Externalities from Medical Innovation: Evidence from Organ Transplantation
APPENDIX

1 Comparative Interrupted Time Series

Our CITS model is specified as follows:

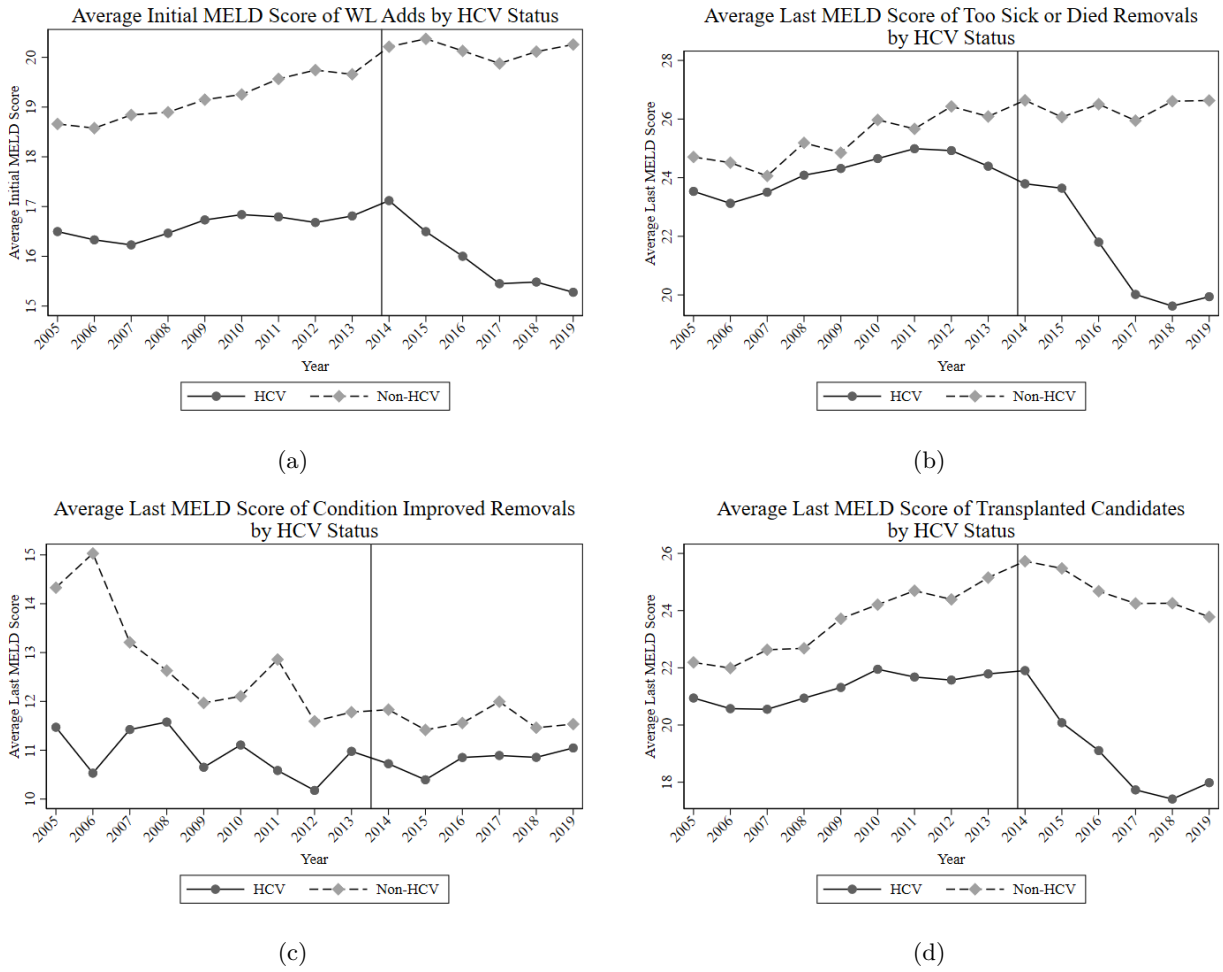
$$\begin{aligned} Y_{dHt} = \beta_1 t + \beta_2(H \times t) + \beta_3 DAA_t + \beta_4(H \times DAA_t) + \\ \beta_5(DAA_t \times t) + \beta_6(H \times DAA_t \times t) + \gamma_{dH} + \epsilon_{dHt} \end{aligned} \tag{1}$$

where d indexes donor service area (DSA),[1] H indexes HCV status, and t indexes year. The first regressor, t, is a linear time trend, such that β_1 measures the slope of the pre-DAA trend for HCV^- candidates and $\beta_1 + \beta 2$ measures the slope of the pre-DAA trend for HCV^+ candidates. DAA_t is an indicator for the post-DAA period (i.e., 2014 through 2019). Thus, β_3 reflects the level change in HCV^- candidates' outcomes associated with the introduction of DAAs relative to their baseline level, while $\beta_3 + \beta_4$ reflects this level change for HCV^+ candidates. Finally, β_5 measures the post-DAA change in slope relative to the pre-DAA slope β_1 for HCV^- candidates, while $\beta_5 + \beta_6$ captures this slope change for HCV^+ candidates. Finally, we include DSA-HCV fixed effects γ_{dH} to address potential unobserved confounders across HCV status and donation service areas, and an idiosyncratic error term ϵ_{dHt} clustered at the DSA-HCV level.

