

Spillover Effects in Complementary Markets: A Study of the Indian Cell Phone and Wireless Service Markets

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This Paper

- Studies how spillovers between two complementary markets affect firm entry and product choice
 - Spillovers occur when the value of a product in one market depends on products in another market
 - ▶ e.g. EV & charging, hardware & software, Internet & streaming services, ...
 - They affect demand, firm pricing, and ...
- Highlights and quantifies a new channel: Presence of technologically more advanced int'l firms in an open market
 - Contributes to the development of a complementary market by encouraging entry (firm entry)
 - Affects domestic firms in the open market by increasing their profits from new products (product variety)

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Setting

Indian mobile industry during the 4G rollout

■ Two markets

- **cell phone market:** int'l cell phone firms play an important role and occupy the higher end of the market
- **wireless service market:** mostly Indian carriers

■ Two complementary markets

- a consumer needs both a cell phone and a service plan to enjoy mobile service
- only enjoys the advanced features and the fast speed with a 4G phone/4G network combination

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The Channel

Cell phone market

Int'l firms more likely to sell
4G phones

Wireless service market

Carriers more likely to
start 4G networks



The Channel

Cell phone market

Int'l firms more likely to sell
4G phones

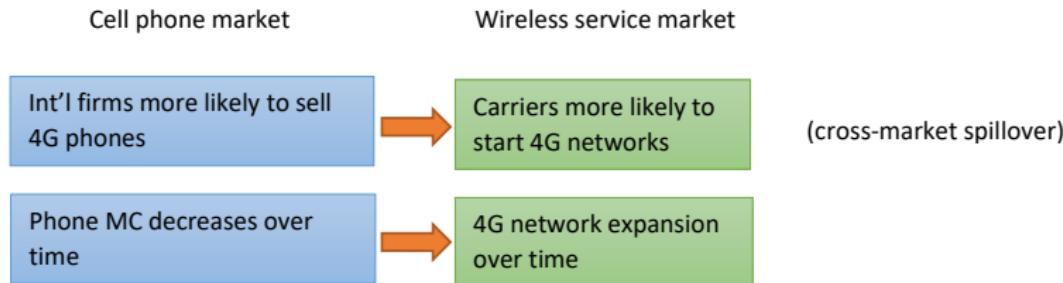
Wireless service market

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(cross-market spillover)

The Channel



The Channel

Cell phone market

Int'l firms more likely to sell
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Wireless service market

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Phone MC decreases over
time

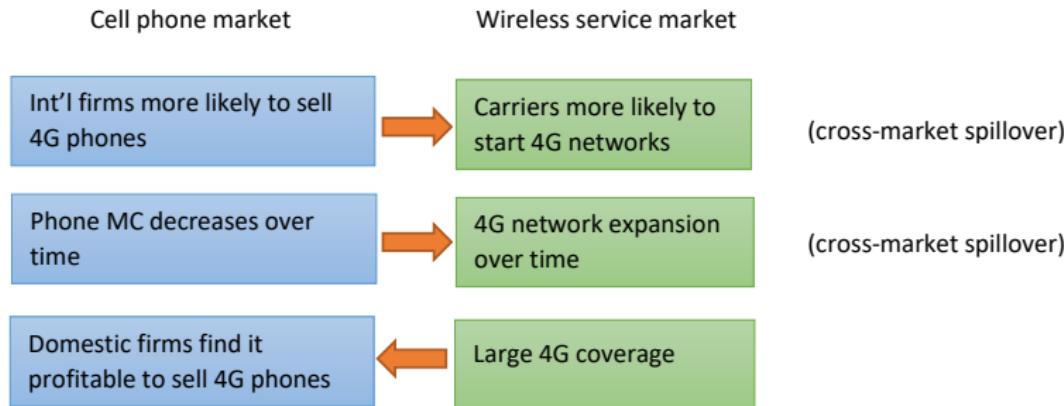
4G network expansion
over time



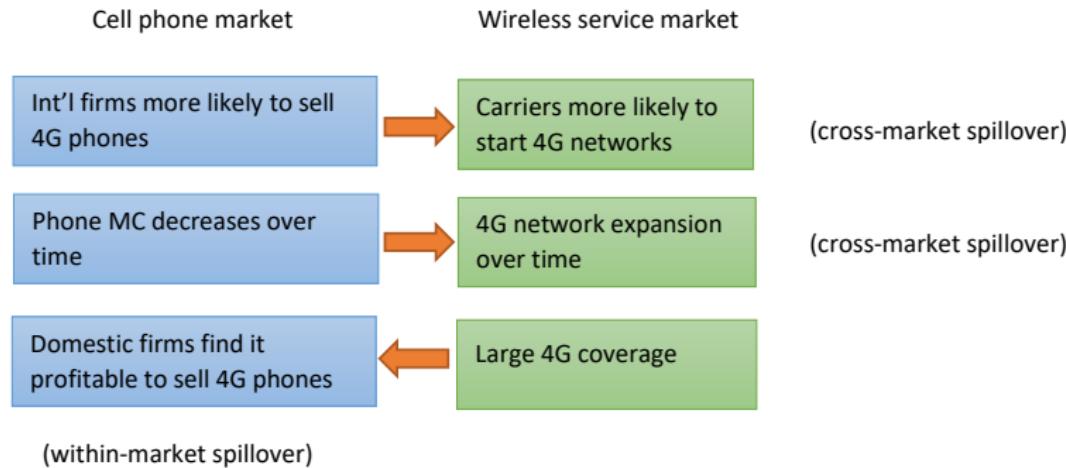
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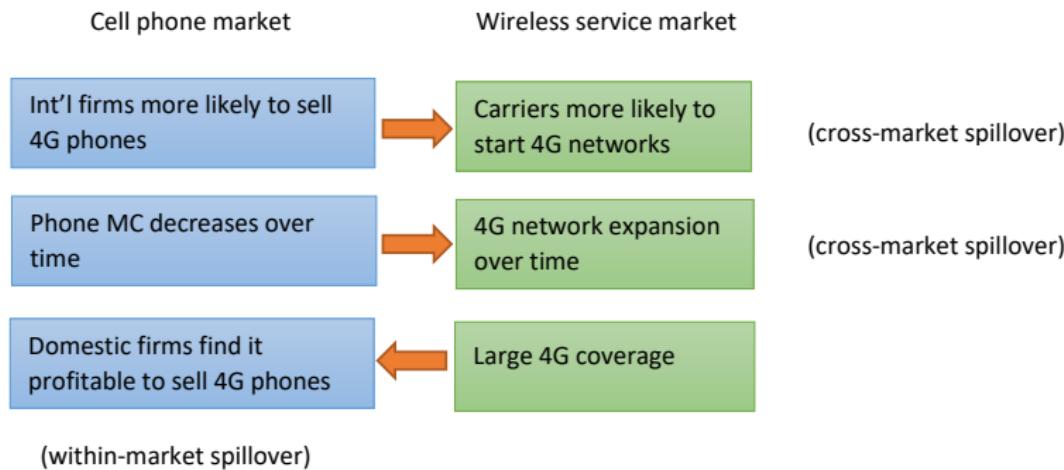
The Channel



The Channel



The Channel



- The presence of the technologically more advanced int'l cell phone firms speeds up the expansion of 4G networks and may accelerate the introduction of 4G phones by domestic firms, benefiting consumers

Research Questions

- 1 How does the presence of int'l cell phone firms affect the rollout of 4G networks?
 - cross-market effect
- 2 How does the presence of int'l cell phone firms affect the introduction of 4G phones by Indian cell phone firms?
 - within-market effect
- 3 What is the welfare effect?
 - margins: 4G networks, product variety, and prices

What We Do

- Develop a structural model of demand, network expansion, product choice, and pricing in the Indian cell phone and wireless service markets
- Estimate the model using data on phones, plans, and networks
 - four key empirical findings
- Quantify the spillover effects and the welfare effects
 - two sets of counterfactual simulations

Literature Review and Contributions (1)

1. We study two complementary markets simultaneously

- Literature on spillovers b/w complementary markets: Gandal, Kende, and Rob (2000), Lee (2013), Li (2019), Springel (2021), etc.
- This paper: a new topic and a new pair of markets
 - How the presence of int'l firms in the cell phone market helps the development of the complementary wireless service market, and in turn, affects domestic firms in the cell phone market
 - How consumers benefit from such spillovers

Literature Review and Contributions (2)

2. We study both the product choices of cell phone firms and the network expansion decisions of carriers

- Literature on endogenous product choice: Draganska, Mazzeo and Seim (2009), Fan (2013), Eizenberg (2014), Wollmann (2018), Fan and Yang (2020, 2024), etc.
- Literature on dynamic entry games: Collard-Wexler (2013), Dunne et al. (2013), Sweeting (2013), Fan and Xiao (2015), Mohapatra and Zhang (2020), etc.
- This paper: we embed a static cell phone product choice model in a dynamic network expansion model to study the endogenous choices in both markets and the interdependence between them

Literature Review and Contributions (3)

3. We study the Indian mobile industry

■ Literature on the telecommunication industry:

Cell phone market: Björkegren (2019), Fan and Yang (2020), etc.

Service market: Fan and Xiao (2015), Granja (2024), and Elliott, Houngbonon, Ivaldi, and Scott (2024), etc.

■ This paper:

- Both markets and their interdependence
- In a developing country, similar to Björkegren (2019) and Granja (2024)

Literature Review and Contributions (4)

4. We study the effect of opening a market to international competitors

- **Foreign competition leading to reduced firm markups:** Levinsohn (1993), Har-rison (1994), Krishna and Mitra (1998), etc. See Tybout (2008) for a survey
- **Mixed evidence on productivity externalities** of foreign direct investment on domestic firms. See Harrison and Rodríguez-Clare (2010) for a survey
- **This paper:** a study where int'l competitors have a spillover effect on domestic firms through helping the development of a complementary market

Industry Background

- **Cell phone market:** 4 Indian, 6 other-Asian, and 2 non-Asian cell phone firms
- **Wireless service market:** 8 carriers – Airtel, Vodafone, Idea, BSNL, Reliance Jio, Reliance Communications, Aircel, MTNL
- **22 telecommunications regions:** 3 Metro regions (most developed: Delhi, Kolkata, Mumbai), 5 Category-A, 8 Category-B, and 6 Category-C regions (least developed) [▶ map](#)

Data

- 2011 – 2018Q2

- Cell phone data

- price and sales from Counterpoint Research
- product characteristics – hand collected

- Wireless service data

- national level: price and sales for each carrier/technology/quarter combination from GSMA Intelligence
- regional level: whether a given carrier offers a particular technology in each quarter [▶ video](#)
- define: plan = carrier/technology

- [▶ summary stats](#)

Data Pattern 1

1. Int'l firms, especially other Asian firms, play an important role in the cell phone market

Origin	Firm	Sales Share	Total
Indian	Intex	3.3%	
Indian	Jio	15.7%	
Indian	Lava	3.2%	
Indian	Micromax	6.0%	28%
Other-Asian	Gionee	1.3%	
Other-Asian	Lenovo	4.9%	
Other-Asian	Oppo	4.8%	
Other-Asian	Samsung	33.0%	
Other-Asian	Vivo	6.2%	
Other-Asian	Xiaomi	13.7%	64%
Non-Asian	Apple	1.7%	
Non-Asian	Microsoft/Nokia	6.1%	8%

- Sales share = $(\text{3G/4G phone sales by a firm in the sample}) / (\text{total 3G/4G phone sales})$

Data Pattern 2

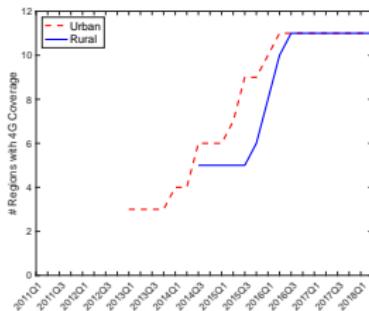
2. While Indian cell phone firms do well in the lower end of the market, international firms dominate the higher end.

Origin	4G Phone Sales Share		
	Low-Price	Medium-Price	High-Price
Indian	59%	5%	1%
Other Asian	41%	95%	89%
Non-Asian	-	-	10%

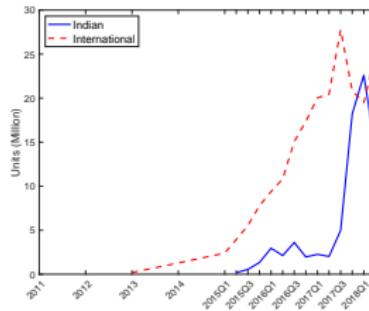
Data Pattern 3

3. Co-movement in the two markets: 4G network coverage expanded and 4G phone sales increased

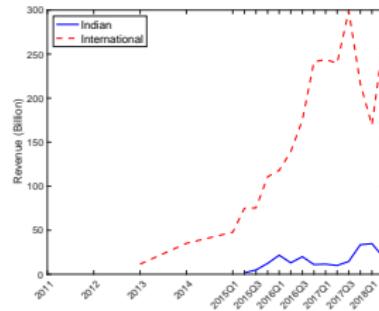
(a) # 4G Regions



(b) Sales of 4G Phones



(c) Rev. of 4G Phones



- Consistent with Pattern 2, the increase in Indian 4G phone sales is largely driven by a set of low-end phones



Data Patterns: Summary

- Int'l cell phone firms play a big role in the phone market
- They started selling 4G phones first and Indian firms later introduced low-end 4G phones
- Concurrent 4G phone sales growth and 4G network expansions

Model Outline

Demand

$$s^{ph} \left(\underbrace{p_t^{ph}}_{\text{phone prices}}, \underbrace{p_t^{pl}}_{\text{plan prices}}, \underbrace{\mathcal{J}_t^{ph}}_{\text{available phones}}, \underbrace{\{\mathcal{R}_{ct}\}_{c=1}^C}_{\text{each carrier's network}} \right), s^{pl}(\dots)$$

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Static product
choice model

Dynamic carrier
4G network
expansion game

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Static product choice model

Stage-2 pricing eqm:

$$p^{*ph}(\mathcal{J}_t^{ph}, \{\mathcal{R}_{ct}\}_{c=1}^C), p^{*pl}(\dots)$$

Stage-1 product choice eqm: $\mathcal{J}_t^*(\{\mathcal{R}_{ct}\}_{c=1}^C)$ Eqm carrier profit given networks: $\pi_{ct}(\{\mathcal{R}_{ct}\}_{c=1}^C)$ **Dynamic carrier 4G network expansion game**

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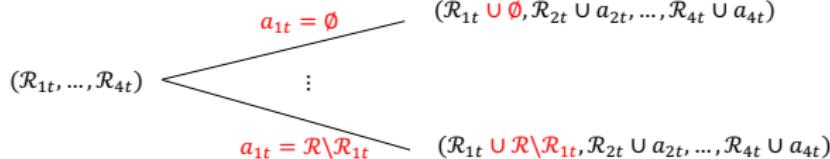
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Dynamic carrier 4G network expansion game

Carrier 1 expansion decision a_{1t} 

$$\pi_{1t}(\mathcal{R}_{1t}, \dots, \mathcal{R}_{4t})$$

$$-f(a_{1t}) + \varepsilon(a_{1t})$$

$$E_{(a_{2t}, a_{3t}, a_{4t})} V_{1t+1}(\mathcal{R}_{1t} \cup a_{1t}, \mathcal{R}_{2t} \cup a_{2t}, \dots, \mathcal{R}_{4t} \cup a_{4t})$$

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Dynamic carrier 4G network expansion game

Carrier 1 expansion decision a_{1t}

$$a_{1t} = \emptyset$$

$$(\mathcal{R}_{1t} \cup \emptyset, \mathcal{R}_{2t} \cup a_{2t}, \dots, \mathcal{R}_{4t} \cup a_{4t})$$

⋮

$$a_{1t} = \mathcal{R} \setminus \mathcal{R}_{1t}$$

$$(\mathcal{R}_{1t} \cup \mathcal{R} \setminus \mathcal{R}_{1t}, \mathcal{R}_{2t} \cup a_{2t}, \dots, \mathcal{R}_{4t} \cup a_{4t})$$

