Regulation and Service Provision in Dynamic Oligopoly: Evidence from Mobile Telecommunications

João Granja

University College London

Amazon, 13 November 2024

Universal Service Regulation (In Telecom)

Market interventions that try to guarantee universal access to services.

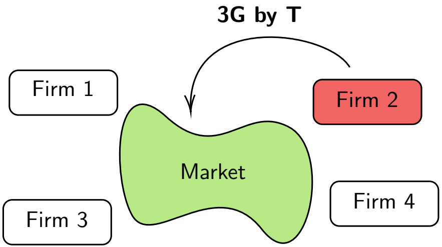
- A feature of many industries: health care, airlines, banking, postal, and **telecommunications**.

Provision of fixed and **mobile** telecom services regulated everywhere

- Why?
  - Positive effects of service access: Jensen (2007), Aker and Mbiti (2010), Jack and Suri (2014), Hjort and Poulsen (2019), Chiplunkar and Goldberg (2022), Van Parys and Brown (2024).
  - Large fixed costs may not be recouped in relatively small and poor areas.
- Different forms of regulation
  - Cost-based subsidies, subsidy auctions, spectrum usage constraints . . .
  - **Coverage requirements** (aka build-out requirements)

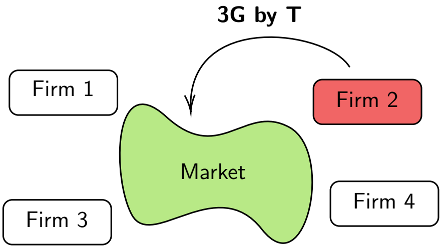
Coverage Requirements (CRs)

- Algeria, **Brazil**, Chile, Czech Republic, Denmark, France, Nigeria, UK, US, . . .



Coverage Requirements (CRs)

- Algeria, **Brazil**, Chile, Czech Republic, Denmark, France, Nigeria, UK, US, . . .

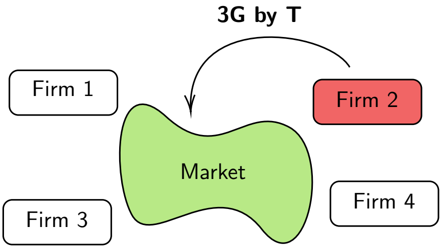


Trade-off

1. (+) Improved/ealier access, more competition.
2. (–) Cost imposed on firms.

Coverage Requirements (CRs)

- Algeria, **Brazil**, Chile, Czech Republic, Denmark, France, Nigeria, UK, US, ...



Trade-off

1. (+) Improved/ealier access, more competition.
2. (–) Cost imposed on firms.

Potential equilibrium effects.

- Regulation is a credible commitment to enter Fudenberg-Tirole example.
- Strategic complementarity

This Paper

Question: How do **CRs** affect the roll-out of new mobile telecom technologies?

+ What are the costs imposed on firms?
+ Can we design more efficient regulation?

Challenge: regulation is universal.

- No unregulated *markets* to compare with regulated ones.

Approach: Compare regulated and unregulated *firms*.

- Estimate dynamic game of entry and tech upgrade with regulation.
  - New data on tech availability for each municipality-carrier 2013-2021.
- Counterfactual analysis:
  - Coverage Requirements vs. No regulation.
  - Subsidy auction (approximate).

Results

Regulation $\Rightarrow$ 3G roll-out **2 years faster** (avg.)

- Heterogeneity across municipalities: $p10 = 0.32$, $p90 = 4.33$.
- 4G roll-out 1.2 years faster.

Equilibrium effects can go in either direction.

- Mostly *delays*, but quantitatively small.

Cost imposed on firms: **14.60%** reduction in aggregate profits.

- Incidence: 91.2% on regulated firms, mostly inactive ones.
- 8.8% fall on unregulated firms due to tougher competition.

