Last-mile Delivery in Health Care: Drone Delivery for Blood Products in Rwanda

Online Appendix

Appendix Figures

Figure A.1 Public Hospitals in Rwanda

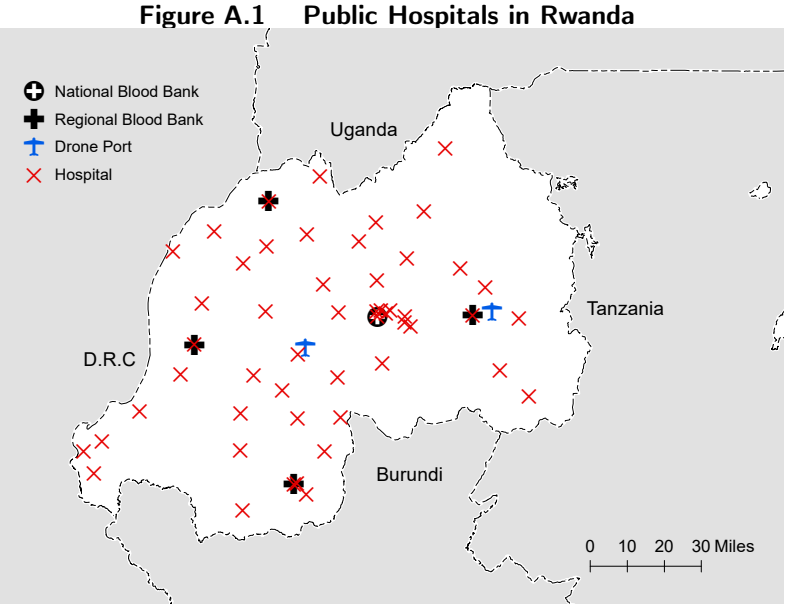
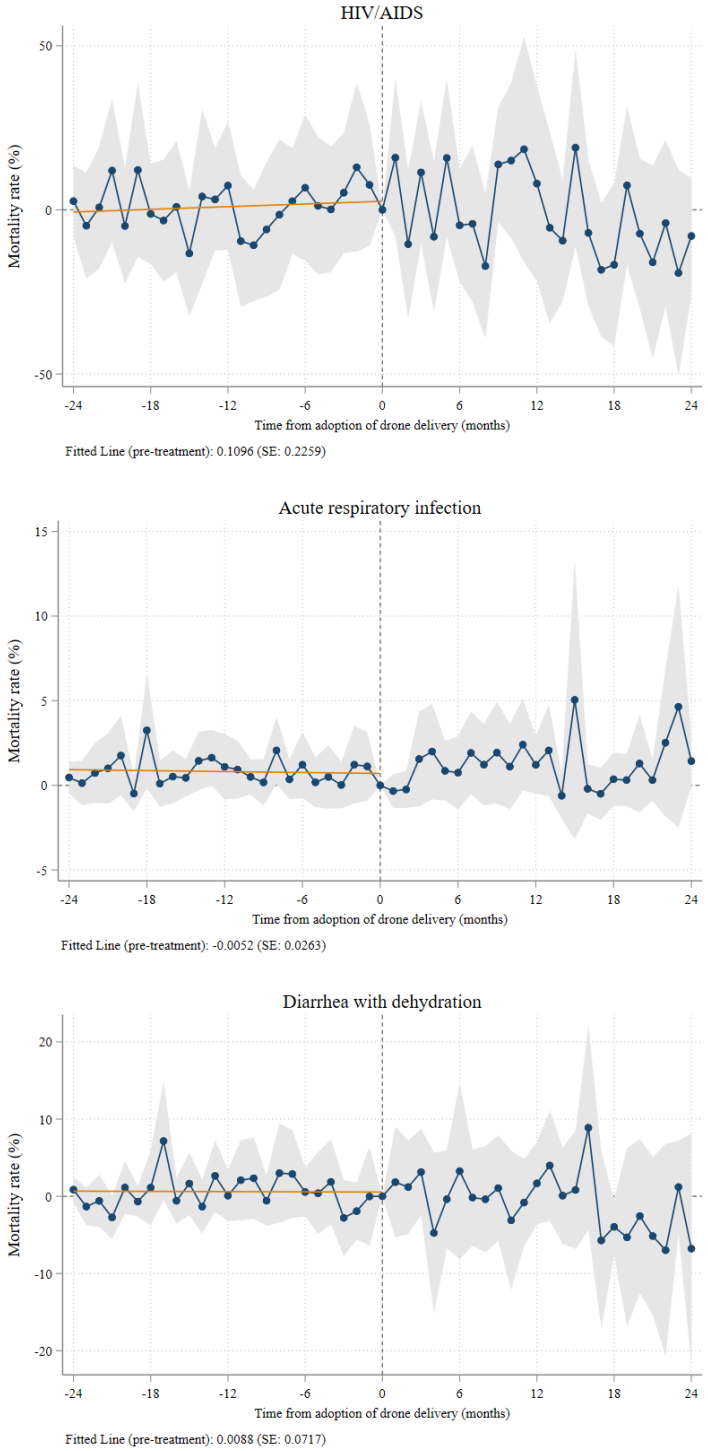
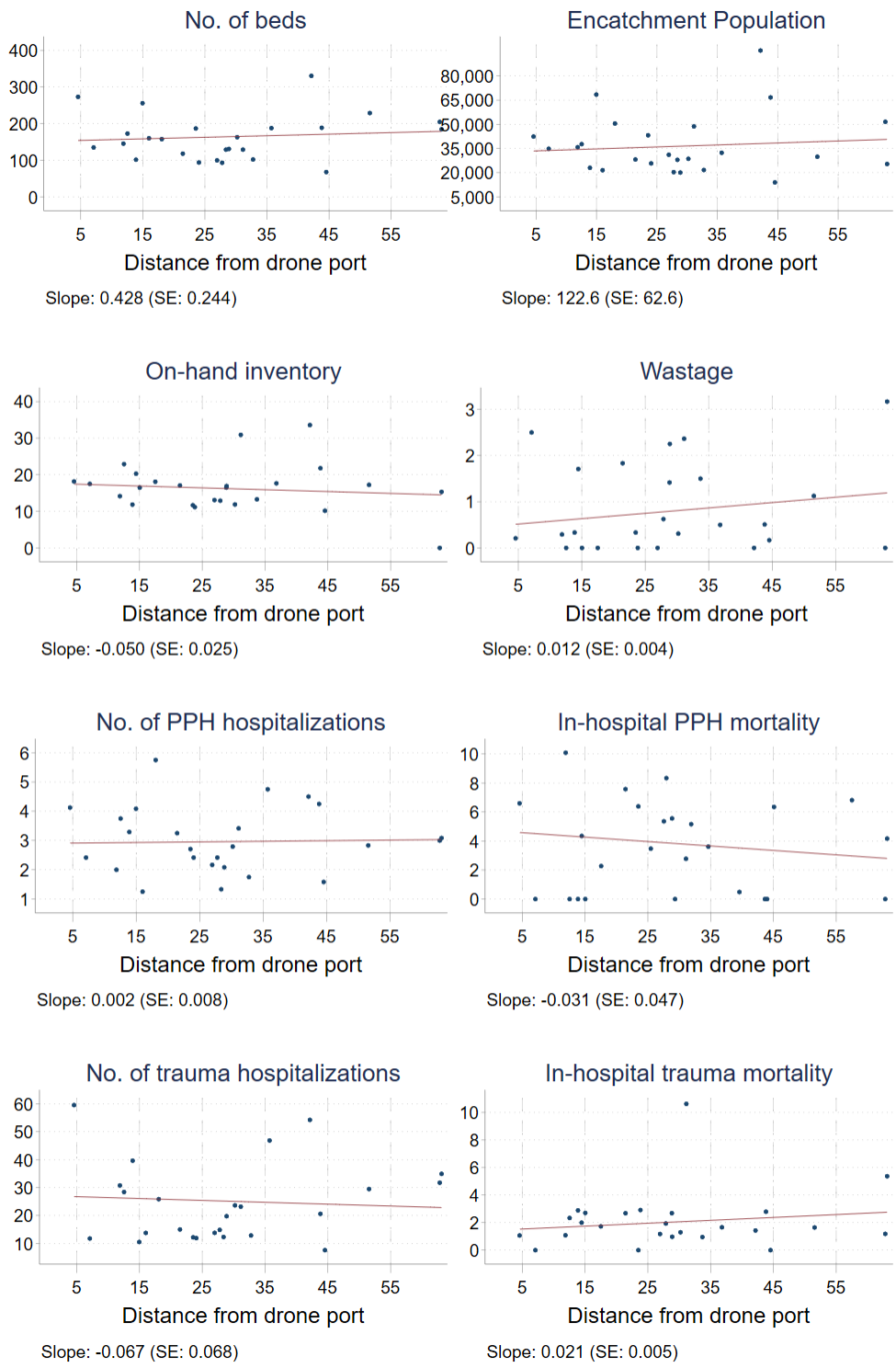