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Model Details (1): Demand

- A consumer needs both a phone (indexed by j) and a wireless plan (indexed by k)
- Utility:
$$u_{ijkt} = x_{jkt}\beta - \alpha_{it}(p_{jt} + \psi p_{kt}) + \xi_{jt}^{(ph)} + \zeta_{kt}^{(pl)} + \varepsilon_{ijkt}$$

↑
 $(x_{jt}^{(ph)}, x_{kt}^{(pl)}, \mathbb{1}(4G,4G)_{jk})$
- Restrictions on the jk combination: (3G phone, 4G plan) \times ; (2G phone, 3G or 4G plan) \times ; (JioPhone, non-Jio plan) \times
- Model implications: s_{jkrt} (market share for a combination jk in region r at time t)
- Aggregation \Rightarrow Market shares: (s_{jt}, s_{kt})

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Model Details (2): Static Product Choice Game

Decisions

To be estimated

Stage 1. Product choice game
Cell phone firms choose phones given the current network

FC

Stage 2. Pricing game
Cell phone firms choose phone prices and carriers choose plan prices given the set of phones and plans

MC

- Details: second-stage pricing game ▶
- Details: first-stage product choice game ▶

Model Details (3): Dynamic 4G Network Expansion

- **Dynamic:** entering a region with 4G services is an absorbing state
- **Finite periods:** by the end of our sample, all four carriers had entered in almost all regions studied in the paper
- **Four carriers:** we focus on the four largest carriers that account for 95% of the 4G services

Estimation Results: Demand

	Est.	Std. Error
Price (10K INR)	-36.66***	8.82
Price × Income	5.36***	1.50
Screen Size (Inch)	0.69***	0.17
Camera (MP)	0.09***	0.04
Storage (10GB)	0.97***	0.22
RAM (GB)	0.69***	0.25
Battery Capacity (Ah)	0.29	0.19
Plan Price Multiplier	56.65***	4.35
$\mathbb{1}(4G\ Phone) \times \mathbb{1}(4G\ Network)$	4.72***	1.26
Phone Technology FE	Yes	
Plan Technology FE	Yes	
cell phone firm FE	Yes	
Carrier FE	Yes	
Time FE	Yes	
Jio First Year FE	Yes	

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▶ Identification

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Complementarity
b/w 4G handsets
& 4G networks

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Estimation Results: Marginal Cost

	Est.	Std. Error
Constant (γ_0)	-0.45***	0.12
Quality (τ_0)	0.14***	0.01
$\mathbb{1}(\text{Indian})$ (γ_1)	-1.80***	0.27
Quality $\times \mathbb{1}(\text{Indian})$ (τ_1)	0.18***	0.05
Time Trend $\times \mathbb{1}(\text{Indian})$	-0.06***	0.01
Time Trend $\times \mathbb{1}(\text{International})$	-0.07***	0.01
Jio Dummy	-0.06	0.05

*** $p < 0.01$, ** $p < 0.05$.

▶ quality

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MC increases
with quality

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Domestic cost advantage at producing low-quality phones

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But Indian firms' mc increase at a faster speed with quality

▶ quality

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MC decreases over time

▶ quality

Estimation Results: Markups

Table: Estimated 4G Phone Markups (INR)

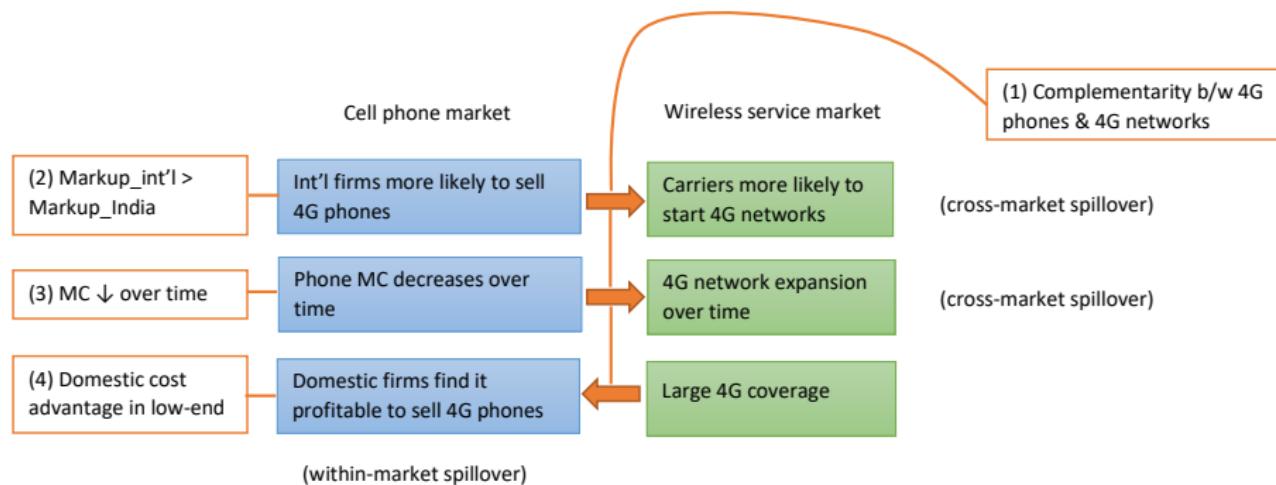
Quantile	25%	50%	75%
Indian 4G phones	1,023	1,055	1,106
International 4G phones	1,143	1,271	1,758

Finding: Higher markups for international cell phone firms

Estimation Results: Summary

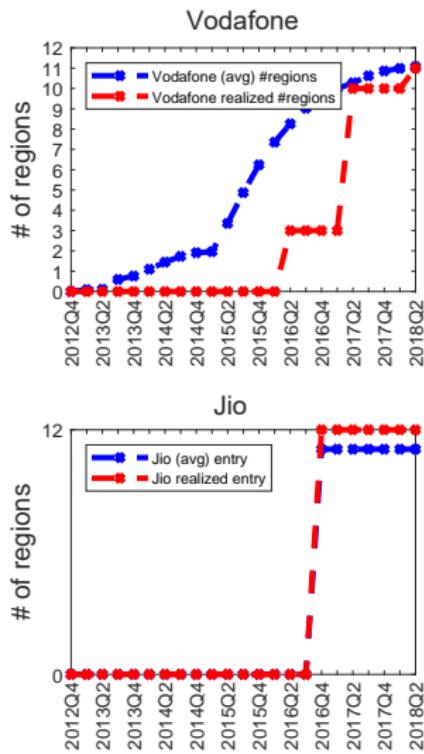
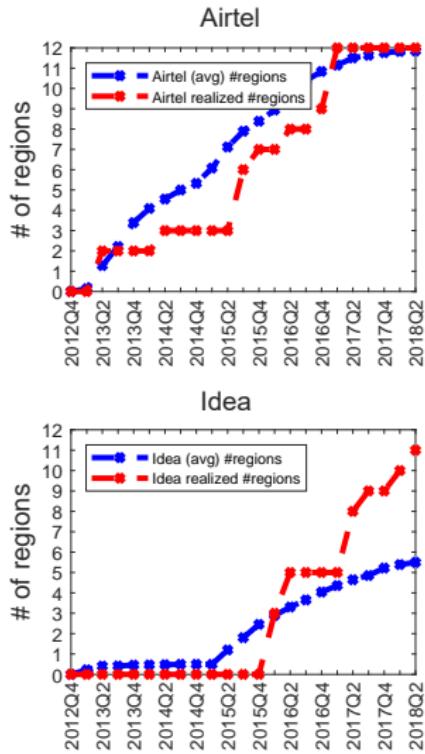
- 1 Complementarity between 4G phones and 4G networks
- 2 Higher markups for int'l cell phones
- 3 Declining marginal cost
- 4 Domestic cost advantage at producing low-quality phones

Key Findings and the Channel



- **Finding 1** is the foundation for the spillover effects
- **Findings 2 and 3** support the cross-market spillover effect at the initial stage of the 4G rollout and in the later stage of the continued expansion
- **Finding 4** gives rise to the within-market spillover effect so that Indian cell phone firms benefit from the presence of int'l cell phone firms

Model Fit



Counterfactual Simulations

- Two sets of counterfactual simulations
- Fixed:
 - 2G and 3G networks
 - each cell phone firm's potential products
- Recomputed:
 - 4G network in each period
 - set of phones in each period
 - phone prices and plan prices in each period

CF1 Details

CF1. ban on budget Chinese phones

- Chinese cell phone firms face a price floor of 12,000 INR
(In 2018Q2, 70% of Chinese phones are priced below 12,000 INR)

- Affects prices
- Affects product choices
- Affects **4G networks**, which, in turn, affects cell phone firms' product choices and pricing competition

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CF2 Details

CF 2. Effect of protectionism in subsidy design

- In the presence of spillover effects, subsidies to 4G phones can accelerate the 4G rollout
 - Consumption subsidy to consumers for purchasing a 4G phone
 - Fixed-cost subsidy to cell phone firms for selling a 4G phone
- Compare two subsidy policies
 - Unrestricted subsidy policy: all 4G phones are eligible
 - Protectionist subsidy policy: only Indian 4G phones are eligible
- Outcomes of interest: as the subsidy amount varies,
 - Consumer surplus
 - Carrier profits
 - Domestic cell phone firm profits
 - Subsidy expenditure

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CF 2. Effect of protectionism in subsidy design

- In the presence of spillover effects, subsidies to 4G phones can accelerate the 4G rollout
 - Consumption subsidy to consumers for purchasing a 4G phone
 - Fixed-cost subsidy to cell phone firms for selling a 4G phone
- Compare two subsidy policies
 - Unrestricted subsidy policy: all 4G phones are eligible
 - Protectionist subsidy policy: only Indian 4G phones are eligible
- Outcomes of interest: as the subsidy amount varies,
 - Consumer surplus
 - Carrier profits
 - Domestic cell phone firm profits
 - Subsidy expenditure

CF1 Results

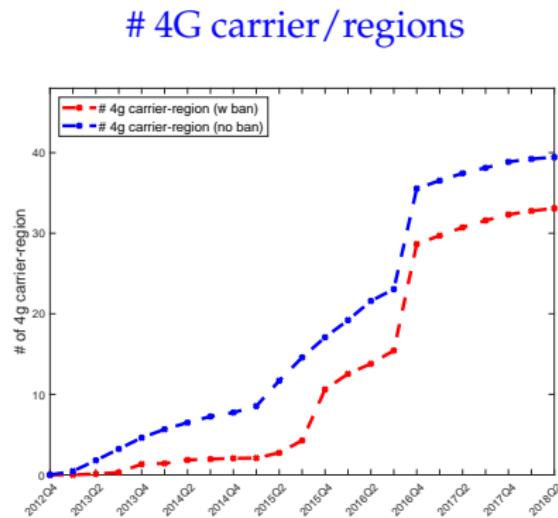
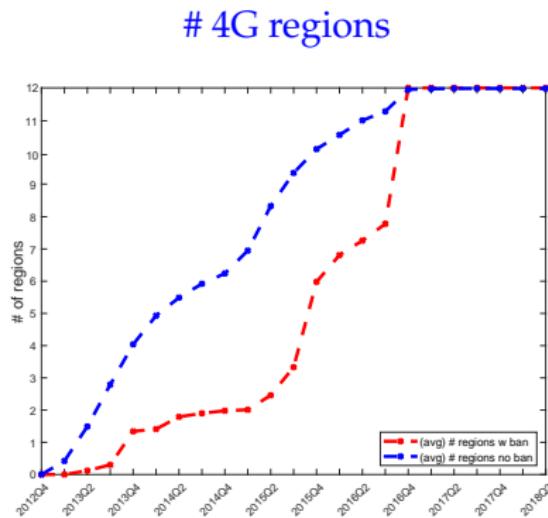
1. Cross-market spillover effect

4G regions

4G carrier/regions

CF1 Results

1. Cross-market spillover effect



CF1 Results (Cont.)

2. Within-market spillover effect

- **Outcome of interest:** evolution of # and sales of Indian 4G phones
- **Expected result:** ambiguous
- **Why**
 - slower expansion of 4G networks → a later intro and a slower growth of domestic 4G phones
 - less competition, higher variable profits → an earlier intro and a faster growth of domestic 4G phones

CF1 Results (Cont.)

3. Welfare – Expected Results

- Consumer surplus ↓ b/c
 - slower expansion of 4G network coverage
 - slower development of the 4G phone market
- Carrier profits ↓ b/c
 - complementarity between the two markets
- Domestic cell phone firms' profits ?
 - less competition in the low-end of the market
 - no within-market spillover effect

CF2 Expected Results

- The unrestricted subsidy policy is more effective at
 - speeding up 4G network expansions
 - encouraging the development of the 4G phone market
 - increasing consumer welfare
 - increasing carrier profits

- Domestic welfare ?

domestic welfare = (consumer surplus)

+ (domestic cell phone firm profits)

+ (carrier profits)

- (subsidy expenditure) \times (1+efficiency cost of taxation)

CF2 Expected Results

- The unrestricted subsidy policy is more effective at
 - speeding up 4G network expansions
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 - increasing consumer welfare
 - increasing carrier profits

- Domestic welfare ?

domestic welfare = (consumer surplus)

+ (domestic cell phone firm profits)

+ (carrier profits)

- (subsidy expenditure) \times (1+efficiency cost of taxation)

Conclusion (1)

- Spillover effects on product variety and firm entry
- A new channel through which int'l competition affects product variety and welfare
 - presence of int'l firms helps the development of a complementary market, which, in turn, affect their own market
- Four key findings supporting the channel
 - 4G-4G complementarity
 - int'l firm higher markups
 - declining MC
 - domestic cost advantage at producing low-end phones
- Quantify the cross-market and within-market spillover effects, and the welfare effects

Conclusion (2)

From a policy perspective

- This paper contributes to the debate on whether the Indian cell phone market needs protection and whether int'l cell phone firms are harming domestic cell phone firms
- Complaints: int'l cell phone firms introduced their 4G phones before 4G networks were widespread in India, crowding out domestic cell phone firms
- This paper: evidence against protectionism in this industry
 - Early entry of 4G phones by international cell phone firms is beneficial due to spillover effects

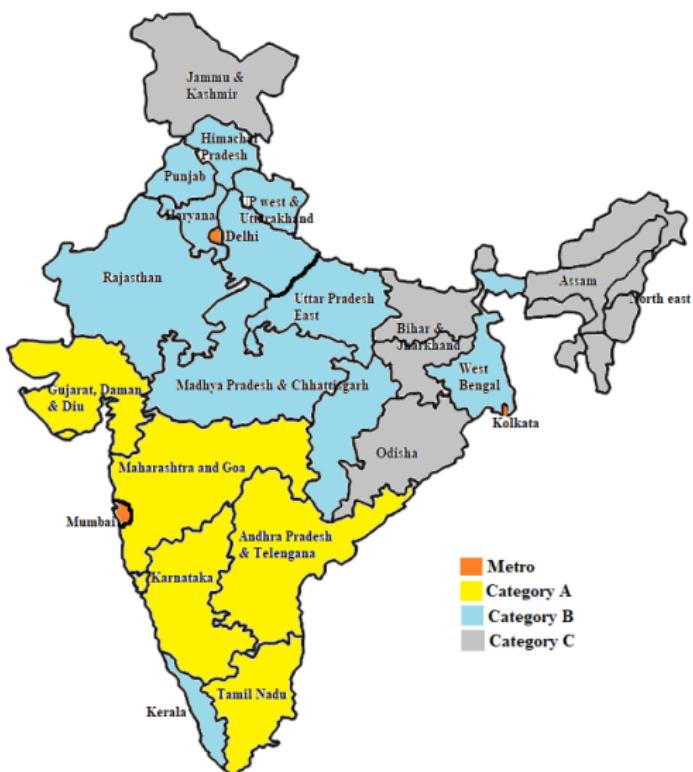
Conclusion (3)

Beyond the Indian mobile industry

- **Our finding:** the presence of technologically advanced firms in one market increases product variety and promotes technology diffusion in both markets to the benefit of consumers
- **This finding is likely to hold for many industries consisting of complementary markets**
- **For developing countries,** technologically advanced firms are typically foreign firms and their presence in a market requires that the market be opened to international competitors

Thank you!