[1] Note that we use modified DSA identifers throughout our analyses due to changes over time in the existence and services of certain DSAs. First, we combine the Sierra Donor Services DSA into the Donor Network West DSA in California, as Sierra Donor Services ended their liver program in 2008/2009 and was geographically entirely surrounded by Donor Network West. Second, the Mississippi Organ Recovery Agency started up in 2013, so we combine that DSA with their pre-existing contiguous DSAs in Tennessee and north Mississippi, Louisiana, and Alabama. Third, because Lifelink of Southwest Florida ended in 2004, OurLegacy in Florida started in 2007, and Lifelink Puerto Rico started in 2012, we combine all Florida and Puerto Rico DSAs into one DSA unit. It is also important to note that 5 DSAs do not have a liver program. Thus, we end up with 50 modified DSA identifiers for kidneys and 45 modified DSA identifiers for livers.

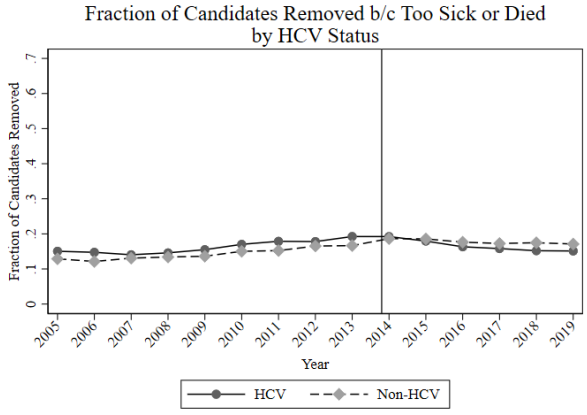
2 Appendix Figures and Tables

Figure 1: MELD Composition of the Liver Transplant Waiting List

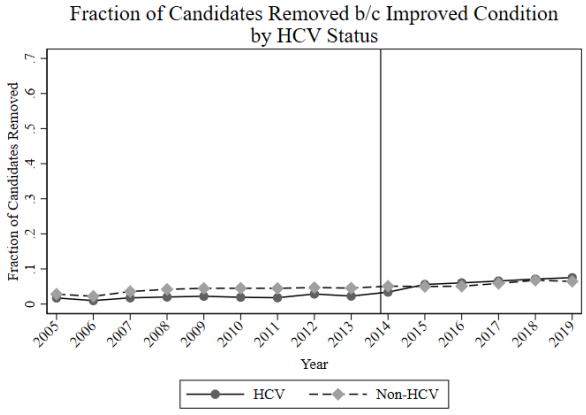


Notes: Authors' calculations of yearly national means using SRTR data. Roughly 20% of candidates have the same initial and last MELD score.

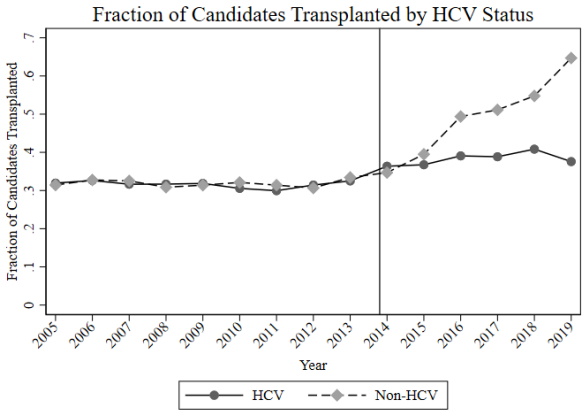
Appendix Figure 2: Liver Transplant Waiting List Inflows and Outflows



