Is the Phone Mightier than the Virus? Cell Phone Access and Epidemic Containment Efforts

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Motivation

- Infectious disease outbreaks remain major burden: 2009-2010 swine flu, 2014 West African and the 2018-2020 DRC Ebola virus disease, 2015-2016 Zika virus in Latin America, 2019 Covid.
- Assessing the effectiveness of tools to contain spread is first-order policy issue
- **Mobile phone technology** is a powerful tool
  - Diagnosis, prediction, delivery of health care
  - Information
- Specific tools have been used in past outbreaks

Research Question

Does cell phones access among the general population help contain (or spread) disease during an outbreak?

Context:

- 2014 **Ebola Virus Disease (EVD)** epidemic in Liberia
- Use mobile phone coverage as a proxy for cell phone access
- Use a Regression Discontinuity (RD) design

⇒ **Objective:** Find the causal effect of cell phone access on likelihood of EVD case

Mechanisms

How are cell phone access and disease (EVD) related?

- *Preventive care channel*:
  - Cell phone access $\Rightarrow$ Exposure to prevention
  - Prevention education and material, hygiene practices, etc.
  - Cell phone access $\Rightarrow \downarrow$ Likelihood of EVD

- *Treatment care channel*:
  - Cell phone access $\Rightarrow$ Access to health care resources
  - Reporting sick and dead, requesting ambulances, etc.
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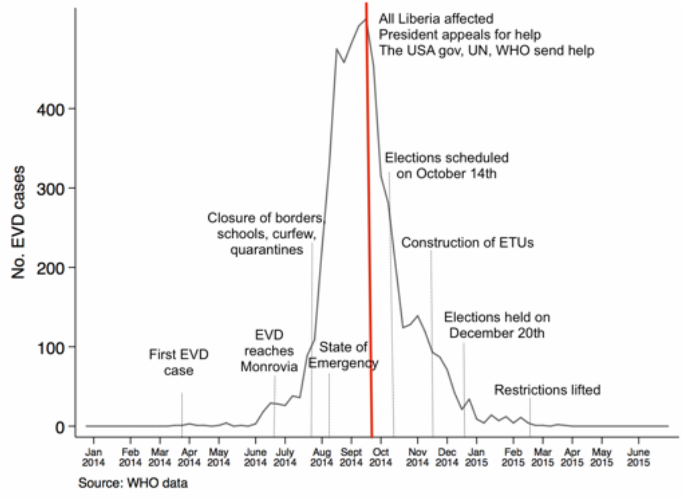
- *Network channel*:
  - Cell phone access $\Rightarrow$ Increases access to network
  - Reliance on network, especially at early stages
  - Unintended consequence: $\uparrow$ P2P interactions within network
  - Cell phone access $\Rightarrow \uparrow$ Likelihood of EVD

Literature

Background on EVD in Liberia

- Largest epidemic in history of the disease
  - 10,675 confirmed, probable, or suspected cases
  - 4,809 deaths –the highest number in West Africa
- Delayed international aid
  - 62 countries and international agencies commit US$806 million
  - Government maintained control and ownership of relief efforts
  - Hotline, Community Care Centers (CCC), Ebola Treatment Units (ETUs), burial teams, etc.
- Timeline: March 2014 - May 2015 (first free-EVD declaration)
- Minor outbreaks, completely over by January 2016

Background on EVD in Liberia



Data: EVD

Measure of EVD, constructed from a proprietary patient database from the MOH

- Contains more than 19,000 patients tested for EVD between March 2014 and July 2015
- Supplemented with a data from Global Community–a development organization that managed burials after July 2014
- Use data on village location (lat,lon) to create village-level measure of EVD

⇒ Indicator equal to 1 if at least one (probable, confirmed, or death) case was recorded in village i during study period

Data: Coverage

Tower locations and radio frequency

- Obtained from Liberia Telecommunication Authority (LTA)
- Year: 2013 (year prior to start of outbreak)
- MTN Lonestar and Cellcom (91% market share in 2013)
- **Measure:** Signal strength on the ground obtained from **Irregular Terrain Model** (Crabtree and Kern, 2018)

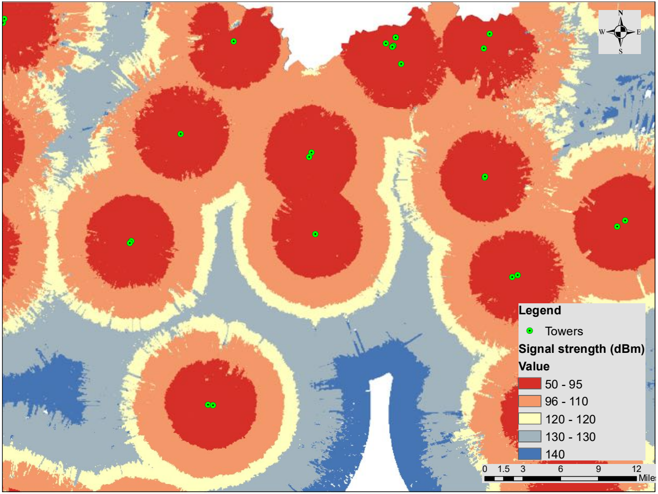
Empirical Strategy: Measure of Coverage

Use a **Radio Wave Propagation Model** to predict signal strength (coverage) (4th gen)

- Takes into account topography, climate, terrain conductivity, etc.
- Better suited for Super High Frequency radio waves
- Model predictions repeatedly validated via on-the-ground measurements (Eppink and Kuebler 1994; Lazaridis et al. 2013; Longley and Rice 1968; Seybold 2005)
- Workhorse model of regulatory agencies (Crabtree 2018)

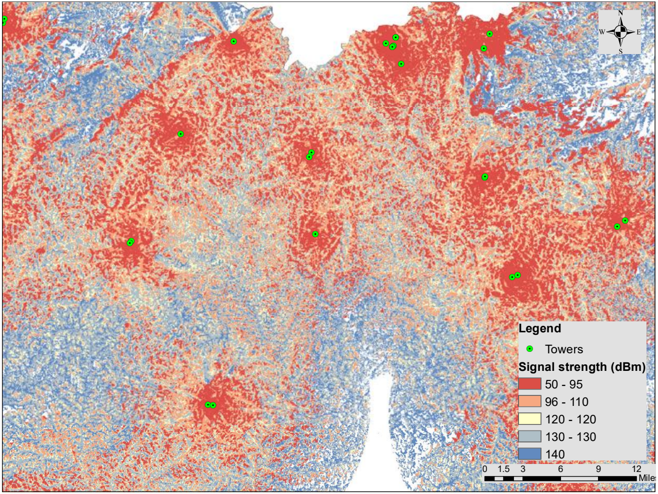
ITM “Free-space” versus ITM with Topography

“Free-space” ITM



ITM "Free-space" versus ITM with Topography

ITM with Topography



Empirical Strategy: Measure of Coverage

Implementing the ITM:

Inputs:

- Location (lat,lon) of cell phone towers
- Raster elevation model (DEM30)
- Transmission frequency of towers
- Other variables related to climate, land coverage, ground conductivity, antenna gain, etc.