Telecommunications Regions in India



Industry

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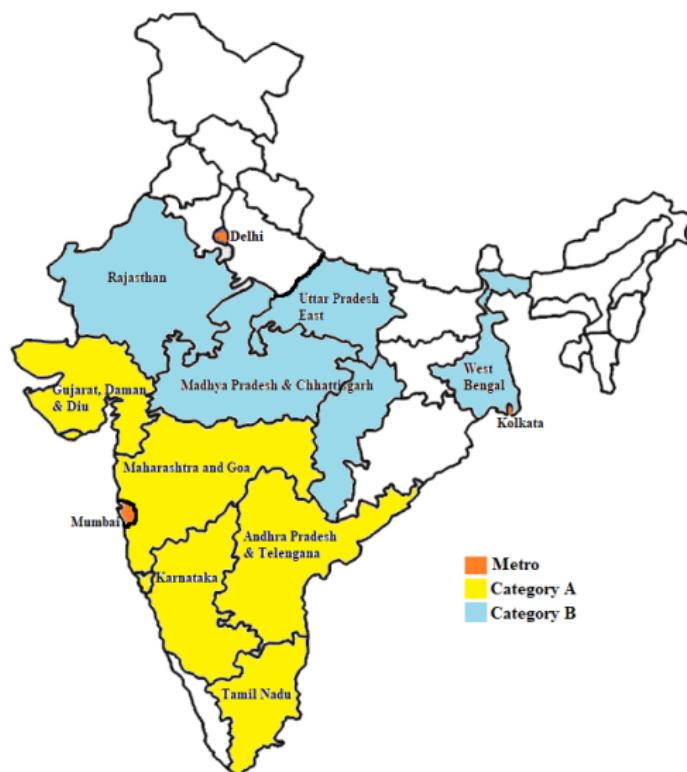
Model
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Estimation 0000

Estimation Results

Counterfactual

The 12 Telecommunications Regions



JioPhone



JioPhone LF-2401

Screen Size	2.4 inch
Rear Camera	2MP
Front Camera	0.3MP
RAM	0.5GB
4G connectivity	Yes
Built-in Apps	Yes
Voice control	Yes
Price	\$22 in 2017

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Industry
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Estimation Results

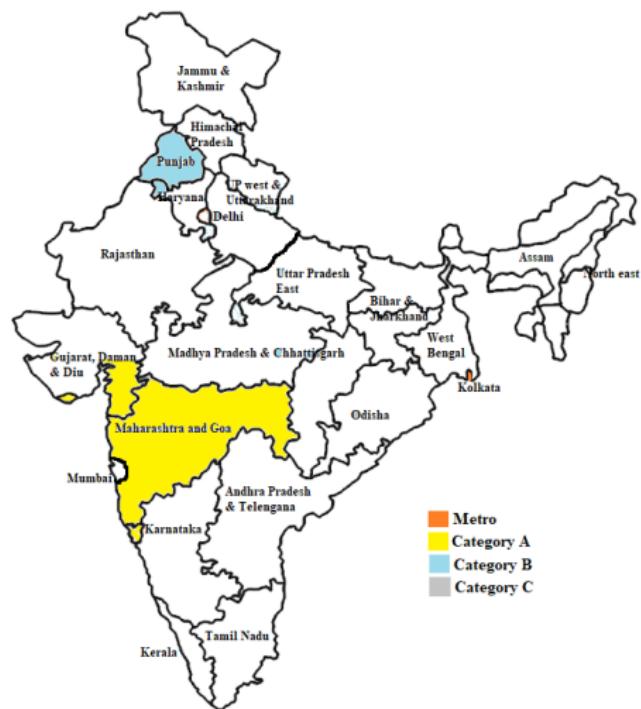
Counterfactual

Jio

LYF Phones					Jio Bundles				Jio Standalone Plan	
Quarter	#Phones	Quantity	Within-Mkt Share	Within-4G Share	#handsets	Quantity	Within-Mkt Share	Within-4G Share	Within-Mkt Share	
2015Q4	1	198,972	0.1%	2.2%						
2016Q1	7	1,545,400	1.1%	12.5%						
2016Q2	8	1,226,209	0.9%	9.5%						
2016Q3	8	2,182,501	1.6%	11.7%					1.7%	
2016Q4	6	1,225,272	0.9%	6.3%					7.2%	
2017Q1	3	462,857	0.3%	2.1%					10.3%	
2017Q2									11.4%	
2017Q3					9	2,719,100	2.0%	8.3%	9.0%	
2017Q4					8	15,473,620	11.2%	39.6%	0.4%	
2018Q1					10	21,132,740	12.4%	50.2%	2.3%	
2018Q2					9	14,219,938	8.3%	36.2%	10.2%	

