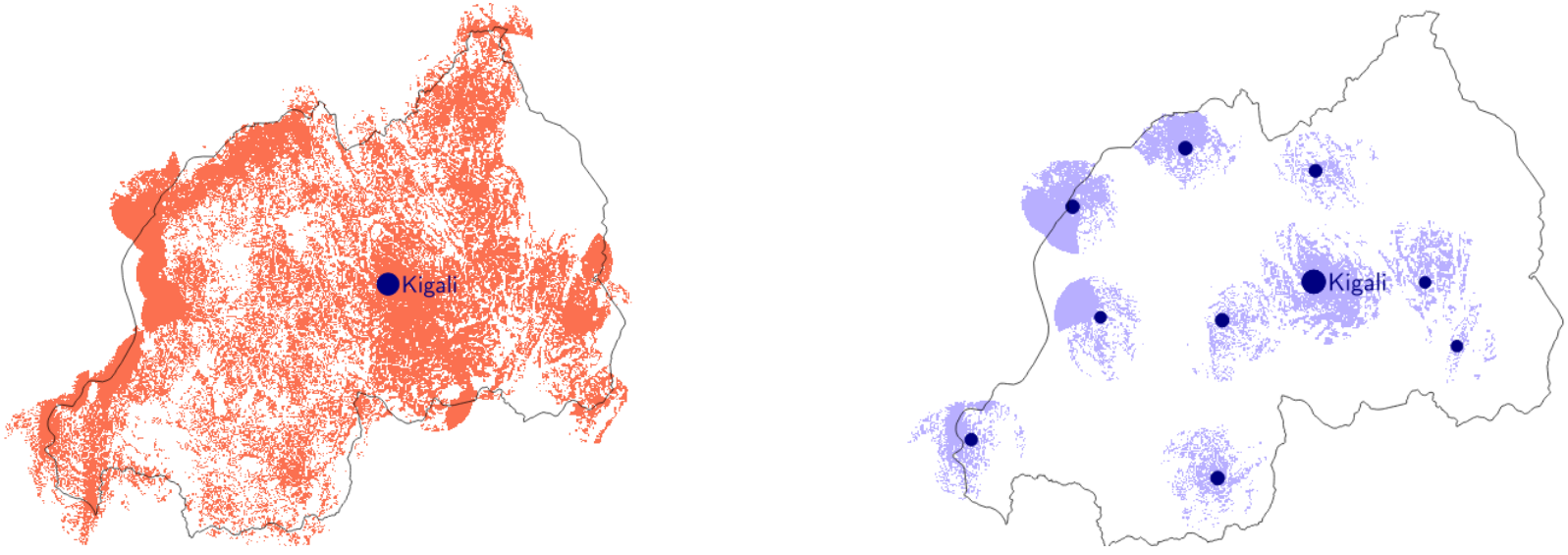
Competition in Network Industries: Evidence from the Rwandan Mobile Phone Network

Daniel Björkegren

Brown University



Network effects

Direct network goods $x_i(\mathbf{x}_{-i}(\cdot))$

- Communication (phones, WhatsApp)
- Social technologies (Facebook)
- Payments (mobile money, WeChat)

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- Systems that learn from users (machine learning, Google)
- Platforms (Uber)

Widespread Concern about Network Industries

Gloves off in fight over mobile termination rates

By KENNETH KWAMA | Published

India's Vodafone-Idea merger may be too late, as Jio accelerates growth

Safaricom faces M-Pesa break up in market dominance war

THURSDAY FEBRUARY 23 2017

How WeChat came to rule China

The multipurpose messaging app is becoming the nation's ID system

Facebook Admits It Was Used to Incite Violence in Myanmar

Fake News on WhatsApp Is Killing People in India

It's Time to Break Up Facebook

Is It Time to Break Up Google?

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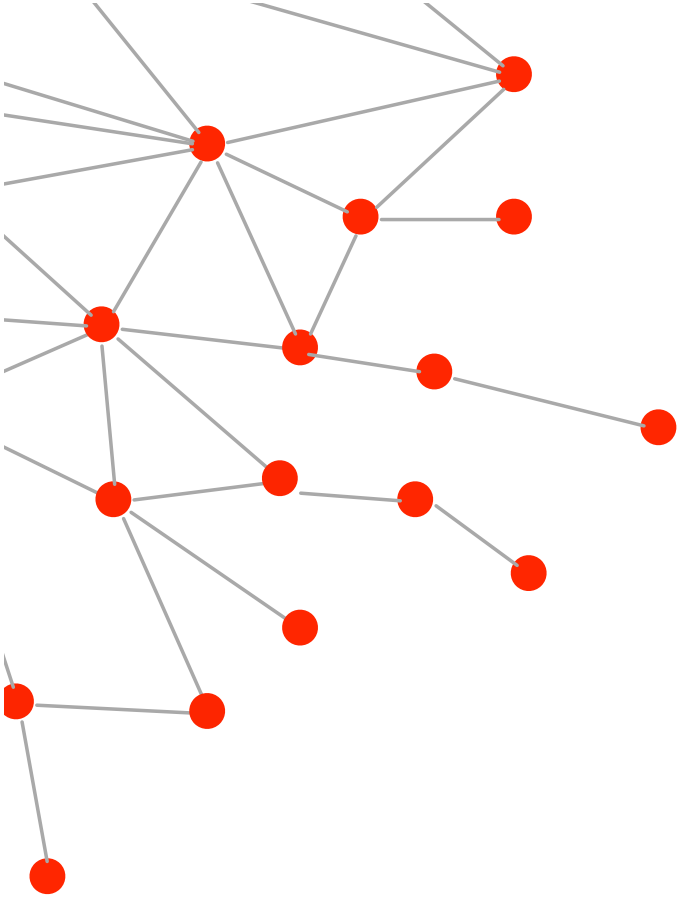
Mobile phone networks in sub-Saharan Africa:

- 2.5% of GDP (7.1% indirect) (GSMA 2018)
- Platform for internet, mobile money, digital credit

How to discipline network industries?



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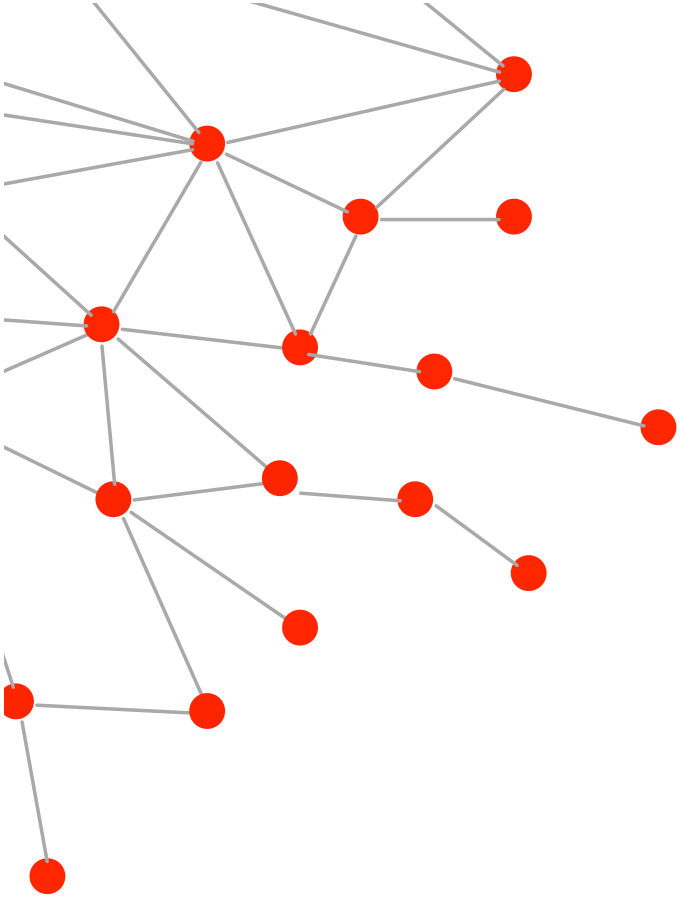

Regulation, but rapid change, large investments

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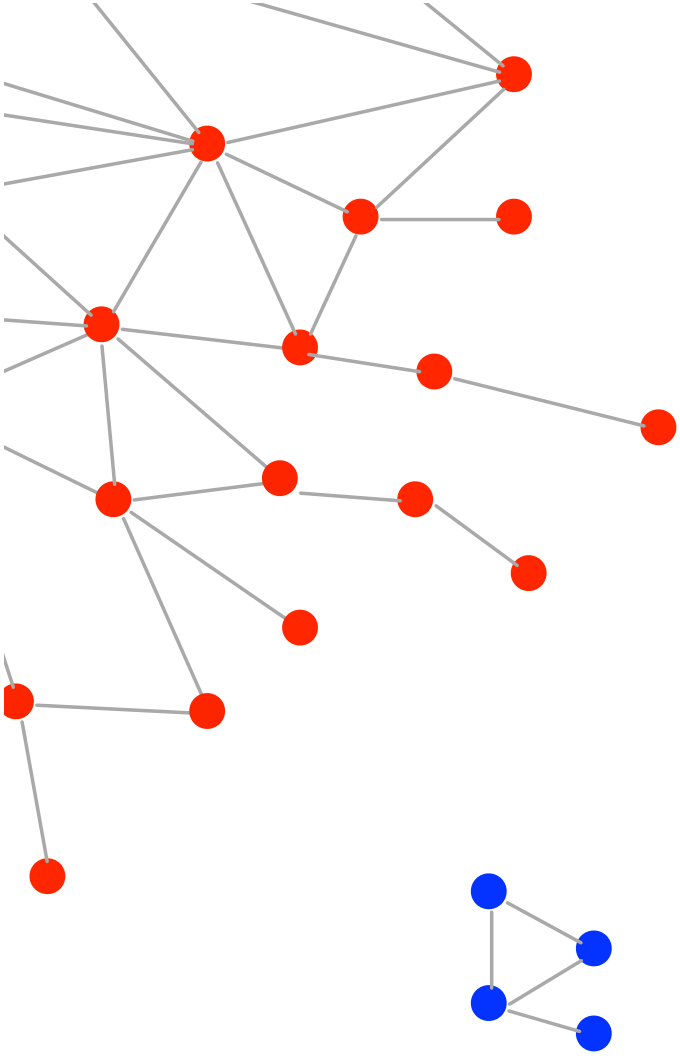

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Competition

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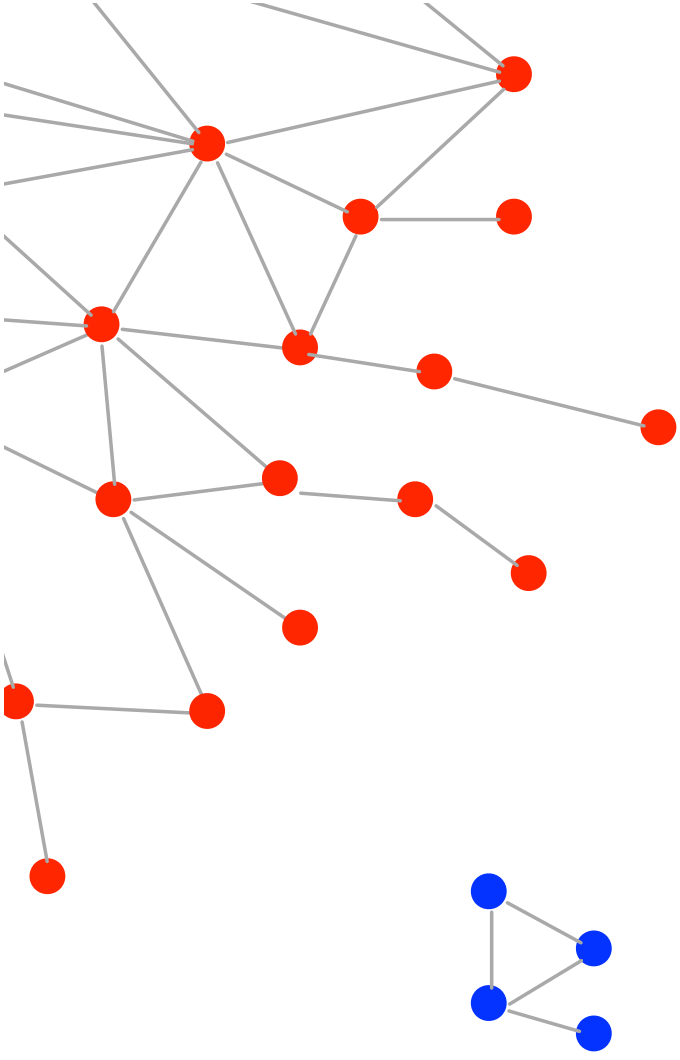

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Competition also requires regulation

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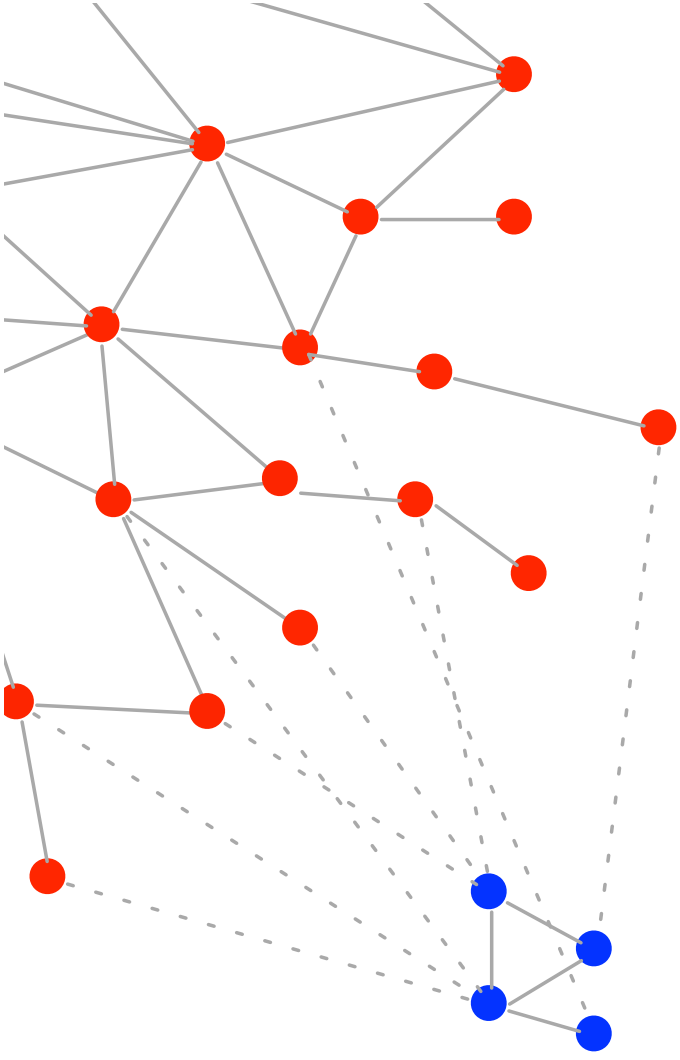

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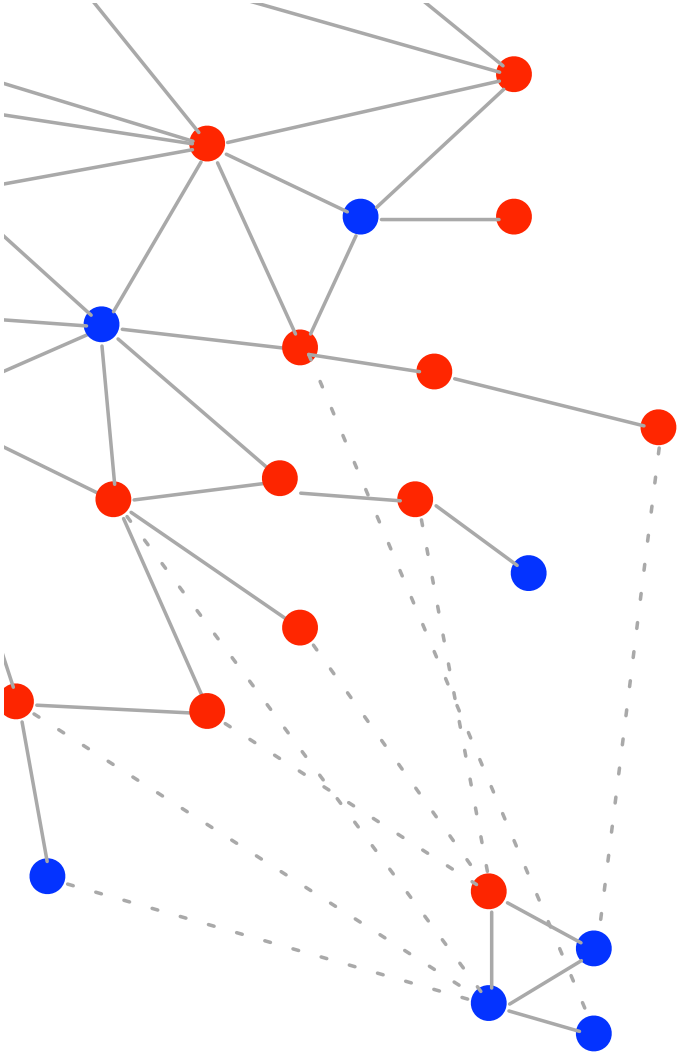
Compatibility

How to discipline network industries?