(a) WL Removal - Too sick or Died



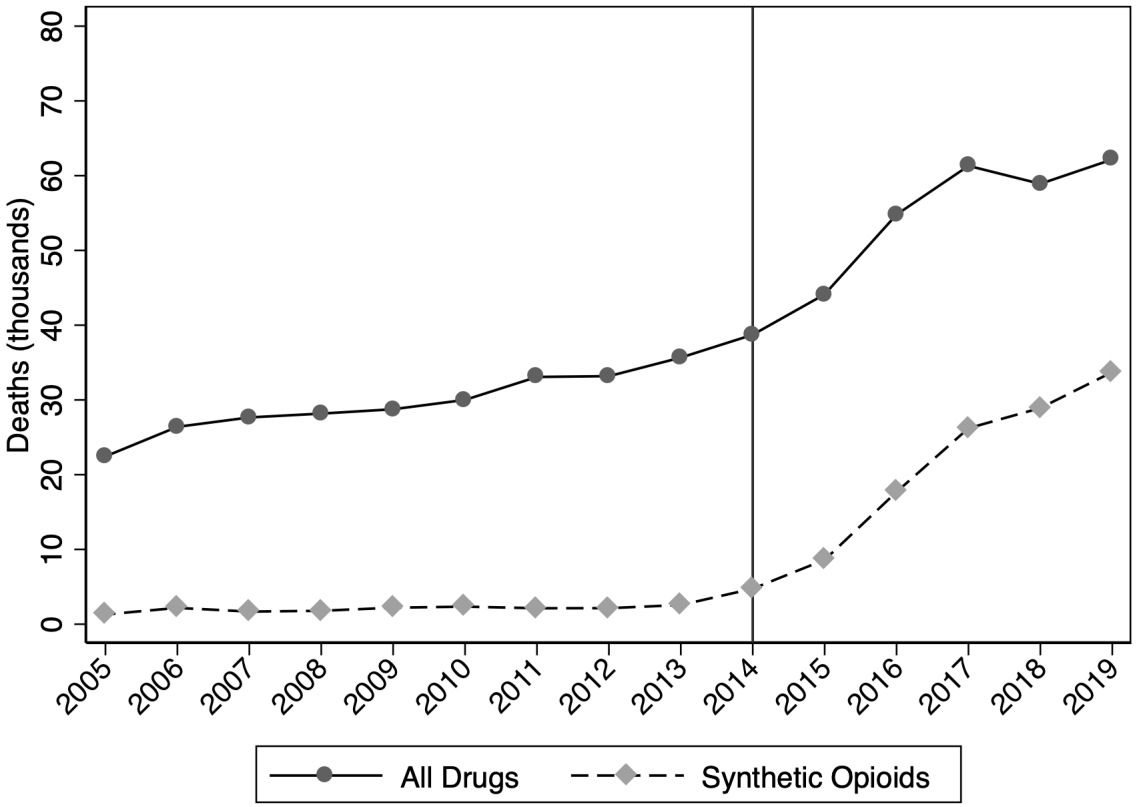
(b) WL Removal - Condition Improved



(c) Transplants

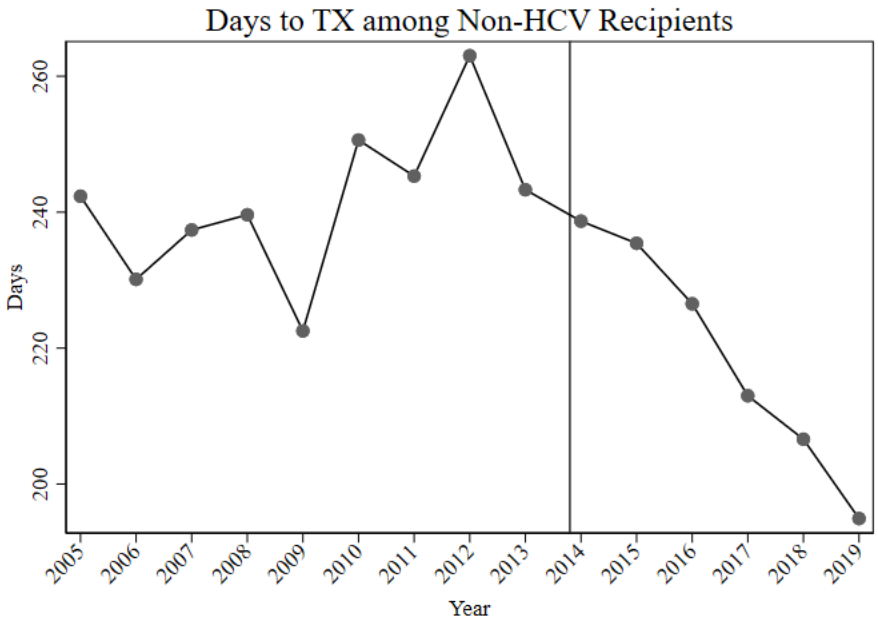
Notes: Authors' calculations of yearly national fractions using SRTR data.

Appendix Figure 3: Drug Overdose Deaths by Year



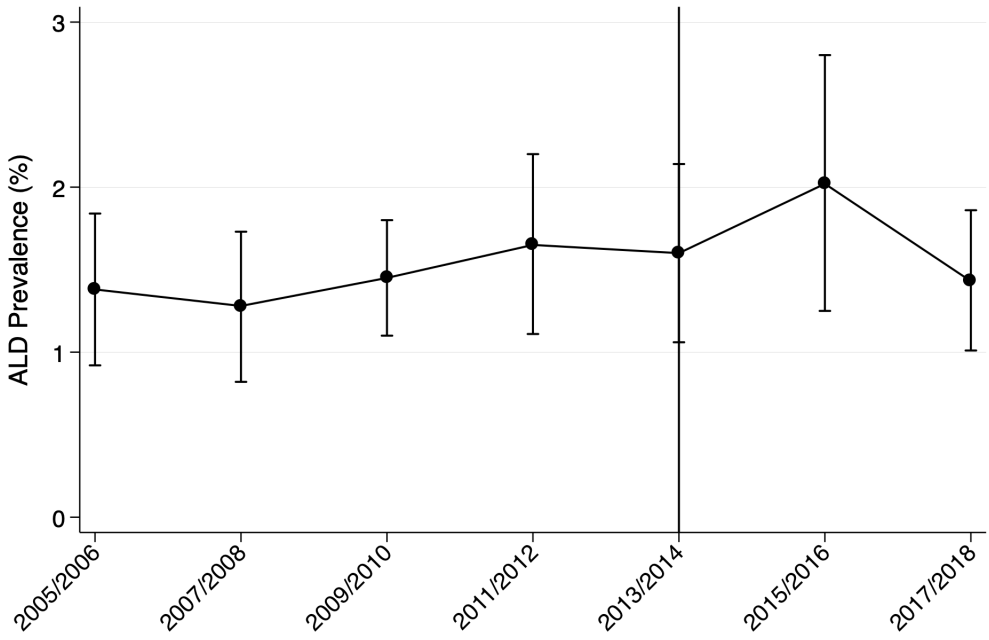
Notes: Figure includes deaths deemed "prevantable or accidental". Synthetic opioids category is "synthetic opioids other than methadone" and includes fentanyl. Source: National Safety Council analysis of National Center for Health Statistics Mortality Data.

