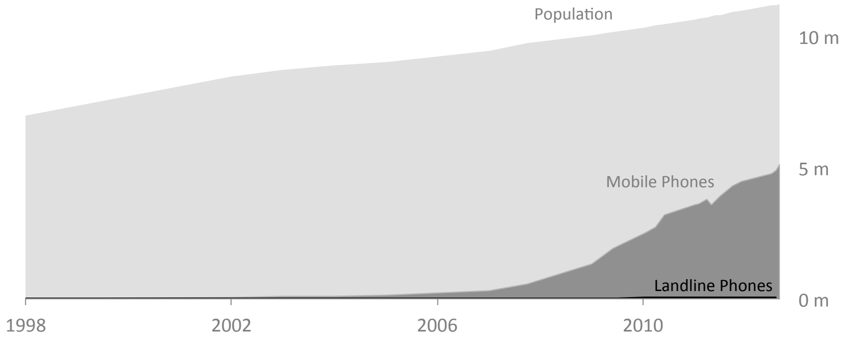

The Adoption of Network Goods:
The Spread of Mobile Phones in Rwanda

Daniel Björkegren

Brown University

Network Goods

- Facebook, Yelp, Waze, NetFlix

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- Mobile phones in developing countries:
  - 2000: 250 million

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- Mobile money
- Mobile internet
- ...

How to attain a critical mass of users?

Network Goods

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- Mobile phones in developing countries:
  - 2000: 250 million
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- ...

How to attain a critical mass of users?

How should industry be regulated?

Benefits from adopting a network good

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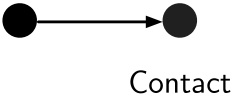
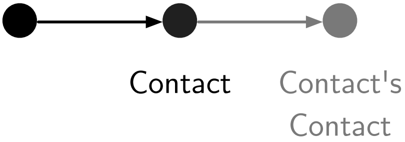


Benefits accrue beyond adopter



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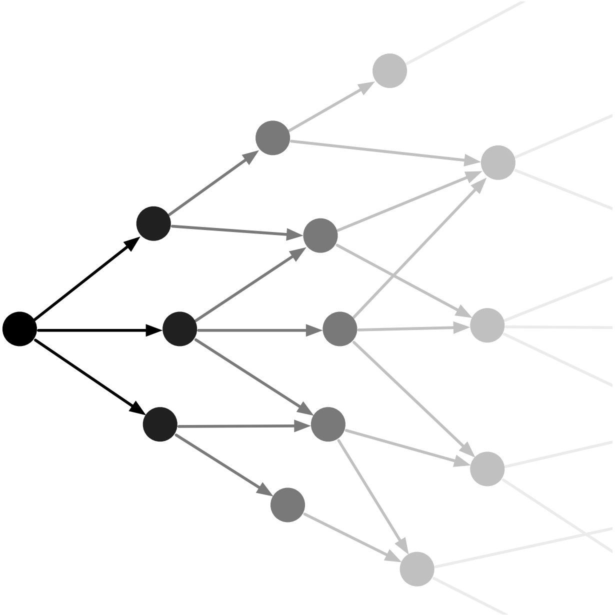
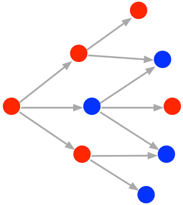


Firms may not fully internalize network effects



Competitive

Benefits of expansion
may spill over into
competitor's network

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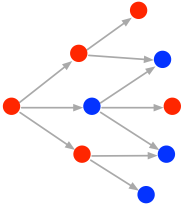

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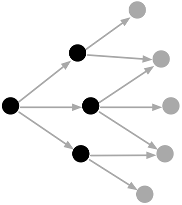

Monopolistic

May underprovide if there are limits to price discrimination

Achieving efficient adoption of network goods

Careful policies needed by both firms and governments

1. **Substantial theoretical work**
   - Rohlfs 1974, Katz and Shapiro 1986, Farrell and Saloner 1985
2. **Little empirical work**
   - Difficult to gather **data** on entire network
   - Difficult to **identify** network effects
   - Difficult to **simulate** effects of policies

This project

Method to estimate and simulate adoption of a network good

Use 5 billion transaction records
from nearly the entire Rwandan cell phone network:

- Estimate structural model of adoption
- Simulate policies
  Alternate tax policies
  Government requirement to serve rural consumers

Regulating Mobile Phones

Public finance opportunity:

- Contributed 7% of government revenue in sample of sub-Saharan Africa countries in 2007 (GSMA)

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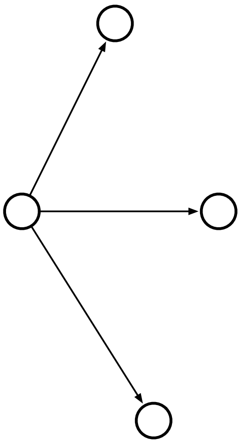
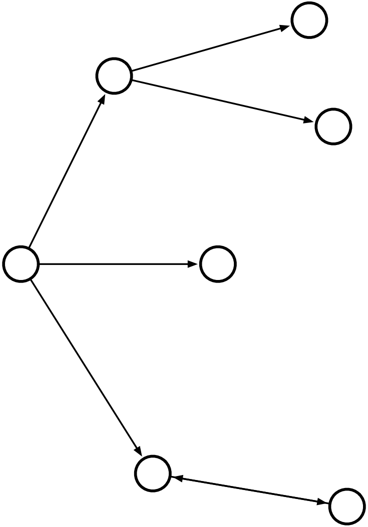
Expansion and univeral access:

- "Extending telecommunications services to rural and low income areas has been a paramount concern." - Mohsen Khalil, former Director of ICT at World Bank

Revealed Network



Revealed Network



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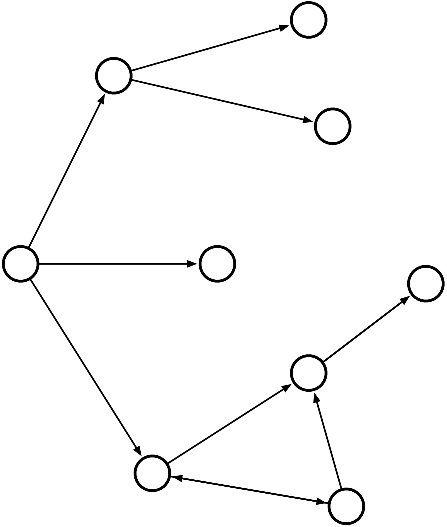
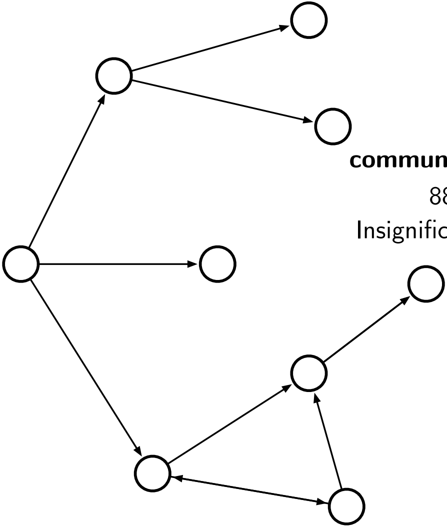


Rwanda: A Convenient Setting



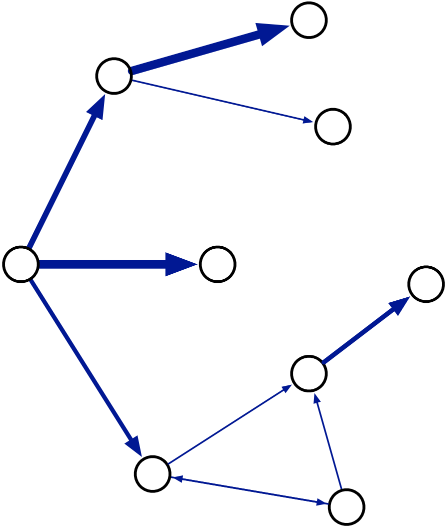
Nearly all remote communication in Rwanda:

88% of mobile phones

Insignificant landline network

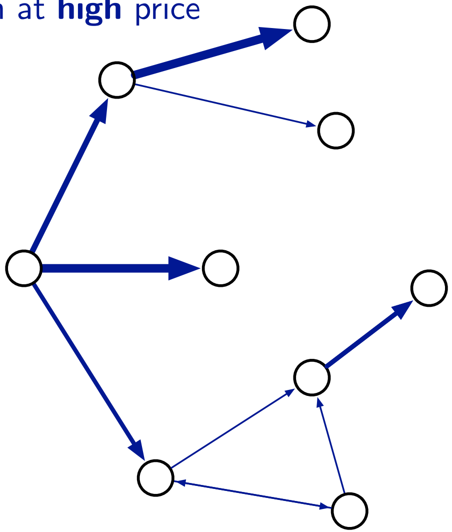
Rwanda: A Convenient Setting

Duration



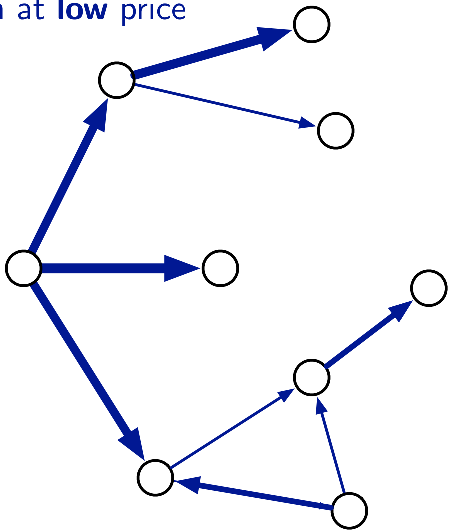
Rwanda: A Convenient Setting

Duration at **high** price



Rwanda: A Convenient Setting

Duration at **low** price



Empirical Approach: Value of the Network

What is the value of a link, θ_{ij}?