Regulation, but rapid change,
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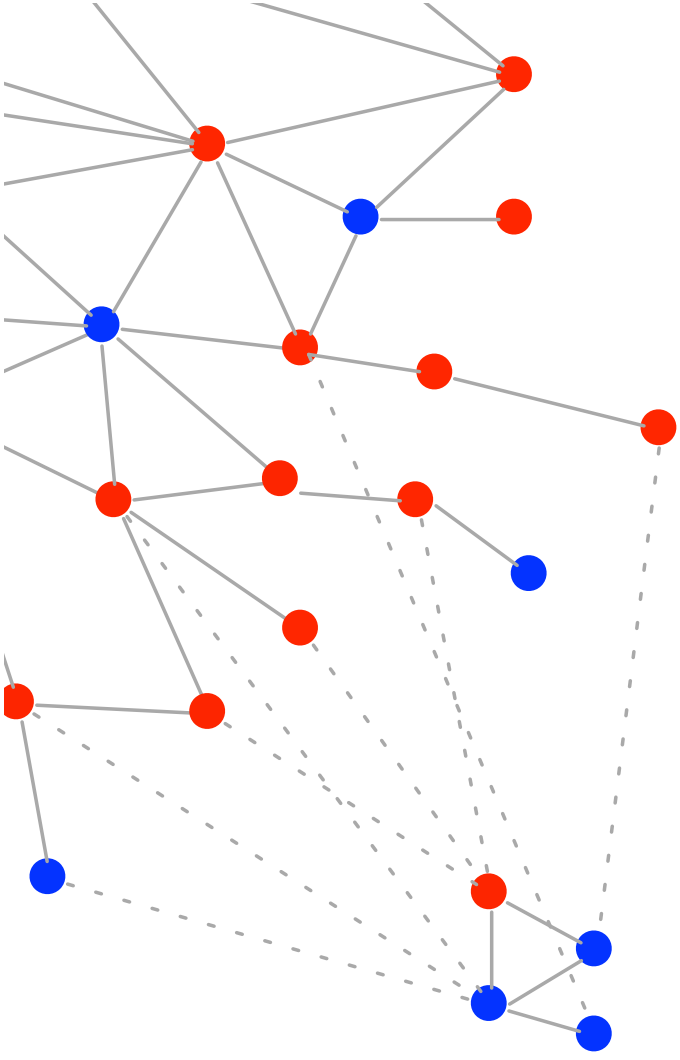
Competition also requires regulation

- Compatibility
- Switching

How to discipline network industries?



Regulation, but rapid change,
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Competition also requires regulation

Compatibility

Switching

...

- **How strongly should we promote?**
- **What rules should govern?**

How to discipline network industries?

Theory (Farrell and Saloner 1985, Economides 1988, Katz and Shapiro 1994; mature telecom markets: Laffont, Rey, & Tirole 1998, Armstrong 1998)

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Empirical

- **Reduced form**
  Increases in telecom competition are associated with price reductions (Faccio and Zingales 2017, Genakos et al. 2018)
  - Investment decisions anticipate future policy
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- **Structural: model objective functions**
  Demand interdependent: $x_i(\mathbf{x}_{-i}(\cdot))$
  - **Identify** network effects
  - **Upon policy change,** account for all ripple effects

This project

Industry of crucial importance to developing societies

$$x_i(\underbrace{\mathbf{x}_{-i}(\cdot)}_{\textit{Contacts}}, \underbrace{\phi(\mathbf{x})}_{\textit{Coverage}}, \underbrace{p(\mathbf{x})}_{\textit{Calling Price}})$$

1. Estimate network demand in monopoly

5.3b records on usage after adoption (Björkegren REStud 2019)

This project

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2. Evaluate effects of competition policy in industry

Add supply side, find full equilibrium

This project: Main Results

- Baseline monopoly: net social welfare of \$334-386m
  $\approx$ 2-3% of Rwanda's GDP over this period

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First analysis of competition between direct network goods using micro data

Competition in a Network Industry

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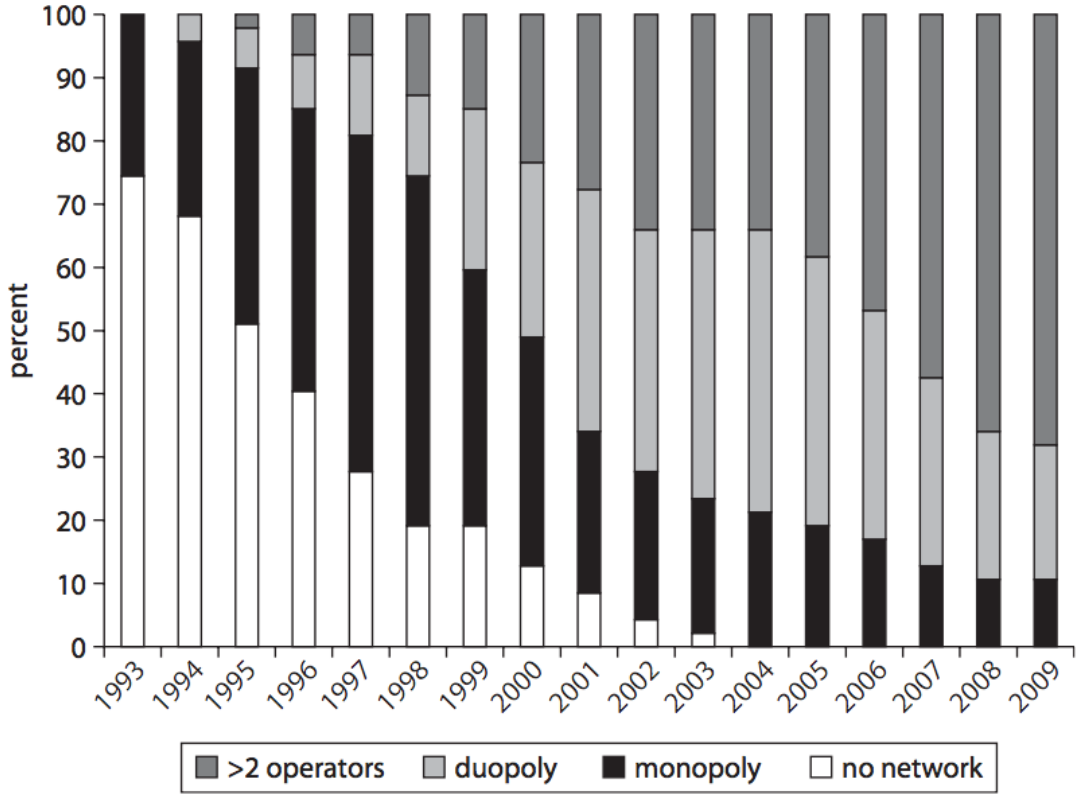
How much competition? At what stage of the network?

Figure 1.1 Competition in Mobile Markets in Sub-Saharan Africa, 1993–2009
percentage of countries with no provider, one provider, two providers, and three or more providers



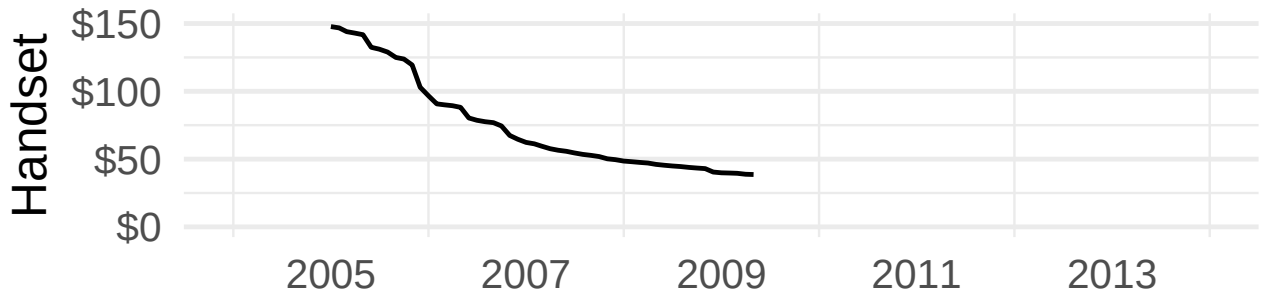
Sources: ITU (2010), regulators, operators.

Williams et al. (2011)

What should the ground rules be?

	Percent of countries in SSA
Interconnection charges are regulated	97%
...based on costs (LRIC or FDC)	71%
...based on benchmarks	43%
...asymmetric between operators	31%
...using multiple zones	34%

Telecommunications in Rwanda



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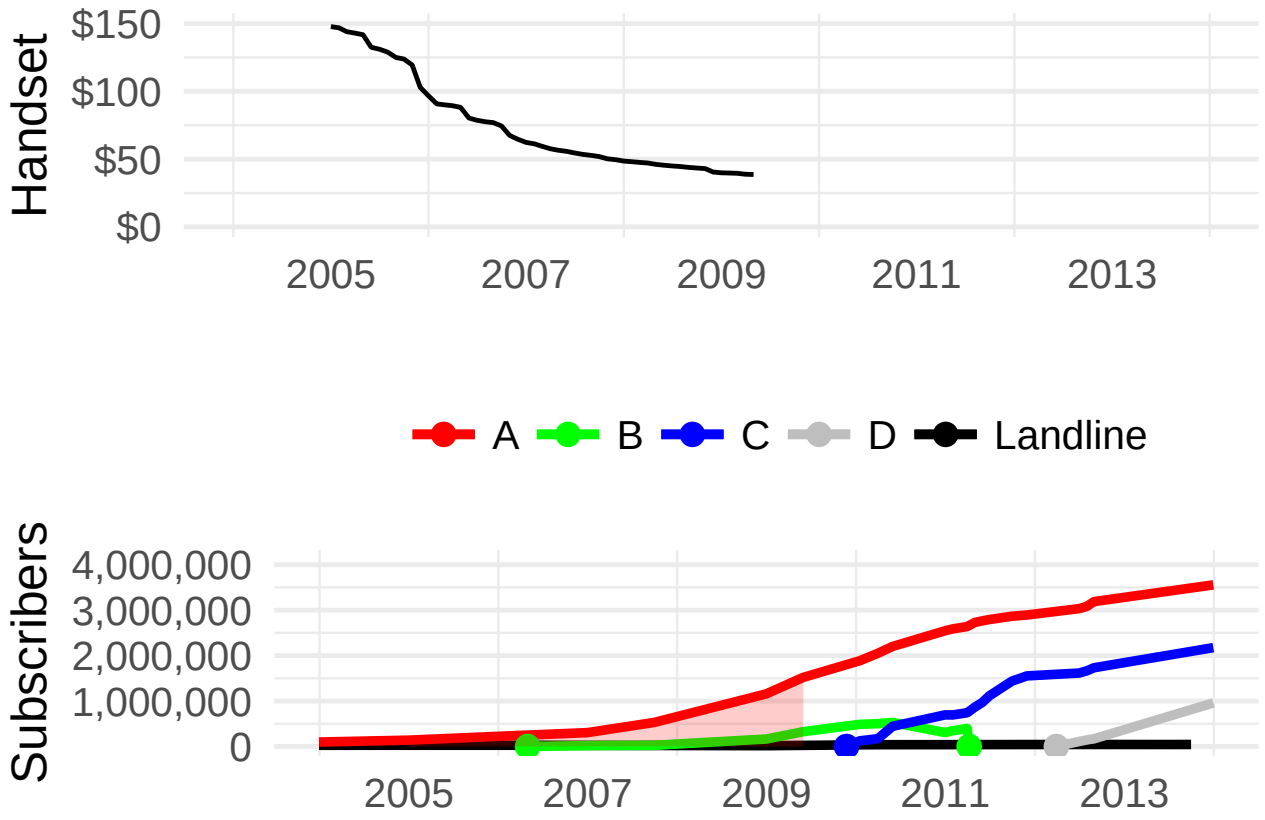

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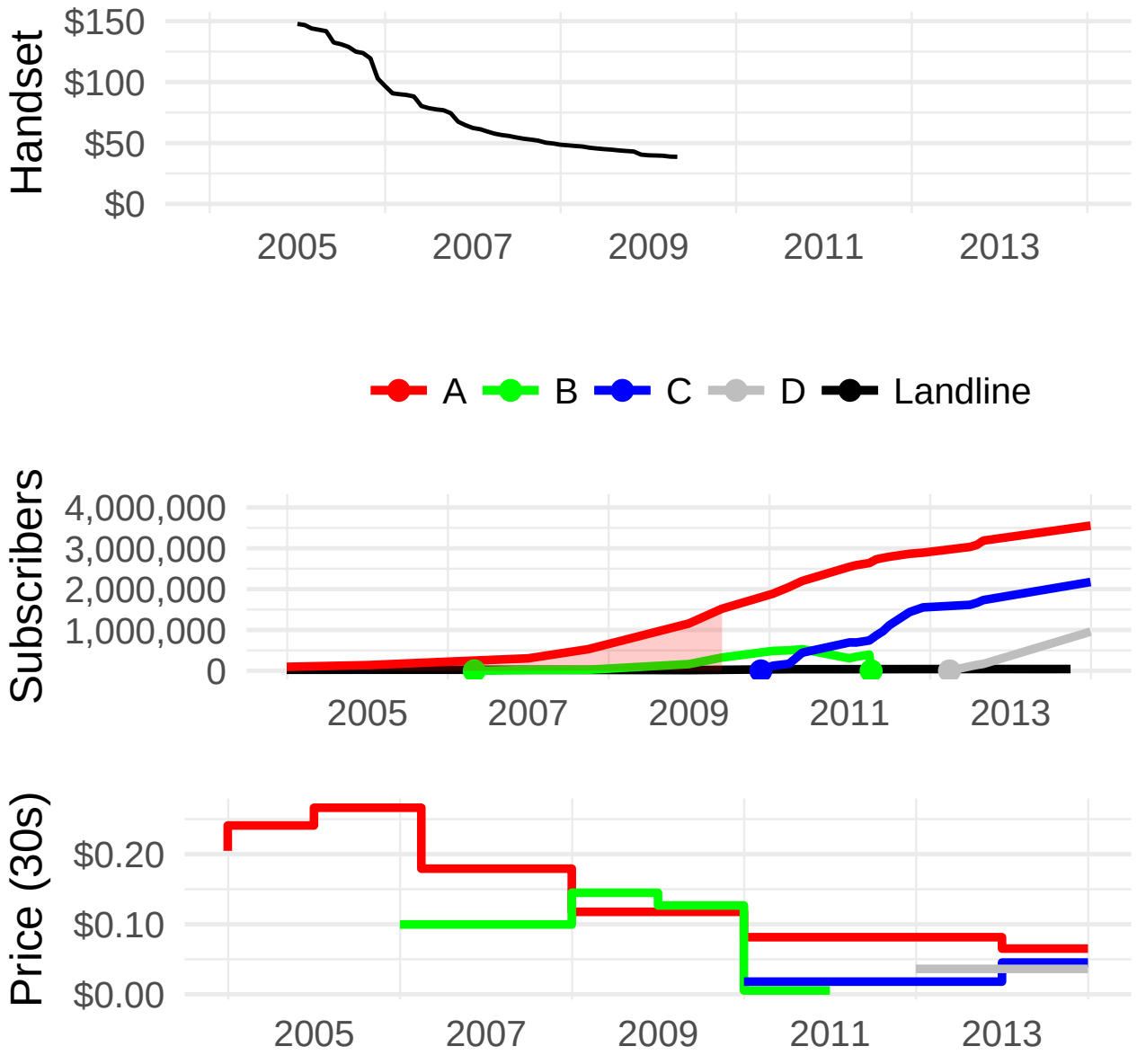
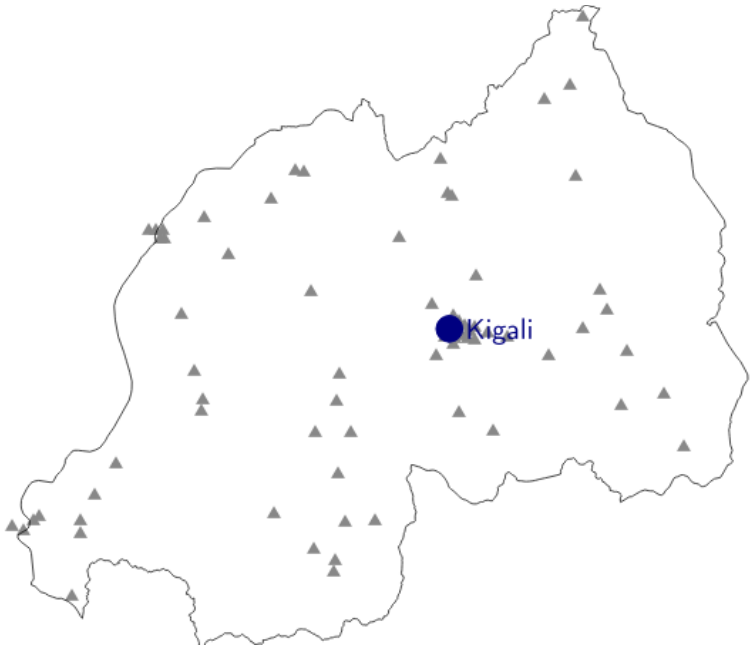
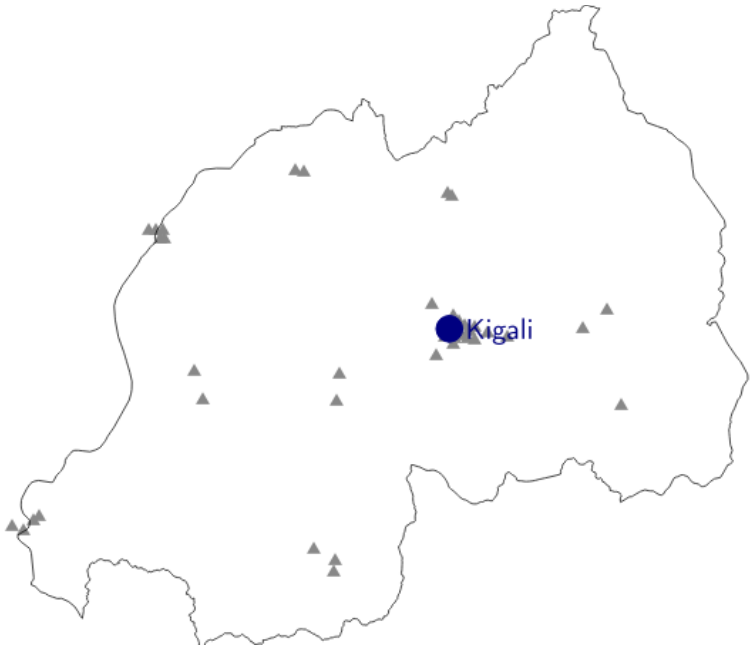


