Externalities from Medical Innovation: Evidence from Organ Transplantation
Online Appendix

Kevin Callison
Tulane University

Michael E. Darden
Johns Hopkins University and NBER

Keith F. Teltser
Georgia State University

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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^- registrants and $\beta_1 + \beta 2$ measures the slope of the pre-DAA trend for HCV^+ registrants. DAA_t is an indicator for the post-DAA period (i.e., 2014 through 2019). Thus, β_3 reflects the level change in HCV^- registrants' outcomes associated with the introduction of DAAs relative to their baseline level, while $\beta_3 + \beta_4$ reflects this level change for HCV^+ registrants. Finally, β_5 measures the post-DAA change in slope relative to the pre-DAA slope β_1 for HCV^- registrants, while $\beta_5 + \beta_6$ captures this slope change for HCV^+ registrants. 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.

Appendix Table 1: Comparative Interrupted Time-Series, Liver Waiting List Additions and Transplants

	Log Transplants	Transplant Rate	Log WL Additions
Years Since DAA	0.1169***	0.0808***	0.0569***
	(0.0154)	(0.0134)	(0.0142)
$HCV^+\times$ Years Since DAA	-0.2604***	-0.0688***	-0.2276***
	(0.0252)	(0.0179)	(0.0224)
DAA	-0.0116	-0.0195	-0.0144
	(0.0376)	(0.0364)	(0.0411)
$HCV^+\times$ DAA	0.2856***	0.0980*	0.0979
	(0.0714)	(0.0559)	(0.0709)
Pre-DAA Trend	0.0097	-0.0166*	0.0300***
	(0.0095)	(0.0091)	(0.0083)
$HCV^+\times$ Pre-DAA Trend	-0.0235*	0.0053	-0.0292**
	(0.0129)	(0.0115)	(0.0122)
HCV^- Mean of DV (Level)	61.27	0.507	115.36
HCV^+ Mean of DV (Level)	46.89	0.506	86.59
Observations	1,350	1,350	1,350
N of Clusters	90	90	90

Notes: The outcome variable in column 1 is the log number of transplants per DSA-year. In column 3, the outcome variable is defined as the log number of waiting list additions. The estimates in columns 1 and 3 can be transformed into percentages using the formula $100 \times (e^{\hat{\beta}} - 1)$. In column 2, the outcome is defined as the number of transplants divided by the HCV-specific number of waiting list registrants. Dependent variable means (at the DSA-year level) are reported in the two rows immediately following the coefficients, and reflect the pre-treatment period (2005-13) means for liver registrants. In columns 1 and 3, 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

2 Health Composition

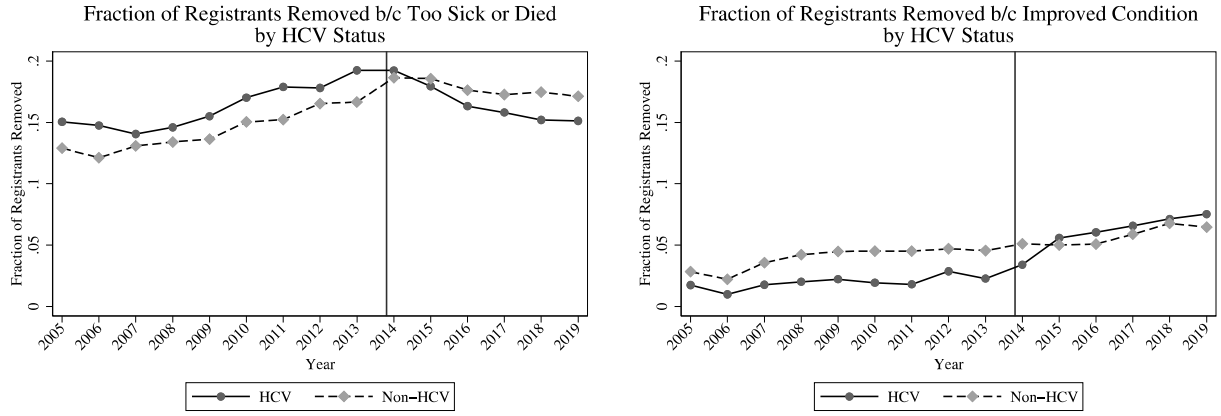
Appendix Table 2: CITS, Health of Liver Waiting List Registrants and Transplant Recipients