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Traditional Approach

i adopts if the value exceeds the cost:

$$a_i = I\left(\theta_{ij} a_j + \eta_i \geq cost\right)$$

If i is only linked to j.

But unobserved shocks η_i are likely correlated (Manski 1993).

Empirical Approach: Value of the Network

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My Approach

A link provides value because it enables calls:

$$\theta_{ij} = u_{ij}(p_t, \phi_t)$$

Response to usage costs identifies value of link

(Has parallels with Ryan and Tucker 2012)

Empirical Approach

Estimate model of adoption and usage,
as a function of coverage and prices

Simulate effect of three policies:

1. Alternate tax policies
   Baseline taxes impose welfare costs up to 3.11 times the revenue raised
   Alternative taxes could have reduced burden on the poor
2. Government requirement to serve rural areas
   Improved welfare
   Benefits dispersed

The Spread of Mobile Phones

Context and Data

Model

Estimation

Simulation

Application: Optimal Telecom Taxation

Application: Incentives to serve rural areas

The Spread of Mobile Phones

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Mobile phone subscriptions in developing economies:

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- **Handset prices declined**
  Rwanda: \$70 (2005) $\rightarrow$ \$20 (2009)
- **Regulators allowed competition**

The Spread of Mobile Phones

Mobile phone subscriptions in developing economies:

250 million (2000)→ 4.5 billion (2011)

- **Handset prices declined**
  Rwanda: \$70 (2005) → \$20 (2009)
- **Regulators allowed competition**
- **Operators adapted to reach poorer consumers:**
  - Coverage expanded
    Rwanda: 60% of country (2005) → 95% (2009)
  - Calling prices reduced
    Rwanda: Reduced over 50% 2005-2009

Source: ITU

Rwandan Households

	All	With mobile phones	
	2005	2005	2010
Fraction of households		5%	40%
Rural	85%	23%	75%
Consumption per capita	$264.81	$925.14	$429.77

Source: Government Survey. Prices deflated to 2006.

Mobile phone usage

Adopting entails...
marginal calling charges:

- Prepaid: no monthly fee
- Caller pays by the second, receiving is free

and a high fixed cost:

- Handsets sold at retail price

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and a high fixed cost:

- Handsets sold at retail price

What are phones used for?
Main purpose of last 10 calls was **social** for 92% of subscribers

Survey: Stork and Stork 2008

Data

Call Detail Records - with Nathan Eagle (Jana Inc.)

Anonymous transaction records from dominant operator, 2005-2009

Transaction	Amount	ID.From	ID.To	Tower	Timestamp
Call					
Call attempt					
SMS					

IDs map to account and handset for sender and recipient.

No other characteristics on subscribers.

5.3 billion transactions

Industry

Simplifications

Focus on domestic calls. Omit:

- SMS: data issues (16% of transaction volume)
- Missed calls

Call utility a proxy for total communication

Mobile Internet not in use, mobile money not yet available.
Model calls between accounts. In the presence of phone sharing, model implies surplus of shared calls accrues to account owner.

The Spread of Mobile Phones

Context and Data

Model

Estimation

Simulation

Application: Optimal Telecom Taxation

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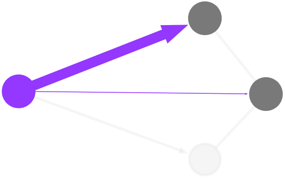
Model

Adoption Decision | Call Decision

$Eu_{ij}(p_t, \text{coverage}_{it}, \text{coverage}_{jt})$

$U_i(p_t^{\text{handset}})$

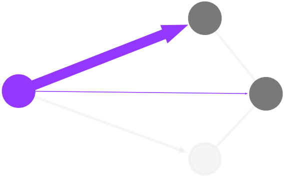


Model

Adoption Decision | Call Decision

$Eu_{ij}(p_t, \text{coverage}_{it}, \text{coverage}_{jt})$

$U_i(p_t^{handset})$



Identification:

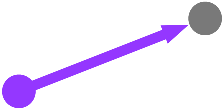
Geographical and policy instruments

Within-link changes in price and coverage

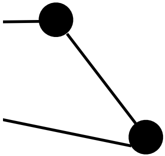
Model: Call Decision

Adoption Decision Call Decision

$Eu_{ij}(p_t, \text{coverage}_{it}, \text{coverage}_{jt})$



Communication graph



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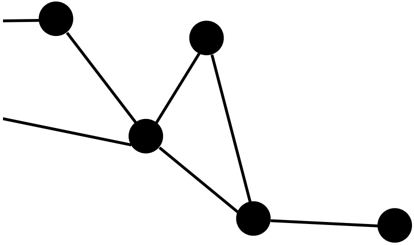

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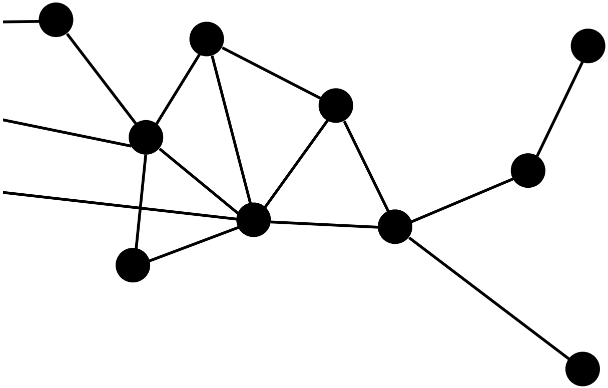

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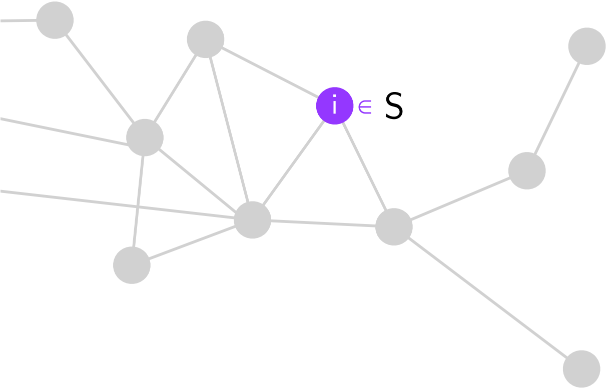
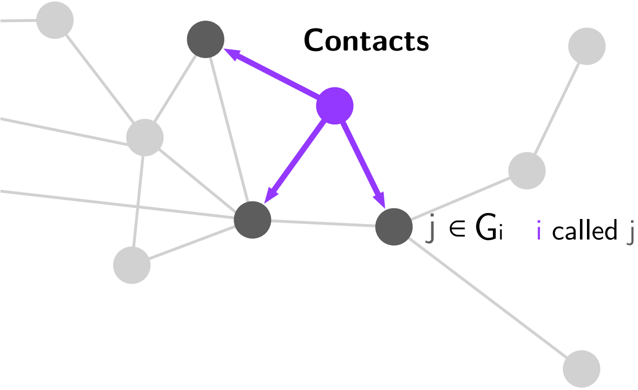


Communication graph

1.5m accounts
415m links



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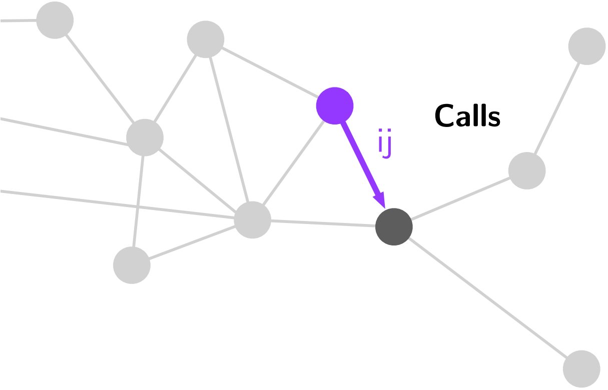
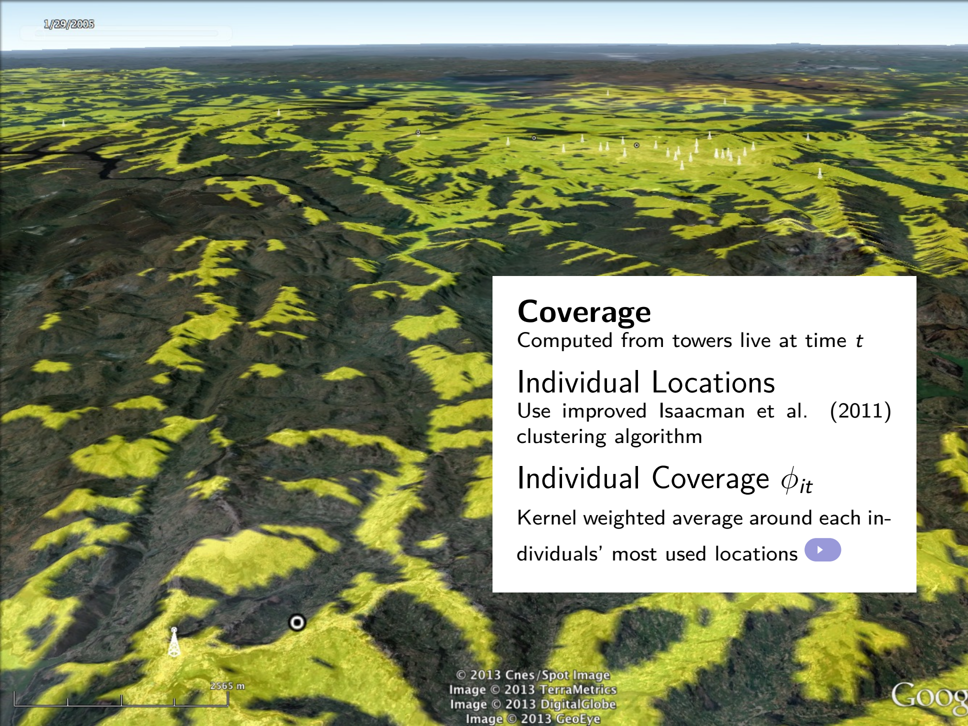