Figure A.2 Effect of Adopting Drone Delivery System on Placebo Health Outcomes



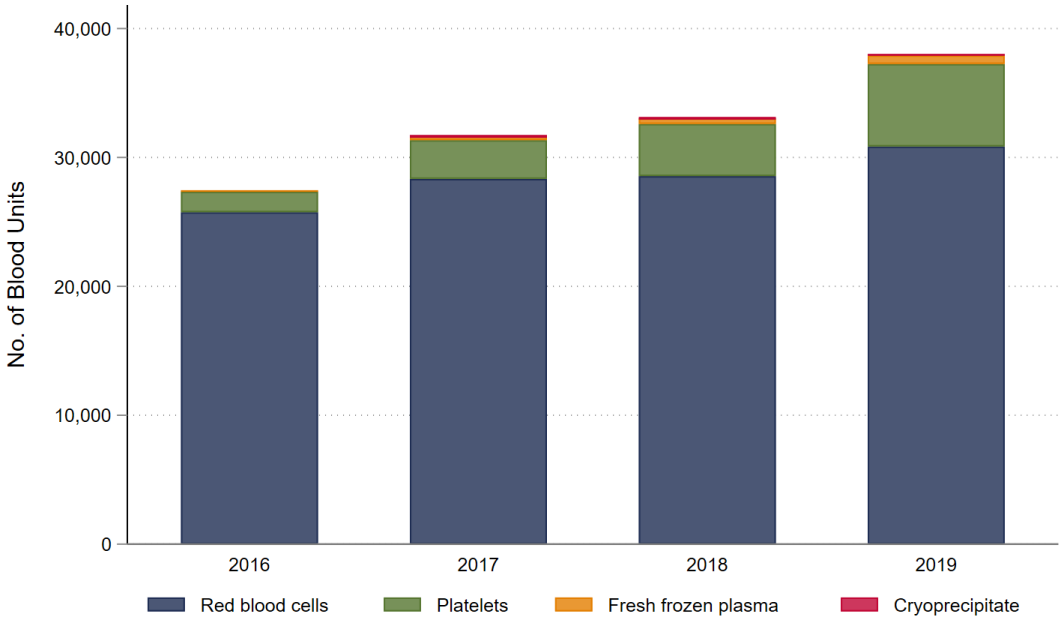
Note. The figure shows coefficients β_l from estimating equation 1 using an analysis sample from January 2015 to June 2020. Estimates are weighted by the number of hospitalizations in each health condition at the hospital and month. Shaded area shows the 95% confidence intervals. Time is shown in months relative to the hospital's adoption of the drone delivery system. Relative time less than -24 months or greater than 24 months is binned into the terminal month shown, respectively. Analysis is subset to hospitals that are outside of Kigali and that are not co-located with regional blood banks. The top and bottom 1% of all measures have been winsorized.

Figure A.3 Binned Scatterplots of Flight Time Between Each Hospital and Its Designated Drone Port and Pre-treatment Variables



Note. The figure shows, for several variables of interest, respectively, binned scatterplots of the flight time for each hospital and its designated drone port and a variable of interest for hospital-months in 2016, prior to any hospital adopting the drone delivery system. Each point shows the mean of the variable of interest and flight time computed from 25 equal-size bins.

Figure A.4 Number of Units Used by Blood Product and Year



Note. The figure shows the number of units used (i.e., transfused) across all hospitals in our analysis sample by blood product in each year.