Appendix Figure 4: Time from Wait-Listing to Transplant for HCV^- Liver Transplant Recipients



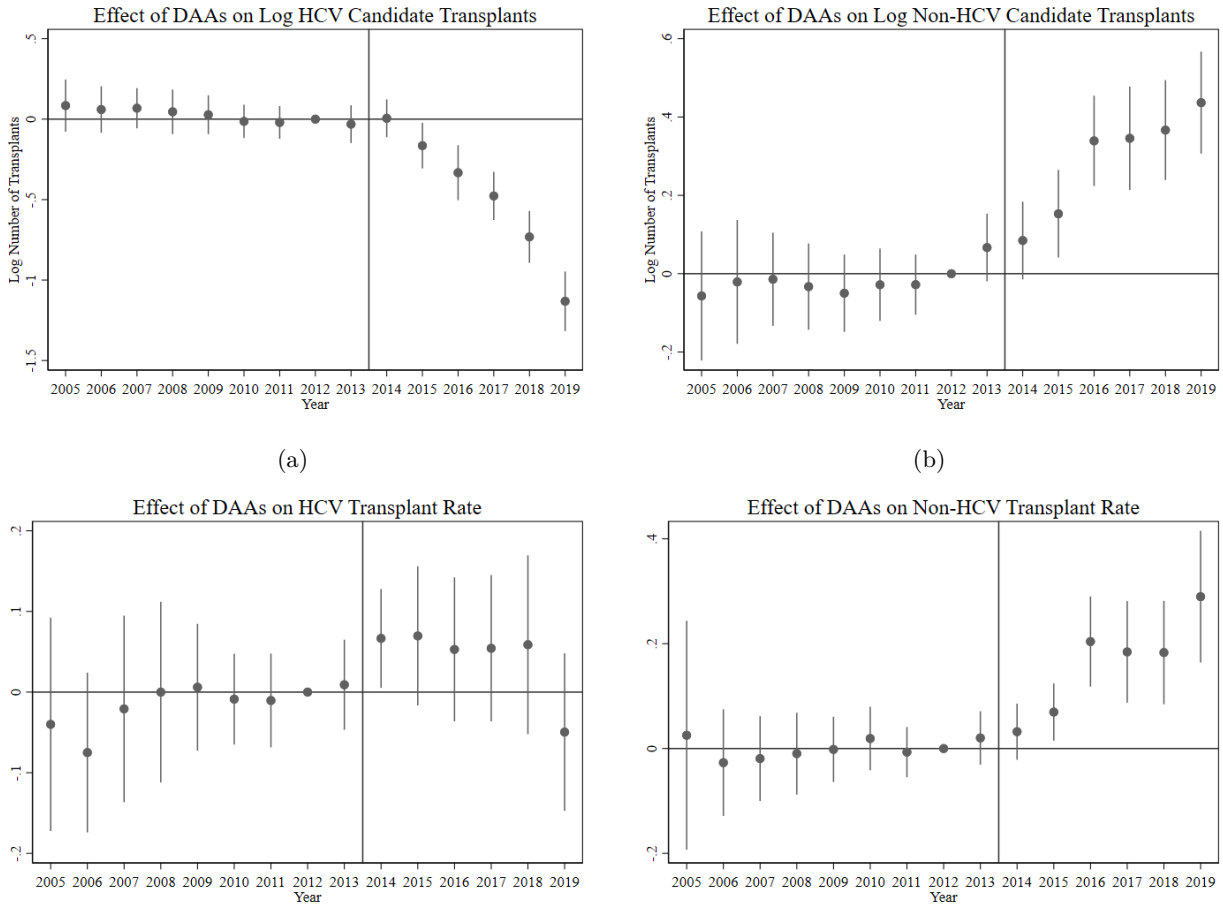
Notes: Authors' calculations of yearly national averages using SRTR data, measured as the difference between date of transplant and date of waiting list registration. In less than 0.2% of transplants, this equals zero. A value of zero can reflect either a true same-day transplant, or a case where a living liver donor recipient did not first join the deceased donor waiting list.