Coverage

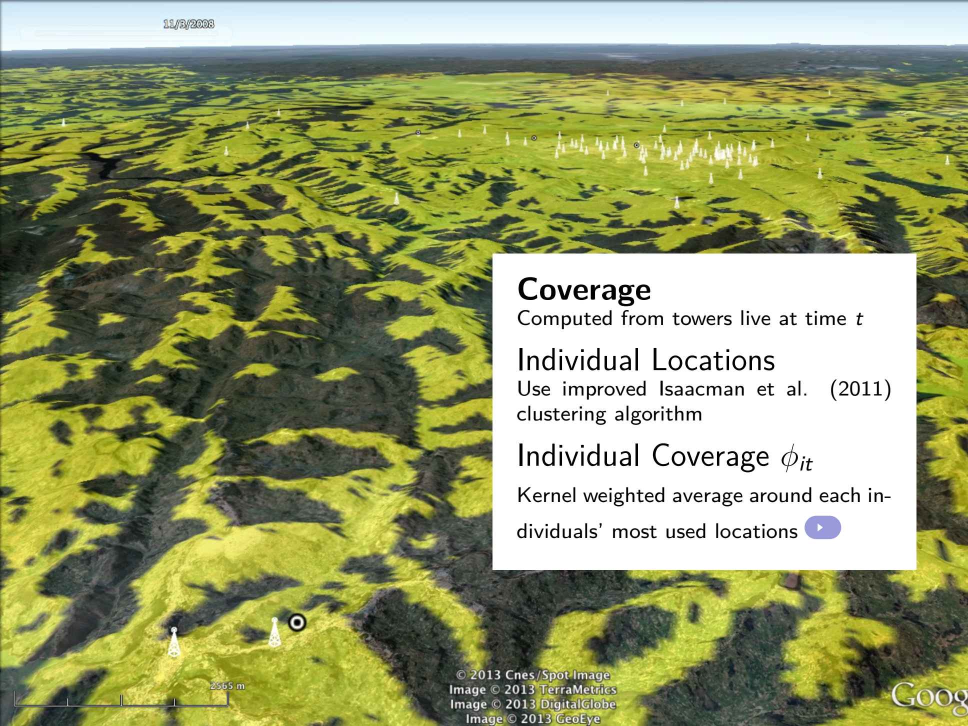
Computed from towers live at time t

Individual Locations

Use improved Isaacman et al. (2011) clustering algorithm

Individual Coverage ϕ_{it}

Kernel weighted average around each individuals' most used locations



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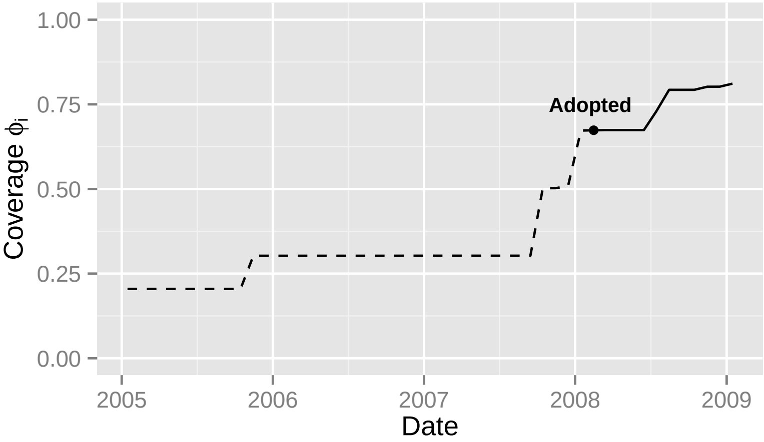
Individual Coverage: Example



Details

Demand for Calls

Conditional on owning a handset

Each month, i draws a shock ϵ_{ijt} for each contact $j \in G_i \cap S_t$, and chooses a total duration for that month:

$$u_{ijt} = \max_{d \geq 0} \left[\frac{1}{\beta_{cost}} v_{ij}(d, \epsilon_{ijt}) - d \cdot c_{ijt} \right]$$

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$$v_{ij}(d, \epsilon) = d - \frac{1}{\epsilon} \left[\frac{d^\gamma}{\gamma} + \alpha d \right]$$

---

v chosen to satisfy 8 intuitive properties.

- γ: diminishing returns
- α: cost-dependent censoring
- β_{cost}: price sensitivity

Functional form

Demand for Calls

Conditional on owning a handset

Based on shock ϵ_{ijt} drawn, i chooses a duration:

$$u_{ijt} = \max_{d \geq 0} \left[\frac{1}{\beta_{cost}} v_{ij}(d, \epsilon_{ijt}) - d \cdot c_{ijt} \right]$$

$$c_{ijt} = p_t + \beta_{coverage} \, \phi_{it} \cdot \phi_{jt}$$

Per second cost:

- calling price p_t
- hassle of obtaining coverage $\phi \in [0, 1]$

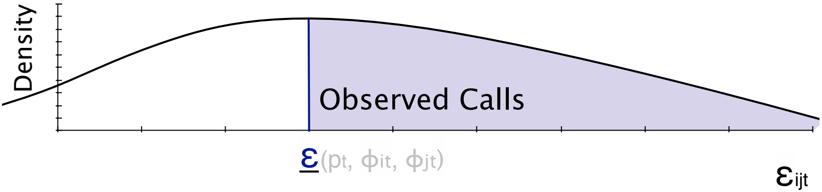
Demand for Calls

If shock is low, no call:

$$\epsilon_{ijt} < \underline{\epsilon}(p_t, \phi_{it}, \phi_{jt})$$

If shock is high enough, call:

$$\epsilon_{ijt} \geq \underline{\epsilon}(p_t, \phi_{it}, \phi_{jt})$$

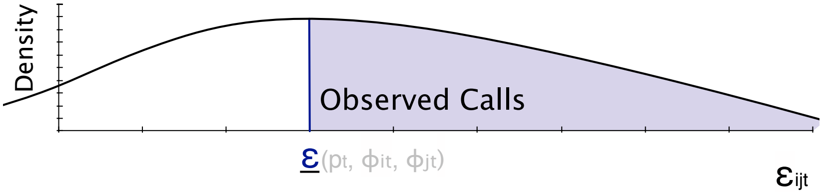


$$\underline{\epsilon}(p_t, \phi_{it}, \phi_{jt}) = \frac{1+\alpha}{1-\beta_{cost}(p_t - \beta_{coverage}\, \phi_{it} \cdot \phi_{jt})}$$

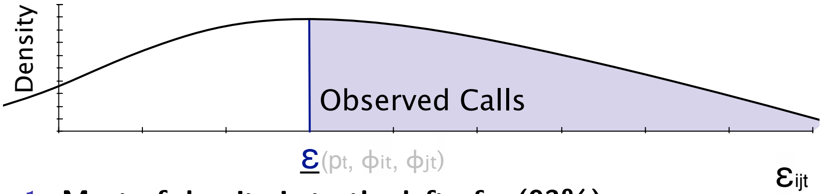
Demand for Calls

Higher shocks lead to longer total duration:

$$d^*_{ijt}(\epsilon) = [\epsilon\,(1 - \beta_{cost}(p_t - \beta_{coverage}\,\phi_{it} \cdot \phi_{jt})) - \alpha]$$

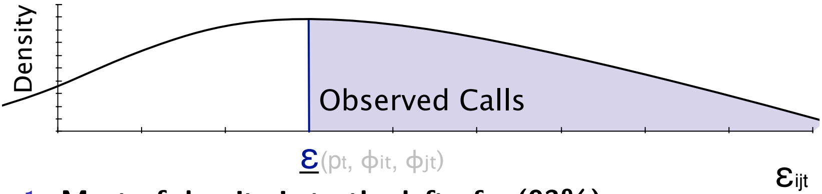


Distribution of ϵ



1. **Most of density is to the left of $\underline{\epsilon}$ (93%)**:
   Use mixture distribution: $\log N(\mu_{ij}, \sigma_i)$ and Bernoulli cost-independent censoring $1 - q_i$

Distribution of ϵ



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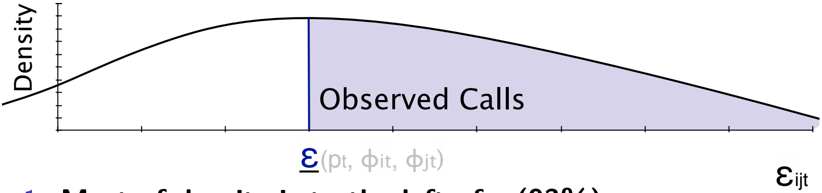
   Over time, prices $\downarrow$ and less talkative individuals subscribe
   Allow shock distributions to be link-specific

