

## SUPPLEMENTARY INFORMATION APPENDIX

### Geographic barriers to establishing a successful hospital referral system in rural Madagascar

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**Supplementary table S1:** Summary of HSS interventions implemented in Ifanadiana district between 2014 and 2021, classified by building block of HSS\* affected. These included the PIVOT intervention at all three levels of care.

<b>Level of care</b>	<b>Ifanadiana district (PIVOT catchment+RoD)</b>	
District hospital Total Ifanadiana: 1	(1) Network of three ambulances for referrals and emergency care; infrastructure renovations, provision of medical and non-medical equipment, including full laboratory capacity; social support for vulnerable patients (2) Staffing of health workers to reach MoH norms; trainings for medical staff (3) Creation of a hospital-based Monitoring and Evaluation team to follow-up progress of activities (4) Supply chain management and reduction of stock-outs (5) Cost of outpatient and inpatient care fully covered for referred patients (6) Creation of a joint PIVOT-MoH executive committee for hospital management and transparency	
	<b>PIVOT catchment</b>	<b>Ifanadiana district (PIVOT catchment+RoD)</b>
Health centres Total Ifanadiana: 21 PIVOT catchments: 7	(1) Infrastructure renovations, provision of medical and non-medical equipment; implementation of IMCI and malnutrition protocols for every child under-five (2) Staffing of health centres above MoH norms; frequent trainings for medical staff (3) Joint MoH-PIVOT training and supervision to improve HMIS data quality (4) Supply chain management and reduction of stock-outs (5) Essential medicines and consumables provided free of charge to all patients (6) Close collaboration with district health managers for the planning and implementation of activities	(1) Provision of medical and non-medical equipment (2) Staffing to bring all health centres up to MoH norms; trainings for medical staff (5) Basic package of health services free of charge for children under-five and pregnant women
Community health Total Ifanadiana: 195 fokontany PIVOT catchment: 123 fokontany	(1) Construction of 81 community health sites by community, with PIVOT support; implementation of IMCI and malnutrition protocols for every child under-five (2) Training and on-site supervision of community health workers by mobile teams of trained nurses every 2months (six nurses for ~40CHWs) (3) Joint MoH-PIVOT training to improve HMIS data quality (4) Monthly provision of MNCH medicine stocks to CHWs and follow-up of medicine stock use (5) Cost of MNCH medicine stocks fully covered by PIVOT and provided free of charge to patients; financial incentives to CHWs for stock management and attendance to supervisions (~\$4 per month); no fees charged to diagnose patients (6) Community engagement and participation	(1) Provision of non-medical equipment and supplies (2) Training every year; monthly performance evaluation at health centres; on-site coaching by technical assistants (one for ~15–35CHWs) every 2months (4) Provision of a free initial stock of products and medicines (subsequent stocks are purchased by CHWs) † (5) CHWs make a profit from a small margin in the sale of medicines (except those in PIVOT catchment who obtain them for free) †; no fees charged to diagnose patients

\*Building blocks of HSS: (1) service delivery; (2) health workforce; (3) health information systems; (4) medicines and supplies; (5) financing; (6) leadership and governance.

†Exceptionally, these two interventions only happened in RoD, since PIVOT substituted the medicine provision and financial incentives to CHWs. CHW, community health worker; HMIS, health management information systems; HSS, health system strengthening; IMCI, integrated management of child illness; MNCH, maternal, newborn and child health; MoH, Ministry of Health; RoD, rest of the district.

**Supplementary table S2:** Description of the motorized vehicle dataset, which includes GPS recordings of all the NGO vehicles every 10 seconds from March 17 to May 5, 2019 and from February 1 to April 4, 2020.

	Distance (km)	%
<b>Slope (%)</b>		
[0,30]	77,229	99.38
(30,70]	428	0.55
(70,100]	52	0.67
<b>Rainfall (mm)</b>		
[0,10]	60,650	78.05
(10,25]	11,130	1.43
(25,50]	4350	5.60
(50,75]	1579	2.03
<b>Bridge</b>		
No	74,427	95.65
yes	3282	4.35
<b>Residential area</b>		
No	68,631	88.32
Yes	9078	11.68
<b>Road</b>		
National road	66,443	85.50
Tertiary road	7330	9.43
Unclassified	3936	5.07
<b>Transport</b>		
Vehicle	61,258	78.82
Motorcycle	16,258	20.92

**Supplementary table S3:** Description of hospital referrals in Ifanadiana District, 2014-2020.

<b>variables</b>	<b>n</b>	<b>%</b>
<b>Means of transport</b>		
Ambulance	3456	40.83
Ambulance pick-up point	169	1.99
Tractor	74	0.87
Taxi-brousse	1705	20.14
Private car	117	1.38
Walking	1602	18.93
Rolling stretcher+Ambulance	51	0.60
Other	1290	15.24
<b>Accessibility</b>		
High	6573	77.66
Medium	1349	15.94
Low CSB2	494	5.84
Low CSB1	48	0.57
<b>Year</b>		
2014	411	4.86
2015	816	9.64
2016	1423	16.81
2017	1403	16.58
2018	1465	17.31
2019	1783	21.07
2020 (January to July)	1163	13.74
<b>Season</b>		
High malaria transmission	4522	53.43
Low malaria transmission	3942	46.57

**Supplementary table S4:** Travelling walking speed values for each class of land cover and motorized speed values for road networks

Land cover type	Dry conditions	Rainy conditions	Travelling Mode
	Travelling speeds (km/h)		
Forest	3	2	Walking
Savanna	4	3	Walking
Residential area	5	4	Walking
Rice field	4	3	Walking
National road	50	40	Motorized vehicle
Tertiary road	30	20	Motorized vehicle
Unclassified road	20	10	Motorized vehicle
Path	5	4	Walking

**Supplementary table S5:** Multivariate analysis of local factors affecting the number of monthly referrals by health centers, (negative binomial linear mixed model, with health center as random intercept)

	Estimate <sup>1</sup>	95% Confidence Intervals
Intercept	0.05	[0.02, 0.11]
<b>Geographic factors<sup>2</sup></b>		
Referral time (hours, linear)	3.29e-24	[1.14e-30, 9.49e-18]
Referral time (hours, quadratic)	1.33e+08	[56.09, 3.15e+14]
<b>Health system factors</b>		
<i>Type of health center</i>		
Basic Health Center (CSB1)	(ref)	
Major Health Center (CSB2)	7.17	[2.99, 17.21]
<i>Removal of user fees</i>		
No	(ref)	
Yes	1.11	[1.08, 1.14]
<b>Time varying factors</b>		
Linear trend (year)	2.30	[1.88, 2.81]
Lagged referrals (1-month lag)	1.02	[1.01, 1.02]

<sup>1</sup> Model coefficients and confidence intervals are exponentiated to reflect relative change

<sup>2</sup> Orthogonal polynomial of degree 2. As results are hard to interpret, please refer to Figure 3 to observe changes in the number of referrals according to changes in geography, health system factors and over time.