Appendix Tables

Table A.1 Public Transfusing Facilities in Rwanda

	(1) All hospitals	(2) Hospitals in analysis sample	(3) Hospitals adopting drone delivery services during study period
No. of public hospitals	51	39	29
Geographic Region			
Kigali City	8	0	0
Eastern Province	9	8	5
Northern Province	8	7	5
Southern Province	13	12	9
Western Province	13	12	10

Note. There are 72 hospitals in Rwanda, of which 21 are private hospitals. The table describes public hospitals authorized to transfuse blood in Rwanda. Column (1) contains all public hospitals. Column (2) shows the number of hospitals included in our analysis sample, which excludes hospitals located in Kigali (the capital) or those that are co-located with a regional blood bank for reasons described in Section 2.2. Column (3) shows hospitals that adopted drone delivery within our study period (January 2012 to June 2020).

Table A.2 Effect of Adopting Drone Delivery System on Inventory Management and Health Outcomes, truncating extreme observations

	Inventory Management		Health Outcomes	
	(1)	(2)	(3)	(4)
[Per hospital-month]	On-hand inventory	Wastage	Post-partum hemorrhage	Trauma
Drone delivery	-11.60***	-0.65*	-2.04**	-0.56*
	(0.93)	(0.26)	(0.67)	(0.25)
Observations	1,897	1,898	2,125	1,878
Month FE	Yes	Yes	Yes	Yes
Hospital FE	Yes	Yes	Yes	Yes
Pre-treatment mean	18.53	1.36	3.56	1.97

Note. The table presents the coefficient β from estimating equation 2. The analysis sample spans from January 2015 to June 2020 for post-partum hemorrhage and from January 2015 to June 2019 for on-hand inventory, wastage, and trauma. Estimates for inventory management outcomes are weighted by the number of beds at each hospital and month. Estimates for health outcomes are weighted by the number of hospitalizations for each health condition at the hospital and month. Standard errors are clustered at the hospital level. Sample is restricted to hospitals that are outside of Kigali and that are not co-located with regional blood banks. Observations strictly greater than the 99th percentile or less than the 1st percentile have been truncated. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.3 Share of Missing Observations by Treatment Period

	Share Missing (%)		
	Sample Period	Pre-Treatment	Post-Treatment
A. Inventory Management			
On-hand inventory	1.7	1.8	1.2
Wastage	1.7	1.8	1.2
B. Health Outcomes			
Post-partum hemorrhage	1.5	1.5	1.6
Trauma	0.7	0.7	0.7

Note. The table presents the share of missing observations for inventory management and health outcome variables, reported for the full sample period and separately for observations at hospitals pre- and post-treatment. Hospitals that were never treated during the study period are classified as pre-treatment observations. For health outcomes, an observation is considered missing if either the number of hospitalizations or deaths is missing for a given outcome.

Table A.4 Effect of Adopting Drone Delivery System on Placebo Health Outcomes

	In-hospital mortality rate (%)		
[*Per hospital-month*]	(1) HIV/ AIDS	(2) Acute respiratory infection	(3) Diarrhea with dehydration
Drone delivery	-2.14	0.34	-0.84
	(4.28)	(0.33)	(1.86)
Observations	2,367	2,103	1,940
Month FE	Yes	Yes	Yes
Hospital FE	Yes	Yes	Yes
Pre-treatment mean	30.20	1.97	5.25

Note. The table presents the coefficient β from estimating equation 2 using an analysis sample from January 2015 to June 2020. Estimates are weighted by the number of hospitalizations for each health condition at the hospital and month. Standard errors are clustered at the hospital level. Sample is restricted to hospitals that are outside of Kigali and that are not co-located with regional blood banks. The top and bottom 1% of all observations have been winsorized. + $p < 0.1$ * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.5 Effect of Adopting Drone Delivery System on Hospitalizations and Deaths

	Post-partum hemorrhage		Trauma	
	(1)	(2)	(3)	(4)
[*Per hospital-month*]	Hospitalizations	Deaths	Hospitalizations	Deaths
Drone delivery	-0.06	-0.05*	-4.39	-0.24*
	(0.31)	(0.02)	(2.62)	(0.10)
Observations	2,537	2,537	1,944	1,944
Month FE	Yes	Yes	Yes	Yes
Hospital FE	Yes	Yes	Yes	Yes
Pre-treatment mean	3.08	0.09	28.04	0.47