Subsidy auction (approximate)

- Costs 32.75% of **CRs**' aggregate cost [622 M BRL vs. 1.9 B BRL]
- Essentially **zero** difference in the speed of roll-out

Related Literature and Contributions ☠

Regulation and Market Structure

Gowrisankaran, Lucarelli, Schmidt-Dengler, and Town (2011), Ryan (2012), Dunne, Klimek, Roberts, and Xu (2013), Fan and Xiao (2015)

- Regulation and the roll-out of new technologies.

Technology Adoption in Oligopoly

Fudenberg and Tirole (1985), Schmidt-Dengler (2006), Igami (2017)

- Interaction between oligopolistic competition and regulation.
- Alternative treatment of non-stationarity.

Telecommunications Markets

Riordan (1992), Valletti, Hoernig, and Barros (2002), Nevo, Turner, and Williams (2016), Björkegren (2019), Marcoux (2022), Lin, Tang, and Xiao (2023), Elliott, Houngbonon, Ivaldi, and Scott (2023), Hidalgo and Sovinsky (2023)

- Empirical model of regulated build-out.

Data

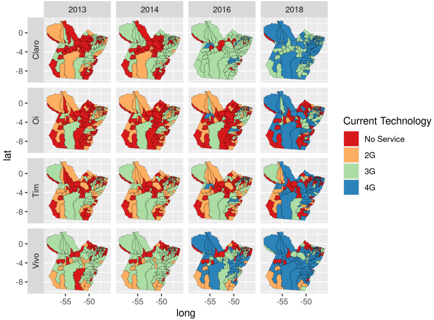


Figure: Technology availability in the state of Pará

- Main source: **ANATEL**
  - 2G, 3G, and 4G availability by carrier-muni-month, June 2013-June 2021.
  - Regulated carrier and regulation deadline.
  - No. subscribers by carrier/tech/area/month.
- **Census**
  - Municipality characteristics, dist. of demographics.
  - Consumer expenditure survey.

Institutional Setting and Sample

Coverage requirements are part of **spectrum licenses**.

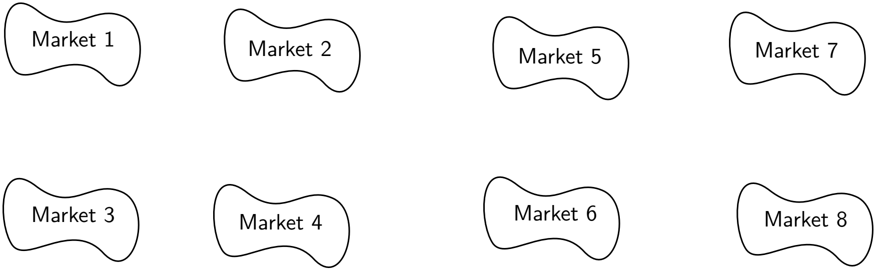
Four large carriers with national licenses.

Enforcement: financial guarantees, litigation, licenses can be revoked.

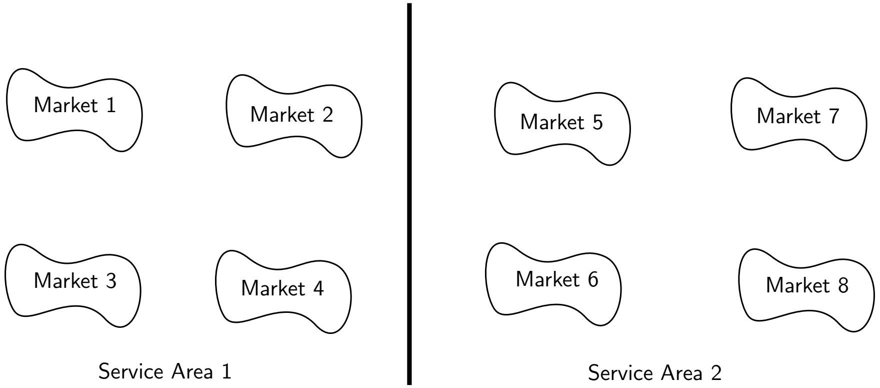
Estimation sample: Focus on municipalities with a **single firm** with a **3G requirement**.