	Initial MELD at Listing	Final MELD before Transplant
Time Since DAA	-0.2198***	-0.8480***
	(0.0729)	(0.0971)
$HCV^+\times$ Time Since DAA	-0.0364	0.0298
	(0.1233)	(0.1846)
DAA	0.5182**	0.9127***
	(0.2590)	(0.3411)
$HCV^+\times$ DAA	-0.6301	-1.3716**
	(0.4281)	(0.6002)
Pre-DAA Trend	0.1614***	0.4257***
	(0.0384)	(0.0505)
$HCV^+\times$ Pre-DAA Trend	-0.0998*	-0.2329***
	(0.0507)	(0.0704)
HCV^- Mean of DV	19.22	23.42
HCV^+ Mean of DV	16.82	21.03
Observations	1,350	1,350
R-squared	0.5800	0.5763
N of Clusters	90	90

Notes: The outcome variable in column 1 is the average MELD score among new waiting list additions by DSA-year. The outcome variable in column 2 is the average last MELD score among individuals receiving a transplant. 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 (at the DSA-year level) are reported in the two rows immediately following the coefficients, and reflect the pre-treatment period (2005-13) means for liver registrants. 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

3 Waiting List Attrition

Appendix Figure 1: Liver Waiting List Outflows



(a) (b)

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

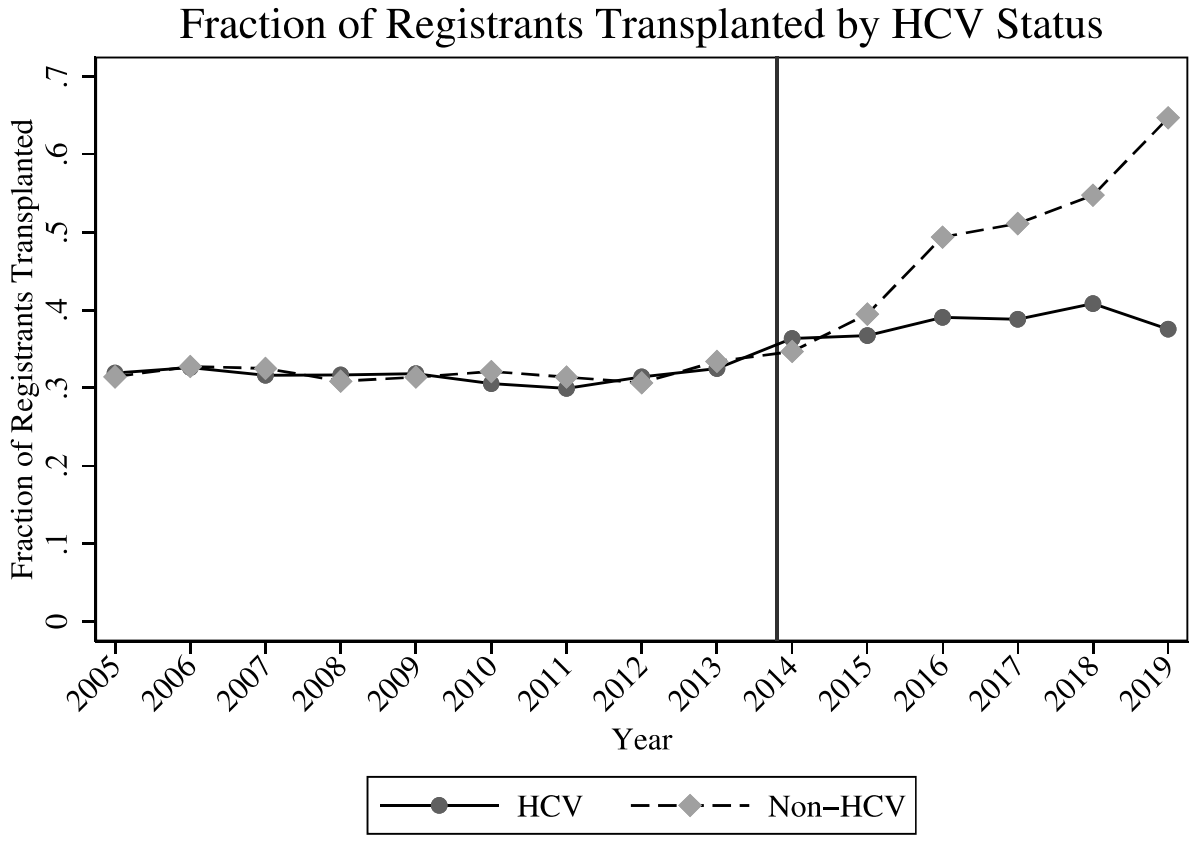
Appendix Table 3: CITS, Liver Transplant Waiting List Outflows