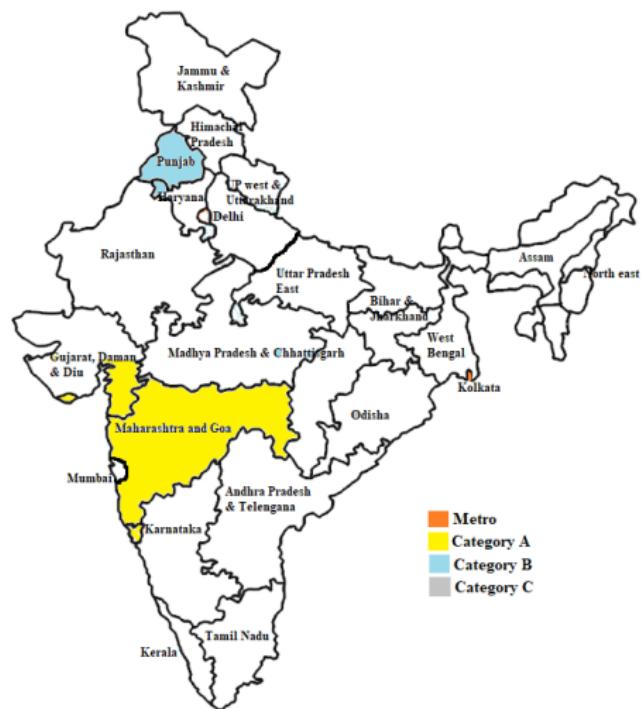
Airtel's 4G Network Expansion

2013Q1



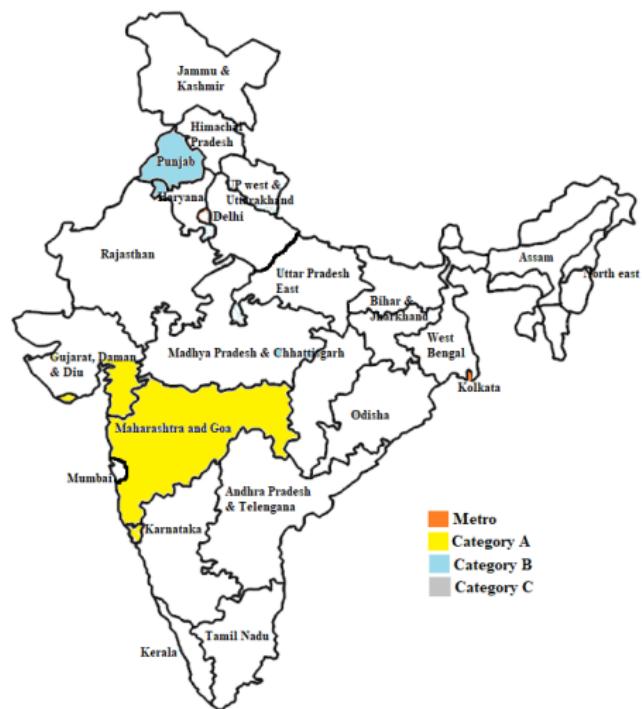
Airtel's 4G Network Expansion

2013Q2



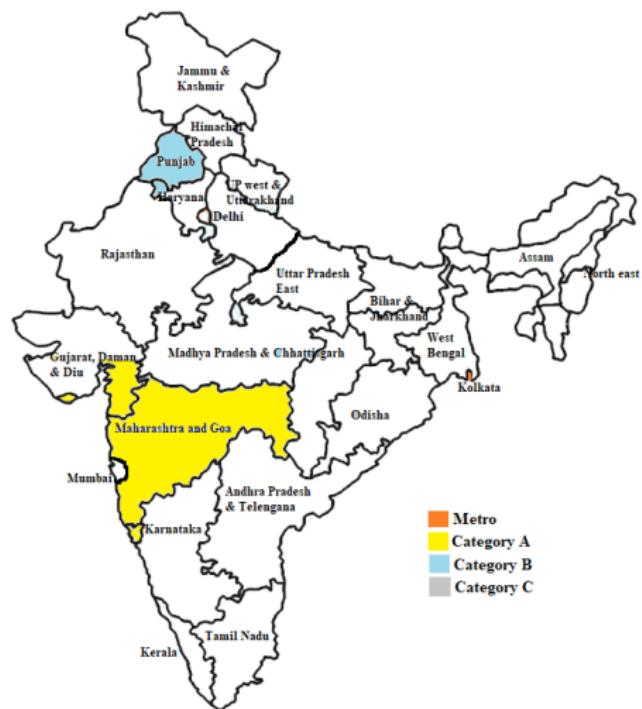
Airtel's 4G Network Expansion

2013Q3



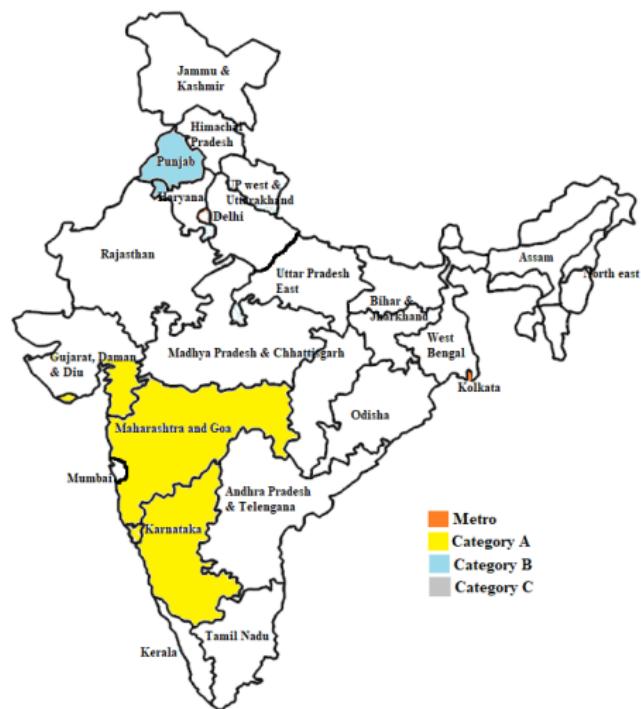
Airtel's 4G Network Expansion

2013Q4



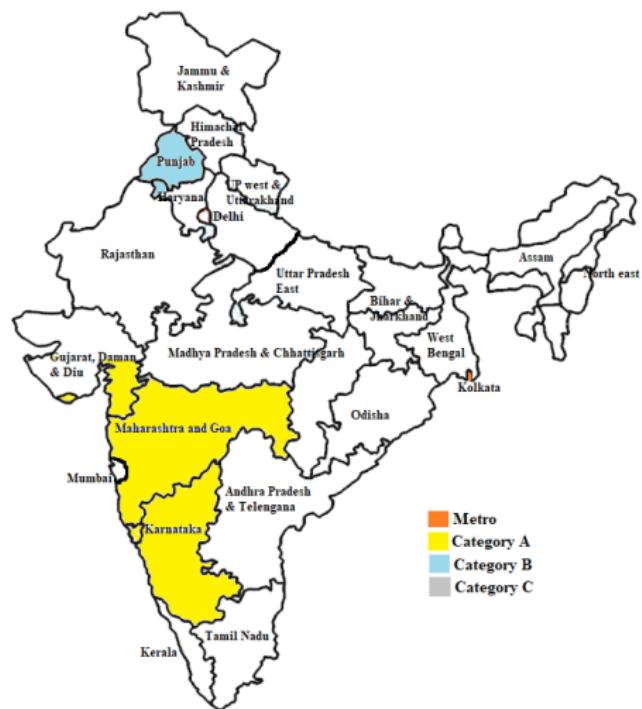
Airtel's 4G Network Expansion

2014Q1



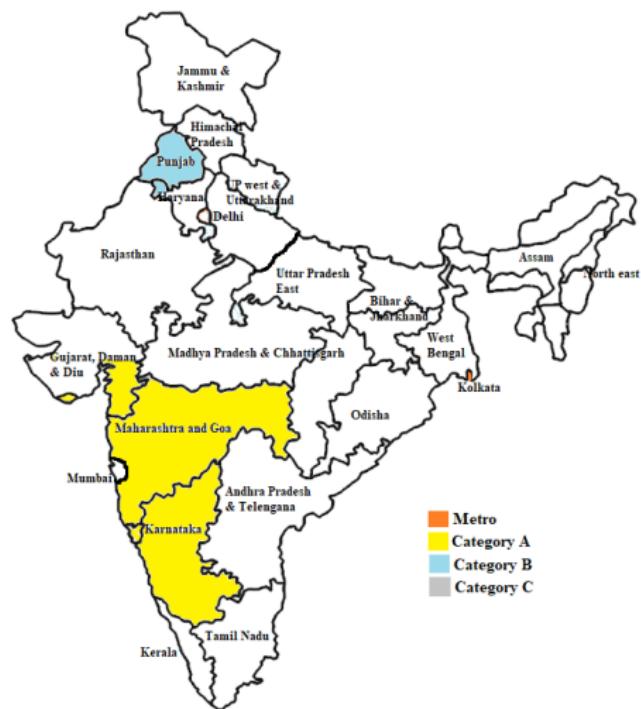
Airtel's 4G Network Expansion

2014Q2



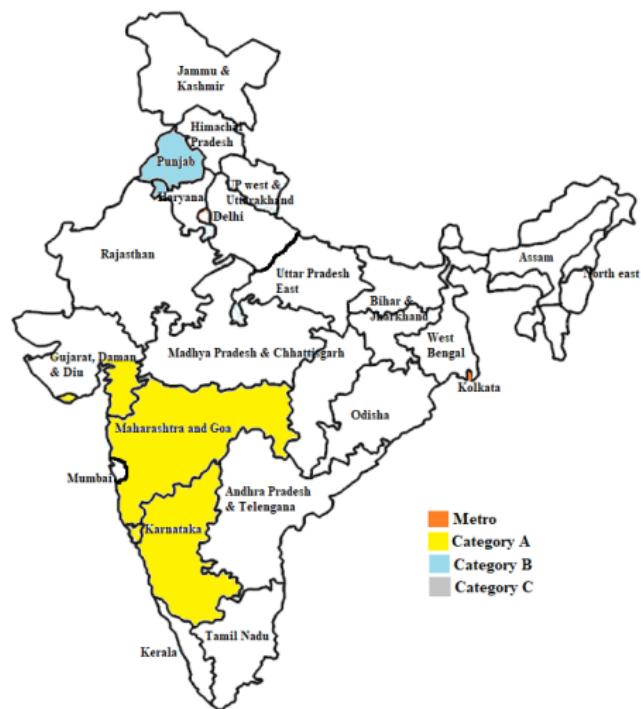
Airtel's 4G Network Expansion

2014Q3



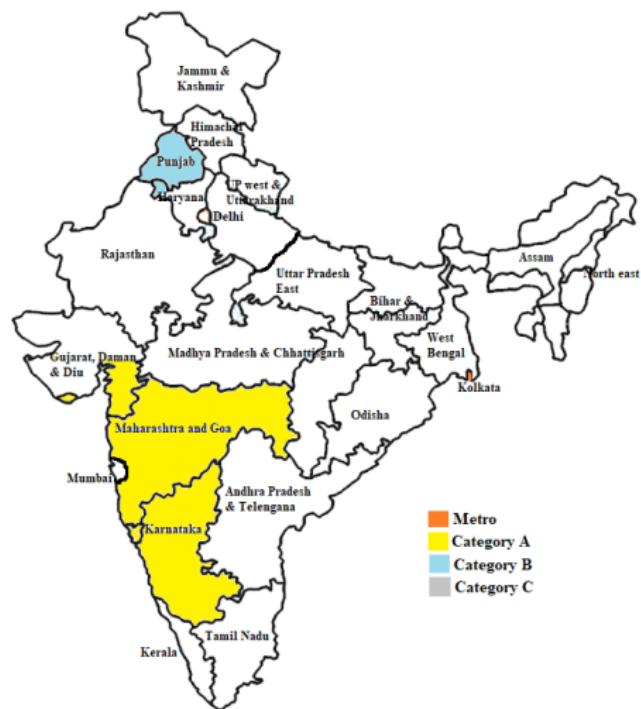
Airtel's 4G Network Expansion

2014Q4



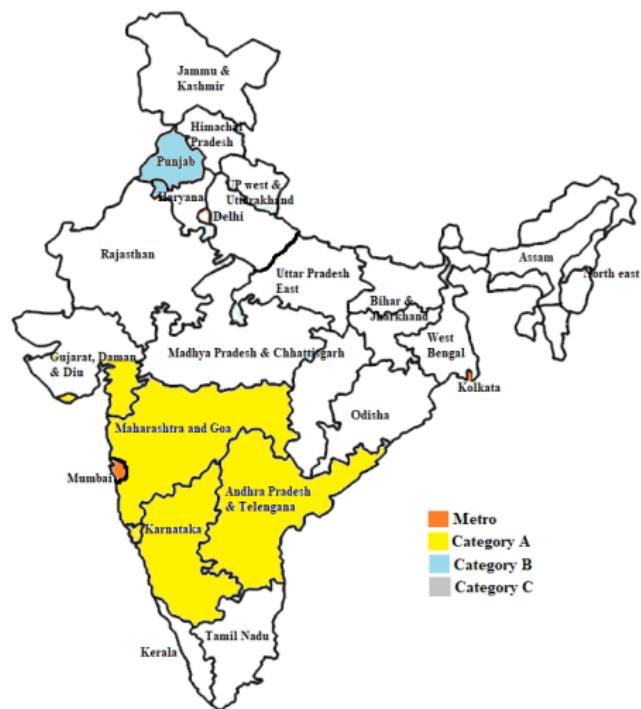
Airtel's 4G Network Expansion

2015Q1



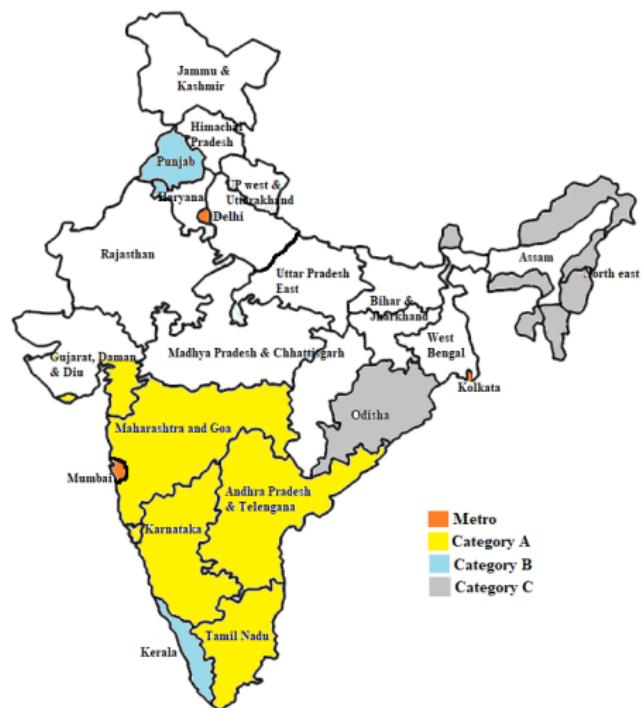
Airtel's 4G Network Expansion

2015Q2



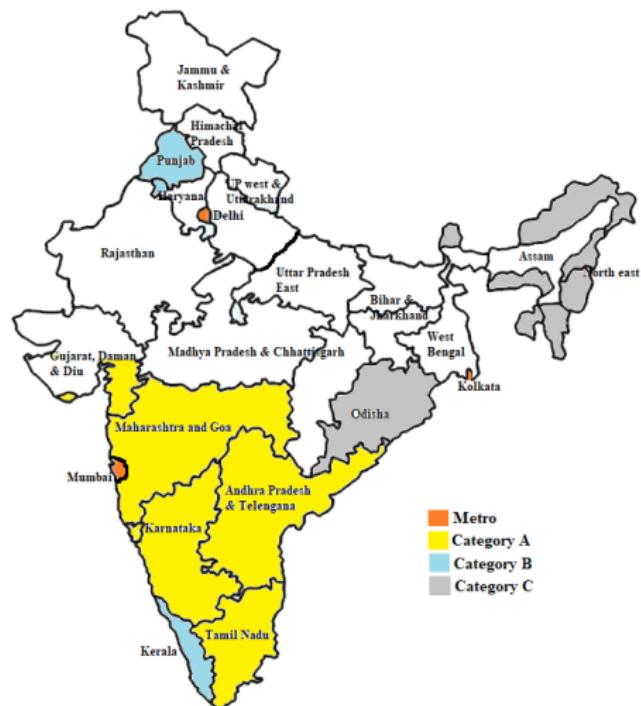
Airtel's 4G Network Expansion

2015Q3



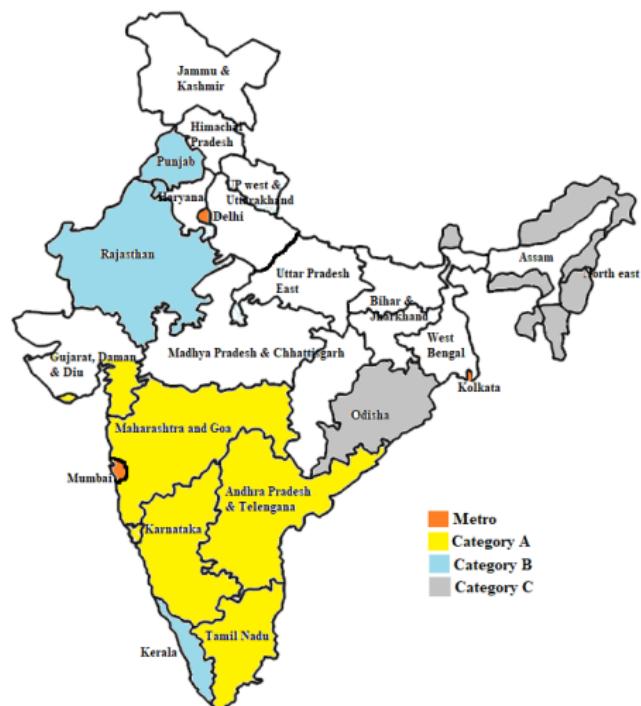
Airtel's 4G Network Expansion

2015Q4



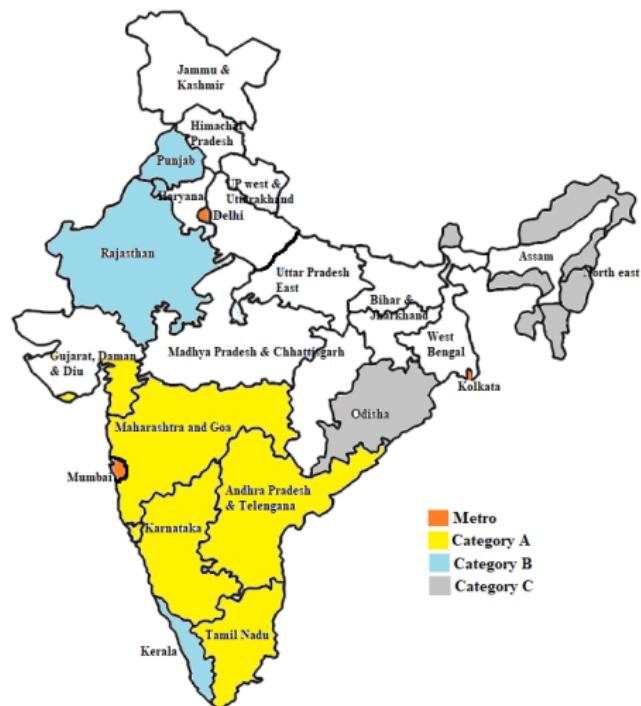
Airtel's 4G Network Expansion

2016Q1



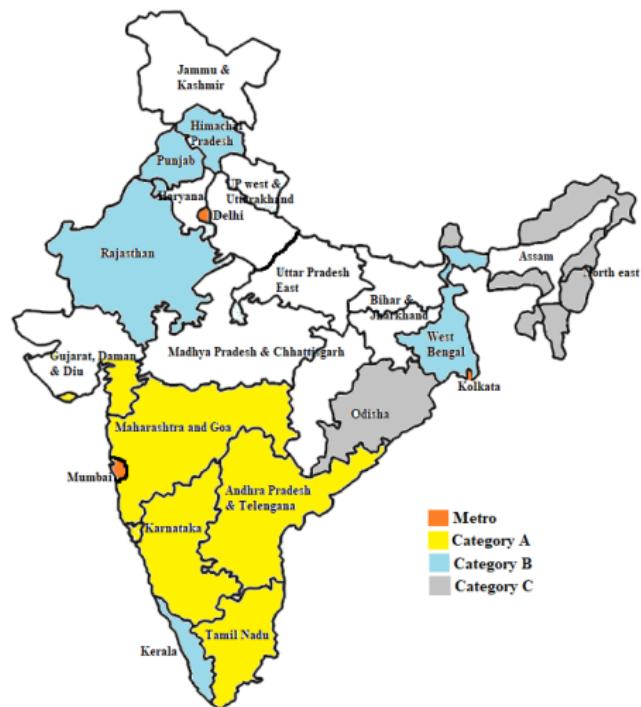
Airtel's 4G Network Expansion

2016Q2



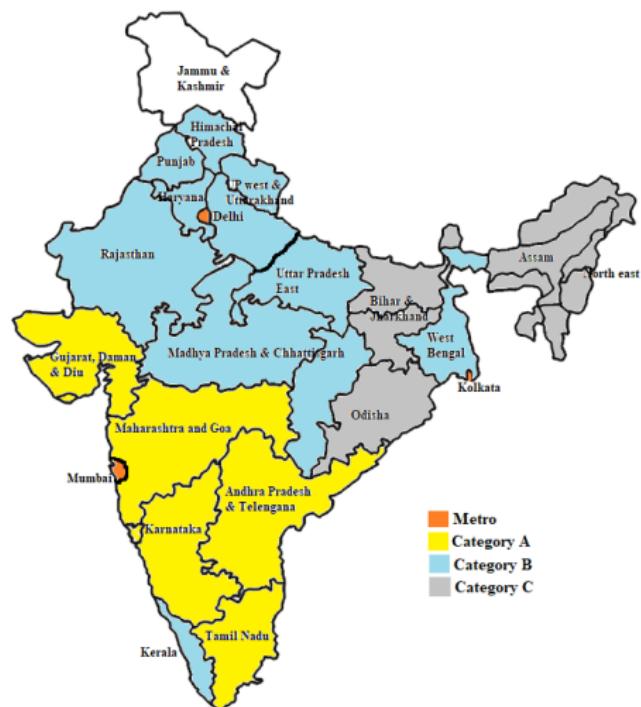
Airtel's 4G Network Expansion

2016Q3



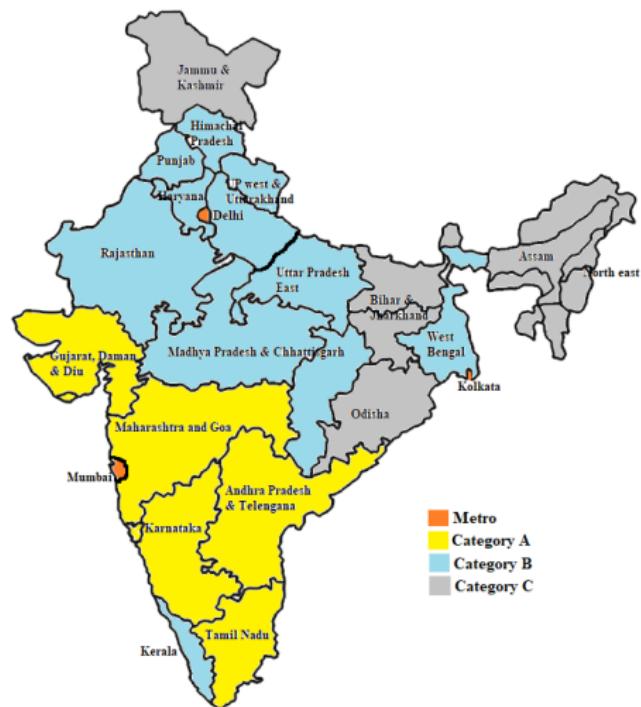
Airtel's 4G Network Expansion

2016Q4



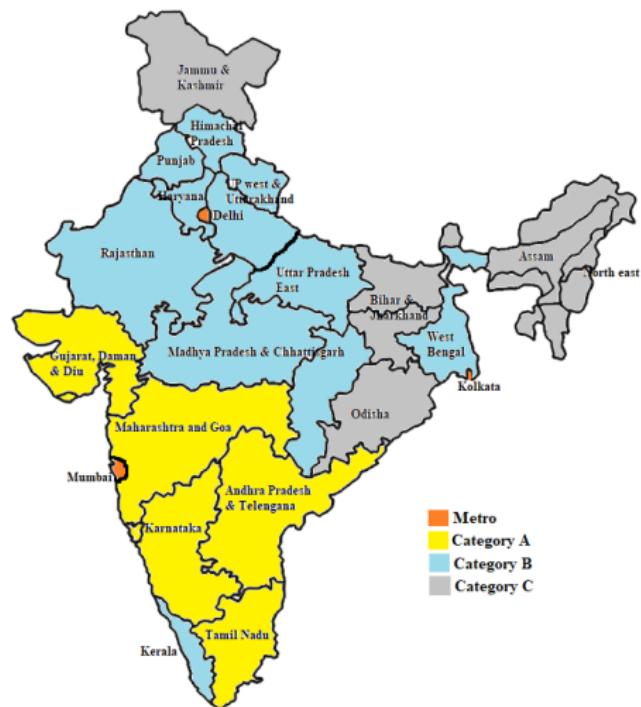
Airtel's 4G Network Expansion

2017Q1



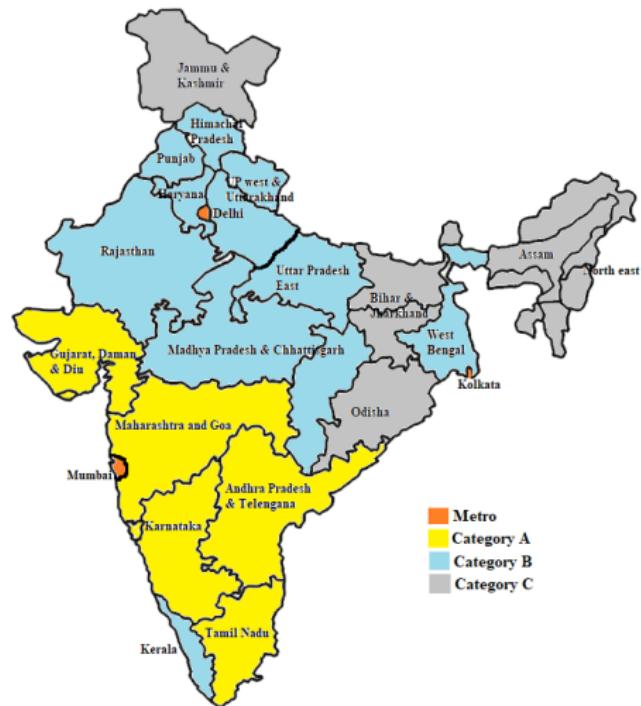
Airtel's 4G Network Expansion

2017Q2



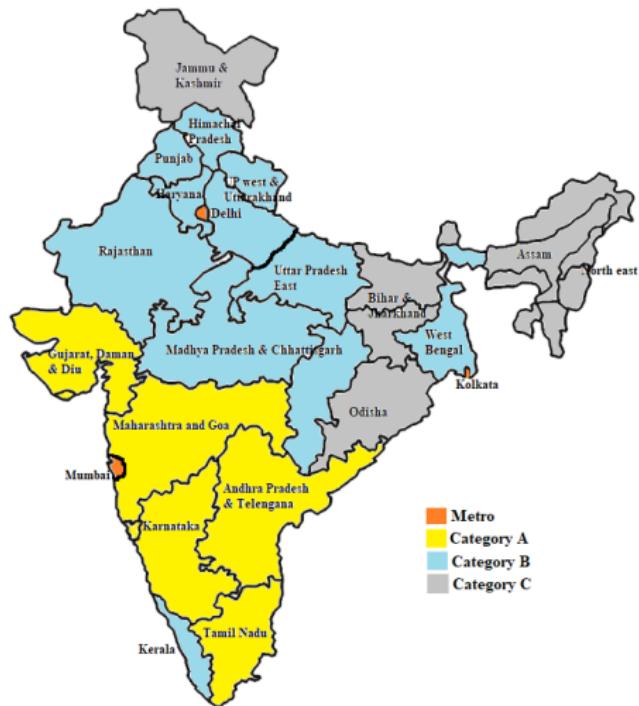
Airtel's 4G Network Expansion

2017Q3



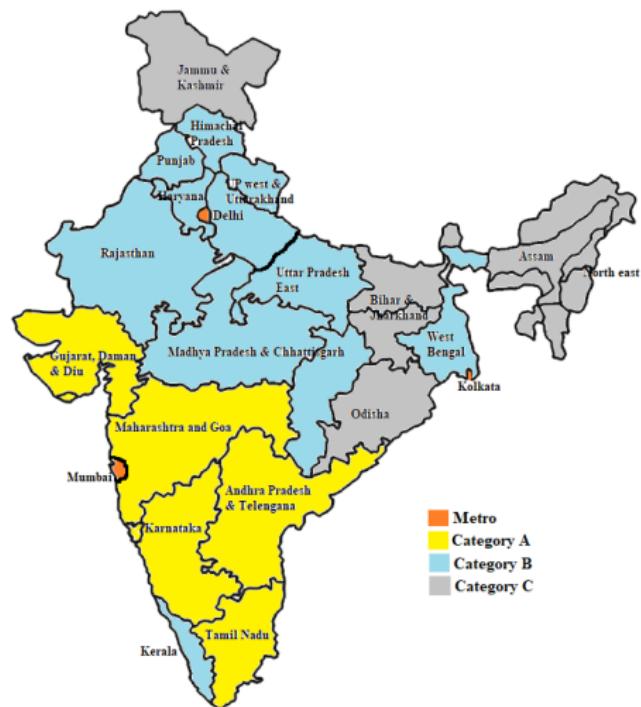
Airtel's 4G Network Expansion

2017Q4



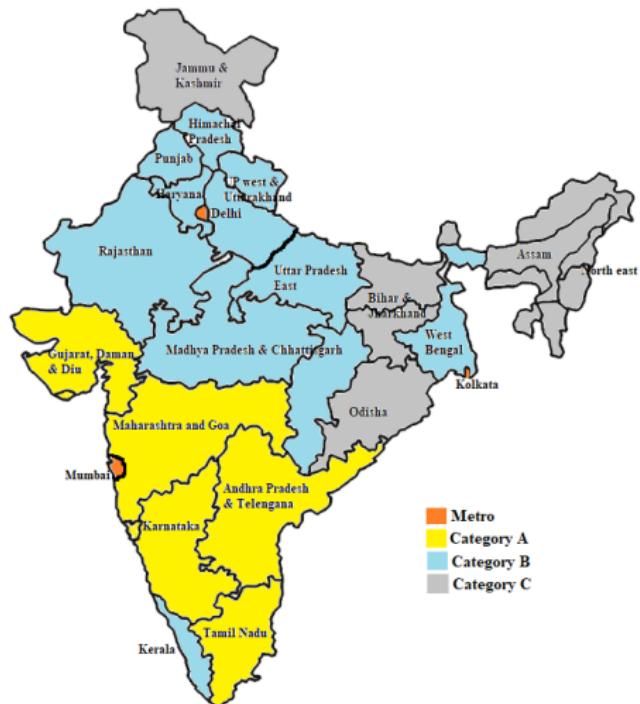
Airtel's 4G Network Expansion

2018Q1



Airtel's 4G Network Expansion

2018Q2 ◀



Spectrum Auctions

- Annual auctions between 2010 and 2016, and then in 2021
 - Each auction corresponds to a specific spectrum of frequencies and specific geographic blocks
 - Carriers seem not constrained: in 2015, 11% of the spectrum offered was unsold; in 2016, 60%

Spectrum usage charges

■ Spectrum usage charges (SUC)

- Prior to 2015: flat rate of 5% of the Adjusted Gross Revenue (AGR)
 - 2016–2017: In October 2016, the Department of Telecommunications announced a new formula for calculating SUC based on a weighted average formula, which varied depending on the amount of spectrum held and the brands of spectrum used. In July 2017, the Telecom Commission approved the weighted average formula
 - 2018: flat rate of 3% of AGR for spectrum acquired in future auctions

- A carrier's profit function: $(\text{price} * (1 - \text{SUC}) - \text{mc}) * \text{quantity}(\text{prices})$

- Our estimated mc is “ $mc/(1-SUC)$ ”

Industry
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Data
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Model
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Estimation
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Estimation Results
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Counterfactual

Carriers

Airtel

Vodafone

Idea

BSNL (Bharat Sanchar Nigam Limited)