Towers in 2005 z^F



Incumbent (Actual)



Entrant (Proposed)

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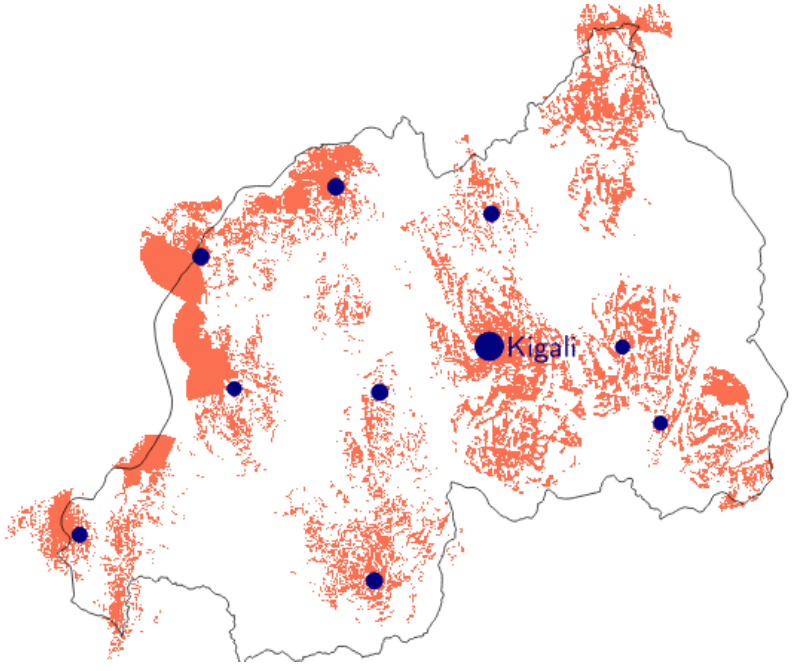
Coverage in 2005 $\phi_0(\boldsymbol{z}^F)$



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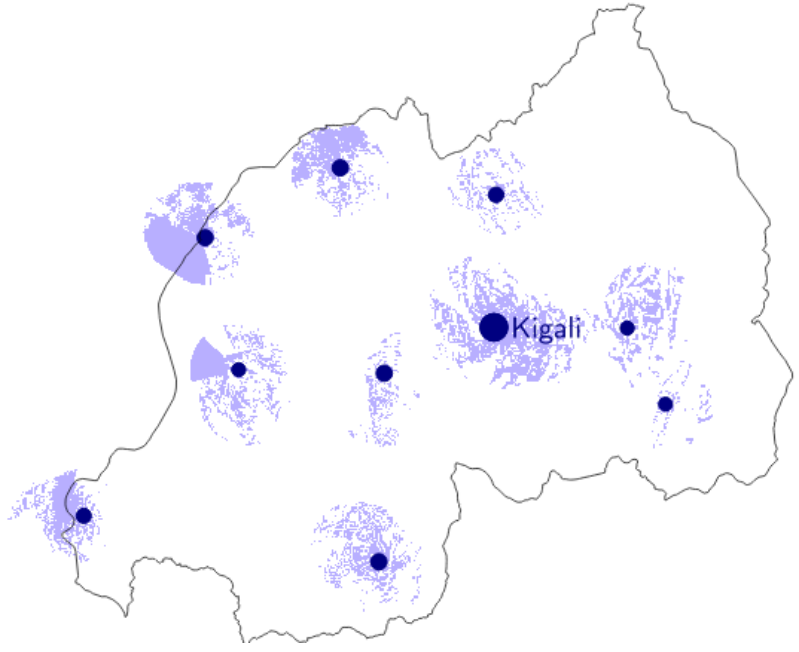

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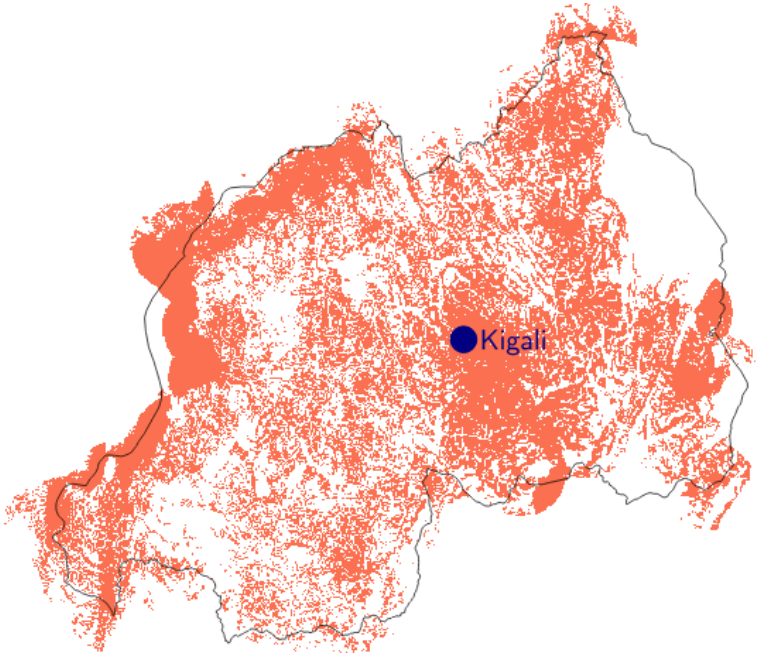
Dots represent major towns; coverage is shaded.

Coverage in 2009 $\phi_T(\boldsymbol{z}^F)$



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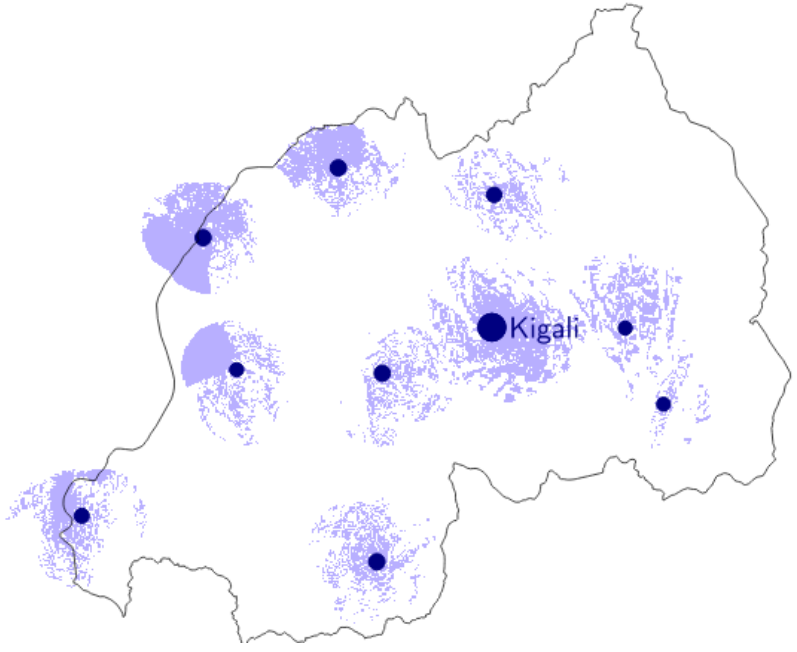

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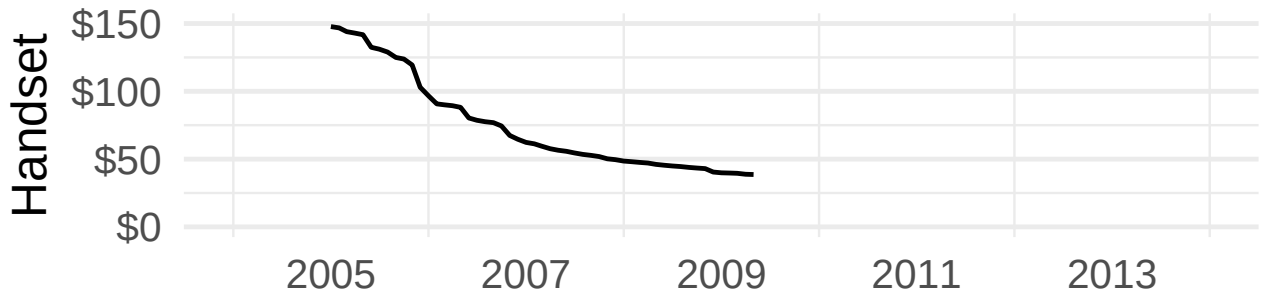
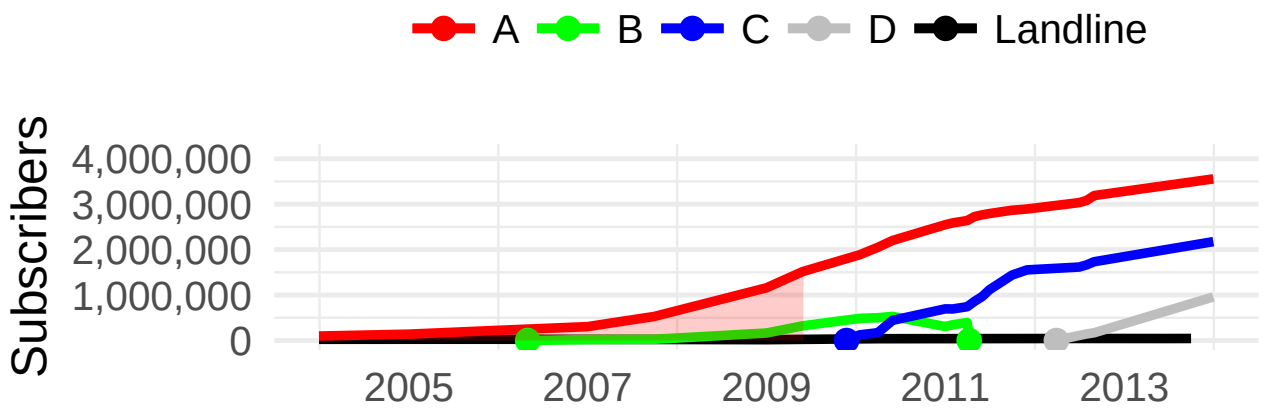
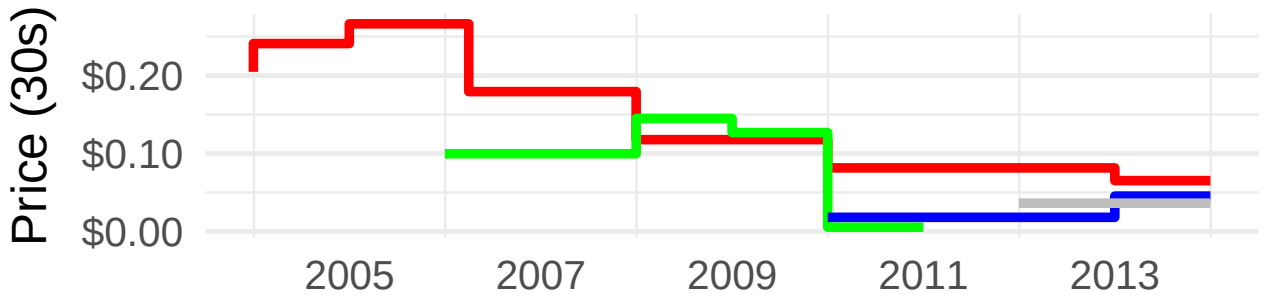
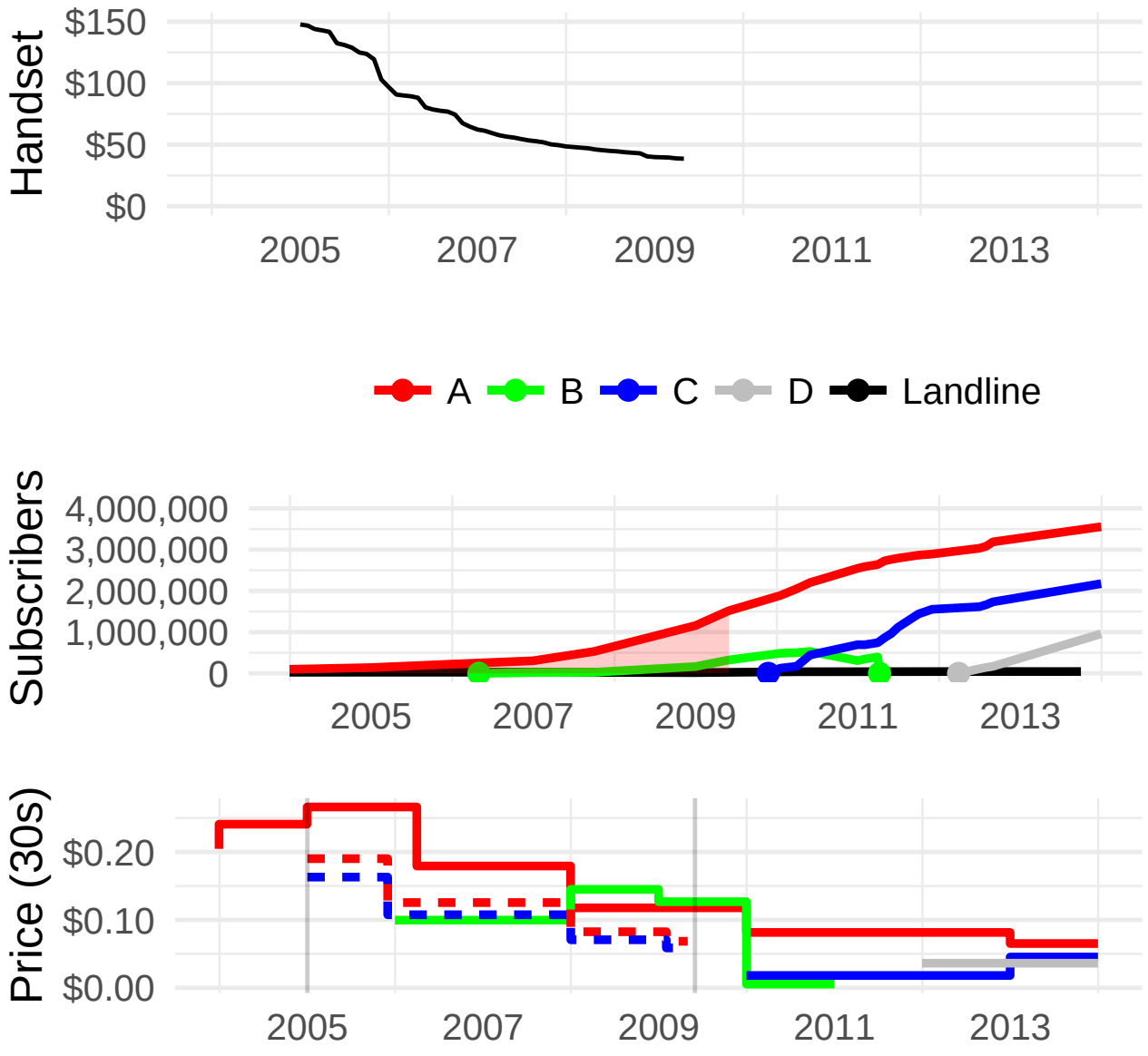






Telecommunications in Rwanda: Preview of Results



Competition in a Network Industry

Data

1. **Call Detail Records**
   5.3b anonymous records from dominant operator, 2005-2009

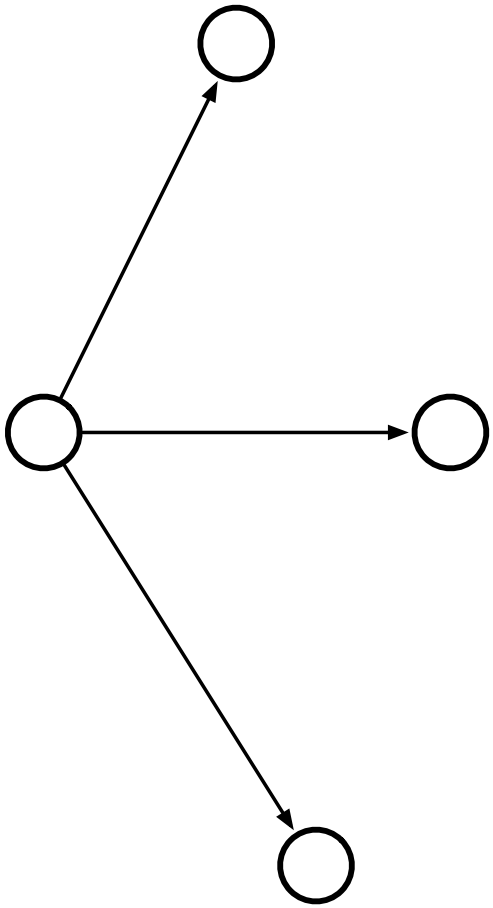
Transaction	Amount	ID.From	ID.To	Tower	Timestamp
Call					