	Log Outcomes		Rates	
	Too Sick / Died	Improved	Too Sick / Died	Improved
Years Since DAA	-0.0470***	-0.0057	-0.0064**	-0.0018
	(0.0168)	(0.0352)	(0.0028)	(0.0035)
HCV^+ x Years Since DAA	-0.1766***	-0.0378	-0.0041	0.0087
	(0.0264)	(0.0499)	(0.0048)	(0.0053)
DAA	0.1176**	-0.0425	0.0258***	0.0014
	(0.0469)	(0.0875)	(0.0097)	(0.0087)
HCV^+ x DAA	-0.0686	0.3017**	-0.0378**	0.0039
	(0.0837)	(0.1324)	(0.0179)	(0.0141)
Pre-DAA Trend	0.0523***	0.0743***	0.0042**	0.0033**
	(0.0096)	(0.0179)	(0.0017)	(0.0014)
HCV^+ x Pre-DAA Trend	-0.0165	-0.0258	0.0014	-0.0008
	(0.0152)	(0.0241)	(0.0027)	(0.0019)
HCV^- Mean of DV (Level)	27.52	7.60	0.161	0.046
HCV^+ Mean of DV (Level)	23.99	2.88	0.181	0.026
Observations	1,350	1,350	1,350	1,350
N of Clusters	90	90	90	90

Notes: Notes: The outcome variables in columns 1 and 2 are the log number of waiting list removals due to condition deterioration/death and condition improvement per DSA-year. The estimates in columns 1 and 2 can be transformed into percentages using the formula $100 \times (e^{\hat{\beta}} - 1)$. In columns 3 and 4, the outcomes are defined as the number of removals divided by the HCV-specific number of waiting list registrants. Dependent variable means (at the DSA-year level) are reported in the two rows immediately following the coefficients, and reflect the pre-treatment period (2005-13) means for liver registrants. In columns 1 and 2, 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

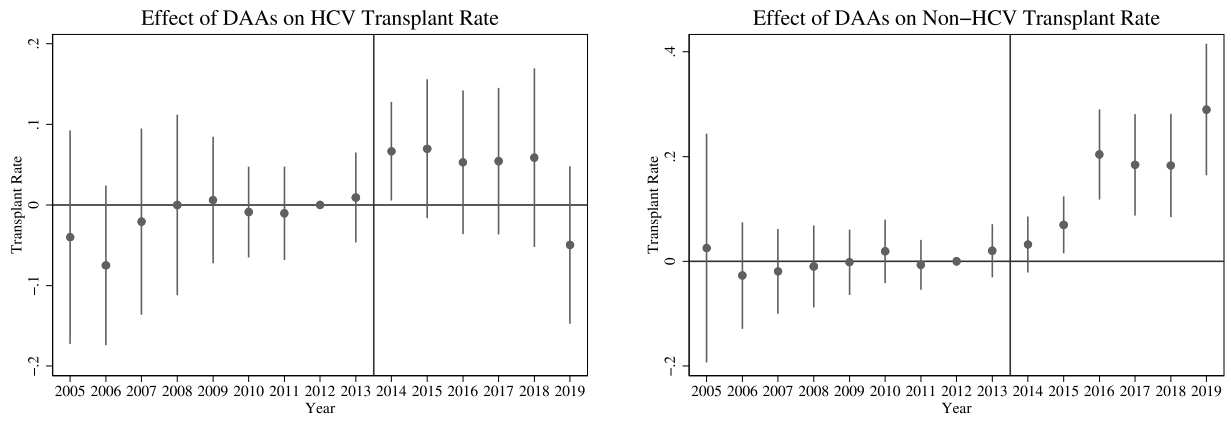
4 Transplant Rates

Appendix Figure 2



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

Appendix Figure 3: Liver vs. Kidney Transplants



(a) (b)

Notes: Each subfigure presents time-disaggregated differences-in-differences estimates, comparing HCV^+ and HCV^- transplants to kidney waiting list additions and transplants. The outcome is defined as transplants divided by number of waiting list registrants. For kidneys, this rate reflects transplants divided by number of kidney registrants. For livers, this rate reflects transplants to HCV^+ registrants divided by number of HCV^+ liver registrants in subfigure (a), and transplants to HCV^- registrants divided by number of HCV^- liver registrants in subfigure (b). The bars around each coefficient reflect the 95% confidence interval using standard errors that are clustered at the DSA-by-organ level.