Appendix Figure 5: Alcoholic Liver Disease Prevalence by Year



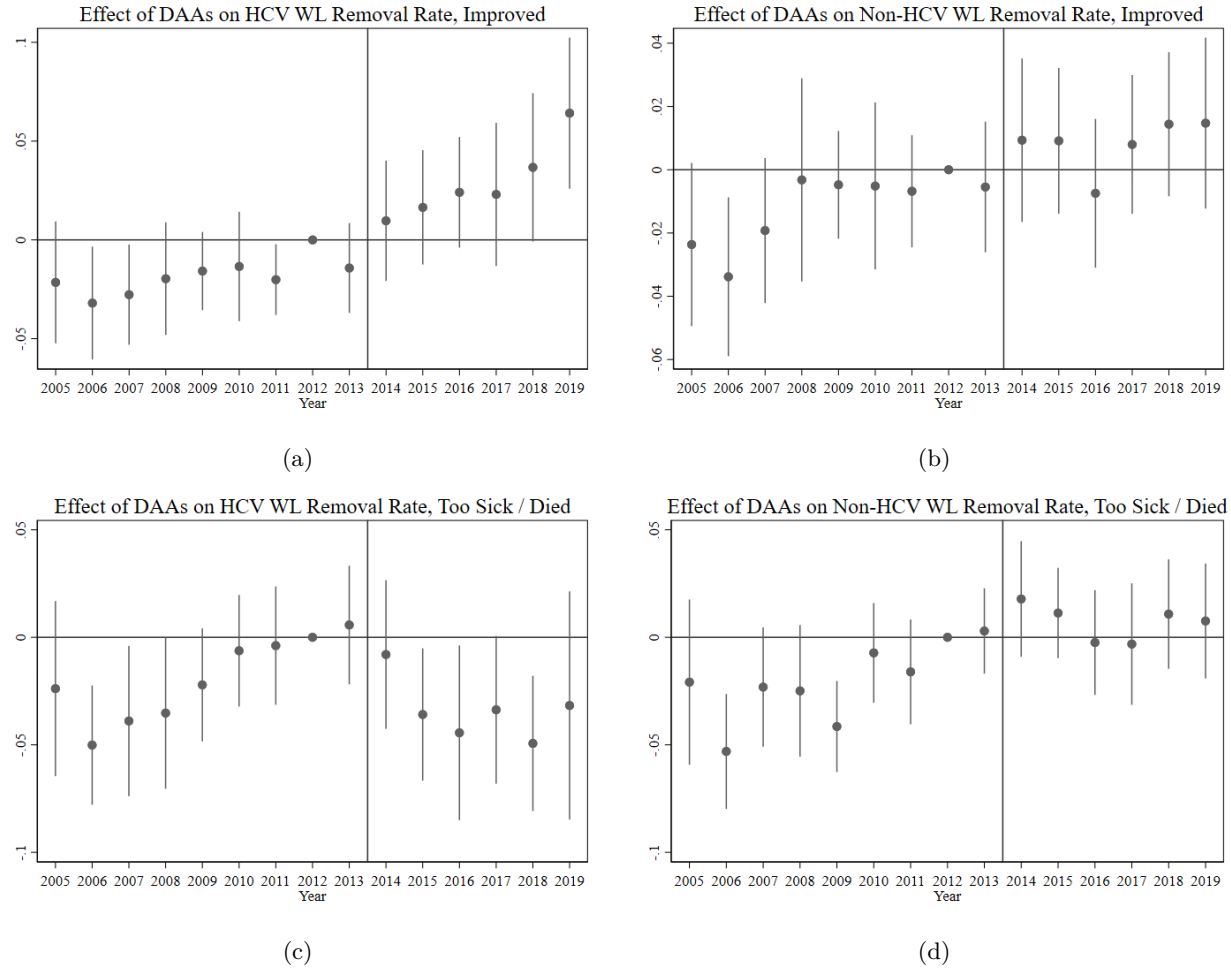
Notes: Alcoholic liver disease is based on the following criteria: 1) average daily alcohol consumption of more than 10 grams for females and more than 20 grams for males and 2) alanine transaminase level or aspartate aminotransferase level greater than 31 U/L in females and an alanine transaminase level greater than 40 U/L or aspartate aminotransferase level greater than 37 U/L in males. Those with Hepatitis B or C infections were excluded. Source: National Health and Nutrition Examination Survey.

Appendix Figure 6: Liver vs. Kidney Transplants



Notes: Each subfigure presents time-disaggregated differences-in-differences estimates, comparing HCV^+ and HCV^- transplants to kidney waitlist additions and transplants. In subfigures (a) and (b), the outcome is the log of the count of transplants (reproduced from the main body of the paper). In Subfigures (c) and (d), the outcome is defined as transplants divided by number of candidates waiting. For kidneys, this rate reflects transplants divided by number of candidates waiting for a kidney. For livers, this rate reflects transplants to HCV+ candidates divided by number of HCV+ candidates waiting for a liver in subfigure (c), and transplants to HCV- candidates divided by number of HCV+ candidates awaiting a liver in subfigure (d). The bars around each coefficient reflect the 95% confidence interval using standard errors that are clustered at the DSA-by-organ level.

Appendix Figure 7: Liver Waiting List Removal Rate Relative to Kidney Waiting List Removal Rate



(a) (b)

(c) (d)

Notes: Each subfigure presents time-disaggregated differences-in-differences estimates, comparing HCV^+ and HCV^- liver waitlist removals due to improved and deteriorated condition to the corresponding kidney waitlist removals. The outcome is defined as waitlist removals divided by number of candidates waiting. For kidneys, this measure reflects waitlist removals divided by number of candidates waiting for a kidney. For livers, this measure reflects HCV waitlist removals divided by number of HCV candidates waiting for a liver in subfigures (a) and (c), and Non-HCV removals divided by number of non-HCV candidates awaiting a liver in subfigures (b) and (d). The bars around each coefficient reflect the 95% confidence interval using standard errors that are clustered at the DSA-by-organ level.

Appendix Table 1: Comparative Interrupted Time-Series, Liver Waiting List Additions and Waiting List/Transplant Outcomes