Empirical Strategy: Measure of Coverage

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Inputs:

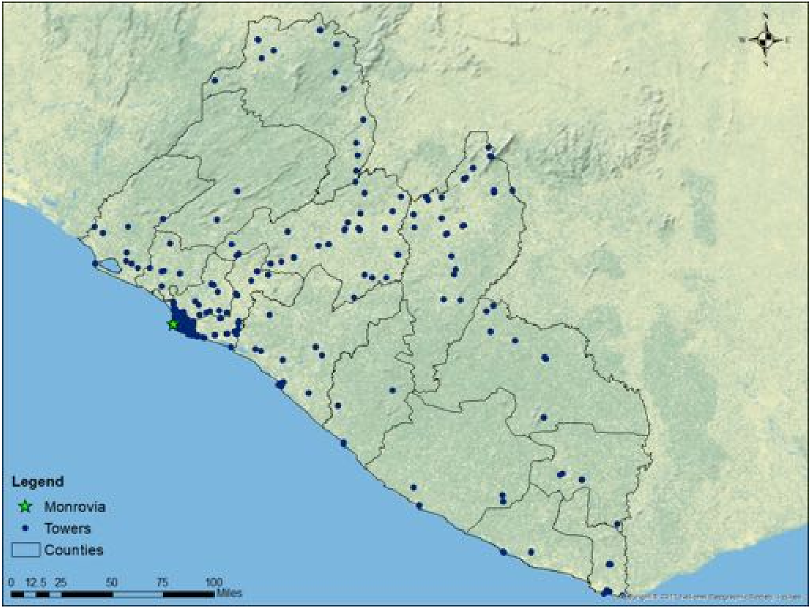
- Location (lat,lon) of cell phone towers
- Raster elevation model (DEM30)
- Transmission frequency of towers
- Other variables related to climate, land coverage, ground conductivity, antenna gain, etc.

Output:

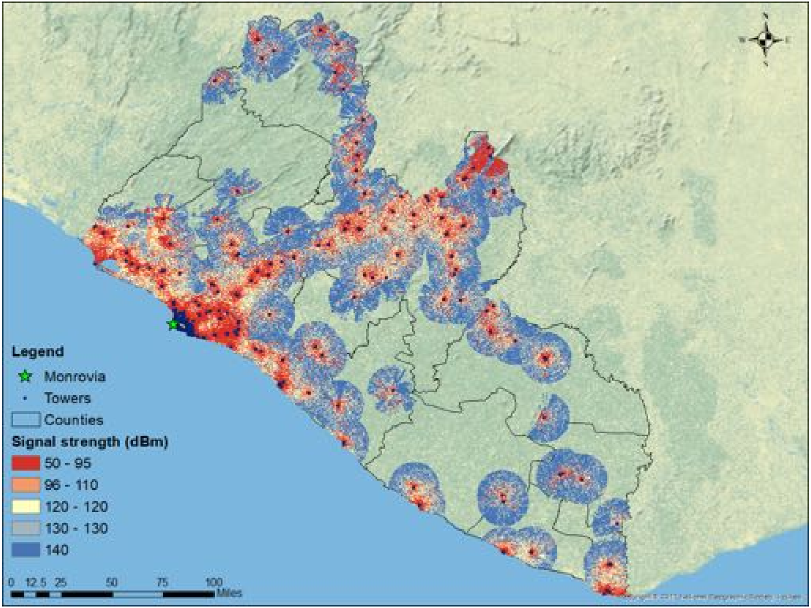
- Power received at any point in the ground (measured in dBm (decibels/milliwatt))
- Power measured in dBm (decibels/milliwatt):
  - Typically ranges between -50 and -140dBm.
  - Use absolute value: 50 to 140dBm; lower dBm = stronger coverage

ITM details Inputs details

Empirical Strategy: Measure of Coverage, Inputs



Empirical Strategy: Measure of Coverage, Output



Empirical Strategy: Measure of Coverage

Estimating the effect of cell phone coverage using ITM

- GSM cell phone networks work if received power is between 95 and 105 dBm
- If received power falls below that threshold–>No calls, dropped calls, no SMS
- Going from 1 bar to no bars

Compare villages within a margin of this threshold Determinants

- At this margin, minor changes in topography is what determines whether you get enough signal strength

Empirical Strategy: Regression Discontinuity

Framing this idea within a **RD design**:

- Quality of communication is a continuous function of power received (dBm)
- Discontinuity in ability to make a call at receiver sensitivity threshold

RD design uses:

- Received power (signal strength) as the forcing variable
- Receiver sensitivity as the cutoff (95-105dBm)

⇒ We use 95 dBM

- Validated in engineering literature (Razally 2015, GSM 2019)
- Empirical tests 3 cutoff tests

Note: Positive correlation (0.55) between ITM predicted coverage and phone ownership (at district level, DHS) Graph

Empirical Strategy: Regression Discontinuity

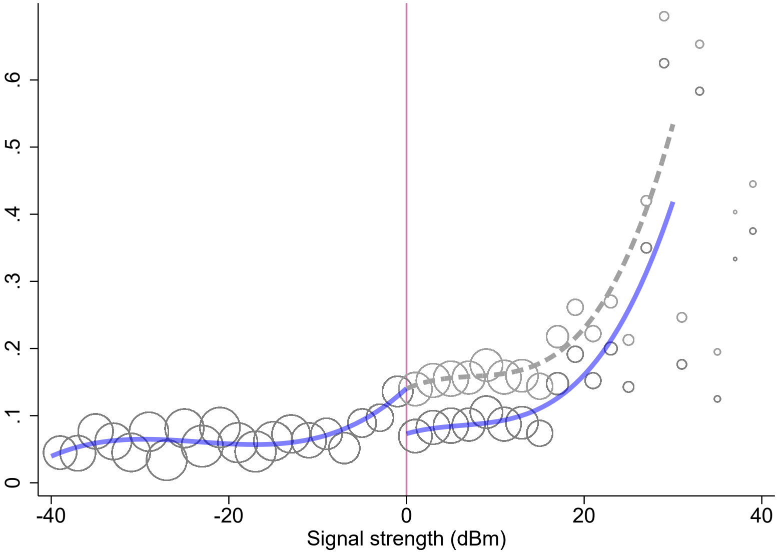
Regression Discontinuity Design:

$$EVD_i = \alpha + \beta D_i + f(\tilde{R}_i) + h(\mathbf{G}_i) + \epsilon_i$$

- EVD_i indicator for village i having at least one EVD case
- $D_i =$ whether village i has coverage (i.e., received power >c)
- $\tilde{R}_i = R_i - c$ is received power in dBm net of cutoff c
- $f(\tilde{R}_i)$ is RD polynomial (LLR)
- $h(\mathbf{G}_i)$ function of topography (elevation, terrain slope)
- Bandwidth h chosen optimally (Calonico et al. (2014))
- Triangular weighting kernel
- Standard errors clustered at district level

Validity

Graphical Evidence: Regression Discontinuity Plots



Main Results: Regression Discontinuity Estimates

Effect of Coverage on Likelihood of EVD Case

	Dep. Variable = $\mathbb{1}\{\text{Number of Reported EVD cases} > 0\}$					
	Baseline	Controls	Topo Poly	Poly RD	Kernel choice	Probit model
	(1)	(2)	(3)	(4)	(5)	(6)
Coverage	-0.108**	-0.101**	-0.110**	-0.096***	-0.105***	-0.429**
	(0.048)	(0.042)	(0.048)	(0.035)	(0.041)	(0.204)
Mean outside coverage	0.09	0.09	0.09	0.06	0.09	0.09
Bwidth (dBm)	8.99	8.13	9.09	50.00	8.24	8.24
Observations	1547	1547	1741	7014	1547	1547
Districts	83	83	84	115	83	83
Marginal	-	-	-	-	-	-0.07