Reliance Jio

Reliance Communications

Aircel

MTNL (Mahanagar Telephone Nigam Limited)

- Reliance Communications exited the market in 2018.

Carriers

- **Airtel, Jio, and Idea:** domestic and owned by Indian entrepreneurs (owned by Bharti Airtel Limited, Reliance Jio and Aditya Birla Group respectively)
- **BSNL and MTNL:** public companies owned by Indian government
- **Vodafone-India:** an Indian subsidiary of UK-based parent company
- **Aircel:** an Indian firm started by Apollo Hospitals; Maxis Communications – a Malaysian firm held 74% stake in the firm

Online vs. Offline Phone Sales

January 2018 - June 2018

Origin	cell phone firm	Online	Offline
Indian	Intex	7%	93%
	Lava	1%	99%
	LYF	38%	62%
	Micromax	4%	96%
Other-Asian	Gionee	1%	99%
	Lenovo	71%	29%
	Oppo	4%	96%
	Samsung	15%	85%
	Vivo	4%	96%
	Xiaomi	67%	33%
Non-Asian	Apple	39%	61%
	Microsoft/Nokia	28%	72%

Summary Statistics: Cell phones

Summary Statistics: Phones

	Mean	S.D.
Price (INR)	11,297	11,118
Sales (Million)	0.35	0.55
Screen Size (Inch)	4.79	0.82
Camera Resolution (Megapixel)	8.47	4.29
Internal Memory (GB)	17.08	17.04
RAM (GB)	1.66	1.11
Battery Capacity (Ah)	2.50	0.83
Number of Obs	1,106	

Note: This table reports the summary statistics of 3G and 4G cell phones. Between 2011 and 2014, one observation is a phone/year. Between 2015Q1 and 2018Q2, one observation is a phone/quarter. We divide the annual sales between 2011 and 2014 by 4 in reporting the

Summary Statistics: 3G Phones

Summary Statistics: 3G Phones

	Mean	S.D.
Price (INR)	7,819	6,720
Sales (million)	0.15	0.15
Screen Size (inch)	4.40	0.78
Camera Resolution (Megapixel)	5.40	3.21
Inernal Memory (GB)	6.89	6.65
RAM (GB)	0.80	0.51
Battery Capacity (Ah)	1.92	0.64
Number of Obs	363	

Summary Statistics: 4G Phones

Summary Statistics: 4G Phones

	Mean	S.D.
Price (INR)	12,996	12,379
Sales (million)	0.36	0.60
Screen Size (inch)	4.98	0.77
Camera Resolution (Megapixel)	9.98	3.93
Inernal Memory (GB)	22.06	18.31
RAM (GB)	2.08	1.09
Battery Capacity (Ah)	2.78	0.76
Number of Obs	743	

Summary Statistics: Plans

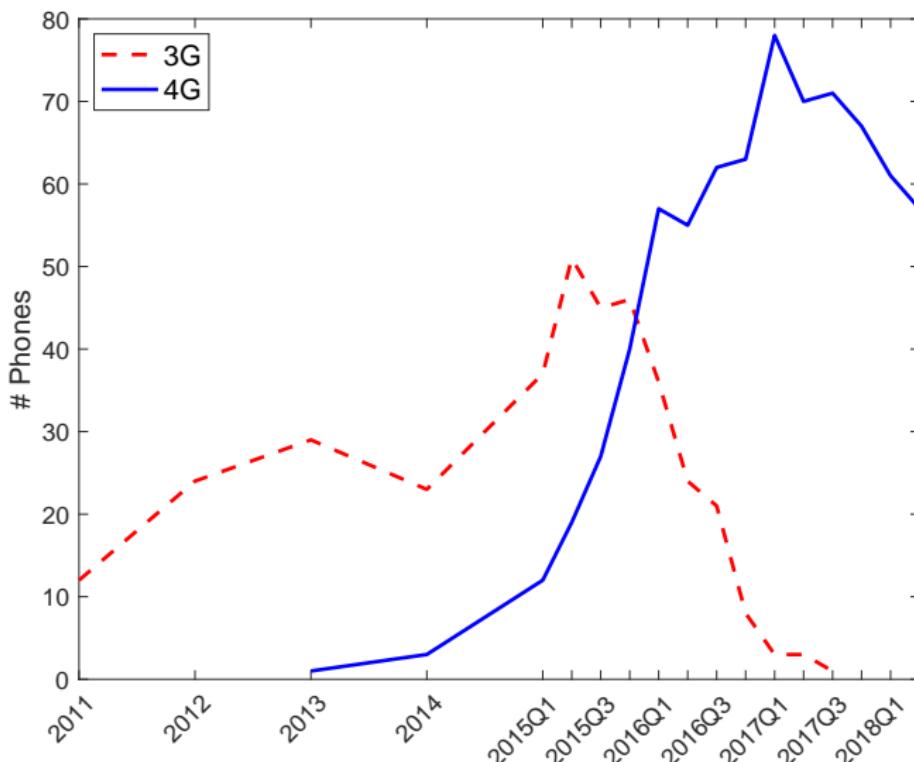
Summary Statistics: Plans

	Mean	S.D.
Monthly Price (INR)	121	41
Sales (Million)	2.83	3.58
Number of Obs	489	

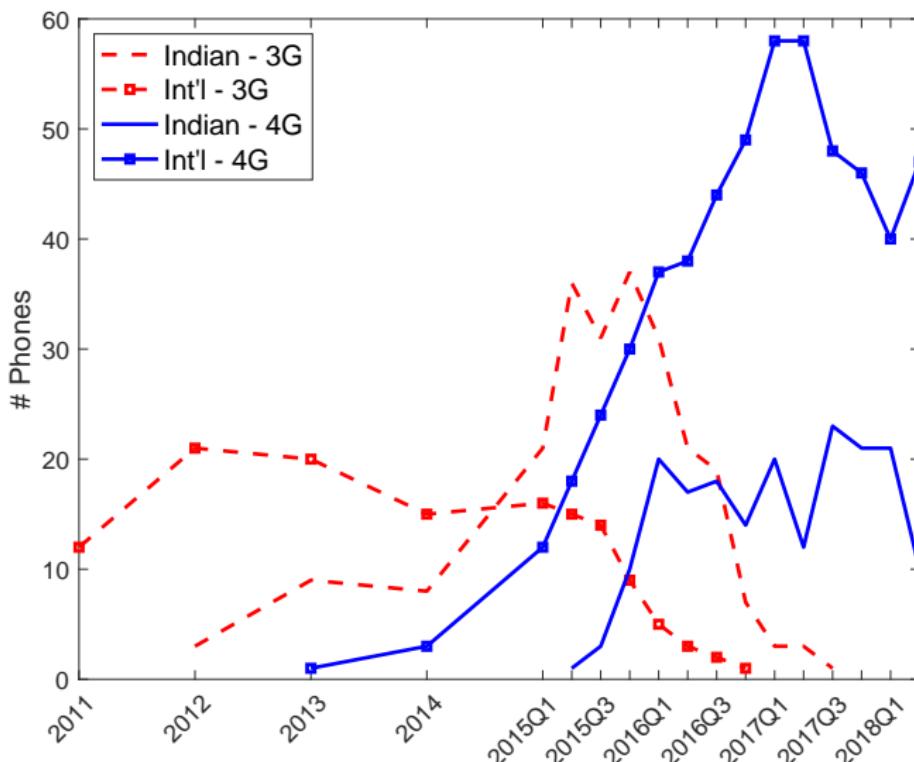
Summary Statistics: Regions

Region	Category	Population	Avg Income
Delhi	Metro	16,787,941	296,709
Kolkata	Metro	4,486,679	225,688
Mumbai	Metro	12,478,447	495,791
Andhra Pradesh & Telangana	A	84,580,777	118,678
Gujarat & Daman & Diu	A	60,682,939	137,067
Karnataka	A	61,095,297	144,777
Maharashtra & Goa	A	101,354,431	145,467
Tamil Nadu	A	72,147,030	139,201
Haryana	B	25,351,462	163,762
Kerala	B	33,470,534	146,118
Madhya Pradesh & Chhattisgarh	B	98,172,007	66,068
Punjab	B	27,743,338	117,132
Rajasthan	B	68,548,437	81,513
UP(West) & Uttarakhand	B	70,029,994.3	67,823
Uttar Pradesh(East)	B	139,868,638.7	31,698
West Bengal	B	86,789,436	75,704
Assam	C	31,205,576	58,972
Bihar & Jharkhand	C	137,087,586	37,288
Himachal Pradesh	C	6,864,602	132,110
Jammu and Kashmir	C	12,541,302	69,644
North East	C	14,566,612	84,396
Orissa	C	41,974,218	68,541