5 Dose-Response Regressions

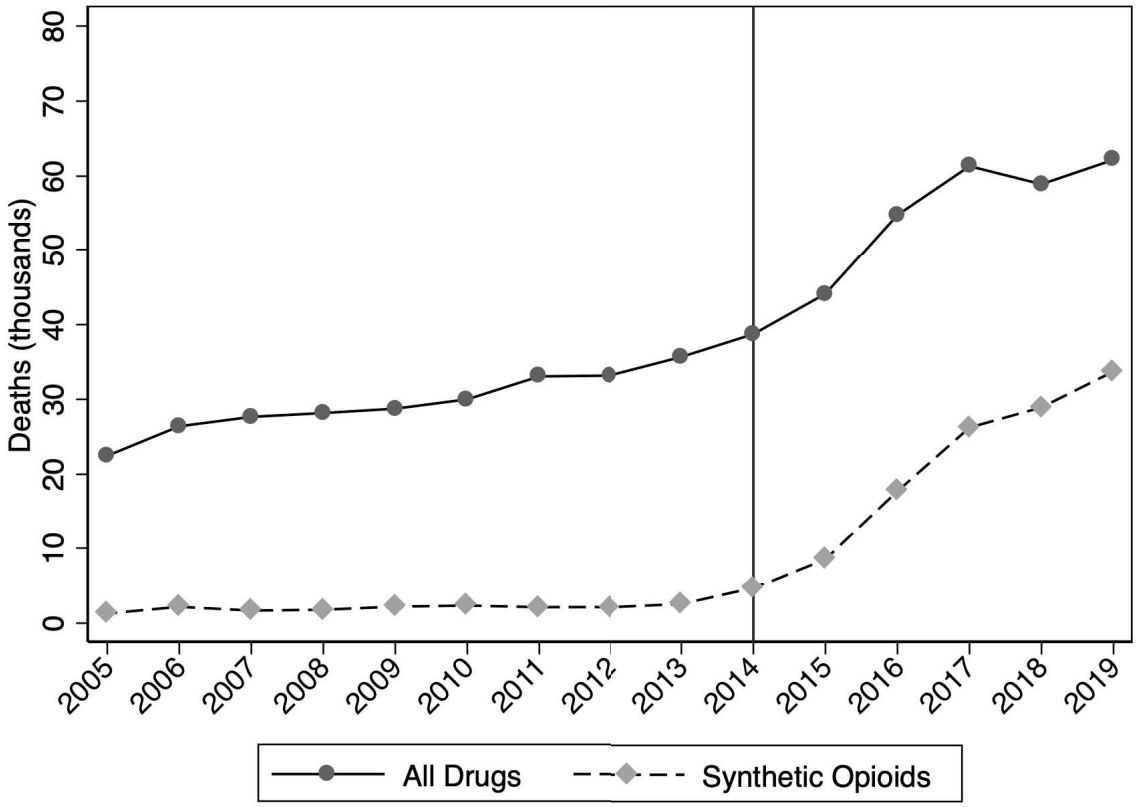
To build further understanding on our results in Table 2 of the main paper, we estimate regressions in which we allow the effects of DAAs to vary by the baseline HCV^+ rate in a DSA. Beacuse our hypothesized mechanism is that DAAs affect HCV^- listing behavior and transplant outcomes through reduced HCV^+ liver demand, we should expect to see larger effects of DAAs in areas with greater HCV prevalence. The regression we estimate is:

$$Y_{dlt} = \beta[\mathbb{1}(l = liver) \times DAA_t] + \tau[\mathbb{1}(l = liver) \times DAA_t]F_d + \gamma_{dl} + \eta_t + \epsilon_{dlt}, \tag{2}$$

where F_d is the pre-DAA mean prevalence of HCV in DSA d. Results are presented in Table 3 of the main paper.