Robustness

Main Results: Regression Discontinuity Estimates

Controlling for "Free-Space" Signal Strength

- Minor changes in terrain topography lead to arbitrary blocking or diffraction of the signal, and thus to *actual* signal on the ground
- We estimate a "free-space" ITM (Olken, 2009), assuming direct line-of-sight between the tower and the receiver
- Control for: free-space predicted signal strength and coverage
- **Goal:** To identify coverage effect using the variation in signal strength *solely* due to idiosyncratic changes in topography

Comparison ITMs

Main Results: Regression Discontinuity Estimates

Dep. Variable = $\mathbb{1}\{\text{Number of Reported EVD cases} > 0\}$

	(1)	(2)	(3)	(4)
Coverage	-0.087**	-0.084*	-0.077**	-0.081**
	(0.038)	(0.041)	(0.037)	(0.040)
Free-space coverage	-0.013		-0.044*	-0.045*
	(0.020)		(0.024)	(0.026)
Free-space signal strength		0.000	-0.000	-0.000
		(0.001)	(0.001)	(0.001)
Free-space coverage × Free-space signal strength			0.003	0.003
			(0.002)	(0.002)
Mean outside coverage	0.093	0.101	0.094	0.093
Bandwidth (dBm)	8.35	7.99	9.14	8.93
Observations	1547	1352	1720	1528
Districts	83	81	84	83
Controls	Yes	Yes	Yes	Yes
Topography Polynomial	No	No	No	Yes

Falsification Tests

Summary of Main Results

- Cell phone coverage leads to a 10 pp drop in likelihood of EVD
- Evidence of contagion effect given an EVD case within district, but diminished if village has cell phone coverage Panel RD estimates
- Main results are robust to alternative EVD measures and range of bandwidths Tests
  - Bandwidth choice
  - Alternative EVD Measures
  - Near cutoff values
  - “Walking into coverage”
  - False coverage

Next: Which are the **mechanisms** explaining the effect of cell phone coverage on EVD?

Mechanisms

Ex-ante ambiguous relationship between cell phone access and disease (EVD):

- *Preventive care channel*:
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    - Cell phone access $\Rightarrow \downarrow$ Likelihood of EVD
- *Network channel*:
    - Cell phone access $\Rightarrow$ Increases access to network
    - Improve collective action (coordination, free-riding)
    - Reliance on network, especially at early stages
    - Unintended consequence: $\uparrow$ P2P interactions within network
    - Cell phone access $\Rightarrow \uparrow$ Likelihood of EVD

Hotline

Channels of Impact: Care Channels

Use **survey data** collected about six months after the end of the epidemic (Maffioli (2018))

- 2,265 respondents in 571 villages across all of Liberia selected through random dialing of phone numbers
- Interviewed through a combination of an Interactive Voice Response (IVR) and a Computer-Assisted Telephone Interviewing (CATI) conducted by a local NGO
- About 30% of individuals surveyed in 2015-2016 were living in areas that did not have coverage just prior to the outbreak in 2013

More info: *"Collecting Data During an Epidemic: A Novel Mobile Phone Research Method"*

Channels of Impact: Care Channels

We create several "prevention" and "treatment" outcomes

Preventive care:

Someone (from government, health workers, local or international NGOs) came to village to:

- Do contact tracing
- Explain EVD
- Hold hygiene meetings
- Share EVD prevention information [Community taskforce]
- Explain how to conduct safe burials
- Bring prevention material (chlorine, buckets, etc.)

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- Bring prevention material (chlorine, buckets, etc.)

Treatment care:

- Someone (from government, health workers, local or international NGOs) came to village to:
  - Take sick people
  - Take dead bodies
- Ambulances arrived on time after being requested
- CCC was built within 10 kilometers of the village

Channels of Impact: Care Channels

Preventive Care

	Contact tracing	Explain EVD	Hygiene meet-ings	Bring info (Task-force)	Explain burials	Prev mate-rial	Prev care index
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Coverage	0.102	0.123	-0.173	0.135	0.090	0.079	0.049
	(0.084)	(0.086)	(0.110)	(0.088)	(0.092)	(0.111)	(0.131)
Mean	0.200	0.897	0.465	0.282	0.174	0.779	0.047
Bandwidth (dBm)	8.80	14.89	17.12	8.94	11.77	16.46	15.17
Observations	268	434	551	296	328	518	447
Villages	86	166	203	86	122	189	175

Channels of Impact: Care Channel

Treatment Care

	Take sick (1)	Take dead (2)	Ambulance on-time (3)	CCCs within 10km (4)	Treatment care index (5)
Coverage	0.223***	-0.006	0.206***	0.416*	0.340**
	(0.036)	(0.044)	(0.076)	(0.235)	(0.146)
Mean outside coverage	0.123	0.070	0.835	0.455	-0.036
Bandwidth (dBm)	8.13	11.17	12.35	9.40	8.00
Observations	268	328	385	317	268
Villages	86	122	139	100	86

Channels of Impact: Network Channel

Network channel cannot be tested directly

- An individual's network is unobserved

Two measures as a way to define a village's closest social network

1. **Call Detail Recording (CDR) database** graph
   - June-July 2015 from Cellcom
   - Connect villages within tower catchment area to other towers by number of calls
2. **Historic Liberian clans**
   - 619 clans, including an average of 38 villages
   - Villages within a clan are more likely to be socially interconnected than villages within other administrative units

Network channel: We expect likelihood of EVD to increase in village *i* if *i* has coverage and other EVD-affected villages within the same network also have coverage

Channels of Impact: Network Channel

Empirical model:

$$EVD_{ijt} = \alpha + \beta Match_{i,j(i)} + \gamma EVD_{j(i),t-1} + \delta Match_{i,j(i)} \times EVD_{j(i),t-1} + \lambda_i + \nu_t + \epsilon_{ijt}$$

- EVD_{ijt} indicator for village i, in network j, in quarter t having at least one EVD case
- $\text{EVD}_{j(i),t-1} = 1$ if at least one village in village i's network was affected by EVD in quarter $t-1$
- $Match_{i,j(i)} = 1$ if village i has coverage and at least one of the EVD-affected villages within village i's network has coverage ("coverage match")
- λ_i village FE
- ν_t quarter FE
- Standard errors clustered at network level

Channels of Impact: Network Channel

Likelihood of EVD within Connected Villages of the Network

	Dep. Variable = $\mathbb{1}\{\text{Number of Reported EVD cases} > 0\}$					
	Network: Call behavior					
	Top tower (1)	Top 5 towers (2)	50% call share (3)	75% call share (4)	90% call share (5)	Network: Clan (6)
$EVD_{j(i),t-1}$	0.0399***	0.0310***	0.0406***	0.0179**	0.0095**	0.0338
	(0.007)	(0.009)	(0.007)	(0.008)	(0.004)	(0.028)
$Match_{i,j(i)} \times EVD_{j(i),t-1}$	0.0061	0.0064	0.0109	0.0112	0.0085	-0.0030
	(0.033)	(0.024)	(0.036)	(0.016	(0.006)	(0.045)
Observations	18864	18864	18864	18864	18864	19372
Villages	9432	9432	9432	9432	9432	9686
Clusters	96	96	96	96	96	631
Village and time FE	Yes	Yes	Yes	Yes	Yes	Yes

Conclusion

Evidence that **mobile phone coverage helps disease containment**

True even in the midst of a crisis and in setting with general mistrust towards authorities

Analysis of **channels of impact** suggests that:

- Interventions designed to improve access to treatment more effective than interventions designed to increase prevention
- Plausible:
  - In the midst of a crisis, return to an additional ambulance likely higher than return to additional information session or preventive material
  - Effects of increasing prevention may take longer to materialize as they entail a change in health behavior

Policy Implications

- Infectious disease epidemics remain a worldwide threat
- Ultimate human and economic costs could be mitigated through appropriate governmental actions
- We show that cell phone coverage play an important role in containing the disease:
  - In normal times: more investment in mobile phone technology (Blumenstock et al. 2020)
  - In the midst of a crisis: exploit cell phone coverage/technology with interventions to improve access to treatment, rather than prevention

APPENDIX SLIDES

Related Literature and Contribution

1. **ICT (Information and Communication Technology) and economic development** (Aker and Mbiti 2010)
    - Market efficiency (Jensen 2007, Aker 2010; Aker, Fafchamps 2014)
    - Education (Aker et al. 2012, 2018)
    - Mobile money & transfers (Jack and Suri, 2011, 2014; Blumenstock et al. 2016)
2. **Mobile phones and health-related outcomes**
    - Management of health records (Argwal et al. 2015)
    - Quality, efficiency or monitoring of care (Braun et al. 2013)
    - Maternal and child health indicators (Obasola et al. 2015)
    - Remote diagnosis of disease (D'Ambrosio et al. 2015)
3. **Mobile phones and infectious diseases**
    - Mobility patterns to predict outbreaks (Lu et al. 2012, Bengstsson et al. 2015; Wesolowski et al. 2015)
    - "Participatory epidemiology" (Yang et al 2009; Freifeld 2010; Sacks et al. 2015, Feng et al. 2018)
4. **Radio propagation models to proxy media exposure** (Olken (2009), Adena et al. (2015), Durante et al. (2017))
    - Employ model using cell phone technology (communication)
    - Frame strategy within a regression discontinuity design

Related Literature and Contribution

Our paper advances this literature in four areas:

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- **Go beyond the evaluation exercise**
  - Explore mechanisms that can explain the relationship between cell phone access and epidemic containment

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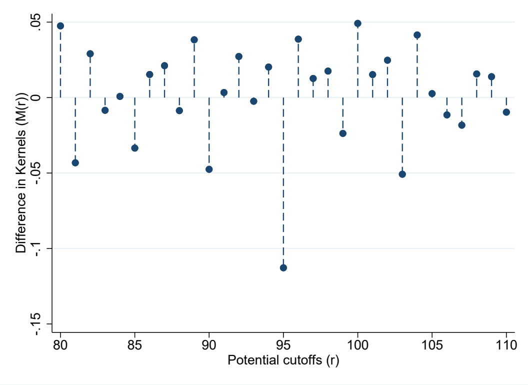
- **Go beyond the evaluation exercise**
  - Explore mechanisms that can explain the relationship between cell phone access and epidemic containment
- **Explore effectiveness of technology during a health crisis**
  - Setting characterized by general mistrust towards local and international institutions

Back to Mechanisms

Tests for cutoff $r = 95dbm$

(1) Difference in Kernels estimator (Qiu 2011, Porter and Yu 2015)

- Intuitively, compare kernel-weighted average of outcome on the right and left of point $r(80 - 110dBM)$ and find jump

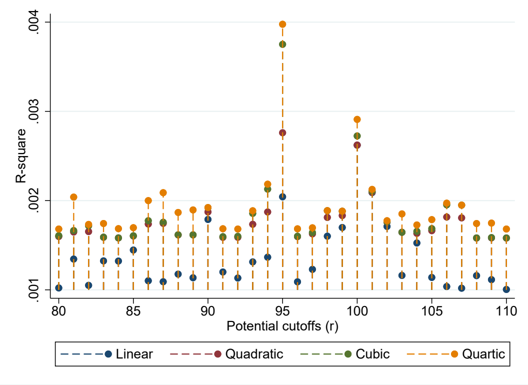


Back to Cutoff

Tests for cutoff $r = 95dbm$

(2) Max R^2 strategy (Card et al 2008)

- Estimate relationship between outcome and signal strength for potential cutoffs within a range; then choose r with highest R^2

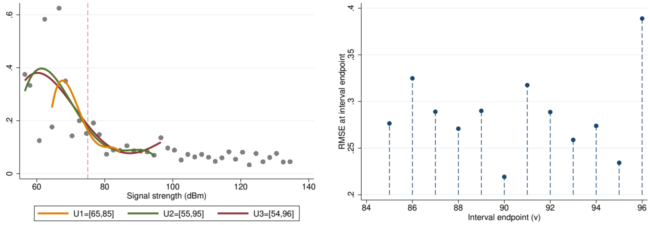


Back to Cutoff

Tests for cutoff $r = 95dbm$

(3) Method by Spokoiny (1998) adapted to RD setting

- Estimate polynomial $f(.)$ in $Y_i = f(R_i - r_0) + \epsilon_i$ within a neighborhood U of point $r_0 = 75$
- Examine $Root - Mean - Square - Error$ of residuals
- Then increase U until there is a clear jump in residuals at r (i.e. endpoint of max interval for which the endpoint residuals "well behave")



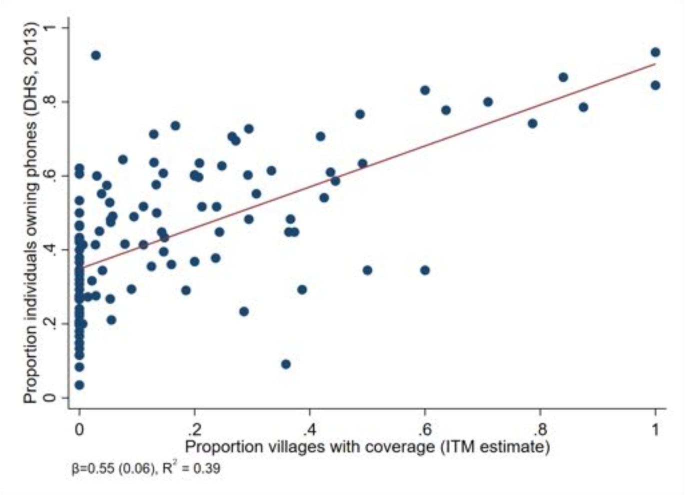
(a) Polynomial within interval U around $r_0 = 75$

(b) RMSE at interval endpoints

Figure: RMSE of Endpoint Residuals

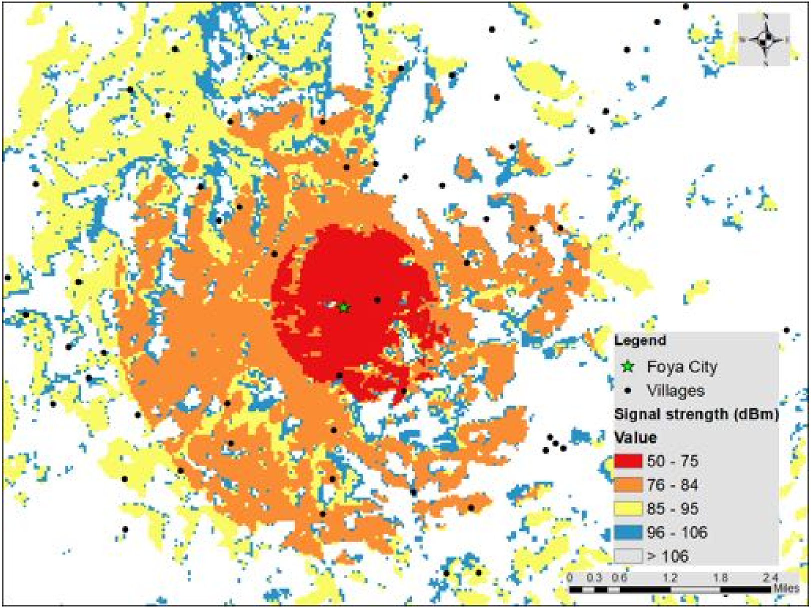
ITM and Cell Phone Ownership

Correlation between proportion of individuals reporting cellphone ownership (DHS, 2013) and proportion of villages with predicted cellphone coverage (ITM), at district level