Distribution of ϵ



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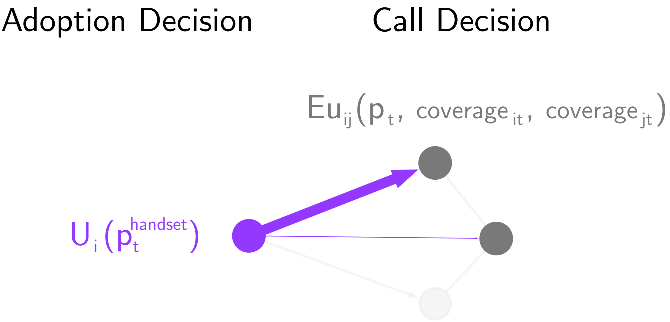
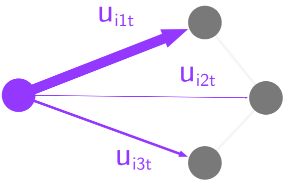
2. **Selection**:
   Over time, prices $\downarrow$ and less talkative individuals subscribe
   Allow shock distributions to be link-specific
3. **Interested in expected utility $E_t u_{ijt}(p_t, \phi_{it}, \phi_{jt})$**
   Assume ϵ_{ijt} is i.i.d. over time, independent over links

Model: Adoption Decision

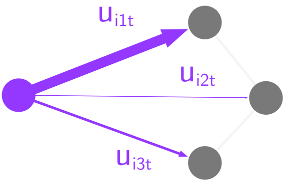


Expected utility from communication



Expected utility from communication

$u_{it} = u_{i1t} + u_{i2t} + u_{i3t}$

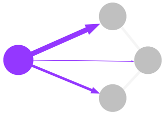


▸ Dependence tests

Utility from owning a handset

Each month owning a handset, *i* receives expected utility:

Outgoing Calls



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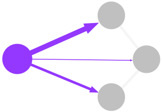
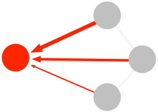


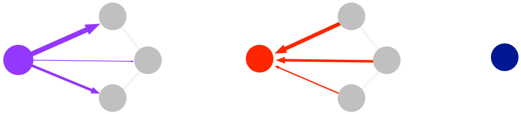
(Incoming Calls)



Utility from owning a handset

Each month owning a handset, i receives expected utility:

Outgoing Calls (Incoming Calls) Unobserved



Utility from owning a handset

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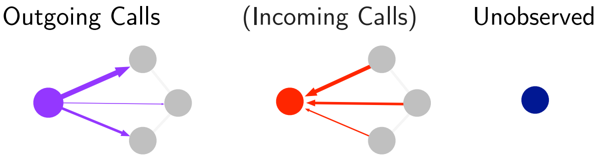

$$Eu_{it} = \sum_{j \in G_i, x_j \leq t} \left[E_t u_{ijt}(p_t, \phi_{it}, \phi_{jt}) + w \cdot E_t u_{jit}(p_t, \phi_{jt}, \phi_{it}) \right] + \eta_i (1 - \delta)$$

G_i: $i's$ contacts
τ_j: j's adoption month
$w \in \{0, 1\}$: include utility from received calls
η_i: idiosyncratic benefit of having a phone

Adopting a handset: an optimal stopping problem

At time t, i expects that adopting in period x yields utility:

$$E_t U_i^x(\boldsymbol{x}_{G_i}) = \delta^x \left[\sum_{s \geq x}^{\infty} \delta^{s-x} E u_{is}(p_s, \phi_s, \boldsymbol{x}_{G_i}) - E_t p_x^{handset} \right]$$

$\boldsymbol{x}_{G_i}$ expected contacts' adoption
$p_x^{handset}$: expected handset price index from sales records

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i adopts at first month x_i where adopting preferred to waiting:

$$\min_{x_i} s.t. \left[E_{x_i} U_i^{x_i}(\mathbf{x}_{G_i}) \geq \max_{s > x_i} E_{x_i} U_i^s(\mathbf{x}_{G_i}) \right]$$

$\mathbf{x}_{G_i}$ expected contacts' adoption
$p_x^{handset}$: expected handset price index from sales records

The Spread of Mobile Phones

Estimation

1 Call Decision

Estimate shape and sensitivity parameters
γ, α, β_{cost}, $\beta_{coverage}$

and shock distribution parameters (4.5 million)
μ_{ij}, q_i, σ_i.

using maximum likelihood

$\downarrow$ compute $E_t u_{ijt}(p_t, \phi_t)$

2 Adoption Decision

Back out η_i. Check β_{cost} using moment inequalities.

Computation

Call Model Parameter estimates

		Estimate
Diminishing returns	γ	2.289
Cost-dependent censoring	α	97.897
Cost sensitivity	β_{cost}	0.200
Coverage sensitivity	$\beta_{coverage}$	-3.845
	N_{nodes}	8,000
	N_{links}	1.3m
	$N_{link-months}$	39m

For tractability, unified parameters estimated on 0.5% subsample of nodes and their complete set of links.

Estimated shock distributions

Structure $\mu_{ij} = \mu_i + \mu_{\max(x_i,x_j),\overline{\phi_{it}\phi_{jt}}}$

Parameters:	Quantile:	0.05	0.25	0.50	0.75	0.95	Number
Fixed Effects	$\mu_{\max(x_i,x_j),\overline{\phi_{it}\phi_{jt}}}$	-1.71	-1.45	-1.12	-0.65	0.00	519
	SE	0.31	0.31	0.31	0.32	0.32	
Node	μ_i	1.95	3.01	3.66	4.95	6.83	1.5m
	SE	0.37	0.32	0.32	0.33	0.34	
	σ_i	0.80	1.30	1.62	1.98	2.58	1.5m
	SE	0.04	0.02	0.02	0.03	0.06	
	q_i	0.06	0.27	1.00	1.00	1.00	1.5m
	SE	0.00	0.01	0.03	0.00	0.00	

$N_{link-months} = 15$ billion

Shock distributions estimated imposing unified parameters. Node likelihoods are separable conditional on unified parameters; standard errors assume unified parameters are estimated without error.

Estimation

1 Call Decision

Estimate shape and sensitivity parameters
γ, α, β_{cost}, $\beta_{coverage}$

and shock distribution parameters (4.5 million)
μ_{ij}, q_i, σ_i.

using maximum likelihood

$\downarrow$ compute $E_t u_{ijt}(p_t, \phi_t)$

2 Adoption Decision

Back out η_i. Check β_{cost} using moment inequalities.

Computation

Handset Adoption: Revealed Preference

Observe i bought a handset at time x_i,
not K months later:

$$\sum_{s=0}^{K-1} \delta^s E u_{ix_i+s}(p_{x_i+s}, \phi_{x_i+s}, \boldsymbol{x}_{G_i}) + (1-\delta^K)\eta_i \geq p_{x_i}^{handset} - \delta^K E_{x_i} p_{x_i+K}^{handset}$$

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Similarly, at time $x_i - K$ i chose to wait, so must have preferred some adoption time $\tilde{K}$ months later:

$$\sum_{s=0}^{\tilde{K}-1} \delta^s E u_{i,x_i-K+s}(p_{x_i-K+s}, \phi_{x_i-K+s}, \boldsymbol{x}_{G_i}) + (1-\delta^{\tilde{K}})\eta_i \leq p_{x_i-K}^{handset} - \delta^{\tilde{K}} E_{x_i-K} p_{x_i-K+\tilde{K}}^{handset}$$

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Back out $[\underline{\eta}_i, \bar{\eta}_i]$

Set $K = 2$, $\delta = (\frac{1}{1.07})^{1/12} \sim 0.9945$ (World Bank)

Handset Adoption: Robustness check

Check if network value implied by call decision corresponds with that implied by adoption, using a traditional approach.

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- Number of contacts receiving subsidized handsets

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If recipients also receive the surplus from incoming calls ($w = 1$):
\$1 of call utility = \$0.27-0.31 of handset price

The Spread of Mobile Phones

Adoption Equilibrium

Compute new equilibrium based on change to the environment.

Adoption Equilibrium

Compute new equilibrium based on change to the environment.

- Over 1 million interconnected adoption decisions
- Usage decisions across 415 million links

Adoption Equilibrium

Compute new equilibrium based on change to the environment.

Equilibrium $\Gamma(\boldsymbol{\eta})$:
Each i adopts at min $x_i \; s.t. \, [E_{x_i} U_i^{x_i}(\boldsymbol{x}_{G_i}) \geq \max_{s > x_i} E_{x_i} U_i^{s}(\boldsymbol{x}_{G_i})]$

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- Apart from constant forecast error (in η_i), anticipates:
  - Contacts' adoption dates $\boldsymbol{x}_{G_i}$
  - Changes in call prices and coverage
  - Forecasts handset prices to follow deterministic trend

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- Apart from constant forecast error (in η_i), anticipates:
  - Contacts' adoption dates $\boldsymbol{x}_{G_i}$
  - Changes in call prices and coverage
  - Forecasts handset prices to follow deterministic trend
- May not condition strategy on actions of others

Simulation Method: Iterated Best Response

1. Propose a candidate adoption path $\boldsymbol{x}^0$
2. Allow each individual to optimize their decision, holding fixed the adoption path of others:[1]
   $x_i^{k+1} = \min\ t\ s.t. \left[U_i^t(\boldsymbol{x}_{G_i}^k) \geq \max_{s>t} E_t U_i^s(\boldsymbol{x}_{G_i}^k) \right]$
3. Iterate until the equilibrium converges: $x_i^{k+1} = x_i^k$ for all i

Multiple Equilibria

For each individual, back out types $[\underline{\eta}_i, \bar{\eta}_i]$ consistent with adoption choice.