Note. The table presents the coefficient β from estimating equation 2. Standard errors are clustered at the hospital level. The analysis sample spans from January 2015 to June 2020 for postpartum hemorrhage and from January 2015 to June 2019 for trauma. Sample is restricted to hospitals that are outside of Kigali and that are not co-located with regional blood bank. The top and bottom 1% of all observations have been winsorized. + $p < 0.1$ * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.6 Heterogeneous Treatment Effect of Adopting Drone Delivery System on Health Outcomes, by flight time to designated drone port

	In-hospital mortality rate (%)	
	(1)	(2)
[Per hospital-month]	Post-partum hemorrhage	Trauma
Drone delivery X 1st Quartile	-3.03*	-0.62+
	(1.23)	(0.32)
Drone delivery X 2nd Quartile	-1.63*	-0.93**
	(0.72)	(0.33)
Drone delivery X 3rd Quartile	-2.19	-0.44
	(1.49)	(0.38)
Drone delivery X 4th Quartile	-0.37	-0.21
	(0.76)	(0.38)
Observations	2,537	1,944
Month FE	Yes	Yes
Hospital FE	Yes	Yes

Note. The table reports coefficients from estimating a version of equation 3 using exact quartile thresholds for flight time. For post-partum hemorrhage, the analysis sample spans from January 2015 to June 2020; for trauma, the sample spans from January 2015 to June 2019, when data collection for this outcome ends. Estimates are weighted by the number of hospitalizations in each health condition at the hospital and month. Standard errors are clustered at the hospital level. Sample is restricted to hospitals that are outside of Kigali City and that are not co-located with regional blood banks. The top and bottom 1% of all observations have been winsorized. + $p < 0.1$ * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.7 Heterogeneous Treatment Effect of Adopting Drone Delivery System on Usage and Share of Blood Products, by flight time to designated drone port, including Butaro District Hospital

	(a) Usage				(b) Share of Blood Products			
[*Per hospital-year*]	(1) RBC	(2) Platelets	(3) FFP	(4) Cryo	(5) RBC	(6) Platelets	(7) FFP	(8) Cryo
Drone delivery X $t_f < 15$ min	165.50*	111.35*	33.29+	-0.03	-0.08***	0.05*	0.03**	-0.00
	(73.13)	(48.45)	(17.71)	(2.73)	(0.02)	(0.02)	(0.01)	(0.00)
Drone delivery X $15 \leq t_f \leq 25$ min	31.52	94.87+	3.97	-3.12	-0.10*	0.08+	0.02+	-0.00
	(50.12)	(47.43)	(10.48)	(2.13)	(0.04)	(0.04)	(0.01)	(0.00)
Drone delivery X $25 < t_f \leq 35$ min	-75.80	68.13	-10.87	-3.73	-0.09*	0.10*	-0.01	-0.00
	(67.34)	(46.94)	(7.90)	(2.47)	(0.04)	(0.04)	(0.02)	(0.00)
Drone delivery X $t_f > 35$ min	90.81	492.66	-4.67	-2.37	-0.11	0.10	0.01	-0.00
	(53.86)	(366.83)	(11.17)	(3.05)	(0.07)	(0.07)	(0.01)	(0.00)
Observations	144	144	144	144	144	144	144	144
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hospital FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note. RBC = red blood cells; FFP = fresh frozen plasma; Cryo = cryoprecipitate. t_f represents the estimated flight time between a hospital and its designated drone port. The table presents the coefficients β_1 through β_4 from estimating equation 3 on hospital-year data. Estimates are weighted by the average number of beds at the hospital and year. Standard errors are clustered at the hospital level. Sample is restricted to hospitals that are outside of Kigali and that are not co-located with regional blood banks. The top and bottom 1% of all observations have been winsorized. + $p < 0.1$ * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.8 Effect of Adopting Drone Delivery System on Inventory Management Outcomes, using equal weights

[*Per hospital-month*]	(1) On-hand inventory	(2) Wastage
Drone delivery	-11.56***	-0.61*
	(0.96)	(0.24)
Observations	1,912	1,912
Month FE	Yes	Yes
Hospital FE	Yes	Yes
Pre-treatment mean	18.70	1.45