	Log WL	Log Outcomes			Outcome/WL Size		
	Additions	Transplant	Too Sick / Died	Improved	Transplant	Too Sick / Died	Improved
Years Since DAA	0.0569***	0.1169***	-0.0470***	-0.0057	0.0808***	-0.0064**	-0.0018
	(0.0142)	(0.0154)	(0.0168)	(0.0352)	(0.0134)	(0.0028)	(0.0035)
HCV^+ x Years Since DAA	-0.2276***	-0.2604***	-0.1766***	-0.0378	-0.0688***	-0.0041	0.0087
	(0.0224)	(0.0252)	(0.0264)	(0.0499)	(0.0179)	(0.0048)	(0.0053)
DAA	-0.0144	-0.0116	0.1176**	-0.0425	-0.0195	0.0258***	0.0014
	(0.0411)	(0.0376)	(0.0469)	(0.0875)	(0.0364)	(0.0097)	(0.0087)
HCV^+ x DAA	0.0979	0.2856***	-0.0686	0.3017**	0.0980*	-0.0378**	0.0039
	(0.0709)	(0.0714)	(0.0837)	(0.1324)	(0.0559)	(0.0179)	(0.0141)
Pre-DAA Trend	0.0300***	0.0097	0.0523***	0.0743***	-0.0166*	0.0042**	0.0033**
	(0.0083)	(0.0095)	(0.0096)	(0.0179)	(0.0091)	(0.0017)	(0.0014)
HCV^+ x Pre-DAA Trend	-0.0292**	-0.0235*	-0.0165	-0.0258	0.0053	0.0014	-0.0008
	(0.0122)	(0.0129)	(0.0152)	(0.0241)	(0.0115)	(0.0027)	(0.0019)
HCV^- Mean of DV (Level)	115.36	61.27	27.52	7.60	0.507	0.161	0.046
HCV^+ Mean of DV (Level)	86.59	46.89	23.99	2.88	0.506	0.181	0.026
Observations	1,350	1,350	1,350	1,350	1,350	1,350	1,350
R-squared	0.9143	0.8950	0.8750	0.6490	0.6793	0.2393	0.2725
N of Clusters	90	90	90	90	90	90	90

Notes: The outcome variable in column 1 is the log number of new waitlist additions per DSA-year. In columns 2-4, the outcome variables are defined as log counts of waitlist/transplant outcomes. In columns 5-7, the outcome variables are defined as waitlist/transplant outcome counts divided by the organ-specific number of candidates on the waitlist. Dependent variable means are reported in the two rows immediately following the coefficients, and reflect the pre-treatment period (2005-13) means for liver candidates. In columns 1-4, the means are of level counts rather than log counts. While there are 57 DSAs in the U.S., we use modified DSA identifiers (see footnote 1) due to changes in DSA existence and services over time, which yields 50 kidney-serving DSA and 45 liver-serving DSA identifiers. Standard errors are in parentheses, and clustered at the DSA level. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 2: CITS, Health of New Liver Waiting List Registrants

	Initial MELD	% High MELD	% Middle MELD	% Low MELD
Time Since DAA	-0.2198***	-0.0033	-0.0089***	0.0121***
	(0.0729)	(0.0023)	(0.0027)	(0.0035)
HCV x Time Since DAA	-0.0364	-0.0039	0.0046	-0.0006
	(0.1233)	(0.0038)	(0.0059)	(0.0070)
DAA	0.5182**	0.0177**	-0.0006	-0.0168
	(0.2590)	(0.0077)	(0.0100)	(0.0132)
HCV x DAA	-0.6301	-0.0028	-0.0327*	0.0351
	(0.4281)	(0.0122)	(0.0189)	(0.0237)
Pre-DAA Trend	0.1614***	0.0016	0.0088***	-0.0104***
	(0.0384)	(0.0012)	(0.0012)	(0.0018)
HCV x Pre-DAA Trend	-0.0998*	0.0009	-0.0083***	0.0075**
	(0.0507)	(0.0015)	(0.0023)	(0.0029)
HCV^- Mean of DV	19.22	0.128	0.451	0.421
HCV^+ Mean of DV	16.82	0.070	0.395	0.535
Observations	1,350	1,350	1,350	1,350
R-squared	0.5800	0.4056	0.4633	0.5419
N of Clusters	90	90	90	90

Notes: The outcome variable in column 1 is the average MELD score among new waiting list additions by DSA-year. In columns 2-4, the outcome variables are defined as the fraction of waiting list additions belonging to the high MELD (32 to 40), middle MELD (16 to 31), and low MELD (6 to 15) categories by DSA-year. A higher MELD score indicates a shorter life expectancy in the absence of a liver transplant, and thus confers higher priority on the waiting list. Dependent variable means are reported in the two rows immediately following the coefficients, and reflect the pre-treatment period (2005-13) means for liver candidates. While there are 57 DSAs in the U.S., we use modified DSA identifiers (see footnote 1) due to changes in DSA existence and services over time, which yields 50 kidney-serving DSA and 45 liver-serving DSA identifiers. Standard errors are in parentheses, and clustered at the DSA level. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 3: Liver and Kidney Waiting List Registrant Summary Statistics

	Liver Registrants				Kidney Registrants			
	2005-19		2005-13	2014-19	2005-19		2005-13	2014-19
	Mean	SD	Mean	Mean	Mean	SD	Mean	Mean
HCV-Related Diagnosis	0.295	0.456	0.365	0.201				
Can't Infer HCV Status	0.148	0.355	0.148	0.148				
Initial MELD	18.00	9.01	17.71	18.38				
Too Sick / Died	0.233	0.422	0.246	0.216	0.235	0.424	0.234	0.237
Improved	0.059	0.235	0.051	0.068	0.005	0.070	0.005	0.005
Dec. Don. TX	0.537	0.499	0.524	0.554	0.349	0.477	0.347	0.350
Liv. Don. TX	0.022	0.145	0.019	0.025	0.175	0.380	0.195	0.151
Days to TX	252.3	482.5	252.3	252.2	698.5	749.8	659.6	747.0
High School or Less	0.494	0.500	0.514	0.471	0.471	0.499	0.502	0.430
White Pct.	0.704	0.457	0.709	0.697	0.455	0.498	0.472	0.432
Primary Payer: Private	0.586	0.493	0.618	0.544	0.449	0.497	0.455	0.441
Primary Payer: Medicare	0.246	0.431	0.223	0.276	0.473	0.499	0.474	0.473
Primary Payer: Medicaid	0.168	0.374	0.159	0.180	0.078	0.267	0.071	0.086
Listing Age 18 to 39	0.095	0.293	0.091	0.100	0.189	0.392	0.197	0.179
Listing Age 40 to 64	0.749	0.434	0.789	0.694	0.634	0.482	0.642	0.624
Listing Age Over 64	0.156	0.363	0.119	0.206	0.177	0.381	0.162	0.197
South Census Region	0.373	0.483	0.355	0.396	0.376	0.484	0.360	0.399
NE Census Region	0.207	0.405	0.220	0.189	0.208	0.406	0.216	0.198
MW Census Region	0.207	0.405	0.207	0.206	0.197	0.398	0.205	0.187
West Census Region	0.213	0.410	0.217	0.209	0.218	0.413	0.220	0.216