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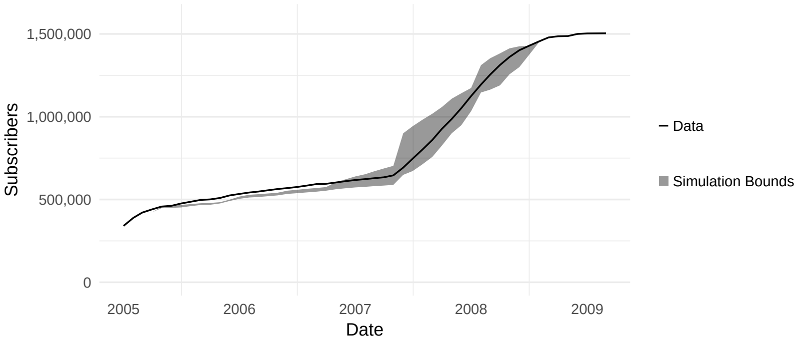
Game has strategic complements; equilibria form a lattice.
Individual bounds $[\underline{\eta}_i, \bar{\eta}_i]$ and bounds on expectations $\boldsymbol{x}^0 \in \left[0, \bar{T}\right]^N$ imply bounds on set of equilibria:

$$\underline{\Gamma}(\underline{\boldsymbol{\eta}}) \leq \Gamma(\boldsymbol{\eta}) \leq \bar{\Gamma}(\bar{\boldsymbol{\eta}})$$

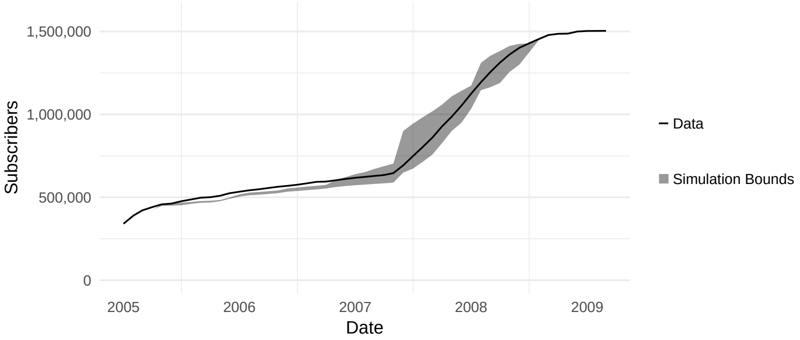
(Topkis 1978, Milgrom and Shannon 1994)

Details

Simulation Fit



Simulation Fit



Total welfare benefit [$474m, $530m]
Split among operator (35%, gross), government (14%), and consumers (51%, net)

Details Results

The Spread of Mobile Phones

Context and Data

Model

Estimation

Simulation

Application: Optimal Telecom Taxation

Application: Incentives to serve rural areas

How, and how much, to tax?

Average Taxes in sub-Saharan Africa (2007):

- 31% on handsets (48% in Rwanda)
- 20% on airtime (23% in Rwanda)
- Network equipment
- Corporate taxes and spectrum fees

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Countries removing handset tax:

- Kenya (2009-2013)
- Rwanda (2010)
- Senegal (2009)

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Theoretically:

- How does incidence overlap with network effect?

Simulating Alternative Taxation

Conservative estimate:

- People outside the data may adopt sooner
- Assume complete passthrough of airtime taxes (no passthrough shown in paper)

Taxation

Tax	Revenue ($m)		Consumer	Avg. Welfare Cost per Dollar of
Handset	Telecom	Government	Surplus ($m)	Public Funds
Baseline: 48%	**[165, 187]**	**[65, 73]**	**[244, 270]**	
Impact of removal				
Total Effect	15, 17	-12, -12	21, 21	$2.94, 3.11

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Total Effect	15, 17	-12, -12	21, 21	$2.94, 3.11
... proximal effect	7, 7	-14, -16	10, 10	$1.22, 1.06
... ripple effects	8, 11	2, 3	10, 11	

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- Estimates of MCF in sub-Saharan Africa $1.21 (1.37 Rwanda), Auriol and Warlters 2012
- Network effects account up to 61% of revenue effect

Taxation

Tax Regime			Revenue ($m)		Consumer
Handset	Usage	Sample Split	Telecom	Government	Surplus ($m)
Baseline					
48%	23%	All	[165, 187]	[65, 73]	[244, 270]
		Above Q60 usage	[140, 160]	[47, 54]	[238, 264]
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Impact of changing taxation					
0%	23%	All	15, 17	-12, -12	21, 21
		Above Q60 usage	12, 15	-2, -1	17, 18
		Below Q60 usage	3, 2	-10, -11	4, 3

Taxation

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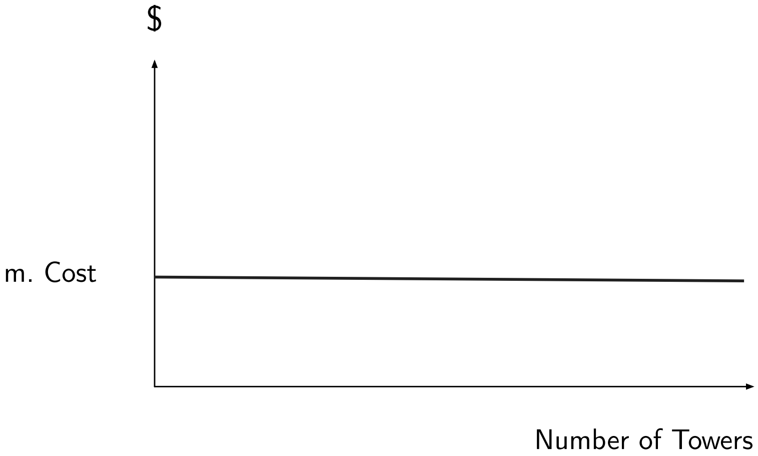
		Below Q60 usage	3, 2	-10, -11	4, 3
0%	30%	All	-5, -6	2.75, 4.18	1, -1
		Above Q60 usage	-5, -5	11, 13	-1, -3
		Below Q60 usage	0, -1	-8, -8	2, 2

Toward an optimal tax

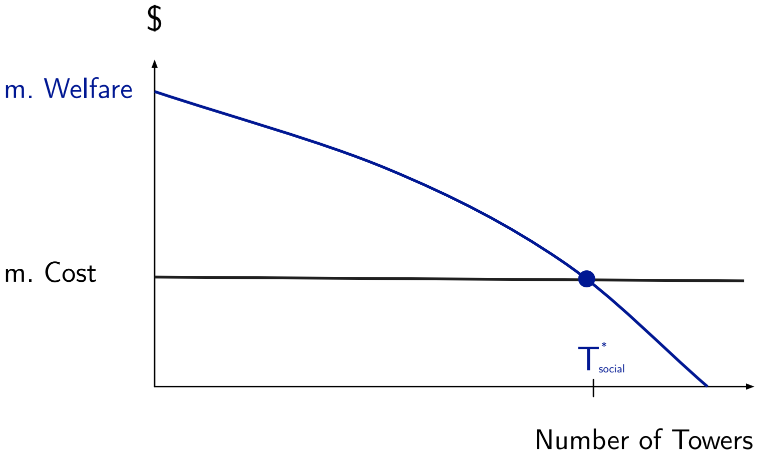
- Marginal users bear a large portion of handset taxes
- Encouraging network adoption:
  - Can shift to marginal usage taxes
  - Can tax initial adoptions that allow access to a new network (e.g., smartphones) lower than upgrades

