter or longer.

BD departures are particularly relevant because a BD that leaves the system before donating cannot fulfill the corresponding obligation to the waitlist. Since a main objective of this paper is to evaluate whether DDICs can be incorporated without substantially reducing donations to the waitlist, it is important to evaluate this effect. Moreover, the number of missed waitlist donations depends not only on the BD departure rate but also on the length of the return period: allowing more time for returning a kidney to the waitlist creates greater matching flexibility and may increase the number of transplants, but it also increases the window during which a BD may depart.

To evaluate this trade-off, we vary the monthly BD departure probability between 0% and 2%, based on an estimate of 1.5% reported by Cowan et al. (2017), and consider return periods of one, two, and three match runs. A return period of two match runs corresponds to the policy used throughout the paper, in which a DD used to initiate a chain must be followed by an LD donation to the waitlist by the end of the next match interval. The results are presented in Table EC.5.

As expected, increasing the return period results in slightly more transplants by providing greater flexibility in constructing chains. In contrast, the BD departure rate has almost no effect on the total number of transplants. The patterns observed in transplant counts for different blood types and cPRA groups are consistent across different BD departure rates and return periods, indicating that the equity benefits of DDICs are robust to both assumptions.

The lower part of Table EC.5 reports the difference in donations to the waitlist between the settings without and with DDICs together with the number of DDs used to initiate chains in the setting with DDICs. As the return period increases, slightly fewer DDs are used. Since a longer

return period leads to more transplants, this effectively reduces the KEP size, leading to less matches between DDs and pairs in the KEP. This is consistent with the sensitivity analysis on pool size (Table 4 in Section 5.4). When BD departures are introduced, DDICs slightly reduce the number of donations to the waitlist relative to the setting without DDICs. This is expected, as departed bridge donors can no longer contribute future donations. However, these effects remain modest. Even in the most pessimistic setting considered (a monthly bridge donor departure probability of 2% and a return period of three match runs), using DDICs results in only 2.9 fewer total donations and 2.2 fewer blood type O donations to the waitlist over the entire 8-year evaluation horizon.

Table EC.5 Outcomes of a KEP with deceased donor-initiated chains (DDICs), for different bridge donor (BD) departure rates and different timing of requirements for donations to the waitlist, showing average transplant numbers, donor use, and donations to the waitlist across 25 simulations that were evaluated over an 8-year horizon.

Model	Enhanced static											
Return period	1	1	1	1	2	2	2	2	3	3	3	3
BD departure prob	0	1.0%	1.5%	2.0%	0	1.0%	1.5%	2.0%	0	1.0%	1.5%	2.0%
Number of transplants in the KEP												
Total	729.2	729.5	729.2	729.4	739.5	739.7	739.3	739.2	746.4	746.5	746.3	744.8
O	295.9	296.1	296.0	295.8	301.2	301.6	301.6	301.5	306.0	305.3	305.8	304.7
A	257.7	257.6	257.6	257.6	259.7	259.7	259.6	259.2	260.5	261.0	260.6	260.3
B	153.0	153.1	153.0	153.2	155.8	155.6	155.4	155.7	157.0	157.2	157.0	157.0
AB	22.6	22.7	22.6	22.8	22.8	22.8	22.8	22.8	22.9	23.0	22.9	22.8
0-95%	473.3	473.5	473.2	473.6	472.2	472.1	472.2	472.1	470.8	470.6	470.6	470.2
95-98%	128.0	128.0	128.0	128.1	132.9	133.2	133.0	132.9	137.5	137.7	137.6	137.4
98-99%	80.8	80.8	80.8	80.6	84.2	84.4	84.3	84.3	85.9	86.1	86.2	85.8
≥99%	47.2	47.1	47.2	47.2	50.1	50.0	49.8	49.8	52.1	52.1	51.8	51.4
Difference in living donor donations to the waitlist (used DDs for setting with DDICs)												
Total	0.0	0.4	0.5	0.8	0.2	1.1	1.0	2.0	-0.1	1.4	1.7	2.9
	(30.3)	(30.5)	(30.5)	(30.6)	(28.4)	(28.8)	(28.9)	(28.6)	(27.1)	(27.0)	(27.2)	(27.2)
O	0.1	0.4	0.5	0.6	0.0	0.6	0.6	1.2	0.2	1.2	1.8	2.2
	(25.3)	(25.4)	(25.5)	(25.5)	(24.0)	(24.2)	(24.3)	(24.0)	(22.8)	(22.6)	(22.8)	(22.8)
A	0.0	0.1	0.1	0.2	0.0	0.3	0.4	0.5	-0.3	0.2	-0.0	0.4
	(4.0)	(4.0)	(4.0)	(4.0)	(3.5)	(3.6)	(3.6)	(3.6)	(3.3)	(3.5)	(3.4)	(3.5)
B	-0.0	-0.1	-0.0	-0.0	0.2	0.2	0.0	0.2	-0.0	-0.1	-0.0	0.2
	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)
AB	-0.1	0.0	-0.0	-0.0	-0.0	-0.0	0.0	-0.0	-0.0	0.1	-0.0	0.0
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)

Note: BD departure probability denotes the monthly probability that a bridge donor leaves the KEP. The return period is the maximum number of match runs within which a compatible living donor must donate to the waitlist after a nondirected donor has become available. A return period of two match runs corresponds to the policy used throughout the paper (return by the end of the next match interval). Letters (O, A, B, AB) indicate blood types and percentages refer to cPRA groups. Numbers in parentheses denote the average number of deceased nondirected donors (DDs) used to initiate chains. The reported differences in donations to the waitlist equal the number of donations in the setting without DDICs minus the number in the setting with DDICs; positive values therefore indicate fewer waitlist donations when DDICs are used. In **bold** we highlight cases where the difference exceeds one donation over the 8-year evaluation horizon.