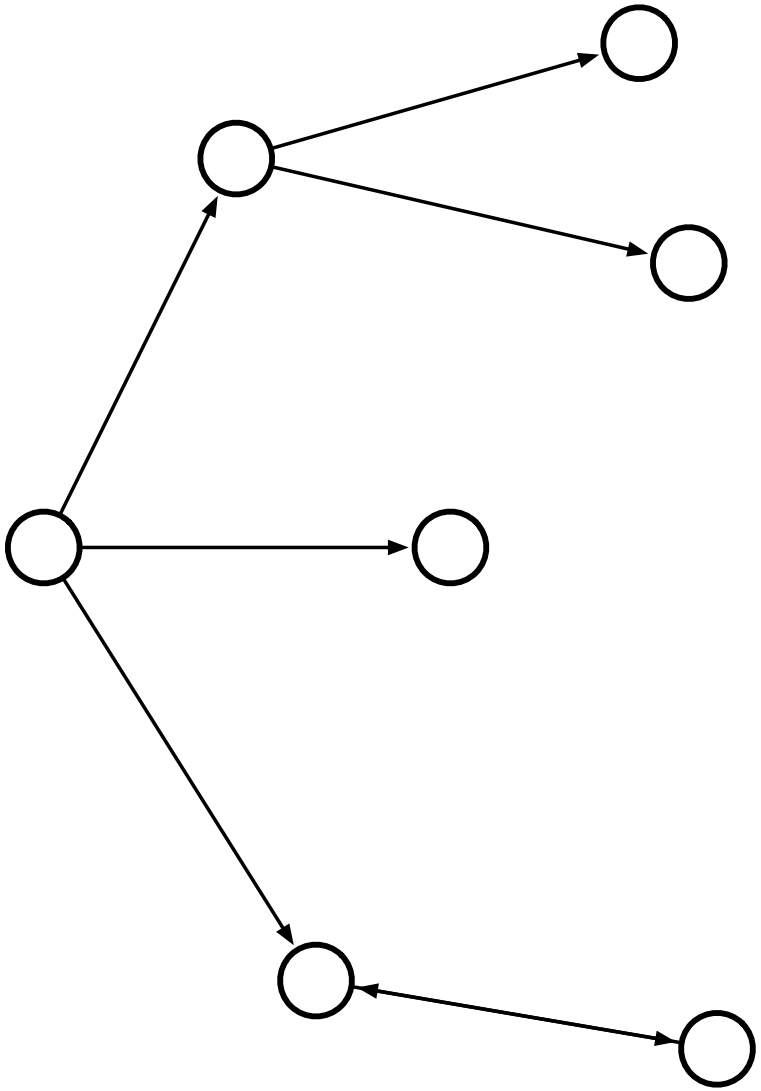
   IDs map to account and handset. No other characteristics.
   Mobile internet, mobile money not available this period.
   (2017: 9% smartphones; voice 60% of partner's African revenue)

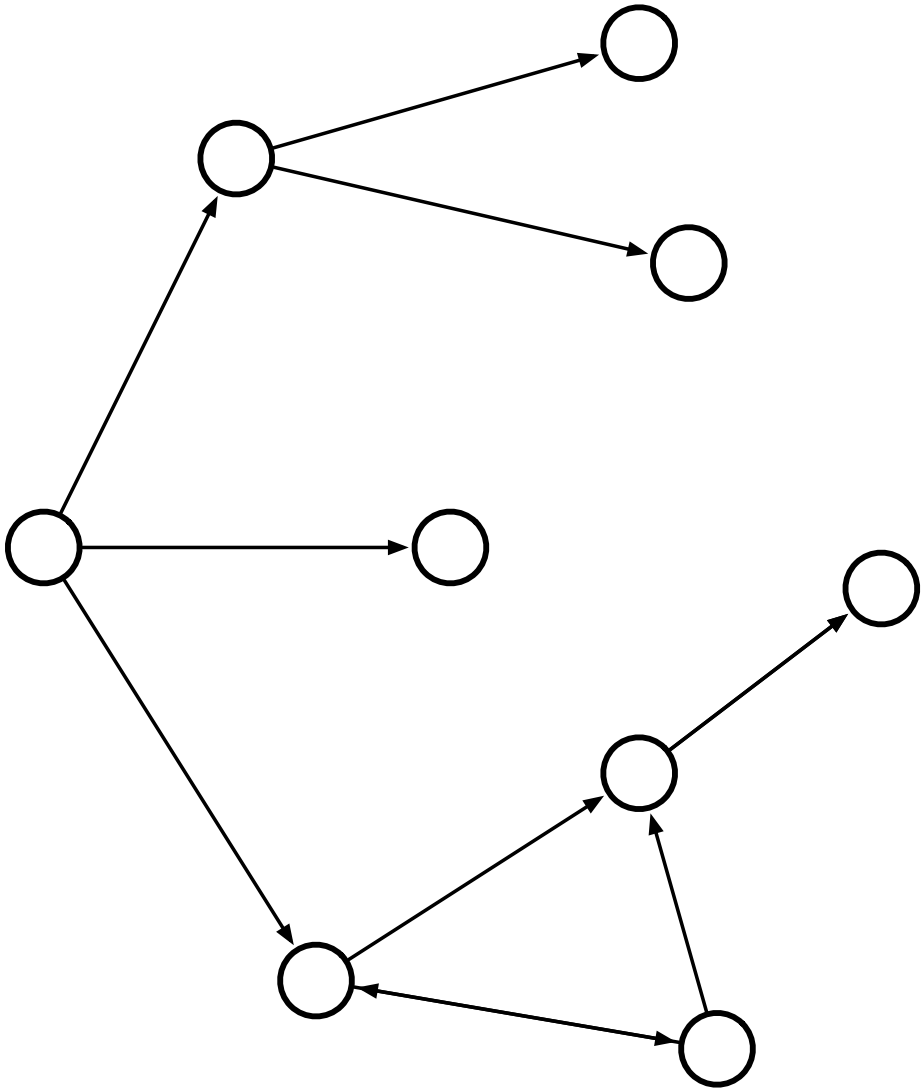
2. **Cost Data**: collected by regulator for interconnection study, accompanied by engineering model

3. **Surveys**: my choice survey (2017), representative survey (RIA 2007-8, 2010-11)

Competition in a Network Industry





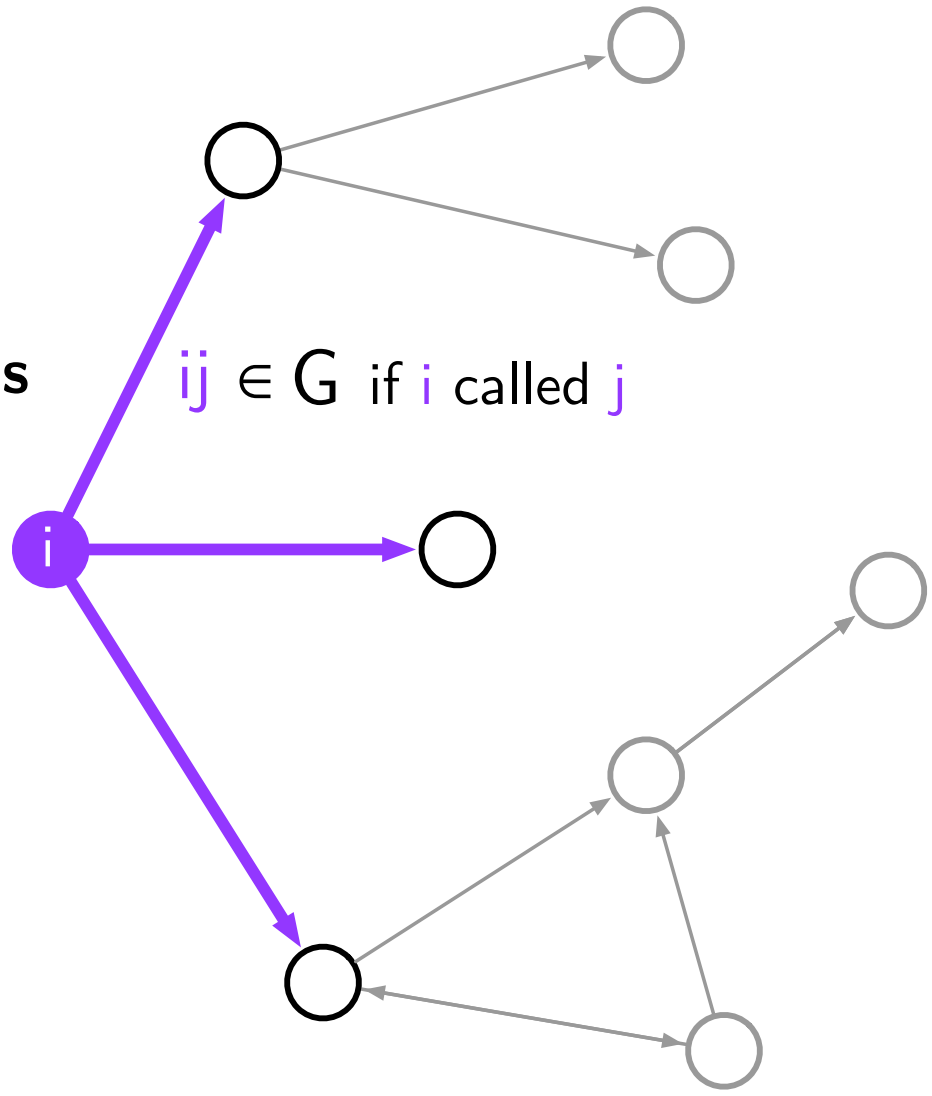


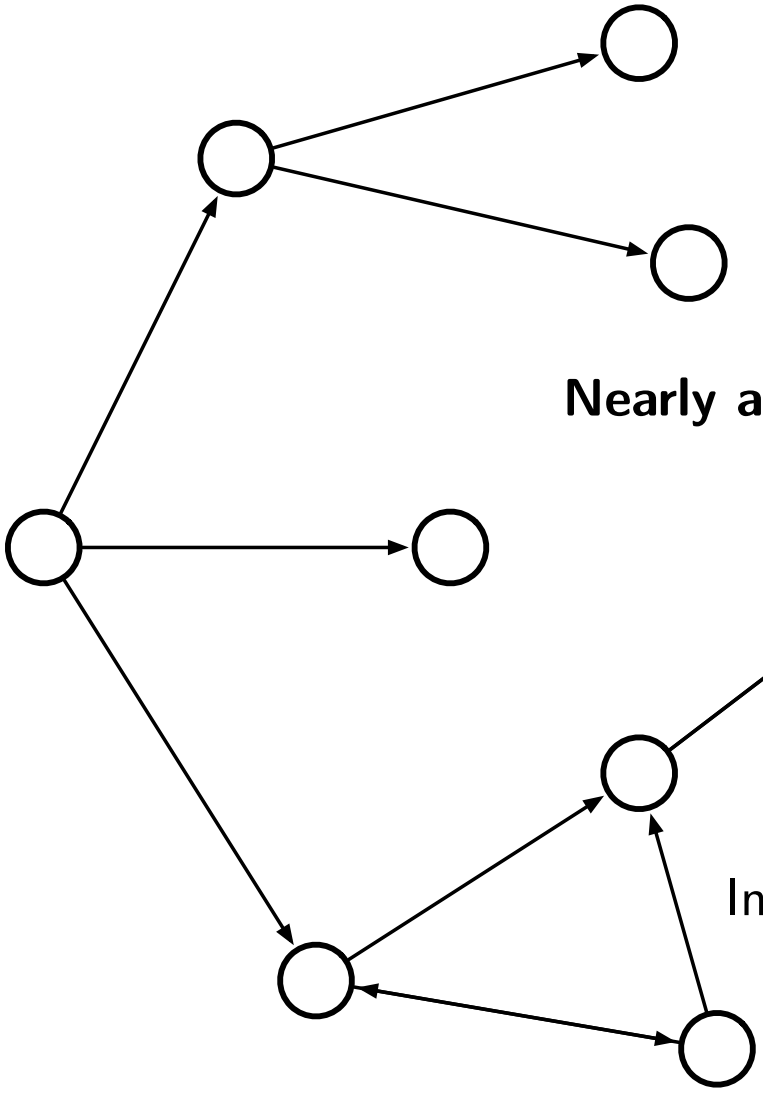
1.5m accounts

415m links

Contacts

$ij \in G$ if i called j



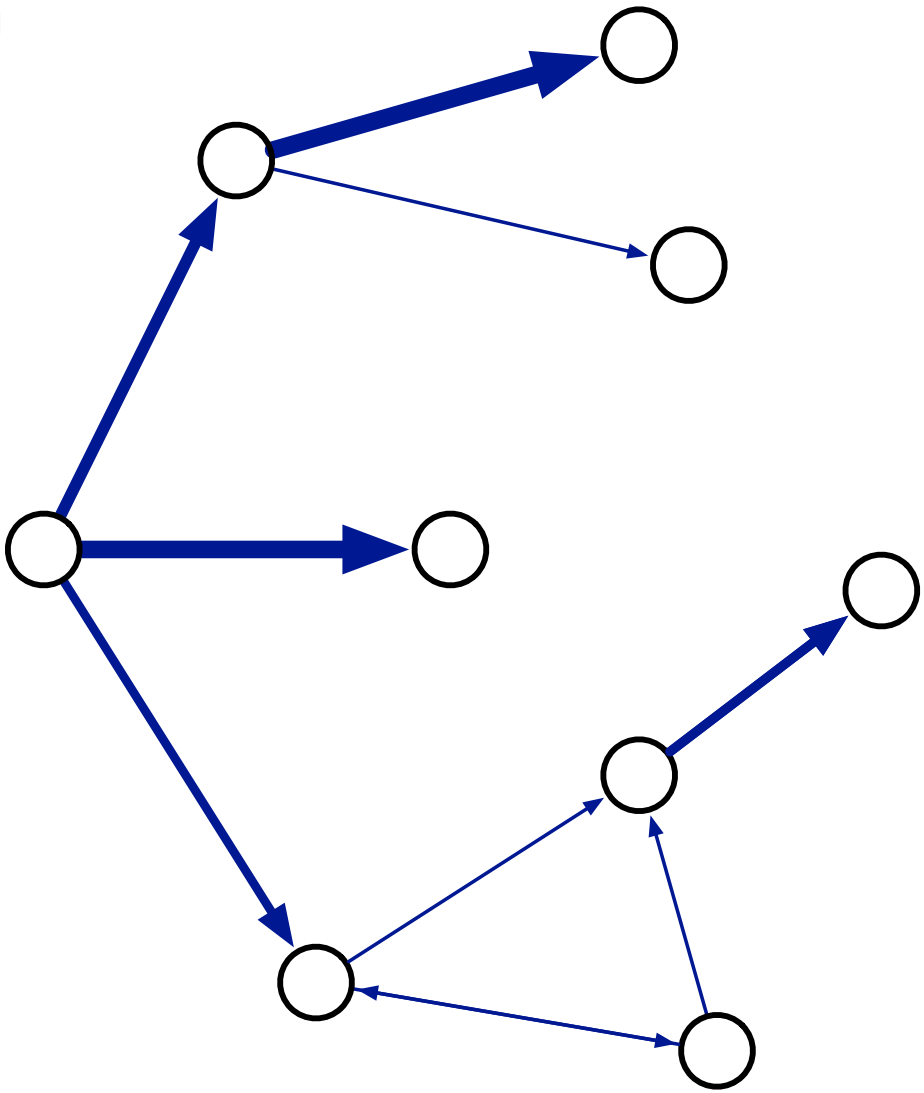


Nearly all remote communication in Rwanda at the time:

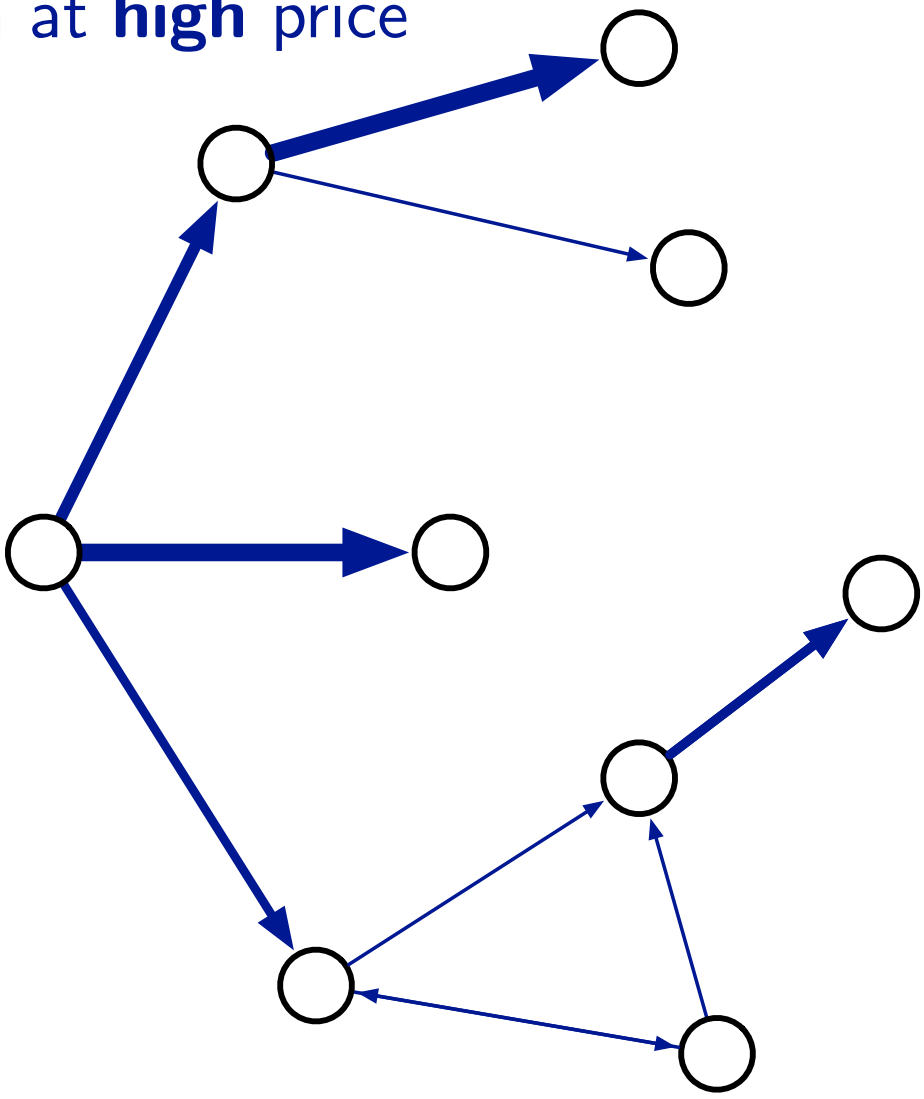
88% of mobile phones subscribing by May 2009

Insignificant landline network

Duration

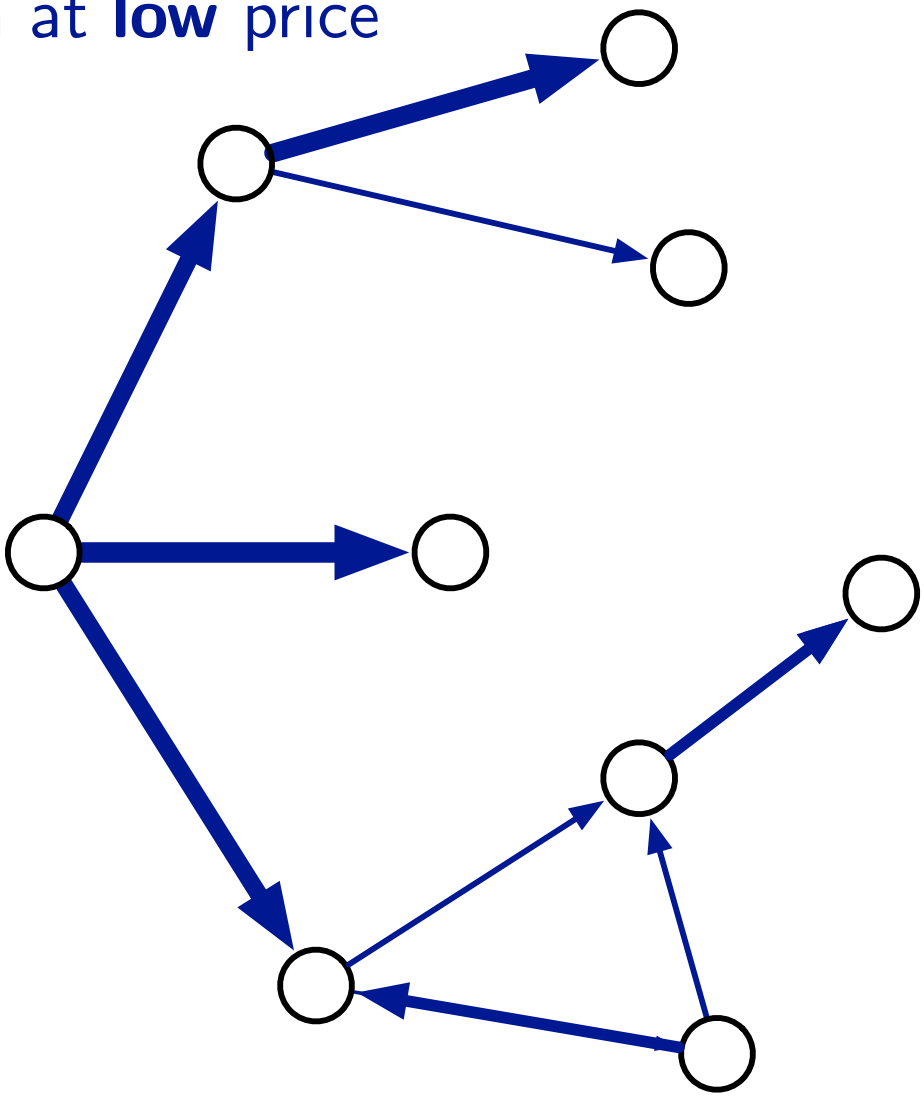


Duration at **high** price



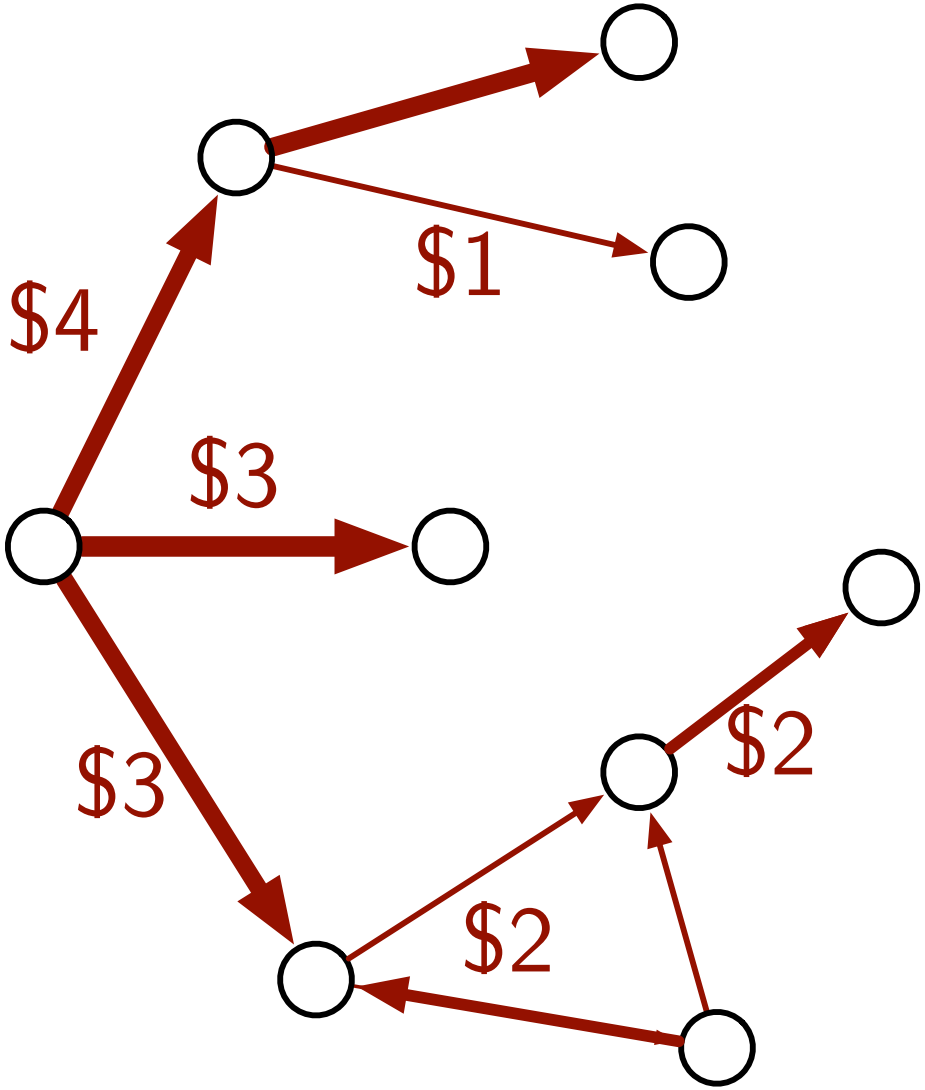
$$\frac{\Delta \text{Duration}}{\Delta \text{Price}}$$

Duration at **low** price

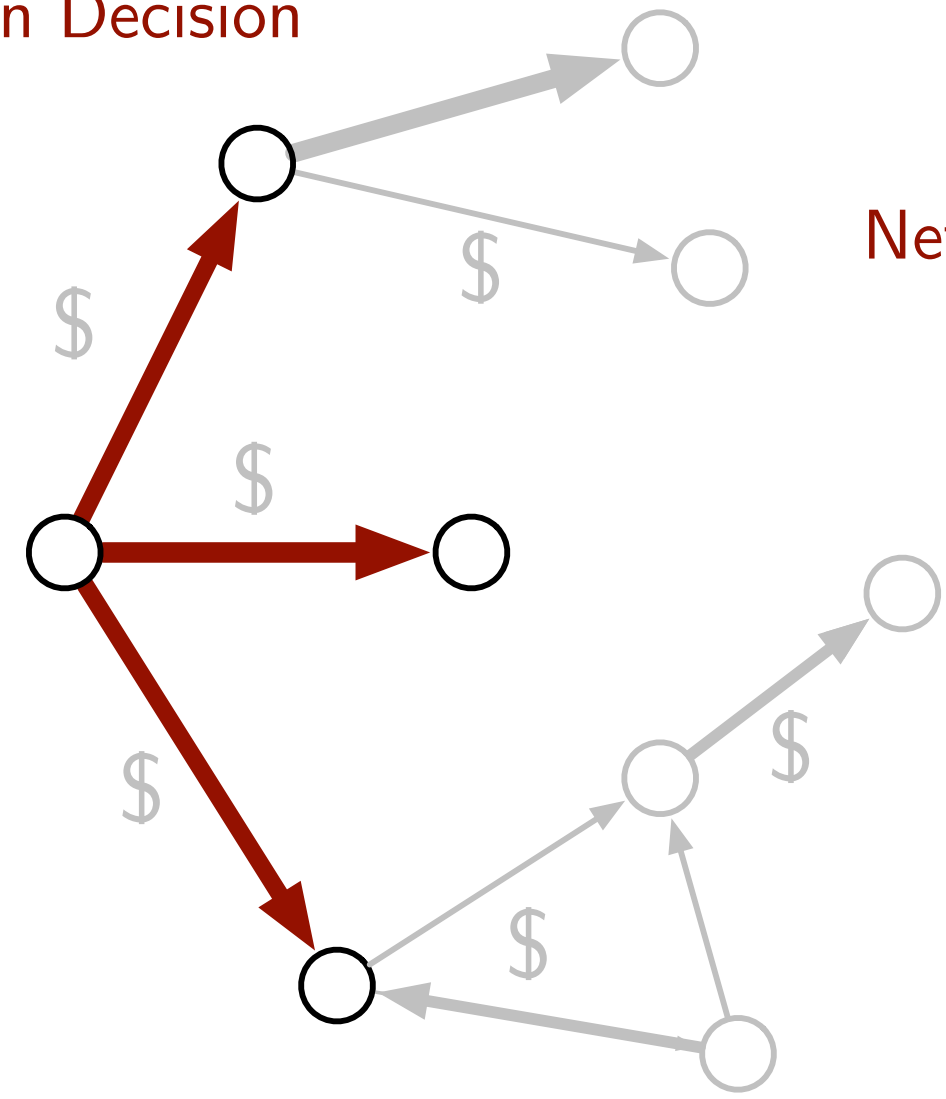


$$\frac{\Delta \text{Duration}}{\Delta \text{Price}}$$

How much value do people get from communicating?



Adoption Decision



Consider:

Handset price

Network benefits

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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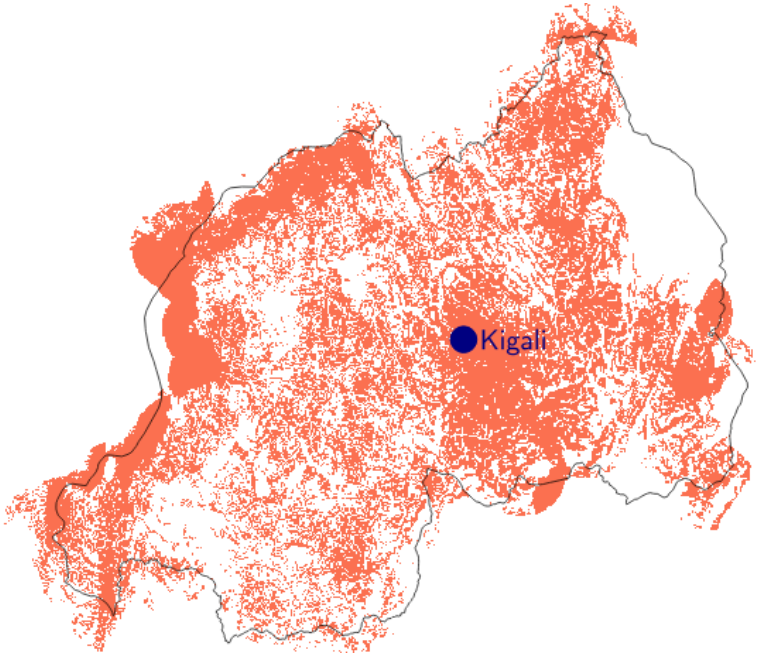
$$c_{ijt} = \underbrace{p_t^{a_{it}}}_{\text{calling price}} + \beta_{coverage} \cdot \underbrace{\phi_{it}(\mathbf{z}^{a_{it}})}_{\text{sender's coverage}} \cdot \underbrace{\phi_{jt}(\mathbf{z}^{a_{jt}})}_{\text{receiver's coverage}}$$

For estimation, operator $a_{it} \equiv I$; for simulation $a_{it} \in \{I, E\}$.
Impose regulation: on-net price = off-net price

$v_{ij}(d, \epsilon) = d - \frac{1}{\epsilon}\left[\frac{d^\gamma}{\gamma} + \alpha d\right]$ chosen to satisfy 8 intuitive properties
$\phi_{it}(\mathbf{z}) \in [0, 1]$: avg. coverage at i's locations, under rollout plan $\mathbf{z}$

Coverage in 2009 $\phi_T(\mathbf{z}^F)$



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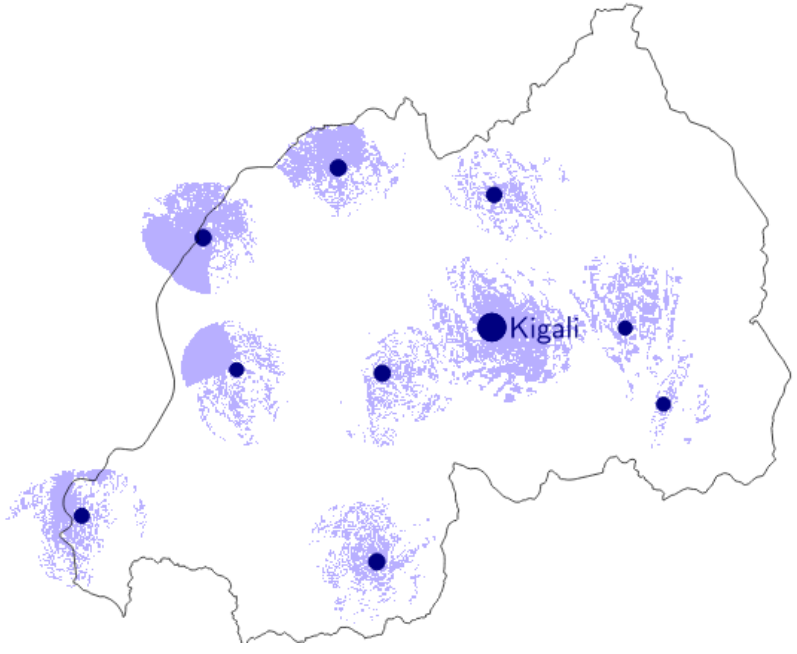

Entrant (Proposed)