Back to RD

Empirical Strategy: The ITM model



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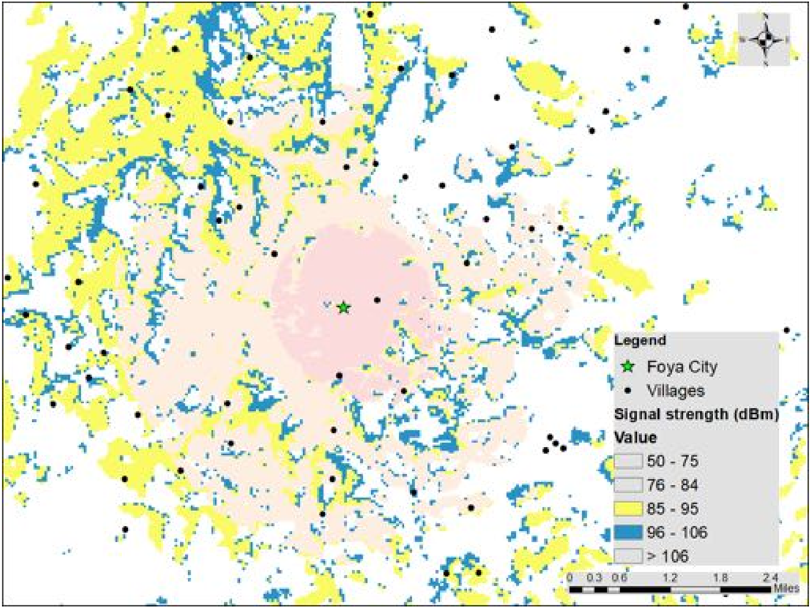

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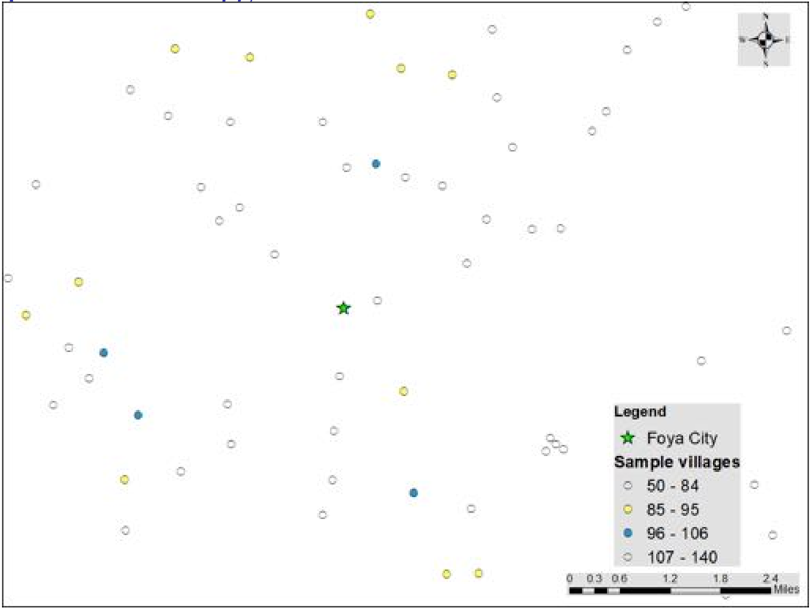

Back to Coverage

Main variables and Parameters of Irregular Terrain Model (ITM)

Model variables	Description	Parameters
Transmitter characteristics		
Transmitter power	Transmission power (Watts)	5
Frequency	Radio wave frequency (MHz)	900
Latitude	Latitude of cell tower	e.g., 37.158
Longitude	Longitude of cell tower	e.g., 70.765
Transmitter height	Height of cell tower above ground (meters)	30
Radius	Maximum coverage radius (kilometers)	20
Antenna gain	Transmitter antenna gain (dBi)	2.14
Receiver characteristics		
Receiver sensitivity	Minimum power received threshold (dBm)	-140
Receiver height	Receiver height above ground (meters)	1.5
Antenna gain	Receiver antenna gain (dBi)	2.14
Geographic characteristics		
Resolution	Topographic model	DSM30
Radio climate	1: Equatorial 2: Continental Subtropical 3: Maritime Subtropical 4: Desert 5: Continental Temperate 6: Maritime Temperate, over land 7: Maritime Temperate, over sea	e.g., 5
Terrain conductivity	Salt water : 80 Fresh water : 80 Good ground : 25 Marshy land : 12 Farmland, forest : 15 Average ground : 15 Mountain, sand : 13 City : 5 Poor ground : 4	e.g., 13

Main variables and Parameters of Irregular Terrain Model (ITM)

Other model inputs:

- ITM reliability: 99
- Output type: 2
- Distance unit: meters
- Knife-Edge difraction: 0
- Antenna code: 39

Estimation of the ITM model uses the SLEIPNIR engine in cloudRF.
Back to Coverage

What determines coverage at the margin?

	Dep. variable: Signal strength (dBm)	
	Full sample	Within 10 dBm
Topographic controls		
Elevation (m)	-0.082***	0.005
	(0.024)	(0.009)
Slope (%)	-0.283	0.828***
	(0.455)	(0.256)
Demographic controls		
Household size	-0.194	0.118
	(0.171)	(0.087)
Population (log)	0.880***	-0.013
	(0.166)	(0.117)
Female (%)	-0.367	1.474
	(2.456)	(1.775)
Married (%)	-4.267*	1.236
	(2.170)	(1.481)
Christian (%)	1.974	-0.340
	(2.593)	(1.603)
Muslim (%)	1.655	-1.721
	(3.180)	(1.982)
African religion (%)	6.102	-0.579
	(5.602)	(7.128)
Kpelle (%)	-0.040	-1.190
	(1.159)	(0.946)
Bassa (%)	3.648	0.497
	(2.229)	(1.163)
Economic controls		
Primary education (%)	-0.347	-1.199
	(1.665)	(1.200)
Secondary education (%)	5.027**	0.925
	(2.091)	(1.137)
Owns house (%)	1.084	-0.403
	(1.189)	(0.568)
House condition: Good (%)	9.476***	0.858
	(2.175)	(0.941)
Assets ownership (%)	2.350	0.505
	(3.844)	(1.621)
Distance to Monrovia (km)	-0.098**	-0.020
	(0.047)	(0.024)
Distance to closest city (km)	-0.306***	-0.035
	(0.113)	(0.049)
Observations	7,014	1,913
Topographic controls (F-test)	0.00	0.00
Demographic controls (F-test)	0.00	0.35
Economic controls (F-test)	0.00	0.79
Demographic and economic controls (F-test)	0.00	0.15

What determines coverage at the margin?