- 3,101 municipalities, Pop $\leq$ 30,000, mostly rural. Requirements map.
- Regulation deadline varies.
- For counterfactuals: municipalities with Dec 2019 and April 2016 deadlines (1,600).
- For profit functions: all of Brazil.

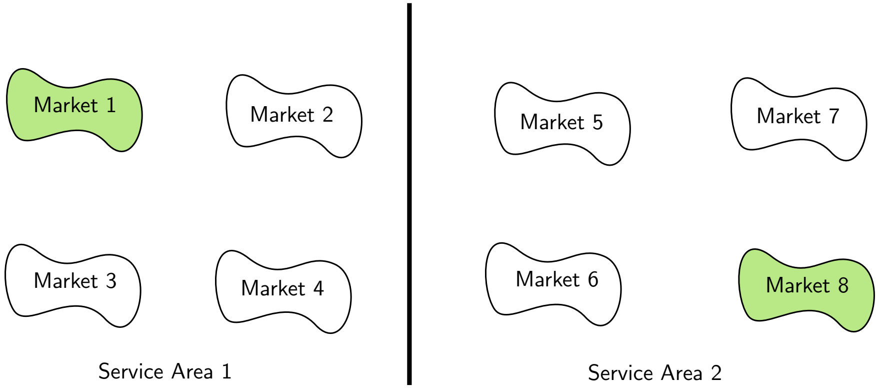
Selecting Markets



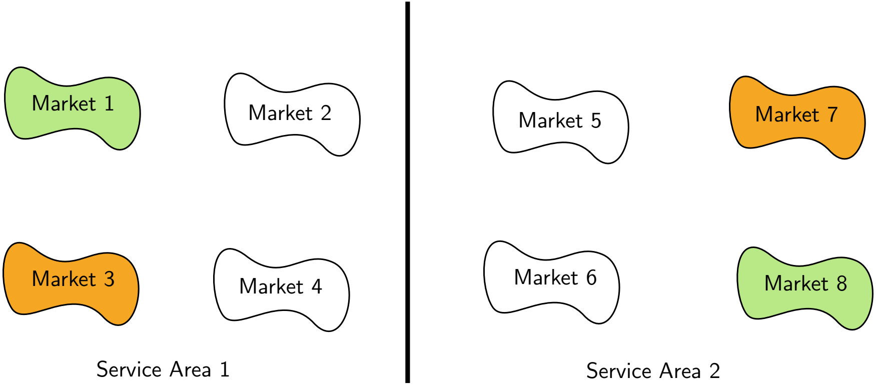
Selecting Markets ☠



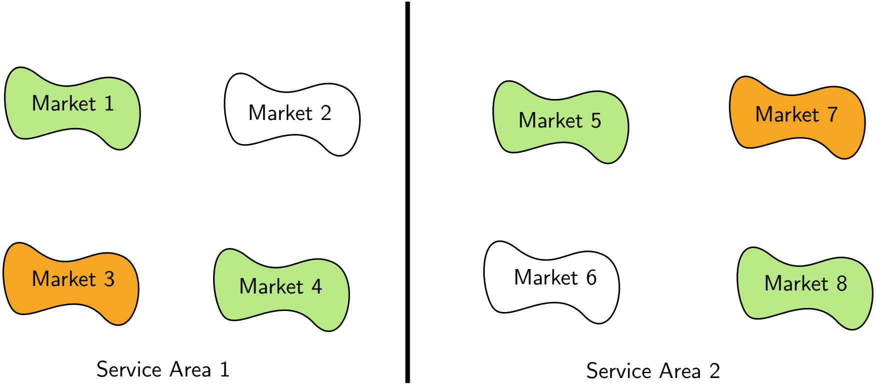
Selecting Markets ☠



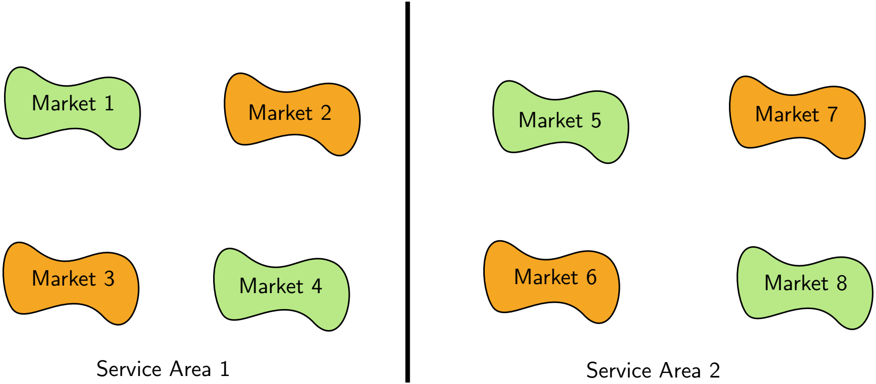
Selecting Markets ☠



Selecting Markets ☠

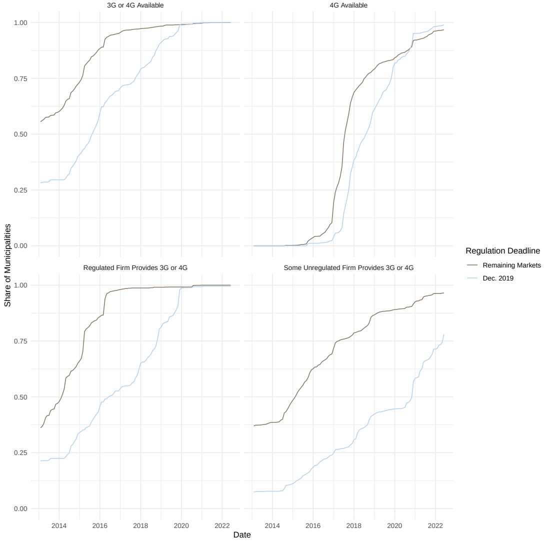


Selecting Markets ☠



- Selection?
  - Service in the municipality: accounted for in the model.
  - Service in neighboring municipalities. Fail to reject H_0 no selection ▸ No selection.
  - Model features rich firm heterogeneity.

Data – Patterns of Adoption



- Non-compliance happens in **4%** of markets.

Data – Regulation Effects

$Y = \mathbf{1}\{\text{Upgrade}\}$

Columns: subsamples conditional on firm's technology.

	Out	2G	3G
Regulated	0.108	0.174	−0.040
	(0.007)	(0.012)	(0.005)
Regulated Competitor - Out	−0.014	0.002	−0.043
	(0.003)	(0.009)	(0.010)
Regulated Competitor - 2G	−0.001	−0.023	−0.068
	(0.004)	(0.004)	(0.007)
Group FE	Yes	Yes	Yes
$\bar{Y}$	0.030	0.077	0.086
Num. obs.	97372	47501	51654

Model

A **municipality** is a market. **Four** potential firms in each market.

Time is discrete and the horizon is infinite.

- 1 period = 6 months.

Firm's state: $s_f \in \{0, 1, 2, 3\}$.

- Firms offer all $g \leq s_f$. Industry state $s = (s_1, \ldots, s_4)$.
- Industry state $\boldsymbol{s} = (s_1, \ldots, s_4)$.

Exactly **one regulated firm**, regulation deadline T.

- Non-compliance after $T \Rightarrow$ fine φ per period.

Model

A **municipality** is a market. **Four** potential firms in each market.

Time is discrete and the horizon is infinite.

- 1 period = 6 months.

Firm's state: $s_f \in \{0, 1, 2, 3\}$.