The Spread of Mobile Phones

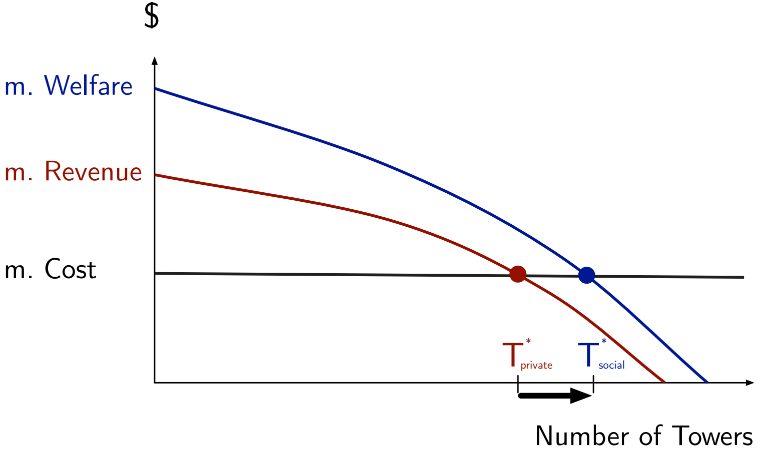
Cost of expanding towers



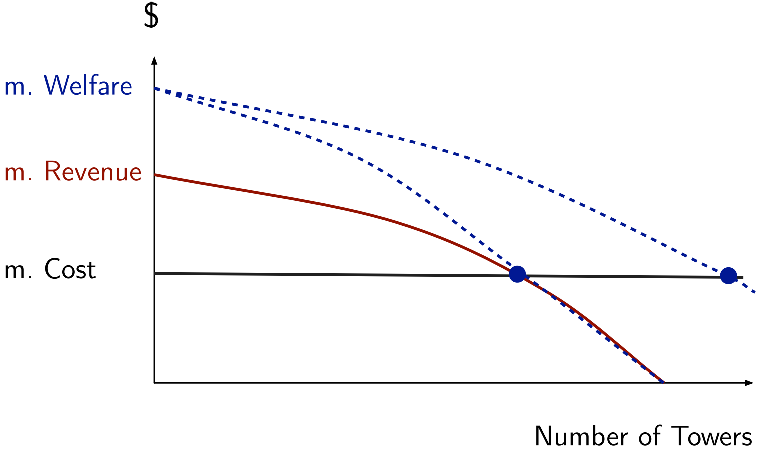
Optimal coverage



Private returns from coverage may differ



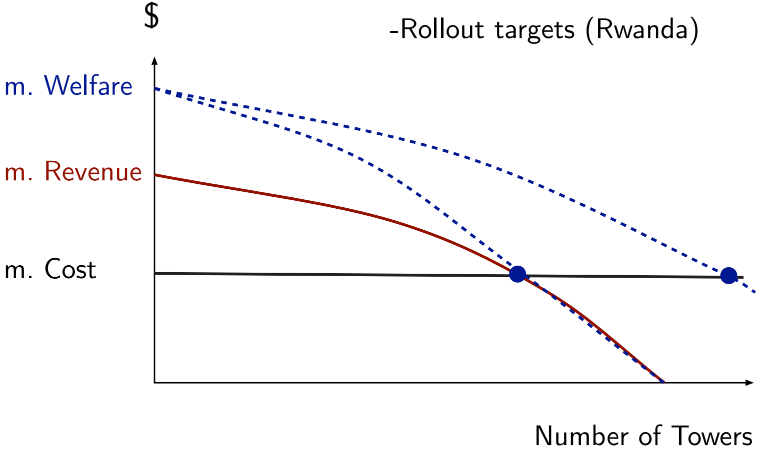
Effect of policy depends on shape of welfare and revenue



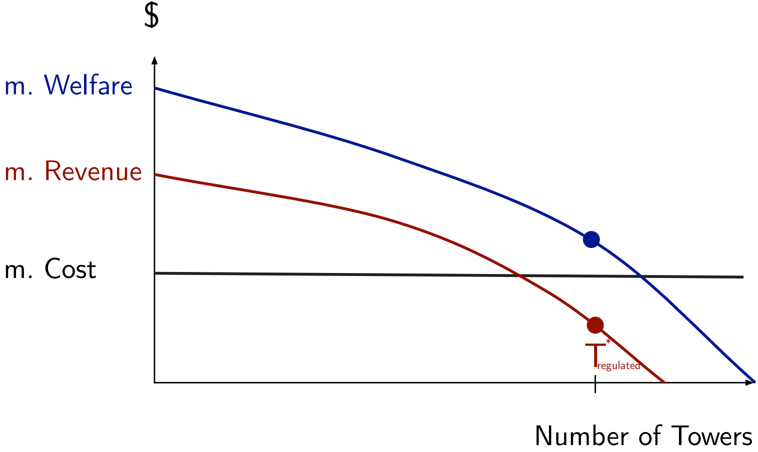
Univeral Access Policies

-Subsidies to serve certain areas

-Rollout targets (Rwanda)



Counterfactual: Coverage in Absence of Regulation



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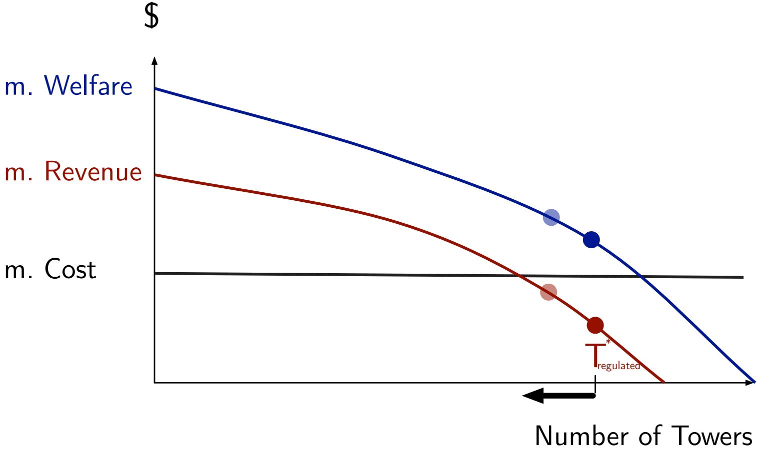

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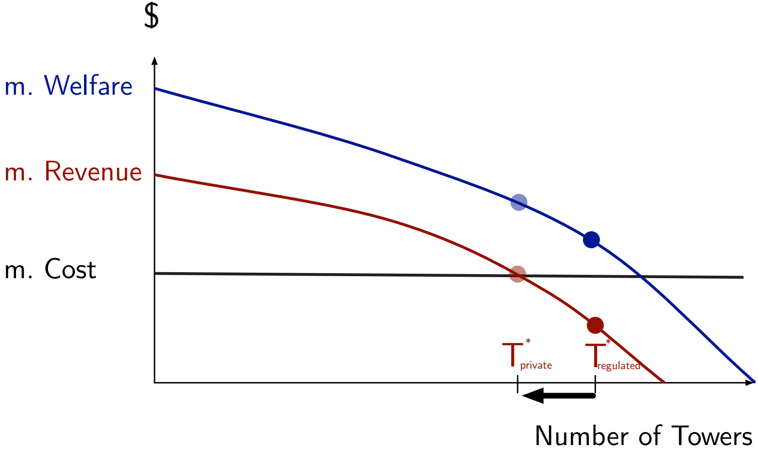
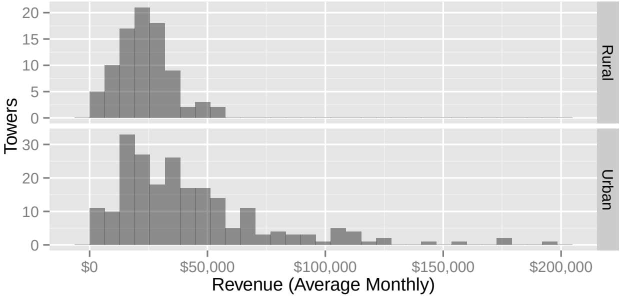


Peel back tower construction (based on realized revenue)



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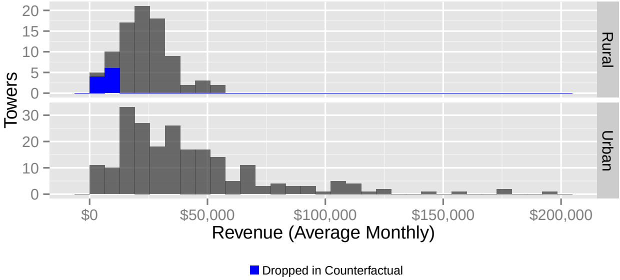
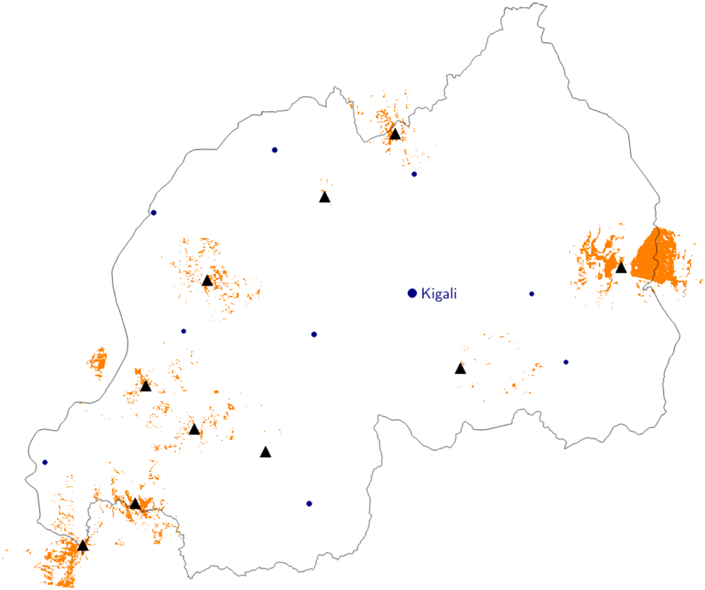


- Don't build the 10 lowest revenue rural towers (11%)
- Save $271,356 in annualized build and operation costs

Difference in final coverage

January 2009



Impact of rural coverage expansion

Revenue (million $)	
Baseline with expansion	[165.06, 187.39]
Effect of expansion	0.09, 0.11

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Profit	**$-178,634; -166,231**

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Consumer Surplus (million $)	
Baseline	[243.55, 269.79]
Effect of expansion	0.36, 0.37
Government Revenue (million $)	
Baseline	[65.29, 73.08]
Effect of expansion	0.03, 0.03
Net welfare effect	**$209,734; 236,365**

Impact of rural coverage expansion

	All Nodes	Nodes in areas where coverage	
		affected	unaffected
N	1.5m	82,523	1.42m
Effect (million $)			
Revenue	0.09, 0.11	0.02, 0.02	0.07, 0.08
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The Spread of Mobile Phones