	Dep. variable: Signal strength (dBm)	
	Full sample	Within 10 dBm
Topographic controls		
Elevation (m)	-0.082***	0.005
	(0.024)	(0.009)
Slope (%)	-0.283	0.828***
	(0.455)	(0.256)
Demographic controls		
Household size	-0.194	0.118
	(0.171)	(0.087)
Population (log)	0.880***	-0.013
	(0.166)	(0.117)
Female (%)	-0.367	1.474
	(2.456)	(1.775)
Married (%)	-4.267*	1.236
	(2.170)	(1.481)
Christian (%)	1.974	-0.340
	(2.593)	(1.603)
Muslim (%)	1.655	-1.721
	(3.180)	(1.982)
African religion (%)	6.102	-0.579
	(5.602)	(7.128)
Kpelle (%)	-0.040	-1.190
	(1.159)	(0.946)
Bassa (%)	3.648	0.497
	(2.229)	(1.163)
Economic controls		
Primary education (%)	-0.347	-1.199
	(1.665)	(1.200)
Secondary education (%)	5.027**	0.925
	(2.091)	(1.137)
Owns house (%)	1.084	-0.403
	(1.189)	(0.568)
House condition: Good (%)	9.476***	0.858
	(2.175)	(0.941)
Assets ownership (%)	2.350	0.505
	(3.844)	(1.621)
Distance to Monrovia (km)	-0.098**	-0.020
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	(0.113)	(0.049)
Observations	7,014	1,913
Topographic controls (F-test)	0.00	0.00
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Economic controls (F-test)	0.00	0.79
Demographic and economic controls (F-test)	0.00	0.15

Back to Coverage

Empirical Strategy: Regression Discontinuity

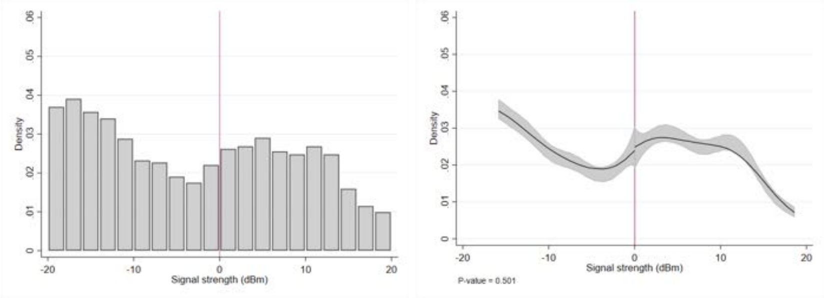
Regression Discontinuity Design

Validity of the design:

- Similar baseline characteristics across coverage threshold RD plots of covariates
- Density of forcing variable is smooth at the threshold Test
- No manipulation of forcing variable at the threshold Test

Back to Empirical Strategy

Histogram and Test for Manipulation of Forcing Variable

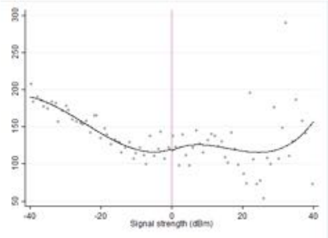


(a) Histogram (b) Test for manipulation

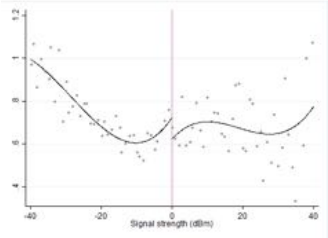
Figure: Histogram and Test for Manipulation of Forcing Variable

Back to RD

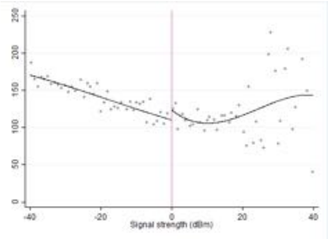
Covariate RD Plots



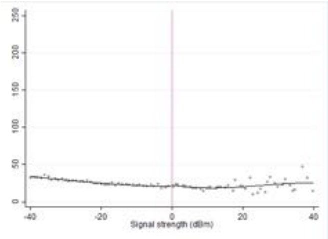
Elevation (m)



Slope (%)



Distance to Monrovia (km)



Distance to closest city (km)

Back to Test

Summary Stats

	Full sample			Within 20 dBm			Within 10 dBm		
	In	Out	S.E.	In	Out	S.E.	In	Out	S.E.
Topographic characteristics:									
Elevation (m)	122.8	165.3	(14.69)***	123.5	124.6	(12.26)	122.3	117.7	(11.69)
Slope (%)	0.68	0.89	(0.05)***	0.68	0.64	(0.04)	0.67	0.62	(0.04)
Demographic characteristics:									
Household size	4.68	5.02	(0.10)***	4.66	4.58	(0.07)	4.64	4.52	(0.08)
Population (log)	4.38	4.32	(0.07)	4.25	4.17	(0.06)	4.16	4.19	(0.08)
Female (%)	0.48	0.48	(0.00)	0.48	0.48	(0.00)	0.48	0.48	(0.01)
Married (%)	0.37	0.38	(0.01)	0.37	0.39	(0.01)**	0.38	0.39	(0.01)
Christian (%)	0.85	0.87	(0.03)	0.85	0.85	(0.02)	0.83	0.85	(0.02)
Muslim (%)	0.11	0.10	(0.03)	0.11	0.13	(0.02)	0.13	0.13	(0.02)
African religion (%)	0.01	0.01	(0.00)	0.01	0.00	(0.00)	0.00	0.00	(0.00)
Kpelle (%)	0.31	0.28	(0.04)	0.31	0.33	(0.03)	0.31	0.36	(0.03)*
Bassa (%)	0.25	0.24	(0.06)	0.26	0.24	(0.04)	0.26	0.21	(0.04)
Other ethnic group (%)	0.43	0.48	(0.05)	0.42	0.42	(0.03)	0.42	0.42	(0.03)
Economic characteristics:									
Primary education (%)	0.28	0.25	(0.01)**	0.28	0.26	(0.01)**	0.26	0.26	(0.01)
Secondary education (%)	0.38	0.33	(0.02)***	0.37	0.34	(0.01)**	0.35	0.35	(0.01)
Owns house (%)	0.80	0.87	(0.02)***	0.81	0.84	(0.01)***	0.82	0.82	(0.01)
House: Good (%)	0.26	0.14	(0.02)***	0.25	0.20	(0.01)***	0.22	0.21	(0.01)
Asset ownership (%)	0.13	0.11	(0.01)***	0.13	0.12	(0.01)*	0.12	0.12	(0.01)
Dist. to Monrovia (km)	112.3	166.9	(12.51)***	111.1	126.1	(10.08)	111.3	119.9	(9.11)
Dist. to closest city (km)	19.82	33.72	(2.15)***	19.67	22.52	(1.36)**	19.58	21.06	(1.24)
Observations	1,856	7,830		1,698	2,141		1,112	801	

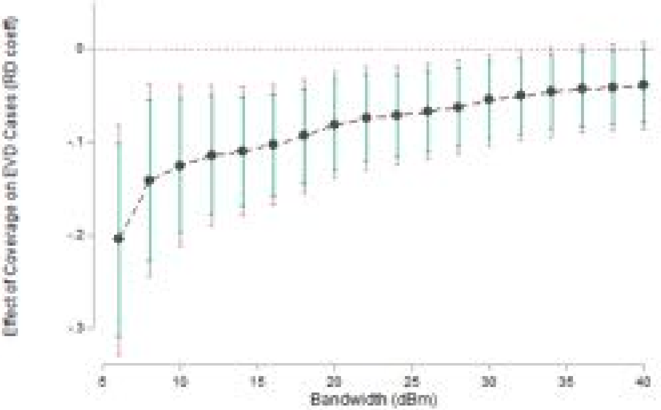
Robustness

- Bandwidth choice
- Alternative EVD Measures
- Free space ITM
- Near cutoff values
- “Walking into coverage”
- False coverage