- Firms offer all $g \leq s_f$. Industry state $s = (s_1, \ldots, s_4)$.
- Industry state $\boldsymbol{s} = (s_1, \ldots, s_4)$.

Exactly **one regulated firm**, regulation deadline T.

- Non-compliance after $T \Rightarrow$ fine φ per period.

Timing within a period:

$$\boxed{s_1, \ldots, s_4} \longrightarrow \boxed{\pi(s)} \longrightarrow \boxed{\varepsilon_f(a)} \longrightarrow \boxed{a_1, \ldots, a_4} \longrightarrow \boxed{c(a, s_f)}$$

$$\longrightarrow \boxed{\left(s_1^{'}, \ldots, s_4^{'}\right) = (a_1, \ldots, a_4)}$$

Model – Actions and Costs

Firms choose action a satisfying $s_f \leq a \leq 3$

- **Potential entrants**: which tech to enter with, if at all.
- **Incumbents** which tech to upgrade to (if at all)

Entry/upgrade costs:

$$c_t\left(a, s_{fmt}, z_m\right) - \varepsilon_{fmt}(a)$$

where

$$c_t\left(a, s_{fmt}, z_m\right) = \begin{cases} 0 & \text{if } a = s_{fmt} \\ \sum_{\{g':g'>s_{fmt}\}}^{a} z_m'\theta_{g',t} + \mathbf{1}\left(s_{fmt} = 0\right) z_m'\theta_e & \text{if } a > s_{fmt} \end{cases}$$

and $\varepsilon_{fmt}(a)$ are T1EV shocks.

Model – Flow Profits

Suppose consumers choose a (firm,technology) pair and expenditure.

$$\pi_{ft}(\boldsymbol{s}) = \sum_{g \in s_f} \sum_{i} \mathbf{1}\{j(i) = (f, g)\} e_i$$

Model – Flow Profits

Suppose consumers choose a (firm,technology) pair and expenditure.

$$\begin{aligned}\pi_{ft}(\boldsymbol{s}) &= \sum_{g \in s_f} \sum_i \mathbf{1}\{j(i) = (f,g)\} e_i \\ &\approx M \sum_{g \in s_f} \int \mu_{f,g}(\boldsymbol{s}, x_i) \mathbb{E}[e_i \mid x_i] dH_t(x_i)\end{aligned}$$

Assumptions

1. Choice of product $j(i)$ and expenditure e_i are independent conditional on x_i.
2. Expenditure e_i is mean-independent of market structure conditional on x_i.

Model – Flow Profits ☠

- $\mu_{f,g}(\boldsymbol{s}, x_i)$ comes from a nested logit model:

$$u_{ijmt} = v_{jmt}(x_i) + \xi_{jmt} + \zeta_{imt}(\lambda) + (1-\lambda)\varepsilon_{ijmt}$$

  $v_{jmt}(x_i)$ includes
  - Technology-year FEs
  - State-carrier FEs
  - Interactions of Tech-Year dummies with population density and income.

- Expenditure, e_i, is modeled as

$$\log(e_{im}) = \alpha_{r(m)u} + \alpha_1 \log(y_i) + \alpha_2 n_i + \eta_{im}$$

Model – Additional Assumption & Solution Concept

Assumption. Parameters stabilize at a known date T_θ.

Quasi-Stationary Markov Perfect Equilibria:

- Firm behavior is given by $\sigma_{fm}(\boldsymbol{s}, t, \varepsilon_f)$. (MPE)
- $\sigma_{fm}(\boldsymbol{s}, t, \varepsilon_f) = \bar{\sigma}_{fm}(\boldsymbol{s}, \varepsilon_f)$ for all $t \geq T_\theta$. (QS)

Model – Additional Assumption & Solution Concept

Assumption. Parameters stabilize at a known date T_θ.