Notes: Except for transplant/waitlist outcomes (too sick/died, improved, transplants, and days to transplant), which are calculated based on transplant timing and waitlist removal timing, all summary statistics are calculated based on when the candidates joined the waitlist.

Appendix Table 4: Liver vs. Kidney Time from Wait-Listing to Transplant by HCV Status

	Log Days to TX	TX Faster Than 2005-12 Median
Panel A: HCV^-		
DAA	-0.1749***	0.0383**
	(0.0543)	(0.0155)
	[245.57]	[0.315]
Panel B: HCV^+		
DAA	-0.0057	-0.0303**
	(0.0505)	(0.0151)
	[295.04]	[0.266]
Observations	1,425	1,425
N of Clusters	95	95

Notes: The dependent variable in the first column equals the log of 1 plus the number of days elapsed from waitlist registration to transplant. For those who got a transplant the same day or did not register on the waitlist before receiving a transplant, days elapsed equals zero. The second dependent variable is a binary indicator for whether the candidate received a transplant more quickly than the median days to transplant during the 2005-12 sample period. Dependent variable means are in brackets, and reflect the pre-treatment period (2005-13) means for liver candidates only. In column 1, the means reflect level number of days rather than log number of days. While there are 57 DSAs in the U.S., we use modified DSA identifiers (see footnote 1) due to changes in DSA existence and services over time, which yields 50 kidney-serving DSA and 45 liver-serving DSA identifiers. Standard errors are in parentheses, and clustered at the DSA-by-organ level. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 5: HCV^- Waiting List Additions by Diagnosis Category and Primary Payer

	Log Non-HCV Waitlist Additions			
	All Payers	Private	Medicare	Medicaid
Time Since DAA	0.0235	0.0291*	0.0077	0.0083
	(0.0146)	(0.0159)	(0.0226)	(0.0217)
Time Since DAA x NASH	-0.0161	-0.0263	0.0242	-0.0003
	(0.0157)	(0.0178)	(0.0224)	(0.0230)
Time Since DAA x ALD	0.0679***	0.0616***	0.0475*	0.0761***
	(0.0142)	(0.0160)	(0.0253)	(0.0208)
DAA	-0.0205	-0.0413	-0.0111	0.0148
	(0.0391)	(0.0495)	(0.0626)	(0.0725)
DAA x NASH	0.0326	0.0704	-0.0518	0.0917
	(0.0498)	(0.0609)	(0.0784)	(0.0870)
DAA x ALD	0.0527	0.0211	0.0615	0.0599
	(0.0573)	(0.0615)	(0.0784)	(0.0949)
Year	-0.0030	-0.0118	0.0225**	0.0080
	(0.0080)	(0.0088)	(0.0110)	(0.0118)
Year x NASH	0.0992***	0.0836***	0.0944***	0.0521***
	(0.0089)	(0.0095)	(0.0128)	(0.0122)
Year x ALD	0.0447***	0.0473***	0.0304**	0.0393***
	(0.0081)	(0.0088)	(0.0114)	(0.0113)
Observations	2,025	2,025	2,025	2,025
R-squared	0.8825	0.8578	0.7756	0.7478
N of Clusters	45	45	45	45

Notes: Includes DSA-by-Diagnosis FEs to mimic subsample analyses. Standard errors are in parentheses, and clustered at the DSA level. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 6: Livers Discarded Due to Poor Quality

	Log #	#/All Organs	#HCV/All HCV
DAA	0.1374**	0.0243***	-0.0353
	(0.0686)	(0.0081)	(0.0237)
Baseline Mean	24.96	0.152	0.377
Observations	1,500	1,500	1,414
N of Clusters	100	100	100

Notes: The outcome variable in column 1 is the log number of livers that were discarded due to reasons related to poor quality per DSA-year (see Footnote 20 in the main text for the definition of "poor quality"). Baseline means reflect the pre-treatment period (2005–2013) means for liver candidates only. In column 1, the mean reflects the level count rather than log count. While there are 57 DSAs in the U.S., we use modified DSA identifiers (see footnote 1) due to changes in DSA existence and services over time, which yields 50 kidney-recovering and 50 liver-recovering DSA identifiers. Note that, even though there are only 45 modified DSAs with liver transplant programs in our data, organ procurement organizations across all 50 modified DSAs recover and allocate livers from deceased donors, which explains the slightly larger number of clusters and observations here relative to Tables 2-4. Standard errors are in parentheses and are clustered at the DSA-by-organ level. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 7: DiD Estimates of Liver vs. Kidney Waiting List Additions by Primary Payer