Back to Main results

Robustness

Bandwidth choice



Robustness

Months affected by EVD

	Number of Months Affected by EVD				
	Baseline	Controls	Topo Poly	Poly RD	Kernel choice
	(1)	(2)	(3)	(4)	(5)
Coverage	-0.209**	-0.188**	-0.220**	-0.158**	-0.199**
	(0.096)	(0.084)	(0.099)	(0.074)	(0.087)
Mean outside coverage	0.128	0.128	0.128	0.090	0.142
Bandwidth (dBm)	8.72	8.97	8.59	50.00	7.10
Observations	1547	1547	1547	7014	1369
Districts	83	83	83	115	81

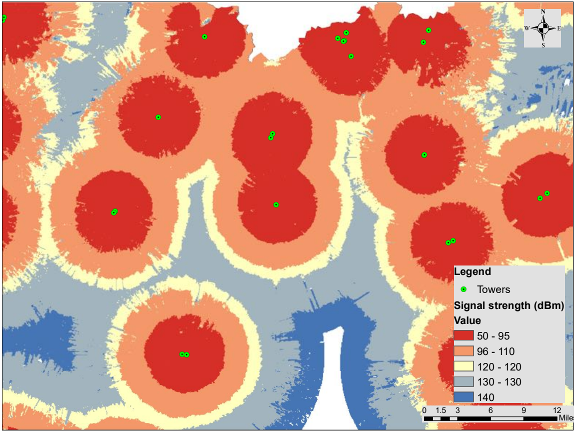
Robustness

Number of suspected EVD deaths

	Dep. Variable = $\mathbb{1}\{\text{Number of Suspected EVD deaths} > 0\}$					
	Baseline	Controls	Topo Poly	Poly RD	Kernel choice	Probit model
	(1)	(2)	(3)	(4)	(5)	(6)
Coverage	-0.069*	-0.074**	-0.069*	-0.058	-0.067*	-0.243*
	(0.037)	(0.030)	(0.036)	(0.036)	(0.035)	(0.129)
Mean outside coverage	0.111	0.111	0.109	0.091	0.106	0.087
Bandwidth (dBm)	10.64	10.26	11.10	50.00	9.02	.
Observations	1913	1913	2139	7014	1741	1741
Districts	86	86	87	115	84	84
Marginal Effect						-0.048

ITM "Free-space" versus ITM with Topography

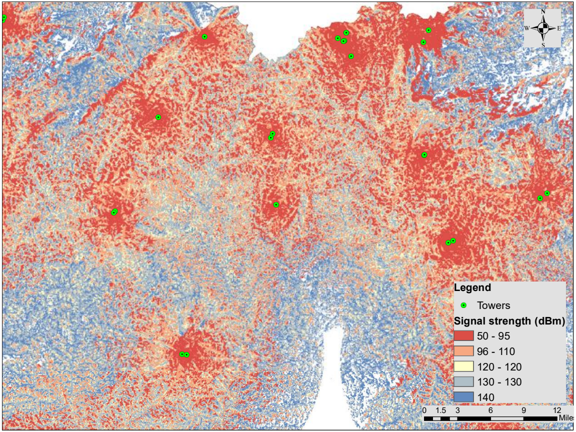
"Free-space" ITM



Back to Free Space

ITM "Free-space" versus ITM with Topography

ITM with Topography



Back to Free Space

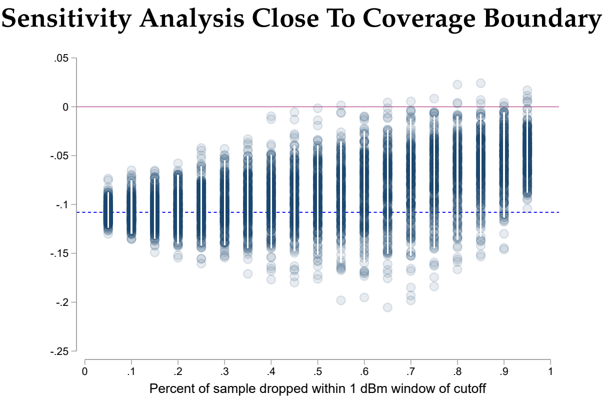
Robustness

RD Estimates Close To Coverage Boundary

Effect of Coverage on Likelihood of EVD Case, By Distance to Coverage Boundary

	No restriction (1)	Within 2km (2)	Within 4km (3)
Coverage	-0.101**	-0.105**	-0.100**
	(0.042)	(0.043)	(0.042)
Mean outside coverage	0.093	0.093	0.093
Bandwidth (dBm)	8.13	8.15	8.07
Observations	1547	1535	1542
Districts	83	83	83
Controls	Yes	Yes	Yes

Robustness



250 reps: for each replication, we randomly drop X% of the obs within a 1dBM window of the cut-off and using RD model using restricted sample

Robustness

“Walking to Coverage Boundary”

Average Travel Distance to Closest Village with Coverage

	No dBm restrictions (1)	Within 20 dBm (2)	Within 10 dBm (3)
Mean (km)	25.94	6.73	5.69
Std. Dev.	45.69	10.45	10.26
Observations	4,639	1,060	367
Share non-coverage sample	0.59	0.50	0.46

Robustness

“Walking to Coverage Boundary”

Effect of Coverage on Likelihood of EVD Case, Non-Coverage Villages close to Coverage

	Closest coverage village within:				
	2km	4km	6km	8km	10km
	(1)	(2)	(3)	(4)	(5)
Coverage	-0.114*	-0.098*	-0.106**	-0.103**	-0.104**
	(0.060)	(0.055)	(0.052)	(0.049)	(0.048)
Obs	1515	1612	1651	1677	1695
Bandwidth	9.082	9.216	9.297	9.348	9.507

Main results

Main Results: Regression Discontinuity Estimates

Falsification Tests

1. Estimate same RD specification with "free-space" coverage
2. Estimate signal strength around towers built in 2015 when the epidemic was practically over
   - Sample of districts with no coverage in 2013
   - Placebo test using boundary that did not exist in 2013

Main Results: Regression Discontinuity Estimates

	Dep. Variable = $\mathbb{1}\{\text{Number of Reported EVD cases} > 0\}$					
	Controlling for Free-space signal strength				Falsification tests	
	(1)	(2)	(3)	(4)	(5)	(6)
Coverage	-0.087**	-0.084*	-0.077**	-0.081**		
	(0.038)	(0.041)	(0.037)	(0.040)		
Free-space coverage	-0.013		-0.044*	-0.045*	-0.003	
	(0.020)		(0.024)	(0.026)	(0.040)	
Free-space signal strength		0.000	-0.000	-0.000	0.002	
		(0.001)	(0.001)	(0.001)	(0.006)	
Free-space coverage × Free-space signal strength			0.003	0.003	-0.008	
			(0.002)	(0.002)	(0.007)	
Coverage (2015)						0.084
						(0.112)
Signal strength (2015)						0.001
						(0.002)
Mean outside coverage	0.093	0.101	0.094	0.093	0.094	0.057
Bandwidth (dBm)	8.35	7.99	9.14	8.93	9.36	-
Observations	1547	1352	1720	1528	1540	383
Districts	83	81	84	83	84	53
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Topography Polynomial	No	No	No	Yes	No	No

Back to ITM

Empirical Strategy: Panel-Regression Discontinuity

Alternative empirical model that deals directly with whether coverage helped contain the spread of the disease