Method to estimate and simulate adoption of a network good

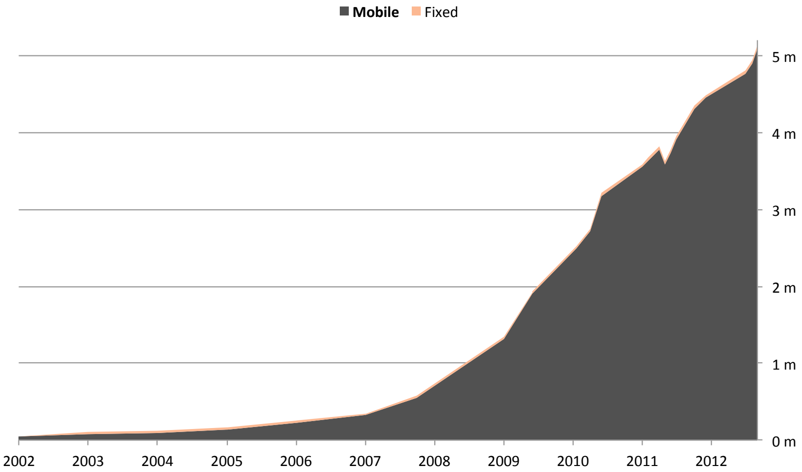
Use data from nearly the entire Rwandan cell phone network:

- Estimate structural model of adoption
  as a function of each individual's social network, coverage, and prices
- Simulate policies
  Alternate tax policies
  Government requirement to serve rural consumers: improved welfare

Appendix

Telecom in Rwanda

Population 11m



Back to context

Telecom in Rwanda

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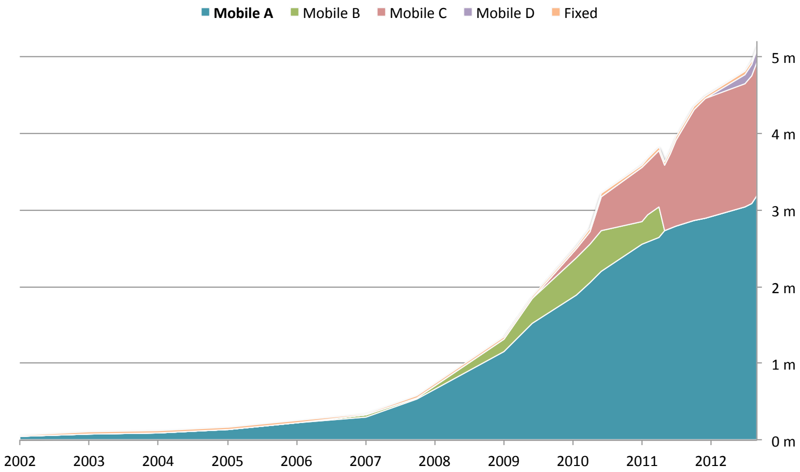

Back to context

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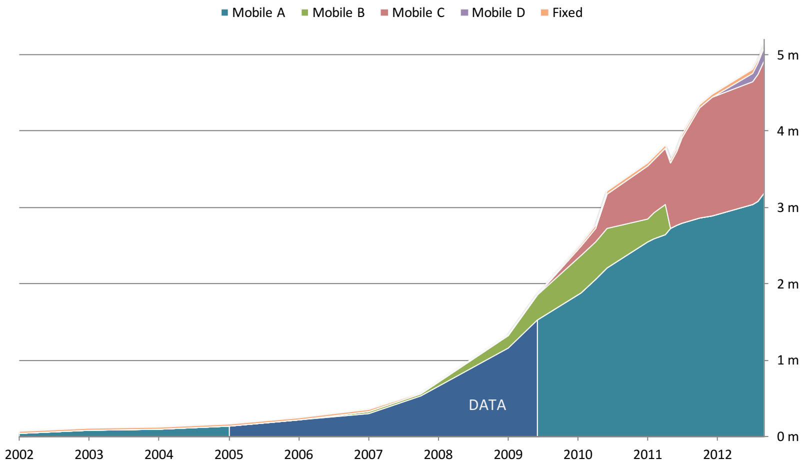
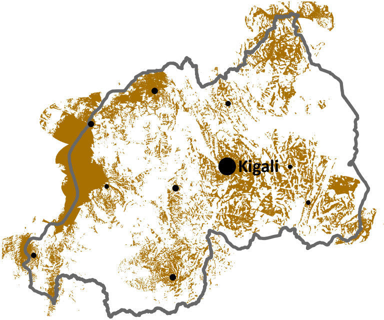
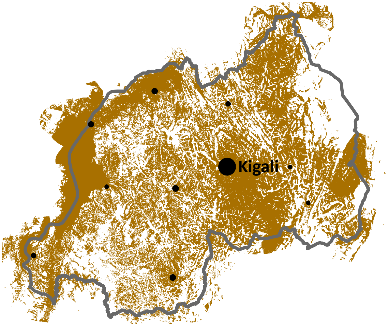


Back to context

Coverage expanded



2005

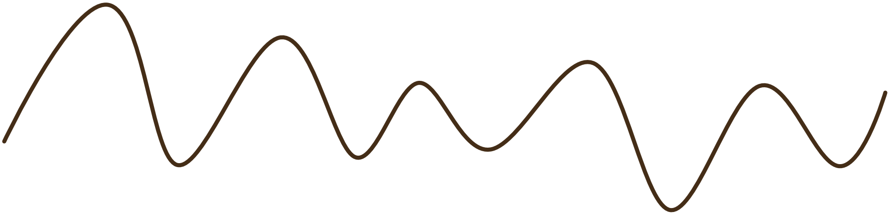


2009

▸ Back to context

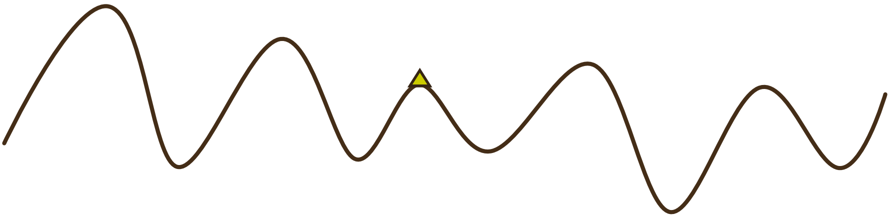
▸ Back to counterfactual

Rwanda is hilly



▸ Back to model

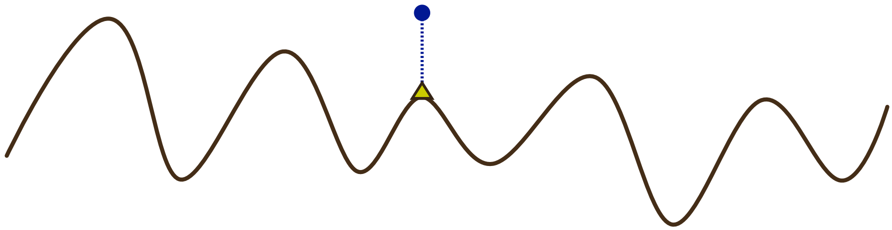
Interaction of topography and electric grid



▸ Back to model

Interaction of topography and electric grid

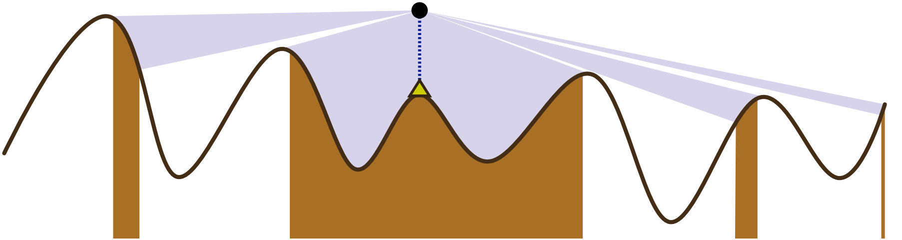
Makes it cheaper to build towers in certain locations



▸ Back to model

Interaction of topography and electric grid

Generates differential costs of serving nearby areas



Back to model

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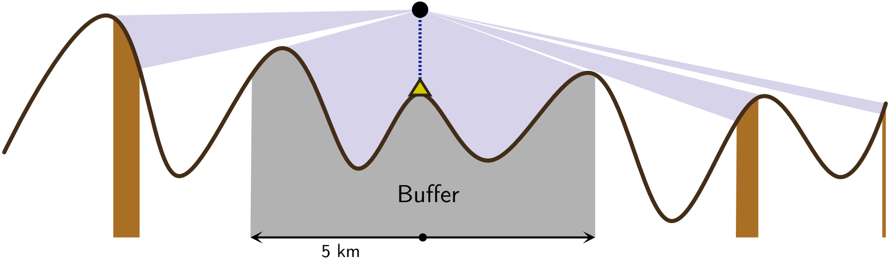
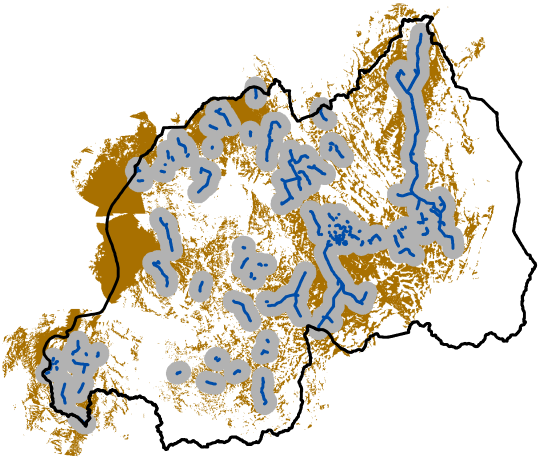


Use variation in coverage that would arise from building hypothetical towers along entire electric line.