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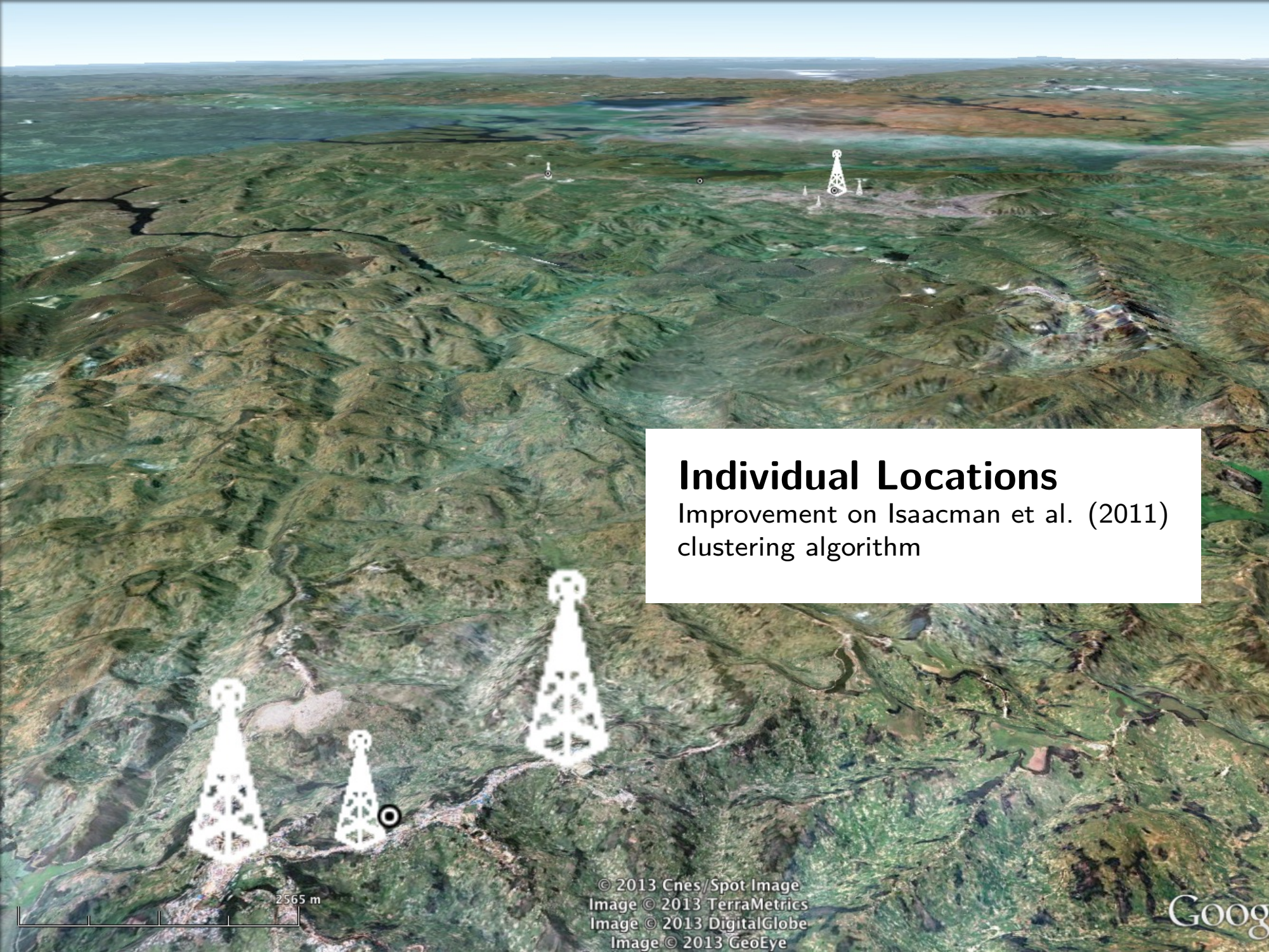
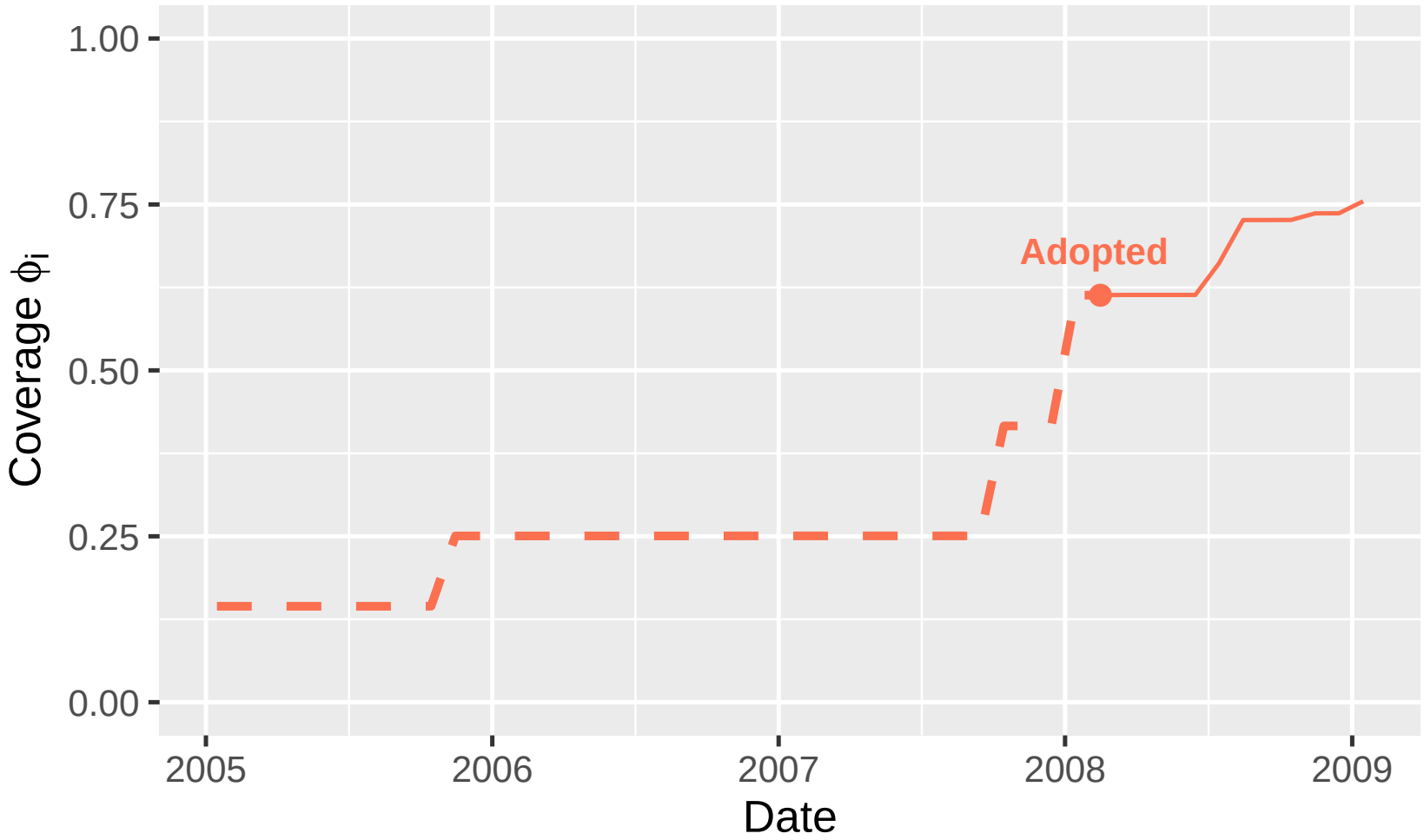


Individual Locations

Improvement on Isaacman et al. (2011) clustering algorithm

Individual Coverage: Example

Locate individuals using tower locations.



Coverage $\phi_{it}(\mathbf{z}^a) \in [0, 1]$

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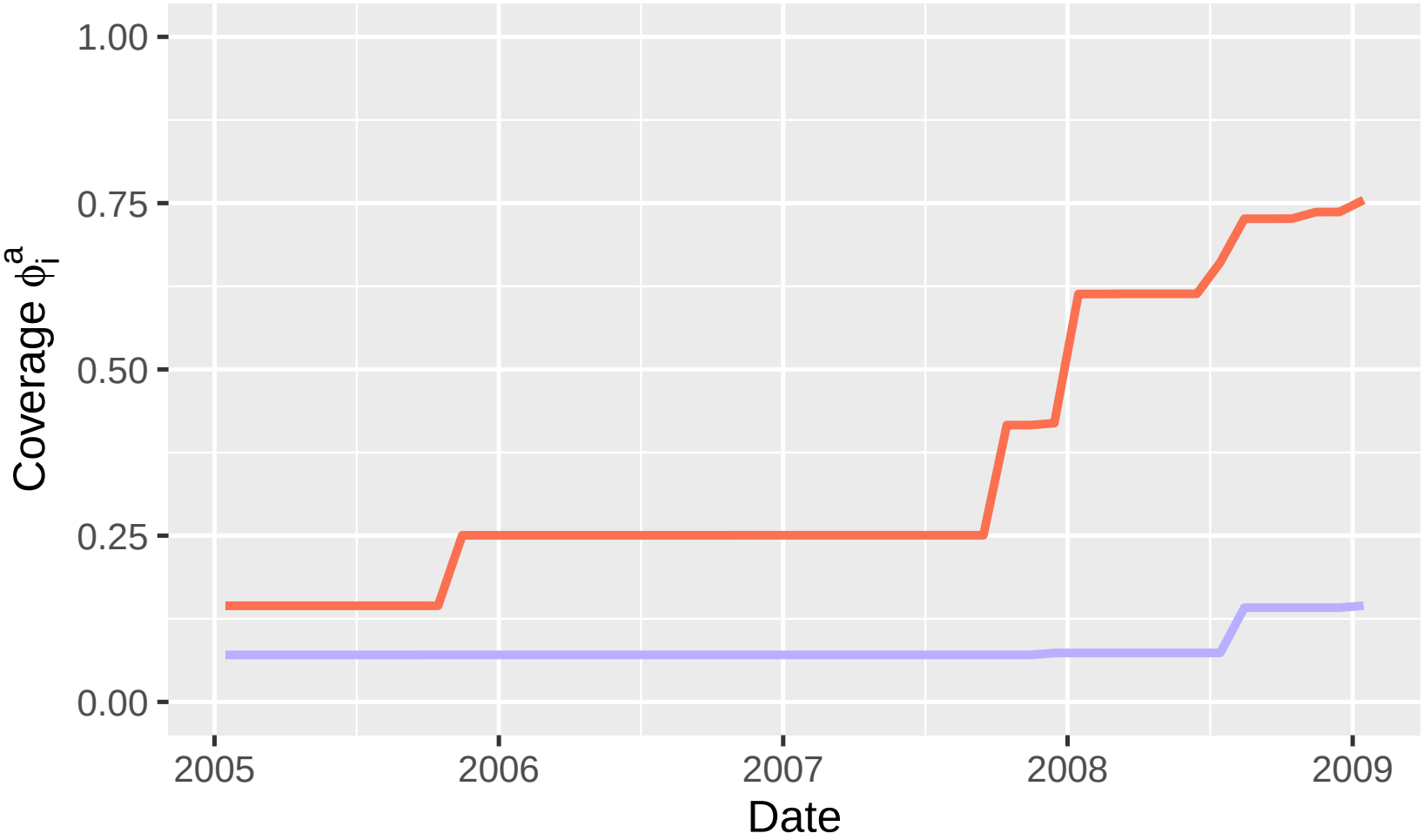

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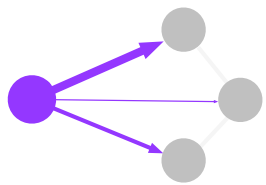
Utility from owning a handset

Each month owning a handset, i receives expected utility:

Outgoing Calls



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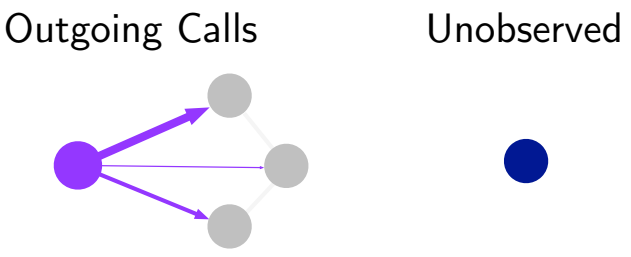
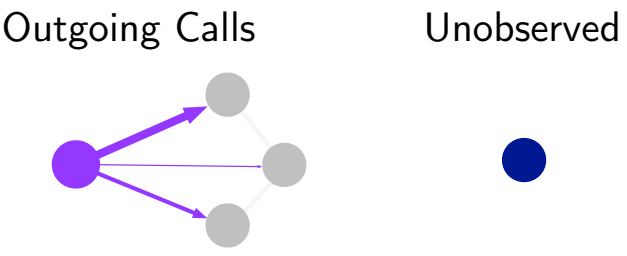


Utility from owning a handset

Each month owning a handset, i receives expected utility:



$$Eu_{it} = \sum_{j \in G_i, x_j \leq t} E_t u_{ijt}(\mathbf{p}_t, \phi_t(\mathbf{z}), \mathbf{a}) + \eta_i^{a_{it}}(1-\delta) - S \cdot 1_{\{a_{it} \neq a_{it-1}\}}$$

G_i: $i's$ contacts
x_j: j's adoption month

η_i^a: idiosyncratic benefit
S: switching cost

Adopt in two steps

1. Chose when to adopt a handset $x_i(\mathbf{p}, \mathbf{z}, \mathbf{x}_{-i}, \hat{\mathbf{a}}_{-i})$:
At time t, i expects that adopting in period x yields:

$$-\delta^x E_t p_x^{handset} + \sum_{s \geq x}^{\infty} \delta^s E u_{is}(\mathbf{p}_s, \mathbf{z}_s, \mathbf{x}_{-i}, [\mathbf{a}_i, \hat{\mathbf{a}}_{-i}])$$

- Believing that j will select operator $\hat{\mathbf{a}}_j(\mathbf{p}, \mathbf{z}_j, \phi_{median})$, optimal for calls to the median individual from j's location

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- Given actual adoption and operator sequence $\mathbf{a}_j$

$p_x^{handset}$: expected handset price index

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Adoption equilibria form a lattice

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Multiple Equilibria:
Adoption equilibria form a lattice
Index extreme equilibria: $\underline{e}^I$, $\bar{e}^I$, $\underline{e}^E$, $\bar{e}^E$ by adoption speed (fastest or slowest) and operator favor (I or E).

Firm Action Space

$F \in \{I, E\}$ commits to
price path $\mathbf{p}^F = \psi \cdot \mathbf{p}^{monopoly}$ and rollout plan $\mathbf{z}^F$ through $\tilde{T}$

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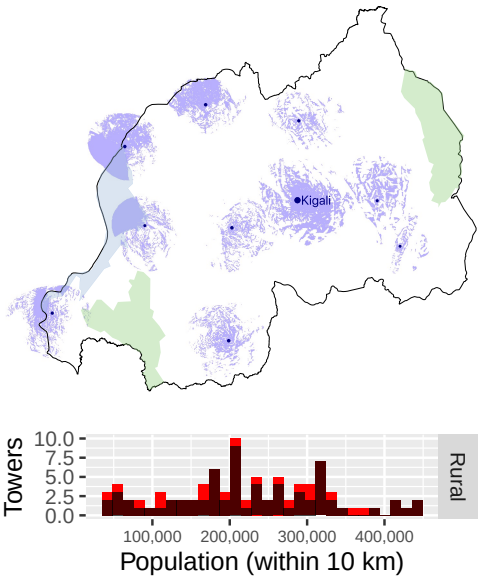
Entrant $\mathbf{z}^E =$

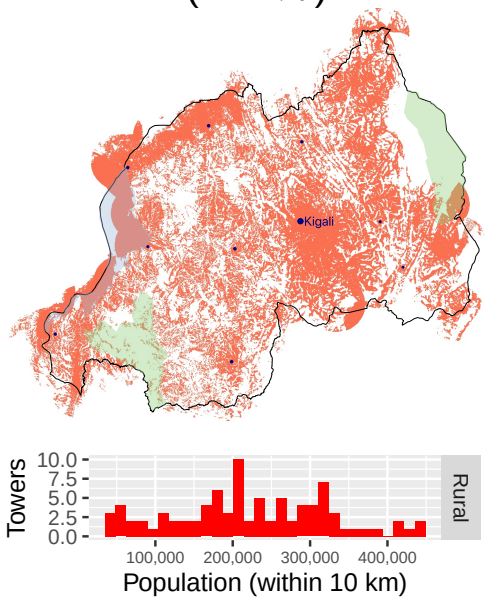
$\mathbf{z}_{(0\%)}$



Only urban towers

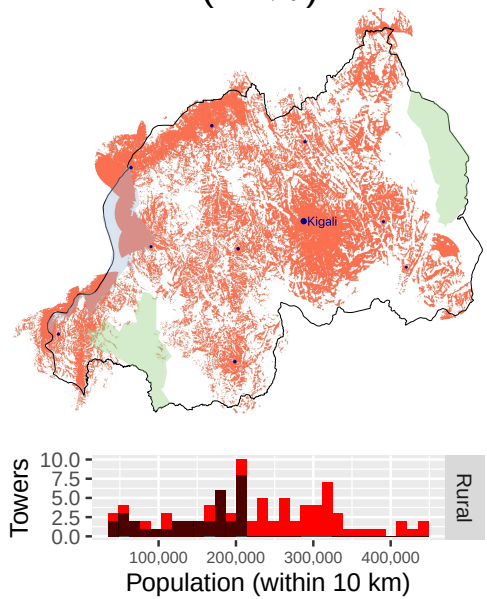
Incumbent $\mathbf{z}^I \in$

$\mathbf{z}_{(100\%)}$



All towers

$\mathbf{z}_{(50\%)}$



Omit low population towers

Coverage as of 2009 is shaded.

Firms

Profit $\pi_F^{\tilde{T}}(\mathbf{p}, \mathbf{z}, \mathbf{a}, \mathbf{x}) = R_F^{\tilde{T}}(\mathbf{p}, \mathbf{z}, \mathbf{a}, \mathbf{x}) - C_F^{\tilde{T}}(\mathbf{p}, \mathbf{z}, \mathbf{a}, \mathbf{x})$

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Revenue:

- Calls made by $F's$ subscribers (price p_t^F per second)
- Interconnection fees (f_{ij} per second, paid to firm that receives the call)

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Cost:

- Incremental cost for each second of calling (long run incremental cost)
- Rural towers: annualized cost of building and operating
- Fixed cost of operation

Handsets sold by perfectly competitive market
Government earns revenue from taxes on adoption and usage
$K_{rural} = \$80,584$ per year, $ic_{L_i, onnet_{ij}}^{direction}$ long run incremental cost reported to regulator
(RURA 2011 and PwC 2011)

Equilibrium e

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- Require on net price = off net price $(p_t^{a_{it}I} = p_t^{a_{it}E})$
- Firms commit to rollout plan and price sequence

Feasible terms: lower bound of potential benefits from competition

Competition in a Network Industry

Identification (Björkegren 2019)

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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.