Number of Phones Over Time



Number of Phones Over Time



Industry

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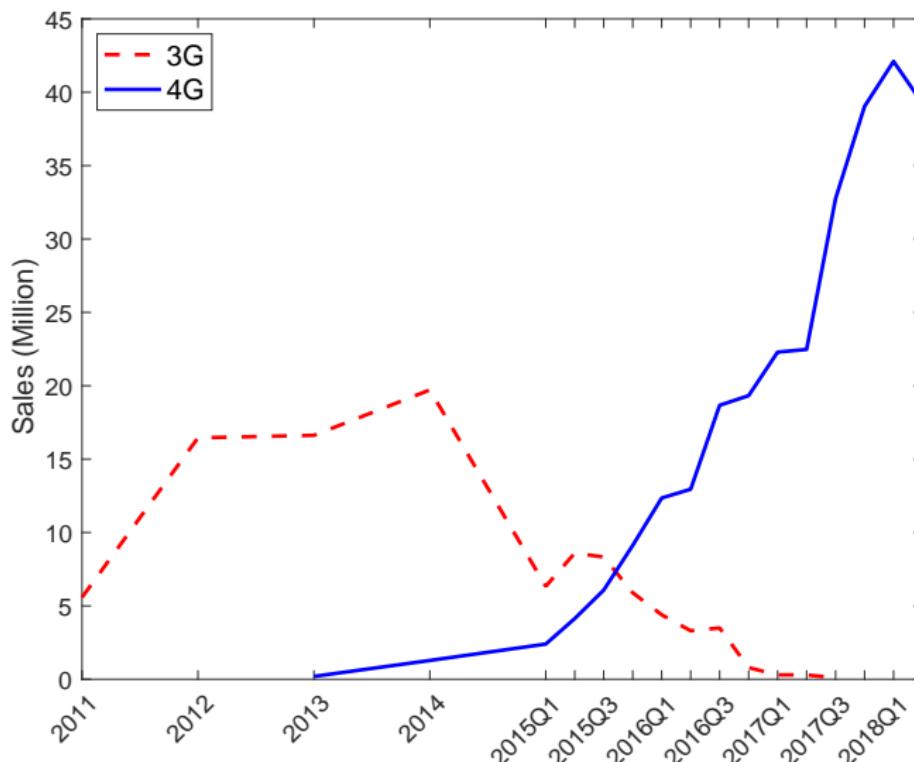
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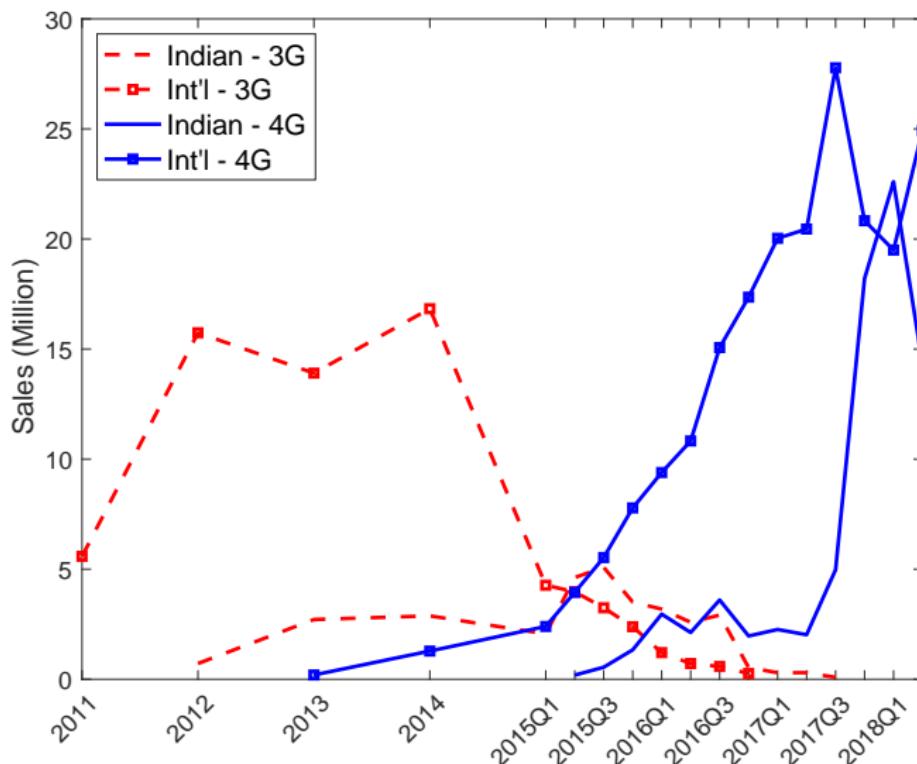
Estimation Results

Counterfactual

Phone Sales Over Time



Phone Sales Over Time



Industry

Data
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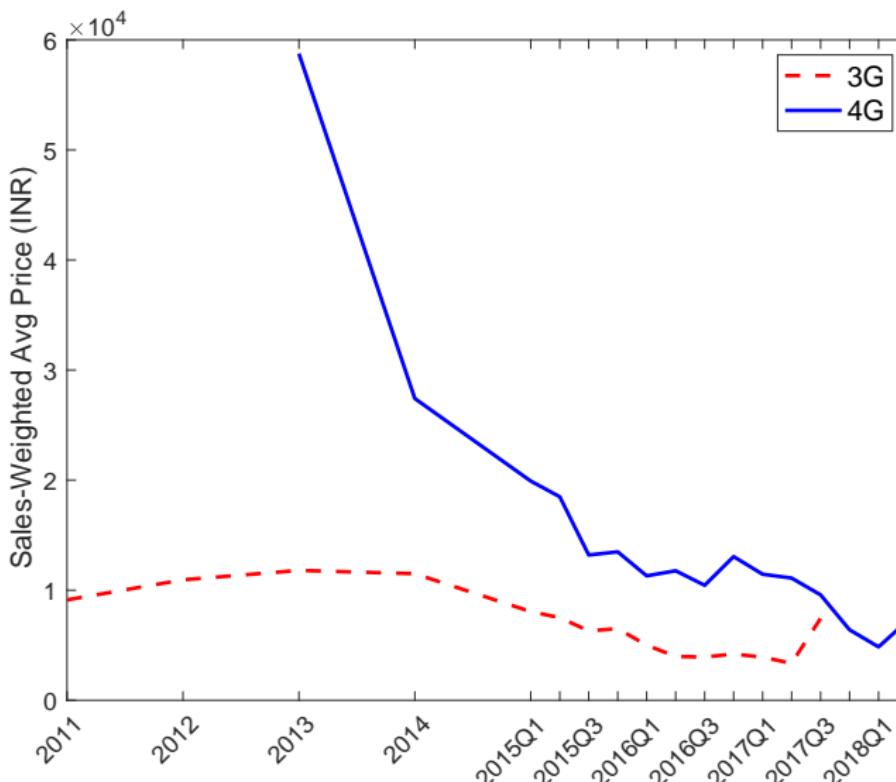
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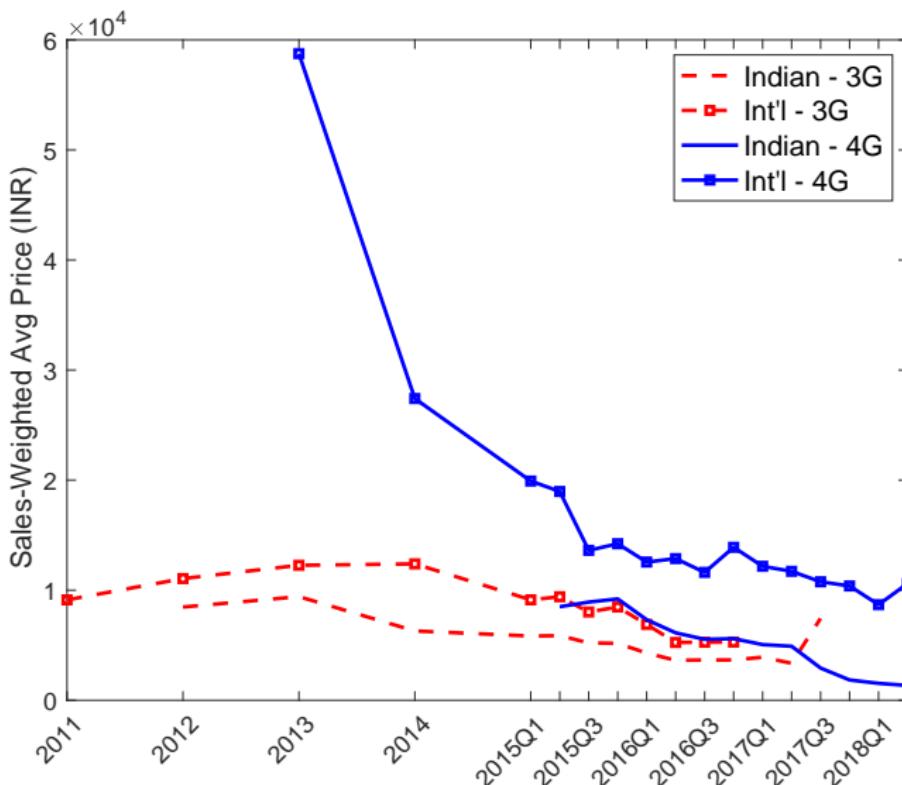
Estimation Results

Counterfactual

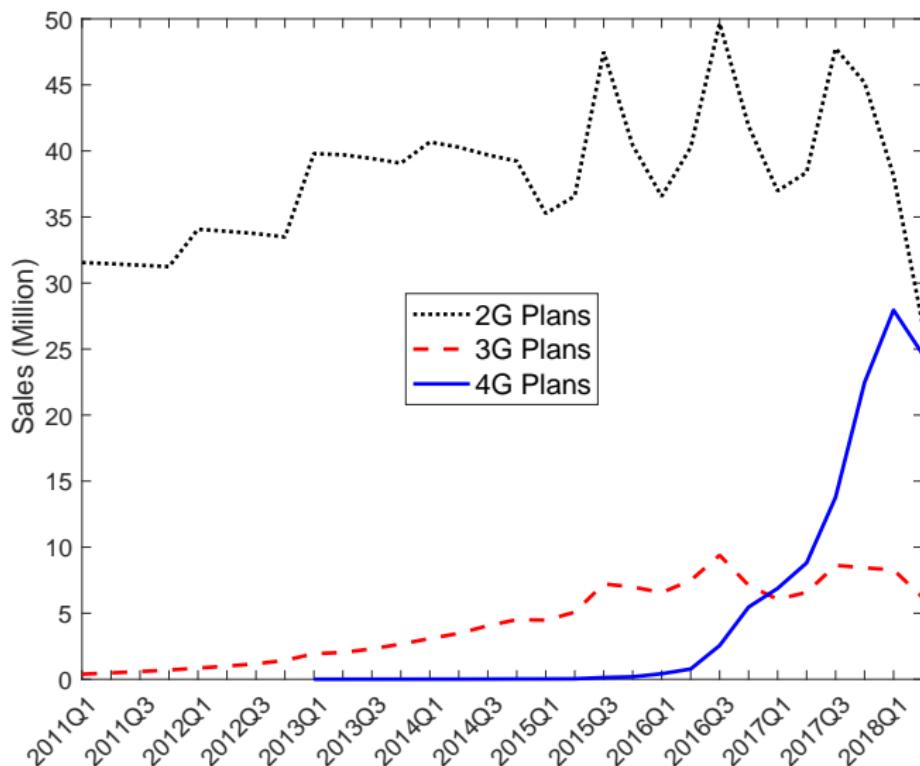
Phone Price Over Time



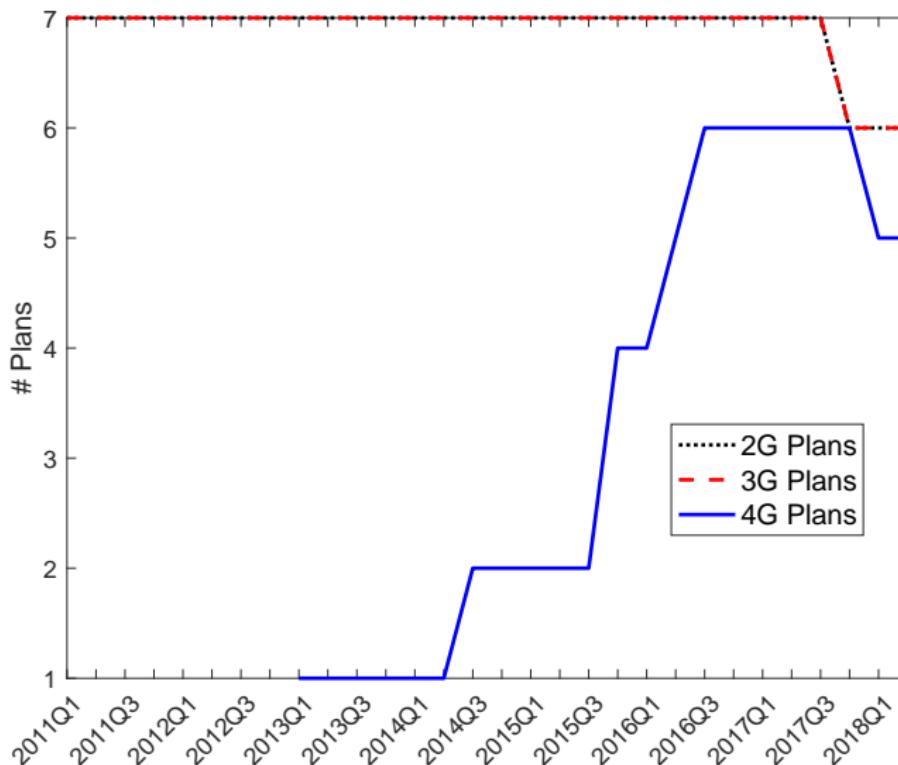
Phone Price Over Time



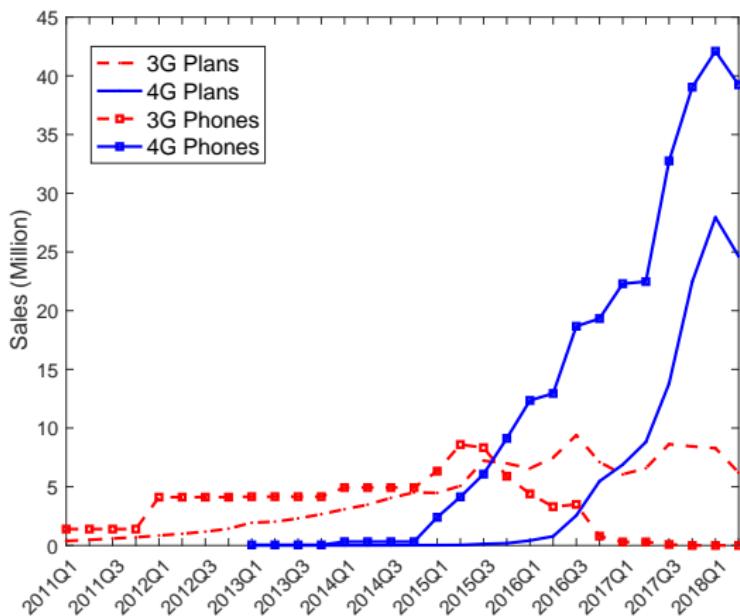
Plan Sales Over Time



Number of Plans Over Time



Phone and Plan Sales Over Time



- In early periods, 3G phones with 2G plans
 - In later periods, 4G phones with 3G plans

Industry

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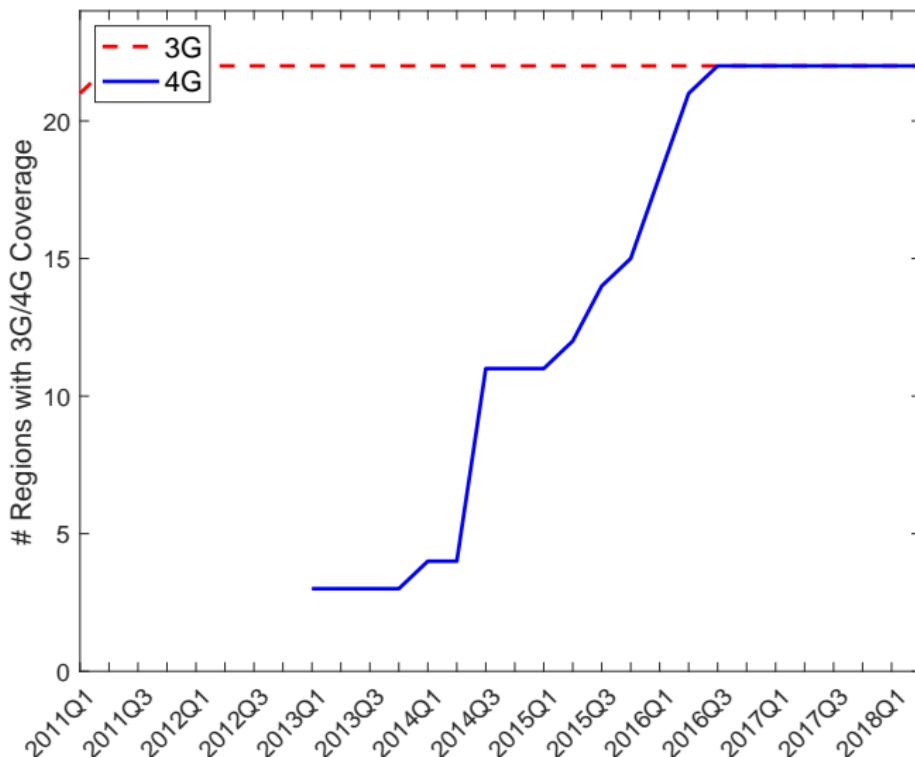
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Estimation