- Disaggregate analysis to monthly level (EVD in village i in month t)
- Assess whether likelihood of EVD varies given EVD in a village *within district*
- Test whether the likelihood that EVD spreads into a village from surrounding affected villages diminishes with cell phone coverage

Empirical Strategy: Panel-Regression Discontinuity

Panel-RD empirical model:

$$EVD_{ijt} = \alpha + \beta D_{ij} + \gamma EVD_{j(i),t-1} + \delta D_{ij} \times EVD_{j(i),t-1} + f(\tilde{R}_{ij}) + \lambda_j + \nu_t + \epsilon_{ijt}$$

- EVD_{ijt} indicator for village i, in district j, in month t having at least one EVD case
- D_{ij} = whether village i has coverage (i.e., received power $>$ c)
- $\tilde{R}_i = R_i - c$ is received power in dBm net of cutoff c
- $\text{EVD}_{j(i),t-1} = 1$ if at least one village in village i's district was affected by EVD in month $t-1$
- λ_j district FE
- ν_t month FE

Panel-Regression Discontinuity Estimates

Effect of Coverage on Likelihood of EVD Contagion

	Dep. Variable = $\mathbb{1}\{\text{Number of Reported EVD cases} > 0\}$				
	(1)	(2)	(3)	(4)	(5)
Cov_i	-0.0069**	-0.0059**		0.0005	0.0014
	(0.003)	(0.002)		(0.002)	(0.002)
$\text{EVD}_{j(i),t-1}$			0.0056**	0.0167**	0.0160**
			(0.002)	(0.007)	(0.007)
$\text{Cov}_i \times \text{EVD}_{j(i),t-1}$				-0.0191***	-0.0186***
				(0.006)	(0.006)
Mean outside coverage	0.007	0.007	0.006	0.007	0.007
Observations	33079	33079	31338	31338	31338
Bwidth (dBm)	9.00	9.00	9.00	9.00	9.00
Districts	84	84	84	84	84
District & month FE	Yes	Yes	Yes	Yes	Yes
Controls	No	Yes	Yes	No	Yes

Panel-Regression Discontinuity Estimates

Effect of Coverage on Likelihood of EVD Contagion

	Dep. Variable = $\mathbb{1}\{\text{Number of Reported EVD cases} > 0\}$				
	(1)	(2)	(3)	(4)	(5)
Cov_i	-0.0069**	-0.0059**		0.0005	0.0014
	(0.003)	(0.002)		(0.002)	(0.002)
$\text{EVD}_{j(i),t-1}$			0.0056**	0.0167**	0.0160**
			(0.002)	(0.007)	(0.007)
$\text{Cov}_i \times \text{EVD}_{j(i),t-1}$				-0.0191***	-0.0186***
				(0.006)	(0.006)
Mean outside coverage	0.007	0.007	0.006	0.007	0.007
Observations	33079	33079	31338	31338	31338
Bwidth (dBm)	9.00	9.00	9.00	9.00	9.00
Districts	84	84	84	84	84
District & month FE	Yes	Yes	Yes	Yes	Yes
Controls	No	Yes	Yes	No	Yes

Panel-Regression Discontinuity Estimates

Effect of Coverage on Likelihood of EVD Contagion

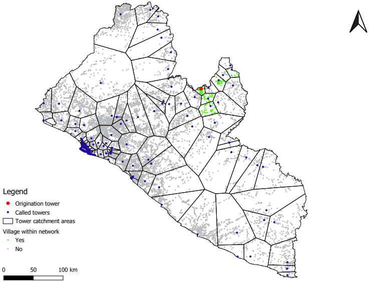
	Dep. Variable = $\mathbb{1}\{\text{Number of Reported EVD cases} > 0\}$				
	(1)	(2)	(3)	(4)	(5)
Cov_i	-0.0069**	-0.0059**		0.0005	0.0014
	(0.003)	(0.002)		(0.002)	(0.002)
$\text{EVD}_{j(i),t-1}$			0.0056**	0.0167**	0.0160**
			(0.002)	(0.007)	(0.007)
$\text{Cov}_i \times \text{EVD}_{j(i),t-1}$				-0.0191***	-0.0186***
				(0.006)	(0.006)
Mean outside coverage	0.007	0.007	0.006	0.007	0.007
Observations	33079	33079	31338	31338	31338
Bwidth (dBm)	9.00	9.00	9.00	9.00	9.00
Districts	84	84	84	84	84
District & month FE	Yes	Yes	Yes	Yes	Yes
Controls	No	Yes	Yes	No	Yes

Back to Summary

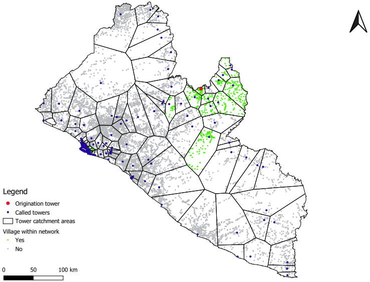
CDR Network

Back to Network

Example of Network for Ganta City

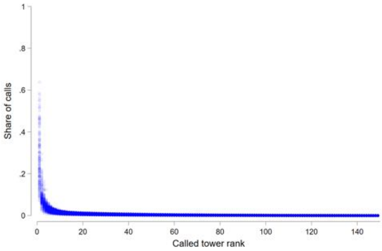


(e) Top 5 towers

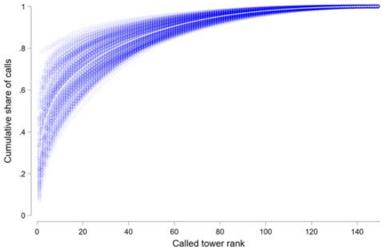


(f) Top 75% calls

CDR Network



(g) Share of calls per tower



(h) Cumulative share of calls per tower

Back to Network

Channels of Impact: Preliminary Evidence

⇒ Use **introduction of Ebola hotline** to assess relative importance of network and care channels

Intuition:

- *Preventive and treatment care* channels depend on tool that connects individuals to preventive and treatment care
- *Network* channel more relevant in *pre-hotline* period when individuals likely relied on network for info/care
- *Care* channels more relevant in *post-hotline* period

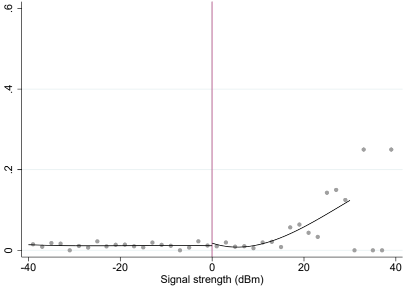
Channels of Impact: Preliminary Evidence

Background on hotline:

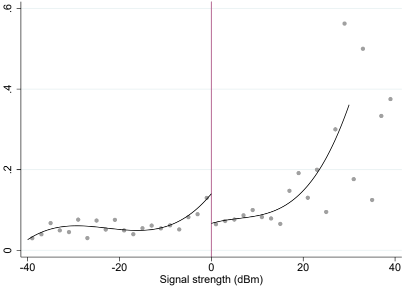
- Toll-free, nationwide phone alert system established for rapid notification and response
- Call center opened on August 7
- Goals included:
  - Answering questions about EVD
  - Enter requests to dispatch ambulances to take sick individuals
  - Dispatch burial teams to pick up suspected corpses
- The overall goal was to create a **link between the public and government-provided relief efforts**

Channels of Impact: Preliminary Evidence

Graphical evidence:



(i) Pre-hotline



(j) Post-hotline

Back to Survey