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My Approach (similar to Ryan and Tucker 2010)
A link provides value because it enables calls:

$$\theta_{ij} = u_{ij}(p_t, \mathbf{z}_t)$$

Response to usage costs identifies value of link

Estimation

Main Demand Parameters (Björkegren 2019)

- **Call Decision.** β_{cost}, $\beta_{coverage}$ and call graph parameters (4.5 million) using maximum likelihood

$$\downarrow \text{compute } E_t u_{ijt}(p_t, \mathbf{z}_t)$$

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Additional Demand Parameters

Consumer survey with hypothetical questions:*

- *Switching cost:* $S = \$36.09$
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Firm Costs from regulator study.

Validate: later behavior Rwanda, other markets, analogues

Handset Adoption: Revealed Preference

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

$$\sum_{s=0}^{K-1} \delta^s E u_{ix_i+s} + (1-\delta^K)\eta_i^I \geq p_{x_i}^{handset} - \delta^K E_{x_i} p_{x_i+K}^{handset}$$

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

Robustness β_{cost}: value of links from call decision correspond with traditional adoption approach ($0.85-0.98 of call utility = $1 of handset price)

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

Validation

How well does this explain decisions that would be made in a competitive environment?

How do actors make decisions

...when competition eventually is introduced in Rwanda?

...in hypothetical survey responses?

...in more competitive SSA markets?

...in analogous situations within data?

- Handset market independent
  - Purchased at retail price, all imported
  - Operator sales records account for only 10% of activations
- Limited price specialization
- Quality regulated: tests similar (dropped call rate, call setup success, network availability, customer complaints)

Competition in a Network Industry

Simulation: Monopoly

Multiple equilibria due to coordination. Strategic complements: equilibria form a lattice. Bound entire set of equilibria $[\underline{e}, \bar{e}]$ (Topkis 1978):

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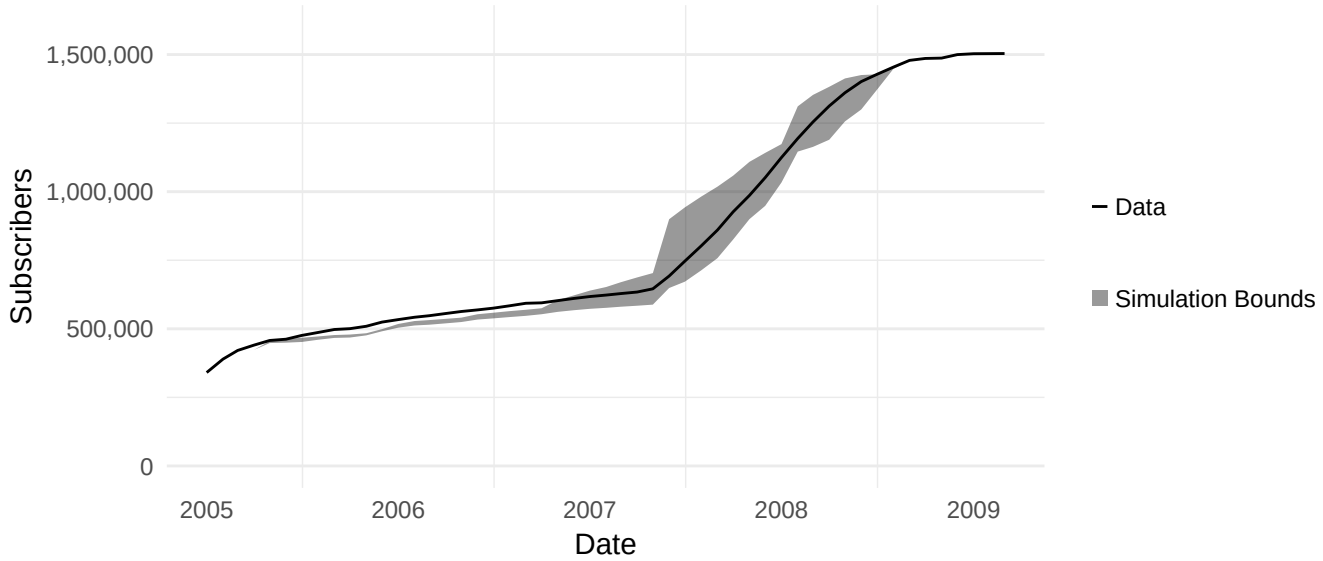

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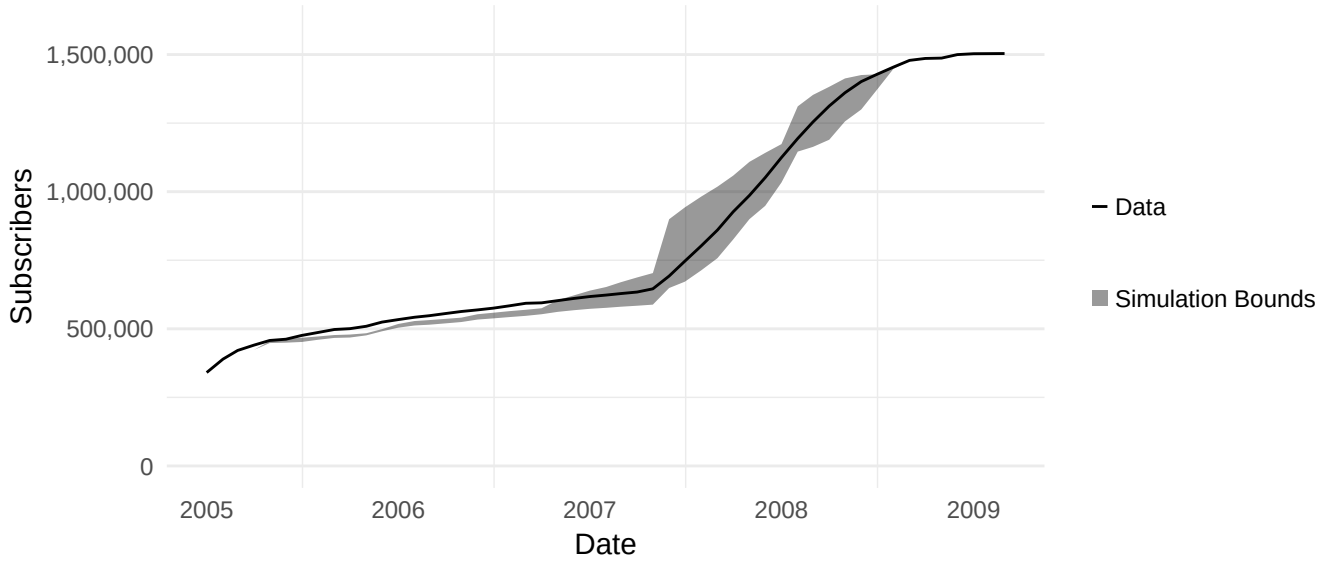

million $	**Consumer Surplus**	**Firm Profit**	**Gov Revenue**	**SS/GDP**
Baseline Monopoly	[244, 270]	[122, 140]	[65, 73]	∼2-3%

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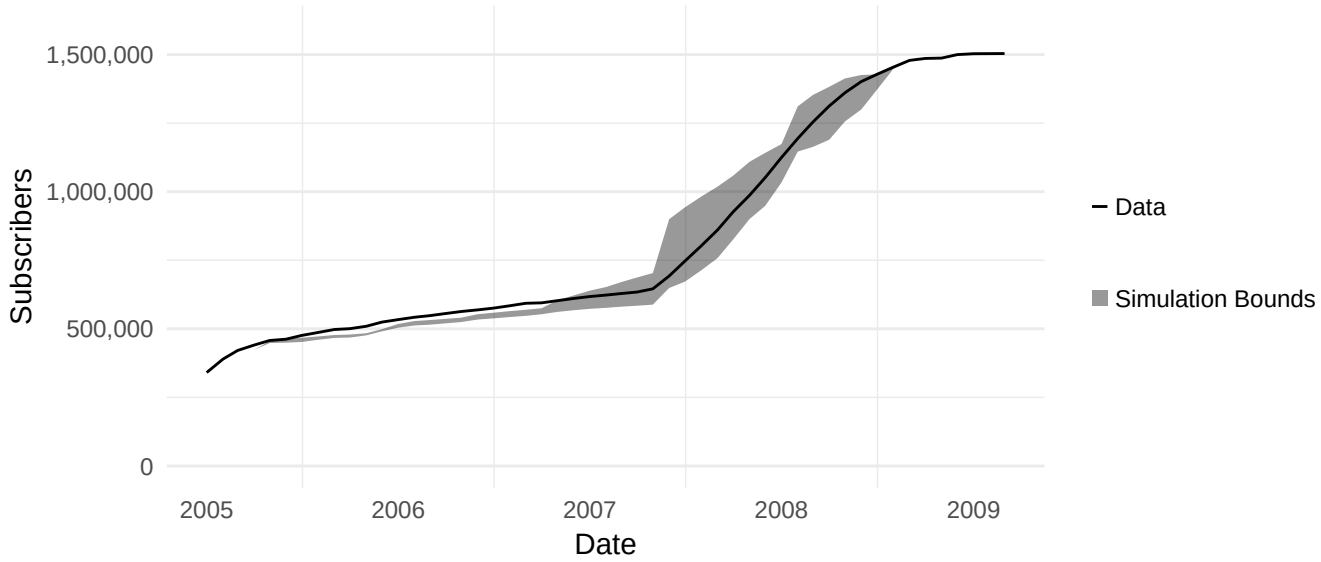

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Baseline Monopoly	[244, 270]	[122, 140]	[65, 73]	∼2-3%
Charge ev. competitive price	+330, +338	-51, -62	-2, -4	∼2%

Competition in a Network Industry

Competitive Equilibrium ($\bar{e}'$)

Interconnection $0.11/min

Coverage	IncumbentPrice	10pct	20pct	30pct	40pct	50pct	60pct	70pct	80pct	90pct	Full
Build all towers	10pct	-23, -1	-22, -2	-22, -2	-22, -2	-22, -2	-22, -2	-22, -2	-22, -2	-22, -2	-22, -2
Build all towers	20pct	39, -37	17, -1	18, -2	18, -2	18, -2	18, -2	18, -2	18, -2	18, -2	18, -2
Build all towers	30pct	**56**, -52	61, -25	45, -1	45, -2	45, -2	45, -2	45, -2	45, -2	45, -2	45, -2
Build all towers	40pct	51, -53	**66**, -28	**71**, -12	69, -1	69, -2	69, -2	69, -2	69, -2	69, -2	69, -2
Build all towers	50pct	38, -45	53, -22	69, -9	**85**, -5	88, -1	89, -2	89, -2	89, -2	89, -2	89, -2
Build all towers	60pct	30, -41	40, -14	54, -1	76, 5	**91**, 2	97, -2	97, -2	97, -2	97, -2	97, -2
Build all towers	70pct	24, -38	31, -8	40, 8	57, 17	77, 13	**98**, 5	**107**, -2	107, -2	107, -2	107, -2
Build all towers	80pct	19, -35	24, -4	30, 14	41, 27	55, 28	78, 20	101, 6	**110**, -2	**111**, -2	
Build all towers	90pct	15, -34	18, -1	23, 19	30, 35	39, 38	53, 36	78, 24	103, 5	110, -2	**110**, -2
Build all towers	Full	12, -33	14, 1	17, 22	23, 39	28, 47	37, 47	51, 41	76, 25	101, 5	108, -2
Don't build last 34 rural towers	10pct	-22, -1		-22, -2							
Don't build last 34 rural towers	20pct	39, -38	18, -1								
Don't build last 34 rural towers	30pct	52, -50	60, -25	45, -1							
Don't build last 34 rural towers	40pct	45, -51	60, -25	71, -12	69, -1						
Don't build last 34 rural towers	50pct	32, -43	48, -21	64, -6	84, -4	88, -1					
Don't build last 34 rural towers	60pct	23, -38	33, -11	48, 2	70, 8	88, 3	97, -1				
Don't build last 34 rural towers	70pct	17, -35	23, -5	34, 11	50, 20	70, 18	96, 6	106, -2			
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Don't build last 34 rural towers	90pct	10, -32	12, 1	16, 23	23, 39	32, 43	46, 40	70, 29	100, 7	109, -2	
Don't build last 34 rural towers	Full	8, -32	10, 2	11, 25	15, 44	21, 51	30, 51	44, 46	68, 31	98, 6	107, -2

Entrant ■ [Incumbent ■ in rows]

Profit (million $), upper adoption equilibrium. **Best response** denoted in bold; equilibrium underlined.

Outcomes as Function of Interconnection Rate

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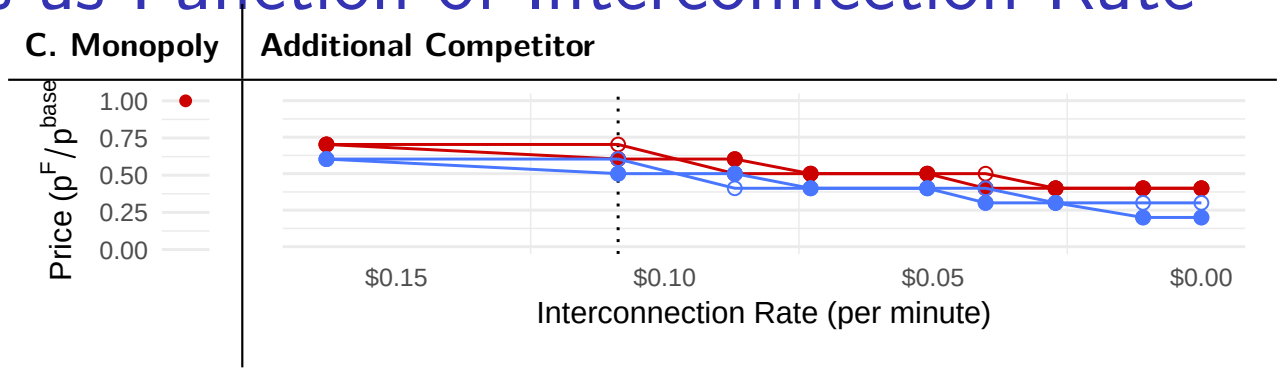

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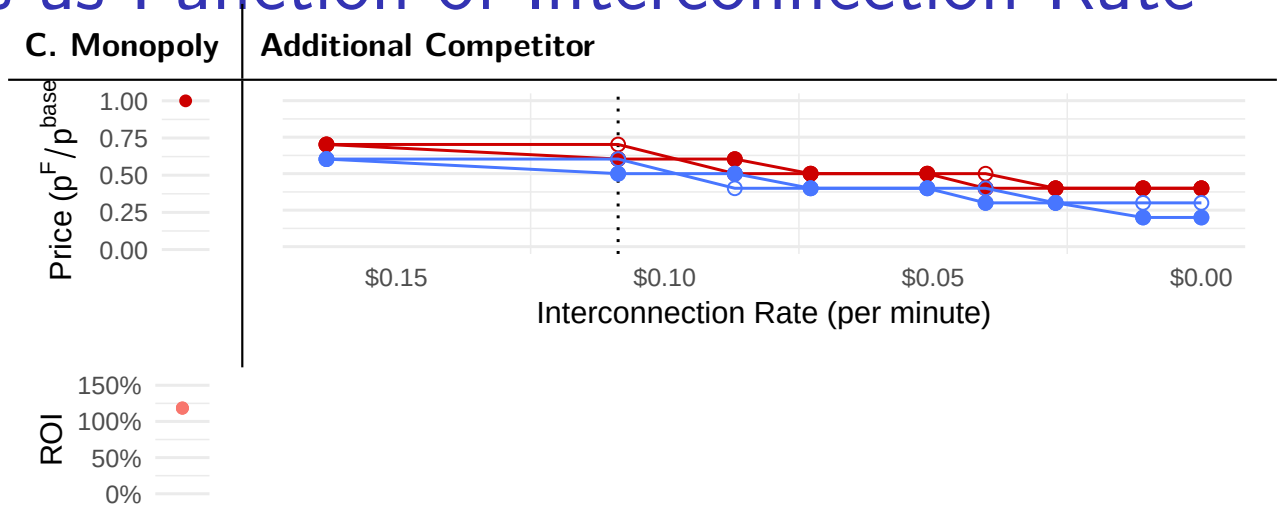