	Log WL Additions		
	Private	Medicare	Medicaid
Panel A: Non-HCV			
DAA	0.2257***	0.4885***	0.2364**
	(0.0542)	(0.0680)	(0.0997)
	[70.88]	[23.94]	[15.60]
Panel B: HCV			
DAA	-0.8476***	-0.2596***	-0.6270***
	(0.0693)	(0.0661)	(0.0971)
	[47.83]	[18.51]	[15.60]
Observations	1,425	1,425	1,425
N of Clusters	95	95	95

Notes: The outcome variable is the log number of new waitlist additions per DSA-year. Dependent variable means are in brackets, and reflect the pre-treatment period (2005-13) means for liver candidates only. The means reflect level counts rather than log counts. While there are 57 DSAs in the U.S., we use modified DSA identifiers (see footnote 1) due to changes in DSA existence and services over time, which yields 50 kidney-serving DSA and 45 liver-serving DSA identifiers. Standard errors are in parentheses, and clustered at the DSA-by-organ level. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 8: ITS Estimates of HCV^+ Donor Liver Transplants Received by HCV^- Registrants

	Log TXs, HCV^+ Donors $\rightarrow$ HCV^- Registrants			
	All Payers	Private	Medicare	Medicaid
Years Since DAA	0.3960***	0.3066***	0.1960***	0.1407***
	(0.0381)	(0.0321)	(0.0300)	(0.0210)
DAA	-0.6053***	-0.4919***	-0.3532***	-0.2305***
	(0.0702)	(0.0654)	(0.0555)	(0.0409)
Pre-DAA Trend	-0.0096*	-0.0080*	-0.0015	-0.0028
	(0.0055)	(0.0044)	(0.0018)	(0.0024)
Mean of DV (Level)	0.111	0.077	0.012	0.014
Observations	675	675	675	675
R-squared	0.5992	0.5390	0.4340	0.4078
N of Clusters	45	45	45	45

Notes: The outcome variable is log number of liver transplants from HCV^+ donors to HCV^- candidates per DSA-year. Dependent variable means are reported in the two rows immediately following the coefficients, and reflect the pre-treatment period (2005-13) means. The means are of level counts rather than log counts. While there are 57 DSAs in the U.S., we use modified DSA identifiers (see footnote 1) due to changes in DSA existence and services over time, which yields 50 kidney-serving DSA and 45 liver-serving DSA identifiers. Standard errors are in parentheses, and clustered at the DSA level. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 9: Liver vs. Kidney Waiting List Additions, Transplants, and Waiting List Removals; Northeast Census Region Only

	Log WL	Log Outcomes			Outcome/WL Size		
	Additions	Transplant	Too Sick / Died	Improved	Transplant	Too Sick / Died	Improved
Panel A: HCV^-							
DAA	0.1884	0.0384	-0.1992	-0.1483	0.2140**	0.0695	0.0248
	(0.1992)	(0.1735)	(0.1724)	(0.3518)	(0.0963)	(0.0407)	(0.0162)
	[168.61]	[78.98]	[47.44]	[16.17]	[0.249]	[0.143]	[0.056]
Panel B: HCV^+							
DAA	-0.7106***	-0.6711***	-1.0248***	0.0394	0.1070	0.0113	0.0357**
	(0.1622)	(0.1598)	(0.1679)	(0.2500)	(0.0751)	(0.0336)	(0.0137)
	[148.37]	[71.24]	[50.04]	[6.76]	[0.280]	[0.173]	[0.029]
Observations	210	210	210	210	210	210	210
N of Clusters	14	14	14	14	14	14	14

Notes: The outcome variable in column 1 is the log number of new waitlist additions per DSA-year. In columns 2-4, the outcome variables are defined as log counts of waitlist/transplant outcomes. In columns 5-7, the outcome variables are defined as waitlist/transplant outcome counts divided by the organ-specific number of candidates on the waitlist. The estimation sample includes only DSAs from the Northeast Census region. Dependent variable means are in brackets, and reflect the pre-treatment period (2005-13) means for liver candidates only. In columns 1-4, the means reflect level counts rather than log counts. Standard errors are in parentheses, and clustered at the DSA-by-organ level. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 10: DID, Heterogeneity in Wait-listing and Transplants among HCV^- Individuals by DSAs' Pre-Treatment Fraction of Transplant Recipients with HCV Antibodies

	Dose-Response	$\geq$ Median HCV^+ Rate	$<$ Median HCV^+ Rate
Panel A: Log Waiting List Additions			
DAA	-0.2709	0.3547***	0.2086**
	(0.2757)	(0.0635)	(0.0836)
DAA x Fraction HCV^+	1.2829**		
	(0.6069)		
Mean of DV (Level)	115.36	145.53	83.81
Panel B: Log Transplants			
DAA	-0.2478	0.3649***	0.2109***
	(0.2860)	(0.0694)	(0.0697)
DAA x Fraction HCV^+	1.2347*		
	(0.6584)		
Mean of DV (Level)	61.27	71.52	50.56
Observations	1,350	690	660
N of Clusters	90	46	44

Notes: This table presents differences-in-differences heterogeneity estimates, comparing log HCV^- liver transplants and waiting list additions to log kidney transplants and waiting list additions, by DSAs' fraction of pre-treatment (2005-13) liver transplant recipients who tested positive for antibodies to HCV. The means of the dependent variables reflect level counts rather than log counts during the pre-treatment period (2005-13) for liver candidates only. While there are 57 DSAs in the U.S., we use modified DSA identifiers (see footnote 1) due to changes in DSA existence and services over time, which yields 50 kidney-serving DSA and 45 liver-serving DSA identifiers. Standard errors are in parentheses, and clustered at the DSA-by-organ level. *** p<0.01, ** p<0.05, * p<0.1