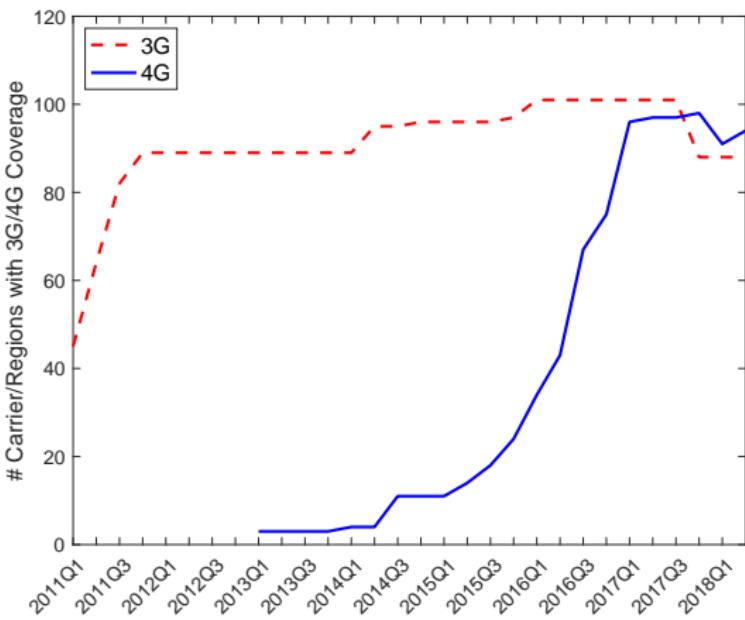
Estimation Results

Counterfactual

Regions with 3G/4G Coverage



Carrier/Regions with 3G/4G Coverage



- #### ■ 3G network is stable

Model Details: Second-Stage Pricing Game

- Cell phone firm: (indexed by f)

$$\max_{\mathbf{p}_f^{phone}} \pi_f^{phone}(\mathbf{p}_f^{phone}, \mathbf{p}_{-f}^{phone}, \mathbf{p}^{plan})$$

- Carriers: (indexed by c)

$$\max_{\mathbf{p}_c^{plan}} \pi_c^{plan}(\mathbf{p}^{phone}, \mathbf{p}_c^{plan}, \mathbf{p}_{-c}^{plan})$$

- Jio 2016Q3–2017Q1: a standalone plan (Jio 4G plan) and standalone phones (under the brand name LYF)

$$\max_{\mathbf{p}_{LYF}^{phone}, \mathbf{p}_{Jio}^{plan}} \pi^{plan}(\mathbf{p}_{LYF}^{phone}, p_{Jio}^{plan}, \mathbf{p}_{-LYF}^{phone}, \mathbf{p}_{-Jio}^{plan}) + \pi^{phone}(., ., ., .)$$

- Jio 2017Q3–2018Q2: a stand-alone plan and bundles (JioPhones)

$$\max_{\mathbf{p}_{JioPhone}^{bundle}, \mathbf{p}_{Jio}^{plan}} \pi^{plan}(\mathbf{p}_{JioPhone}^{bundle}, p_{Jio}^{plan}, \mathbf{p}^{bundle}, \mathbf{p}_{-Jio}^{plan}) + \pi^{bundle}(., ., ., .)$$

Model Details: First-Stage Product Choice Game

- First-stage product-choice game: cell phone firms choose phones given the current network (i.e., available plans)
 - Definition of potential products
 - a product = (cell phone firm, 3G/4G, quality index)

• Step 1. Define a grid of qualities: (min: gap: max)

• Step 2. Add qualities of observed products of the same firm and technology in t

• Step 3. Remove grid points close to observed qualities

Model Details: First-Stage Product Choice Game

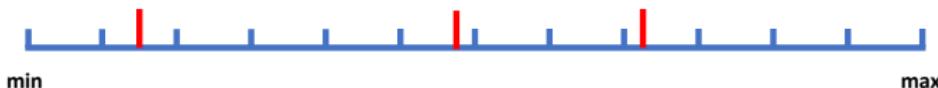
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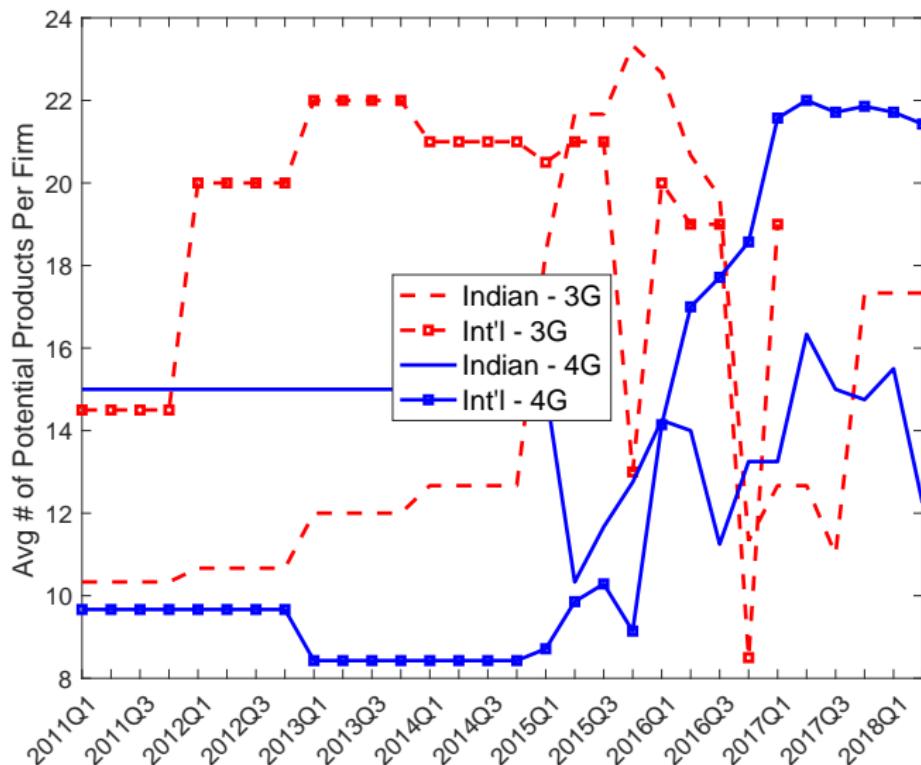


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 - Step 3. Remove grid points close to observed qualities

Definition of Potential Products (Cont.)

- Range of the grid for firm f in time t (3G)
 - min: $\min_{j \in \mathcal{J}_{ft}^{(3G)}} q_{jt} - 5$
 - max: $\max_{j \in \mathcal{J}_{f\tau}^{(3G)}, \tau \leq t} q_{j\tau} + 5$
- Range of the grid for firm f in time t (4G) – similar
- Int'l 3G: $\{3G \text{ potential products}\}_{ft} = \emptyset$ for
 - f with no 3G phones in the sample
 - ft s.t. f is int'l and $t \geq 2017Q2$ (one quarter after Int'l firms stopped selling 3G phones in India)
- Int'l 4G: $\{4G \text{ potential products}\}_{ft} = \{4G \text{ potential products}\}_{f, 2013Q1}$ for $t < 2013Q1$ (before Int'l 4G phones were sold)
- Indian 4G: $\{4G \text{ potential products}\}_{ft} = \{4G \text{ potential products}\}_{f, 2015Q2}$ for $t < 2015Q2$ (before Indian 4G phones were sold)

Potential Products Per-Firm



Identification

- BLP IVs and Gandhi-Houde IVs
- Timing assumption:
 - firms do not know demand shocks when choosing products
- Justification:
 - include a rich set of fixed effects – phone technologies, plan technologies, cell phone firms, carriers, and time
 - firm-specific time-varying transitory shocks are unknown to firms when they make their product choices
- Identification of the coef of $\mathbb{1}(4G_j, 4G_k)$
 - how phone sales vary with variations in plan choices
 - how plan sales vary with variations in phone choices



Fixed cost estimation

- For $j \in \mathcal{J}_{ft}$: $C_{jt} \leq \tilde{\pi}_{ft}^{(phone)}(\mathcal{J}_{ft}, \mathcal{J}_{-ft}, \dots) - \tilde{\pi}_{ft}^{(phone)}(\mathcal{J}_{ft} \setminus j, \mathcal{J}_{-ft}, \dots)$
For $j \notin \mathcal{J}_{ft}$: $C_{jt} \geq \tilde{\pi}_{ft}^{(phone)}(\mathcal{J}_{ft} \cup j, \mathcal{J}_{-ft}, \dots) - \tilde{\pi}_{ft}^{(phone)}(\mathcal{J}_{ft}, \mathcal{J}_{-ft}, \dots)$
- Estimated fixed-cost bounds

Quantile	25%	50%	75%
Upper Bound for Phones in the Data	238	755	2,167
Lower Bound for Phones not in the Data	0.52	27	376

Details on Estimating Dyn Network Expansion Game

- 12 regions (66.8% of the total population): all 3 Metro regions, all 5 Category-A regions, and the 4 largest Category-B regions Delhi, Kolkata, Mumbai (Metro), Andhra Pradesh & Telangana, Gujarat & Daman & Diu, Karnataka, Maharashtra & Goa, Tamil Nadu (A), Madhya Pradesh & Chhattisgarh, Rajasthan, Uttar Pradesh East, and West Bengal (B)
- Restrictions on action space – consistent with the observed data
 - Jio enters all regions at once
 - sequence:
 - ▶ a carrier will not expand into a Category B region unless it has deployed its 4G networks in a Metro or a Category A region
 - number of regions at a time:
 - ▶ no more than two Metro regions, no more than three Category-A regions, no more than three Category-B regions at a time
 - ▶ Airtel and Idea: no more than four regions (across categories) at a time.

Deal with the Large State Space

■ Large action space:

- state variables: $\mathcal{R}_t = (\mathcal{R}_{1t}, \dots, \mathcal{R}_{4t})$ and \mathcal{R}_{ct} is a subset of 12 regions
- there are $(2^{12})^3 \times 2$ possible values for \mathcal{R}_t

■ Solution: following Sweeting (2013)

- compute the value function for a subset of possible state variable values
- approximate the value function at other state variable values with a linear function of some summary statistics of the state variables
- lower-dimensional statistics: total market size of the category-g regions that carrier c has entered with its 4G network

$$s_t(\mathcal{R}_t) = \{(M_{1gt}(\mathcal{R}_{1t}), M_{2gt}(\mathcal{R}_{2t}), M_{3gt}(\mathcal{R}_{3t}), M_{4gt}(\mathcal{R}_t))\}_{g=1}^{g=3}$$

Industry
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Data
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Model
oooo

Estimation
oooo

Estimation Results
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Counterfactual

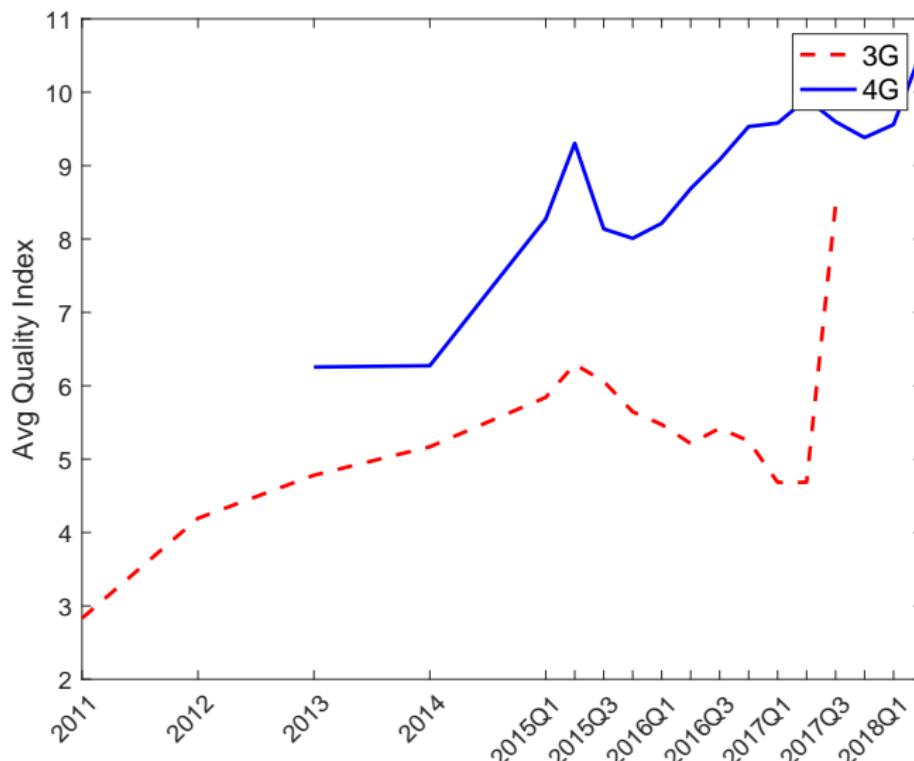
Quality Range

Quality index range:

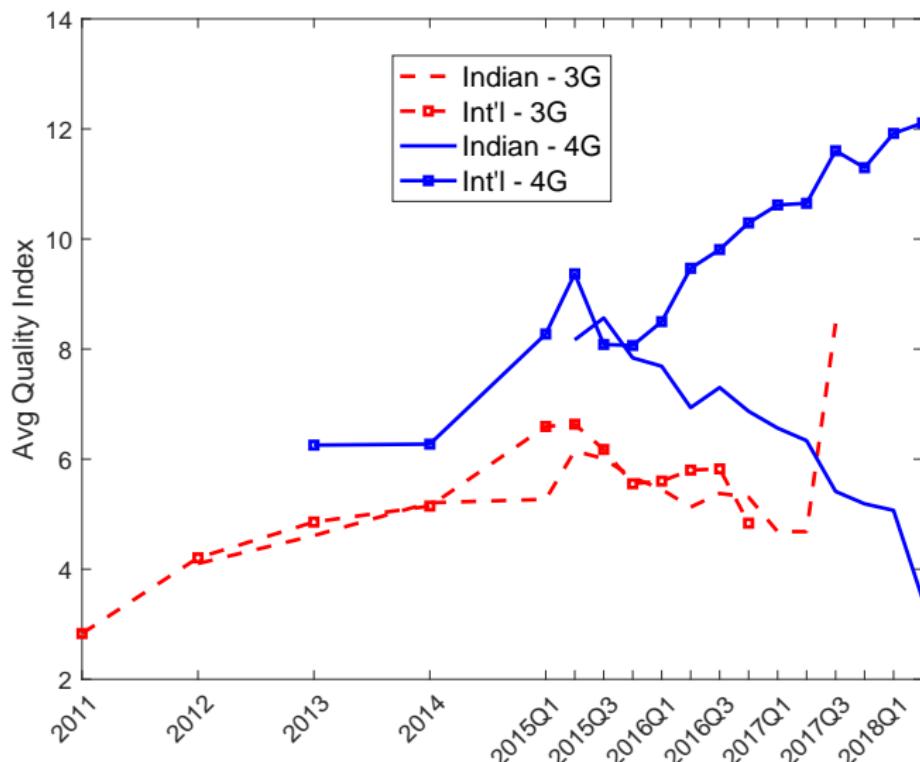
- Indian phones: (2.99, 16.85), mean = 8.37, median = 8.18
- Int'l phones: (2.38, 37.07), mean = 11.89, median = 12.00
- # phone/quarters w/ quality < 4.5 (cutoff when Indian MC becomes smaller): Indian = 259 (out of 2,716), Int'l = 212 (out of 3,528)