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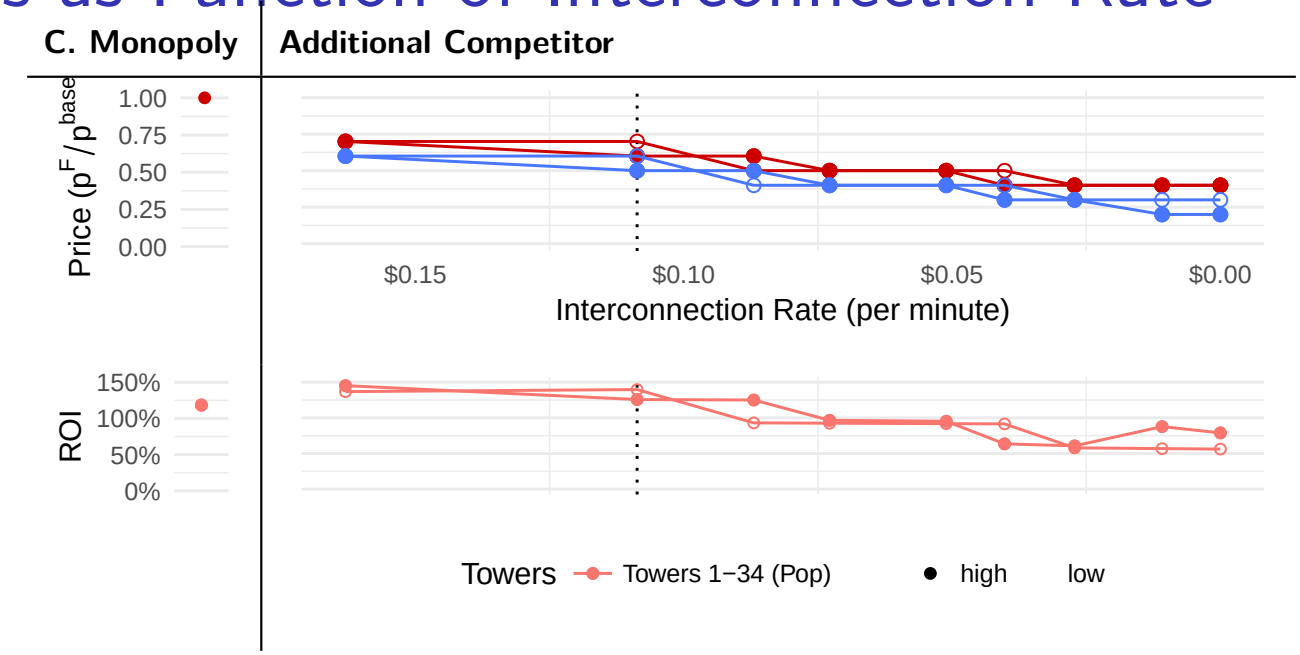

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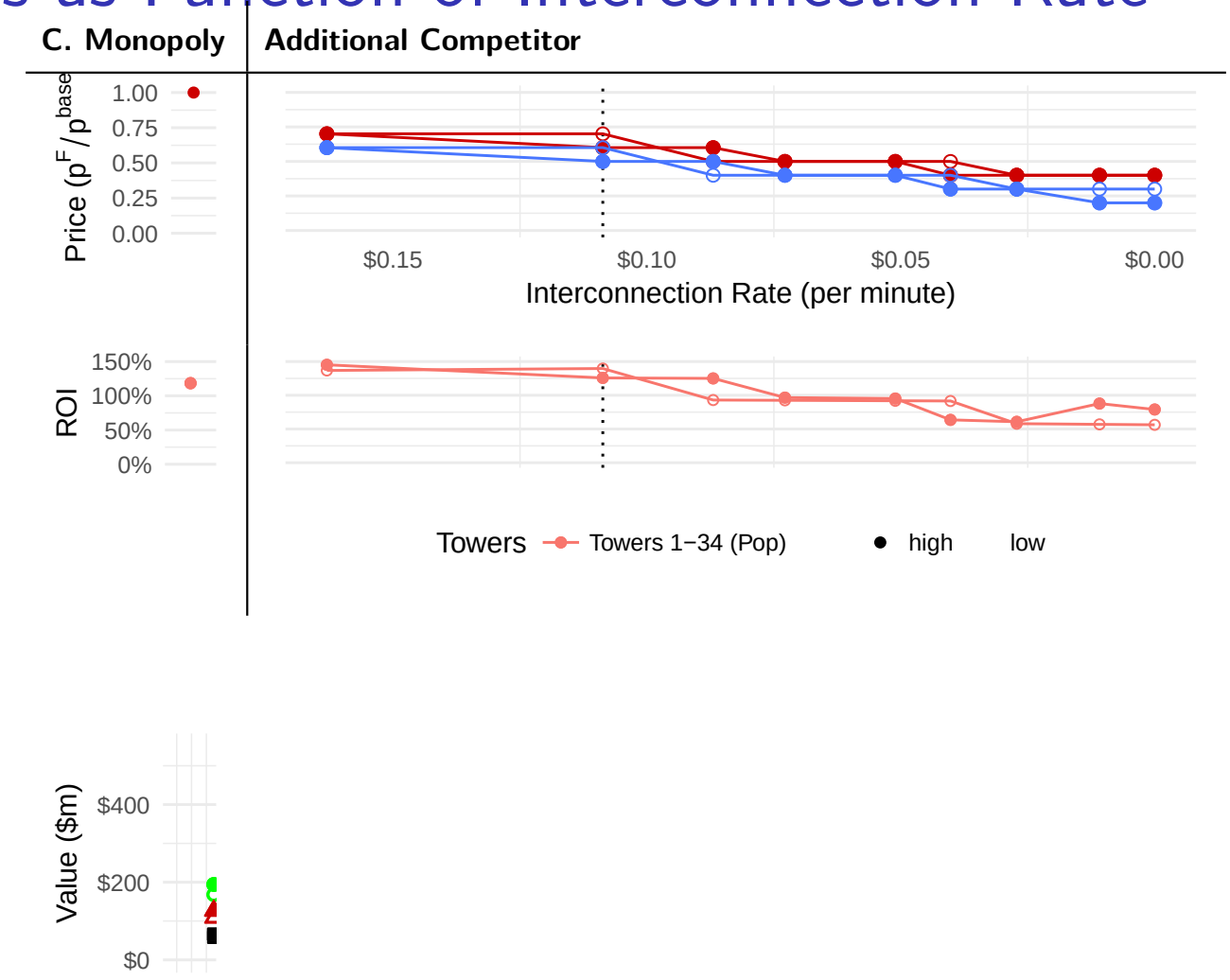

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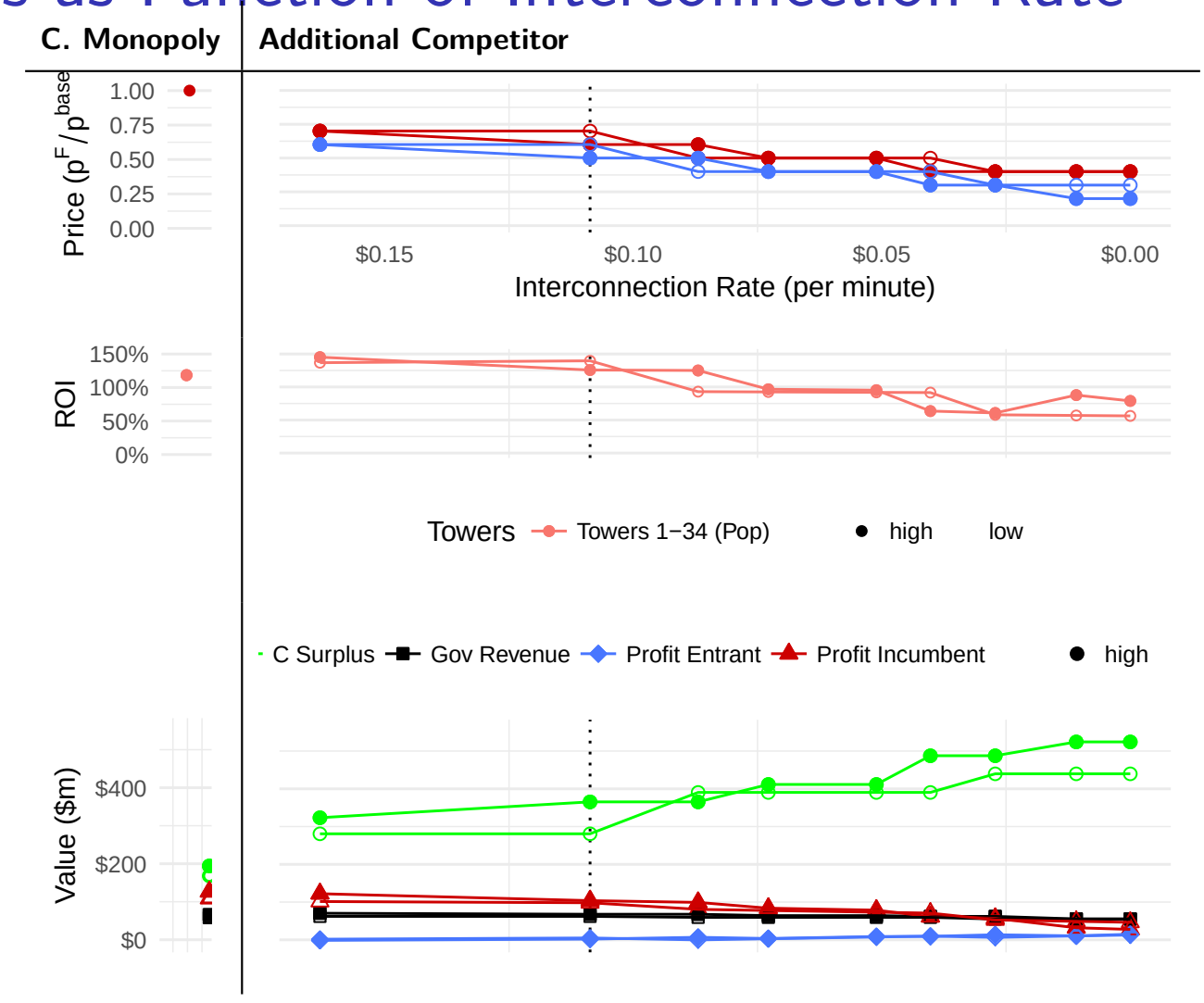

Welfare +≈1% GDP, 3-5% official development aid

Investment in coverage under monopoly

Urban Network

Rural

Investment in coverage under monopoly

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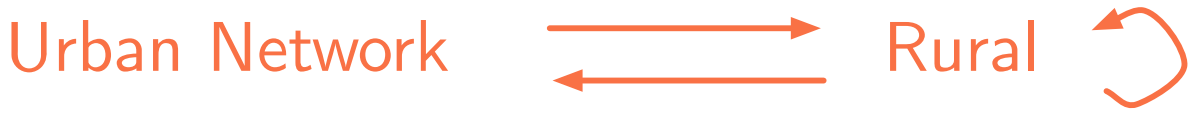
Investment in coverage under monopoly



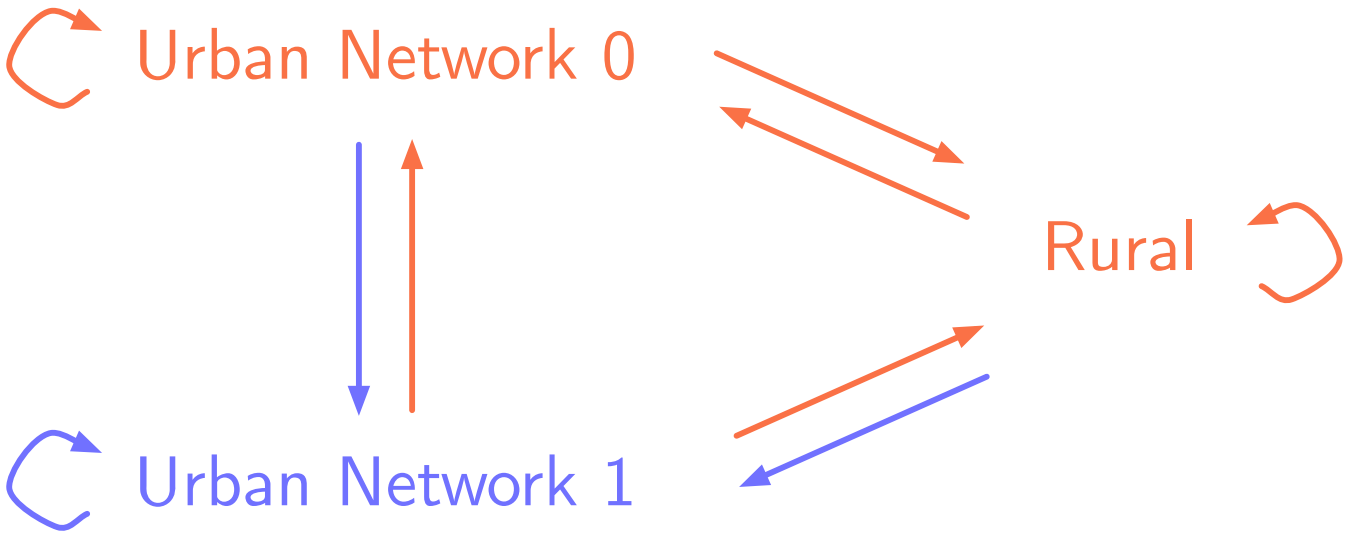
Investment in coverage under monopoly

Impact of building rural towers under competition

Urban Network 0

Urban Network 1

Impact of building rural towers under competition



Impact of building rural towers under competition

	Equilibrium		Effect of Incumbent Building			
			Low Population Towers			
	Call Prices		ΔProfit		ROI	
	$\frac{\mathbf{p}^I}{\mathbf{p}^{base}}$	$\frac{\mathbf{p}^E}{\mathbf{p}^{base}}$	Incumbent	Entrant	Incumbent	Social
			$m	$m		
Baseline Scenario	1.00, 1.00	-	1.27, 1.23	-	0.98, 1.00	6.64, 6.49

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			$m	$m		
Baseline Scenario	1.00, 1.00	-	1.27, 1.23	-	0.98, 1.00	6.64, 6.49
Additional Competitor						
...fixing operator			0.39, 0.22	0.022, 0.002	0.43, 0.25	6.89, 6.92

Impact of building rural towers under competition

	Equilibrium		Effect of Incumbent Building			
			Low Population Towers			
	Call Prices		ΔProfit		ROI	
	$\frac{\mathbf{p}^I}{\mathbf{p}^{base}}$	$\frac{\mathbf{p}^E}{\mathbf{p}^{base}}$	Incumbent	Entrant	Incumbent	Social
			$m	$m		
Baseline Scenario	1.00, 1.00	-	1.27, 1.23	-	0.98, 1.00	6.64, 6.49
Additional Competitor						
...fixing operator			0.39, 0.22	0.022, 0.002	0.43, 0.25	6.89, 6.92
...add'l effect of operator choice			1.60, 1.65	-1.30, -1.26	-	-

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Baseline Scenario	1.00, 1.00	-	1.27, 1.23	-	0.98, 1.00	6.64, 6.49
Additional Competitor	0.70, 0.60	0.60, 0.50	1.99, 1.87	-1.27, -1.25	1.40, 1.26	7.74, 7.96
...fixing operator			0.39, 0.22	0.022, 0.002	0.43, 0.25	6.89, 6.92
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Diagnosing effects of network competition on investment

Forces:

1. Lower prices $(-)$
2. Network effects not internalized $(-)$
   - How large are ripple effects?
     - Are marginal consumers connected?
     - Structure of the network
3. Business stealing effect $(+)$
   - How responsive are consumers to the desired dimension of quality/investment?
   - How large is the mass of marginal consumers?

Diagnosis using properties of monopoly network

Interconnection important; moderate internal spillovers to urban network

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million $	All links	Urban-Urban	Urban-Rural	Rural-Urban	Rural-Rural
Baseline Revenue	[165, 187]	[95, 108]	[24, 28]	[17, 18]	[30, 33]

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Impact					
Don't build rural network	**-32, -42**	**-14, -20**	**-6. -8**	**-4, -4**	**-9, -10**

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Baseline Revenue	[165, 187]	[95, 108]	[24, 28]	[17, 18]	[30, 33]
Impact					
Don't build rural network	**-32, -42**	**-14, -20**	**-6. -8**	**-4, -4**	**-9, -10**
...only proximal	-30, -35	-12, -15	-6, -7	-4, -4	-8, -9
...ripple effects	-2, -7	-1, -5	-0, -1	-0, -0	-0, -1

Under competition prices may be lower; firm may partially expand coverage.
Connections classified by subscriber main location, not location at time of call.

Impact of Alternate Policies

		Outcomes (January 2005-December 2008)					
	Switch. Cost s $	Call Prices $\frac{\mathbf{p}^I}{\mathbf{p}^{base}}$	$\frac{\mathbf{p}^E}{\mathbf{p}^{base}}$	C. Surplus $m	Incumbent Profit $m	Entrant Profit $m	Gov. Revenue $m
Baseline Scenario	-	1.00, 1.00	-	168, 194	108, 126	0, 0	58, 68
Additional Competitor	36	0.70, 0.60	0.60, 0.50	281, 365	98, 104	5, 2	62, 68
Number portability	19	0.50, 0.60	0.50, 0.50	384, 366	88, 101	-1, 5	61, 68
Delayed entry (7/2008)	36	0.70, 0.70	0.40, 0.30	259, 284	98, 109	2, 2	59, 65

Each row presents the outcomes under a given policy, in the low and high incumbent-favoring equilibria. All competitive results are under $f = \$0.11$/minute; unless denoted, entry is 1/2005. Profits omit fixed costs of operation and license fees. Utility and revenue reported in 2005 U.S. Dollars, discounted at a rate of δ. Consumer surplus includes the surplus utility each individual receives from the call model through December 2008, minus the cost of holding a handset from the time of adoption until December 2008.

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- Imposing full eq prices:
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Competition in a Network Industry

Method

- Observe network prior to being split by competition
- Carefully model choice under competition

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Evaluate wide class of policies

- Encouraging earlier entry
  - Can increase incentives to invest in rural towers
  - Increase welfare $\approx$ 1% GDP, 3-5% official development aid
- Level of compatibility: importance effect
- Switching cost (number portability): small effect
- Timing of entry: large effect