▸ Back to model

Instrument: incidental coverage from electric lines



Back to model

Functional form of utility: properties

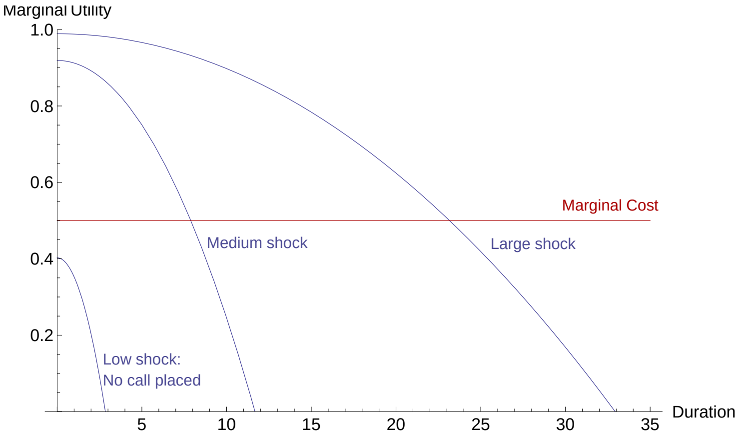
$$u_{ijt}(d, \epsilon) = v_{ij}(d, \epsilon) - c \cdot d$$

1. Cost is separable across contacts
2. Zero duration yields zero utility
3. Diminishing returns to duration
4. For some values of ϵ, calls are placed
5. Even if calls were free, you wouldn't talk forever
6. Changing the cost affects the extensive decision to call
7. Changing the cost of a call affects longer calls more than shorter calls
8. There is an analytic, one to one mapping between d^* and ϵ
9. Relationships with higher information flows provide higher utility

Back to model

Functional form of utility

$$v_{ij}(d, \epsilon) = d - \frac{1}{\epsilon}\left[\frac{d^\gamma}{\gamma} + \alpha d\right]$$



Back to model

Individual location l_i

Algorithm Isaacman et al. 2011

Back

Individual location l_i

Algorithm Isaacman et al. 2011

1. Consider all towers i used

Back

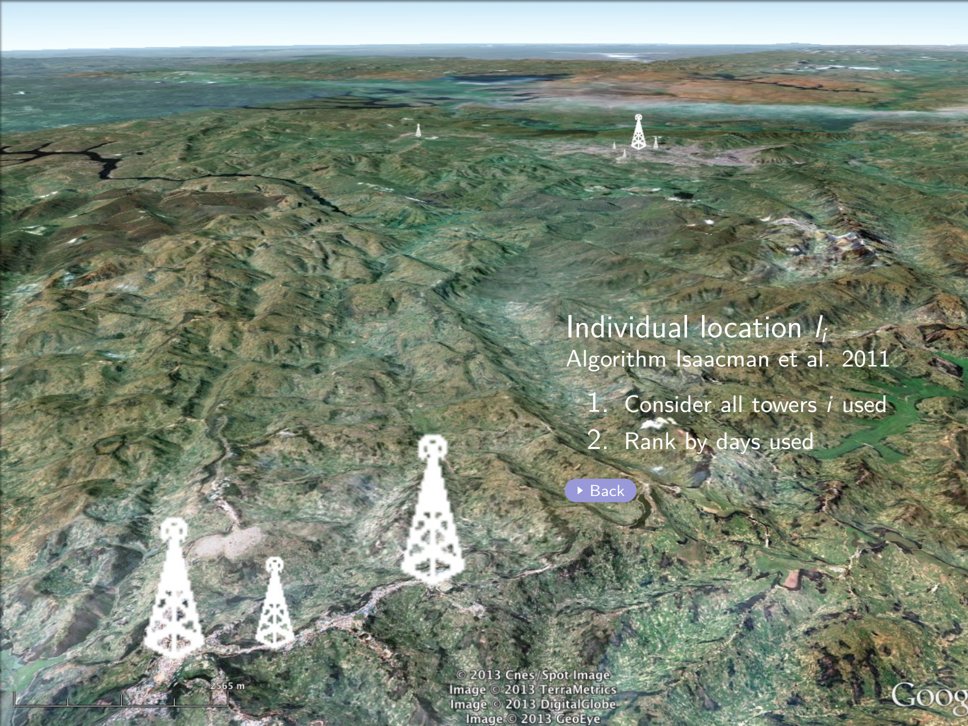

Individual location l_i
Algorithm Isaacman et al. 2011
1. Consider all towers i used
2. Rank by days used
Back
2565 m
© 2013 Cnes/Spot Image
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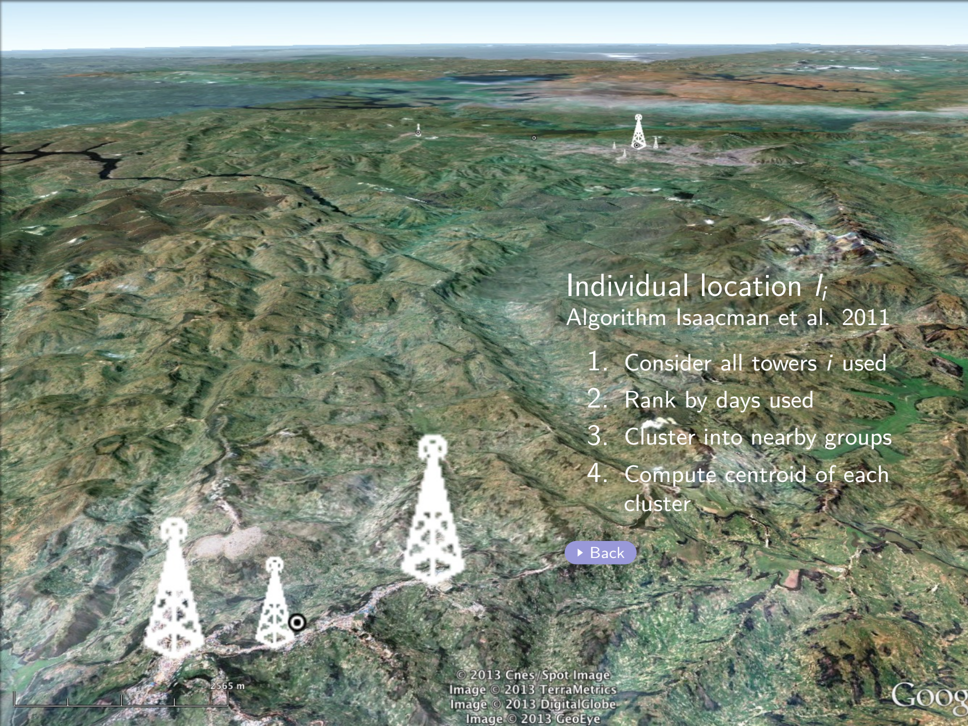
Image © 2013 GeoEye



Individual location l_i

Algorithm Isaacman et al. 2011

1. Consider all towers i used
2. Rank by days used
3. Cluster into nearby groups
4. Compute centroid of each cluster

Back

Individual location l_i

Algorithm Isaacman et al. 2011

1. Consider all towers *i* used
2. Rank by days used
3. Cluster into nearby groups
4. Compute centroid of each cluster

Back

Coverage $\phi_{l,2005}$

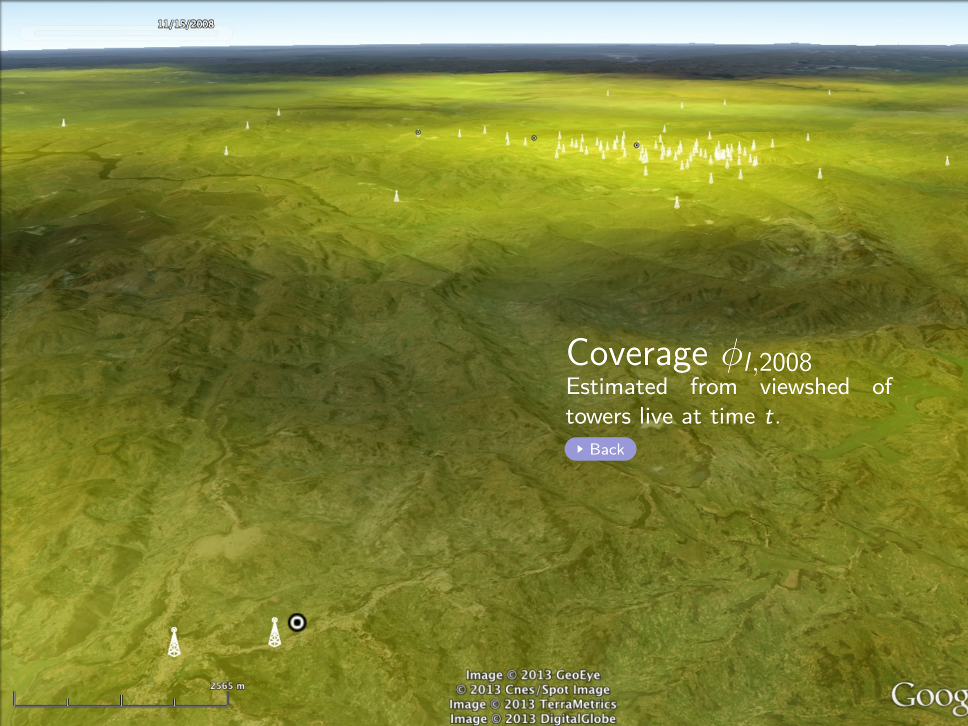
Estimated from viewshed of towers live at time t.

Back

Coverage $\phi_{l,2008}$

Estimated from viewshed of towers live at time t.

Back



Coverage $\phi_{l,2008}$

Estimated from viewshed of towers live at time t.

Back

Coverage $\phi_{l,2005}$

Estimated from viewshed of towers live at time t.

Back