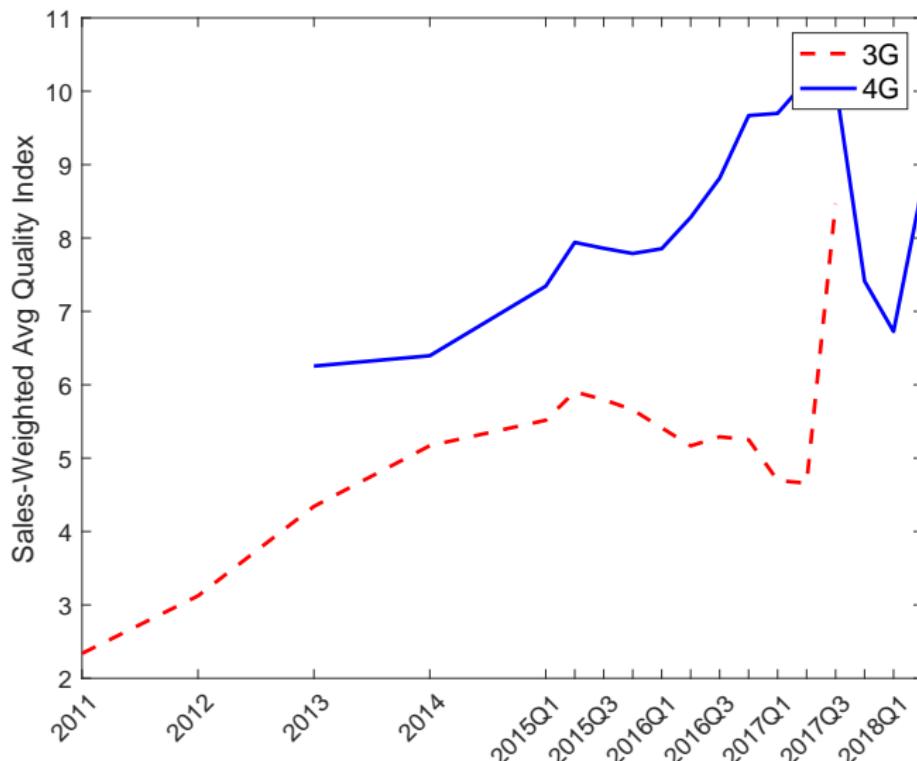
Quality over time



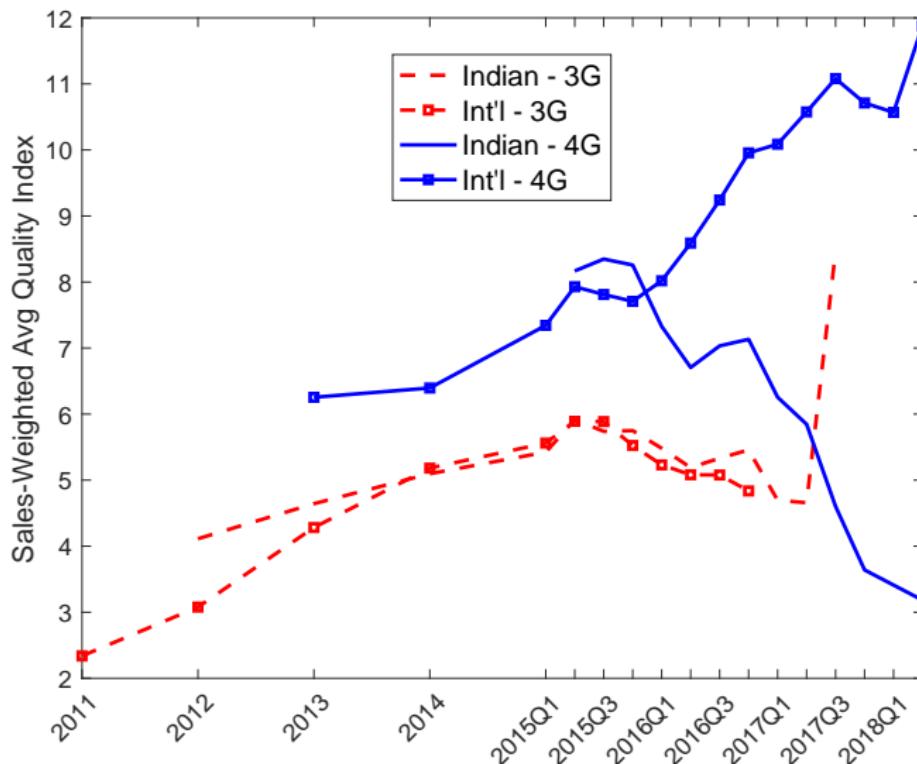
Quality over time



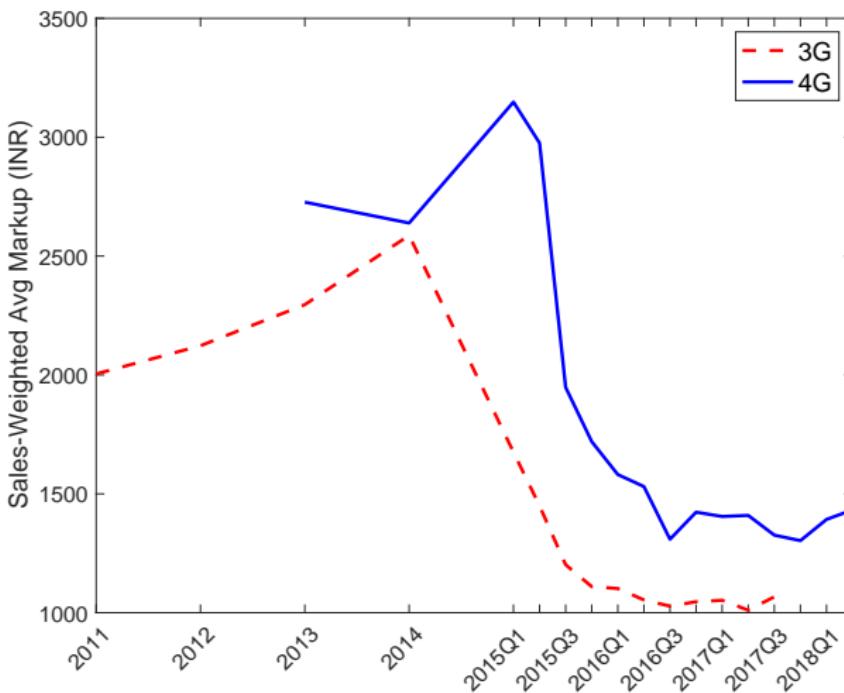
Quality over time



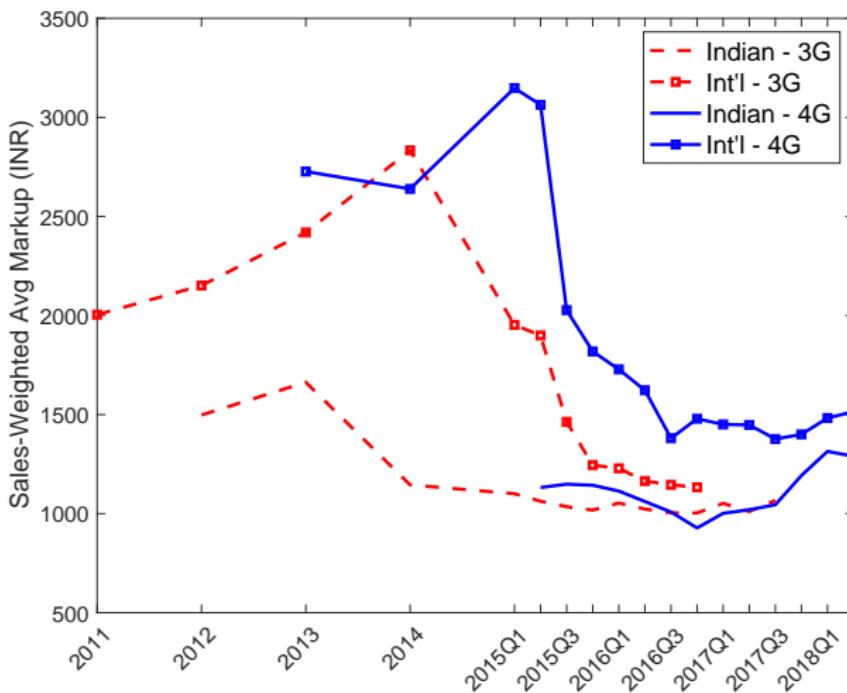
Quality over time



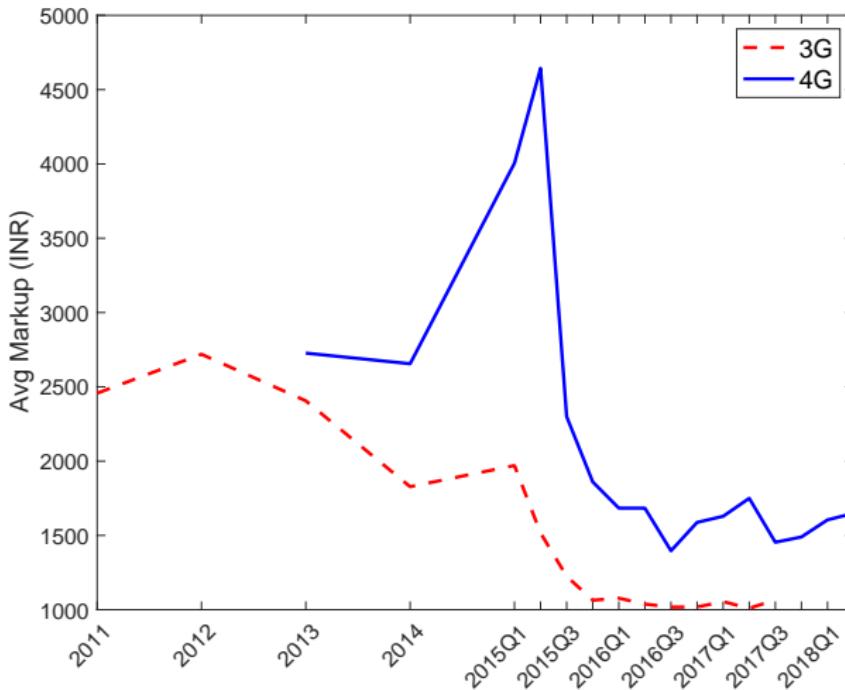
Phone Markups



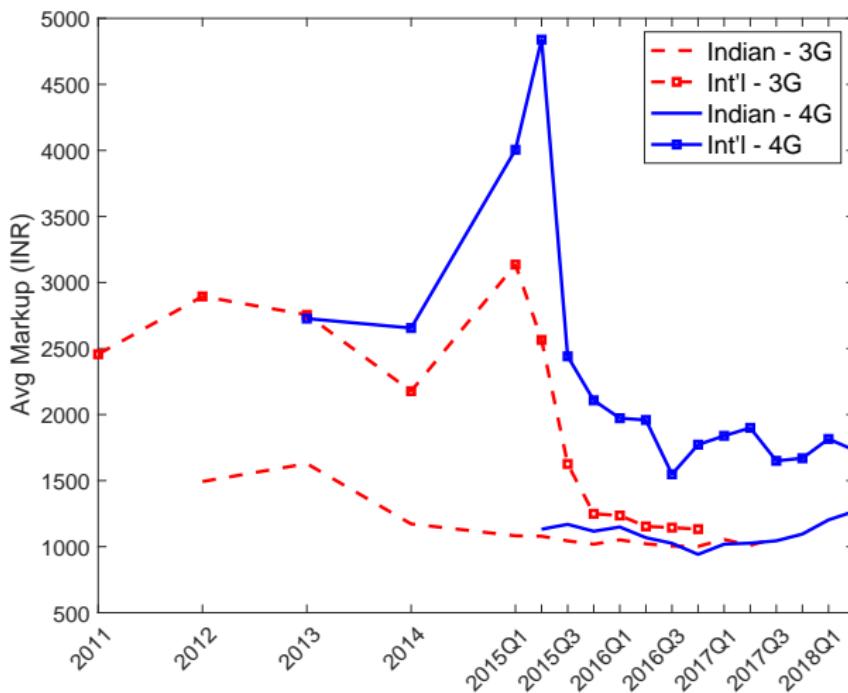
Phone Markups



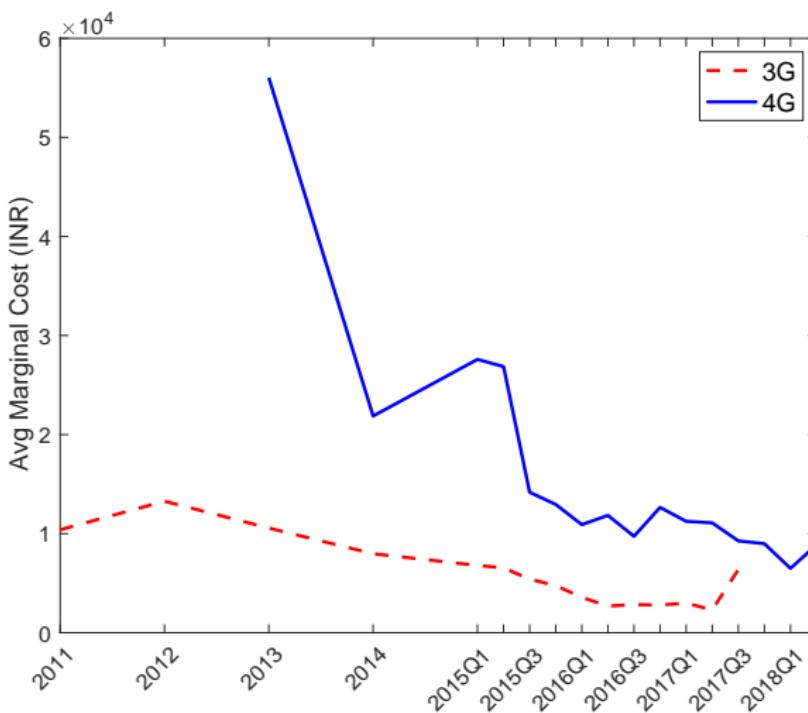
Phone Markups



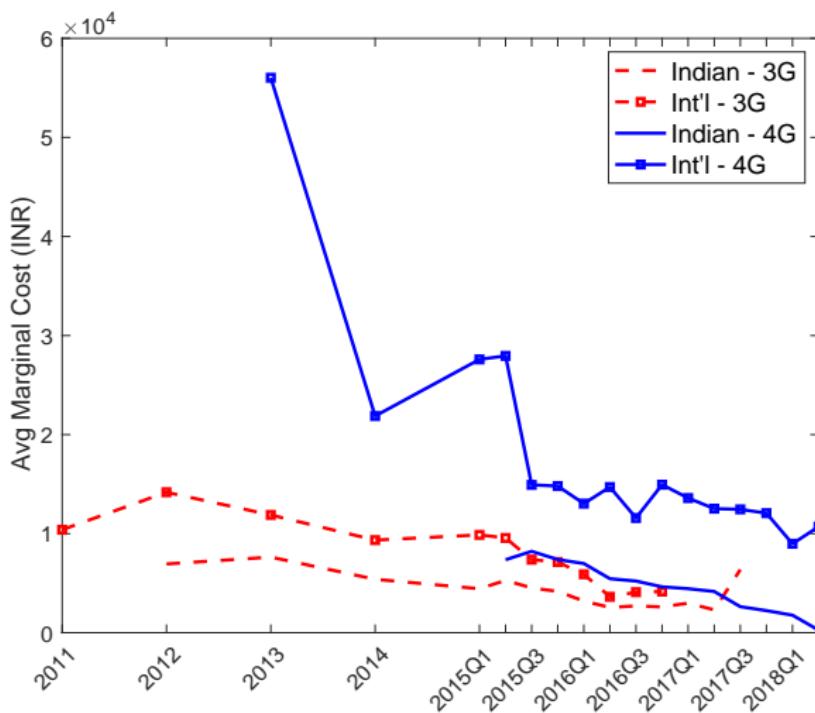
Phone Markups



Phone Marginal Costs



Phone Marginal Costs



Industry
ooooooooooooData
ooooooooooooooooooooModel
ooooEstimation
ooooEstimation Results
oooooooooooo

Counterfactual

Count of 4G Phones Over Time

Time	# 4G phones	# Chinese 4G phones	# Budget Chinese 4G phones
2013	1	0	0
2014	3	0	0
2015Q1	12	3	3
2015Q2	19	6	5
2015Q3	27	11	9
2015Q4	40	15	13
2016Q1	57	21	17
2016Q2	55	21	14
2016Q3	62	29	19
2016Q4	63	29	20
2017Q1	78	35	24
2017Q2	70	31	23
2017Q3	71	29	18
2017Q4	67	28	22
2018Q1	61	25	19
2018Q2	57	20	14

Budget phone: price < 12,000 INR