Note. The table presents the coefficient β from estimating equation 2 using an analysis sample from January 2015 to June 2019. Standard errors are clustered at the hospital level. Sample is restricted to hospitals that are outside of Kigali and that are not co-located with regional blood banks. The top and bottom 1% of all observations have been winsorized. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.9 Effect of Adopting Drone Delivery System on Health Outcomes, using equal weights

	Transfusion-reliant		Placebo		
	(1)	(2)	(3)	(4)	(5)
[*Per hospital-month*]	Post-partum hemorrhage	Trauma	HIV/ AIDS	Acute respiratory infection	Diarrhea with dehydration
Drone delivery	-3.13**	-0.97*	-3.64	-0.06	-0.70
	(0.98)	(0.42)	(4.45)	(0.99)	(2.98)
Observations	2,537	1,944	2,367	2,103	1,940
Month FE	Yes	Yes	Yes	Yes	Yes
Hospital FE	Yes	Yes	Yes	Yes	Yes
Pre-treatment mean	3.56	2.08	30.20	1.97	5.25

Note. The table presents the coefficient β from estimating equation 2. The analysis sample spans from January 2015 to June 2020 for all health outcomes other than trauma, which spans from January 2015 to June 2019. Standard errors are clustered at the hospital level. Sample is restricted to hospitals that are outside of Kigali and that are not co-located with regional blood banks. The top and bottom 1% of all observations have been winsorized. + $p<0.1$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table A.10 Effect of Adopting Drone Delivery System on Inventory Management Outcomes, using alternative estimators

	Borusyak et al. (2024)		Stacked DiD	
	(1)	(2)	(3)	(4)
[Per hospital-month]	On-hand inventory	Wastage	On-hand inventory	Wastage
Drone Delivery	-11.70***	-0.47***	-10.65***	-0.78*
	(0.69)	(0.08)	(1.08)	(0.32)
Observations	1,912	1,912	1,912	1,912
Month FE	Yes	Yes	Yes	Yes
Facility FE	Yes	Yes	Yes	Yes
Pre-treatment Mean	18.70	1.45	18.70	1.45

Note. The table presents the coefficient β from estimating equation 2 using alternative estimators robust to potential bias that arises in estimating staggered difference-in-differences using TWFE. Columns (1) and (2) use an imputation estimator proposed by Borusyak et al. (2024), which is our preferred robustness approach given its known efficiency property under standard assumptions. Columns (3) and (4) use a stacked DiD estimator proposed by Cengiz et al. (2019). The analysis sample spans from January 2015 to June 2019. Estimates are weighted by the number of beds at the hospital and month. Standard errors are clustered at the hospital level. Sample is restricted to hospitals that are outside of Kigali and that are not co-located with regional blood bank. The top and bottom 1% of all observations have been winsorized. + $p<0.1$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table A.11 Effect of Adopting Drone Delivery System on Health Outcomes, using alternative estimators

	Borusyak et al. (2024)		Stacked DiD	
	(1)	(2)	(3)	(4)
[Per hospital-month]	Post-partum hemorrhage	Trauma	Post-partum hemorrhage	Trauma
Drone Delivery	-1.90*	-0.63*	-2.08**	-0.63*
	(0.81)	(0.26)	(0.65)	(0.24)
Observations	2,537	1,944	2,537	1,944
Month FE	Yes	Yes	Yes	Yes
Facility FE	Yes	Yes	Yes	Yes
Pre-treatment mean	3.56	2.08	3.56	2.08

Note. The table presents the coefficient β from estimating equation 2 using 2 alternative estimators robust to potential bias that arises in estimating staggered difference-in-differences using TWFE. Columns (1) and (2) use an imputation estimator proposed by Borusyak et al. (2024), which is our preferred robustness approach given its known efficiency property under standard assumptions. Columns (3) and (4) use a stacked DiD estimator proposed by Cengiz et al. (2019). The analysis sample spans from January 2015 to June 2020 for post-partum hemorrhage and January 2015 to June 2019 for trauma. Estimates are weighted by the number of hospitalizations in each health condition at the hospital and month. Standard errors are clustered at the hospital level. Sample is restricted to hospitals that are outside of Kigali and that are not co-located with regional blood banks. The top and bottom 1% of all observations have been winsorized. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.