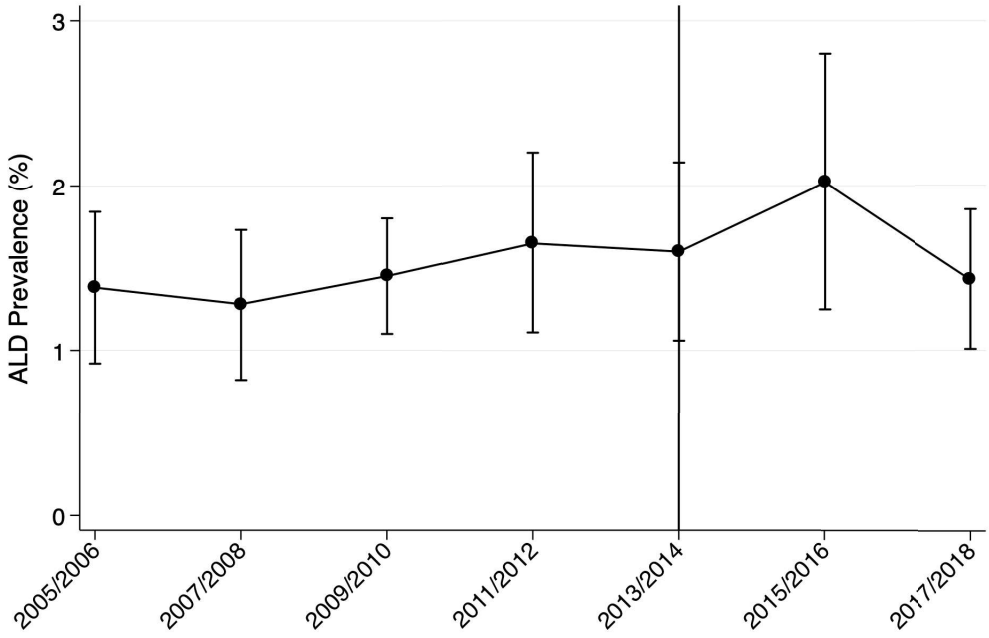
6 Concurrent Shocks

Appendix Figure 4: 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 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.

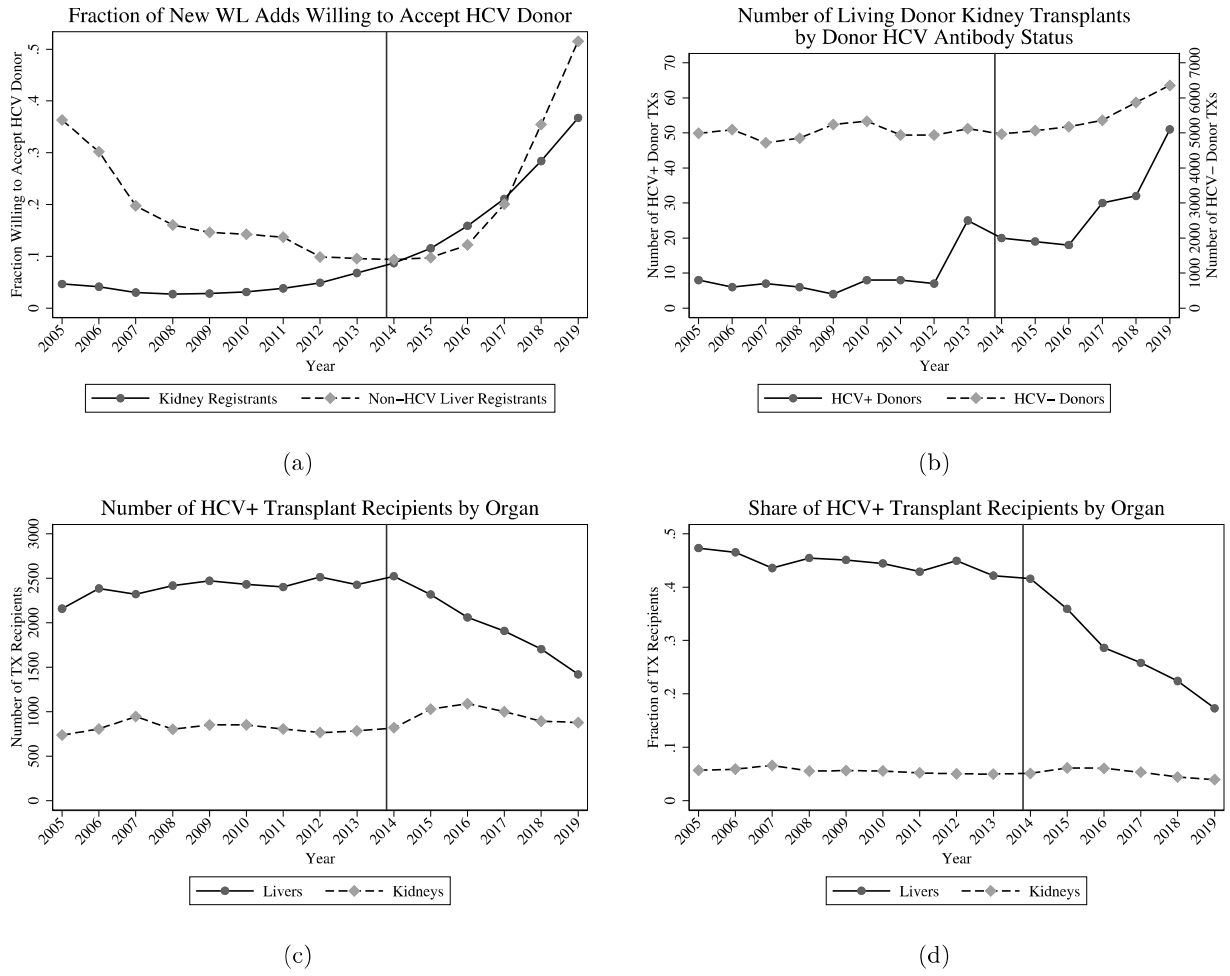
Appendix Table 4: CITS, HCV^- Liver Waiting List Additions by Diagnosis Category

	Log HCV^- WL Adds
Time Since DAA	0.0235
	(0.0146)
Time Since DAA x NASH	-0.0161
	(0.0157)
Time Since DAA x ALD	0.0679***
	(0.0142)
DAA	-0.0205
	(0.0391)
DAA x NASH	0.0326
	(0.0498)
DAA x ALD	0.0527
	(0.0573)
Year	-0.0030
	(0.0080)
Year x NASH	0.0992***
	(0.0089)
Year x ALD	0.0447***
	(0.0081)
Observations	2,025
R-squared	0.8825
N of Clusters	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

7 Potential Spillovers

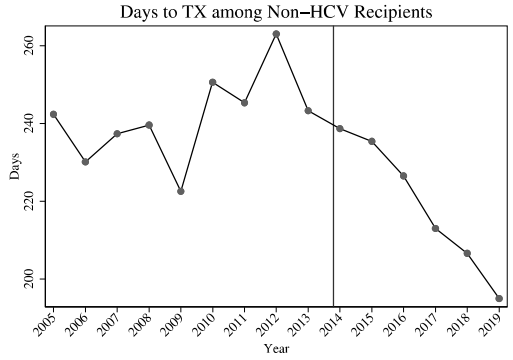
Appendix Figure 6: Potential Supply- and Demand-Side Spillovers to Kidney Context



Notes: Authors' calculations of yearly national counts and fractions using SRTR data. In panel (a), we exclude kidney registrants who are known to have an HCV-related diagnosis using the optional diagnosis text field in the data. This is a very small fraction of kidney candidates: only 0.13% of registrants from 2005 to 2019. Panels (c) and (d) use known HCV antibody test results at the time of transplant to identify HCV^+ transplant recipients. These results are conditional on receiving a transplant.

8 Further Evidence

Appendix Figure 7: 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 Table 5: 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^-		
Liver x DAA	-0.1749***	0.0383**
	(0.0543)	(0.0155)
	[245.57]	[0.315]
Panel B: HCV^+		
Liver x DAA	-0.0057	-0.0303**
	(0.0505)	(0.0151)
	[295.04]	[0.266]
Observations	1,425	1,425
N of Clusters	95	95

Notes: Difference-in-differences estimates from Equation 1 of the main text. The dependent variable in the first column equals the log of 1 plus the number of days elapsed from waiting list registration to transplant. For those who got a transplant the same day or did not register on the waiting list 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 (at the DSA-year level) are in brackets, and reflect the pre-treatment period (2005-13) means for liver registrants 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 6: 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/waiting list outcomes (too sick/died, improved, transplants, and days to transplant), which are calculated based on transplant timing and waiting list removal timing, all summary statistics are calculated based on when the candidates joined the waiting list.

Appendix Table 7: Livers Discarded Due to Poor Quality

	Log #	#/All Organs	#HCV/All HCV
Liver x 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: Difference-in-differences estimates from Equation 1 of the main text. 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 21 in the main text for the definition of "poor quality"). Baseline means reflect the pre-treatment period (2005–2013) means for liver registrants only. In column 1, the mean reflects the DSA-year 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