Quasi-Stationary Markov Perfect Equilibria:

- Firm behavior is given by $\sigma_{fm}(\boldsymbol{s}, t, \varepsilon_f)$. (MPE)
- $\sigma_{fm}(\boldsymbol{s}, t, \varepsilon_f) = \bar{\sigma}_{fm}(\boldsymbol{s}, \varepsilon_f)$ for all $t \geq T_\theta$. (QS)

Note. 2nd source of non-stationarity: **CRs** themselves. Resolves prior to T_θ.

- Accommodates non-stationarity and retains dynamics.
  - In contrast with finite-horizon approaches.

Model – Additional Assumption & Solution Concept

Assumption. Parameters stabilize at a known date T_θ.

Quasi-Stationary Markov Perfect Equilibria:

- Firm behavior is given by $\sigma_{fm}(\boldsymbol{s}, t, \varepsilon_f)$. (MPE)
- $\sigma_{fm}(\boldsymbol{s}, t, \varepsilon_f) = \bar{\sigma}_{fm}(\boldsymbol{s}, \varepsilon_f)$ for all $t \geq T_\theta$. (QS)

Note. 2nd source of non-stationarity: **CRs** themselves. Resolves prior to T_θ.

- Accommodates non-stationarity and retains dynamics.
  - In contrast with finite-horizon approaches.

Aguirregabiria and Mira (2007): MPE can be defined in CCP-space and P^* is a MPE iff

$$P^* = \Psi(P^*)$$

Eqm details.

Identification and Estimation: Static Parameters

Expenditure equation: OLS on expenditure survey data.

Market-share model

- 2013-2018 data: code-area level.
- 2019-2021 data: muni level.

With **muni-level data**, usual nested-logit inversion applies:

$$\log(s_{jmt}) - \log(s_{0mt}) = v_{g(j)mt} + \lambda \log(s_{j|\mathcal{J}_{mt}}) + \xi_{jmt}$$

Can form moment conditions

$$\mathbb{E}[\xi_{jmt}(\theta) Z^1_{jmt}] = 0$$

IV for λ: numbers of regulated firms (3G and 4G).

Estimation: Static Parameters ☠

Assumption. $\xi_{jmt} = \boldsymbol{\xi_{jc(m)t}} + \eta_{jmt}$, $\eta_{jmt} \overset{iid}{\sim} F$

$$\sigma_{jct} = \sum_{m \in c} \omega_m \int \sigma_{jmt}(s_{mt}, v_{g(j)mt}, \boldsymbol{\xi_{j,c(m),t}}, \eta_{jmt}; \theta) dF(\eta_{jmt})$$

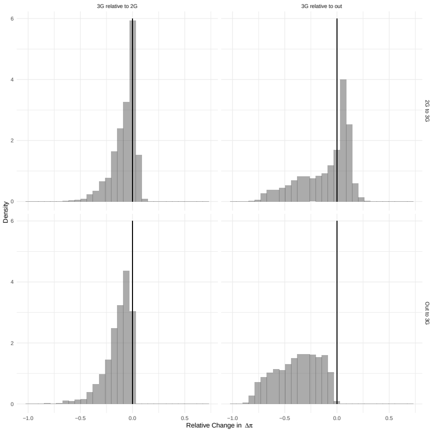
Use equation above to solve for $\xi_{j,c(m),t}(\theta)$, form MCs

$$\mathbb{E}[\xi_{j,c(m),t}(\theta) Z^2_{jct}] = 0$$

Z^2_{jct}: weighted-averages of muni characteristics included in $v_{g(j)mt}$.

GMM using the two sets of MCs. ▸ Estimation Details

Implications of Flow Profit Estimates



- Profit differences-in-differences: $\Delta\pi_f(s_f, s'_f, s_r, \cdot) - \Delta\pi_f(s_f, s'_f, s'_r, \cdot)$.
  - Technology upgrades are mostly *strategic substitutes*.
  - Can be *strategic complements* for *incumbents*.

Identification and Estimation: Dynamic Parameters

- m-specific CCPs P^m: eqm uniqueness + continuity.

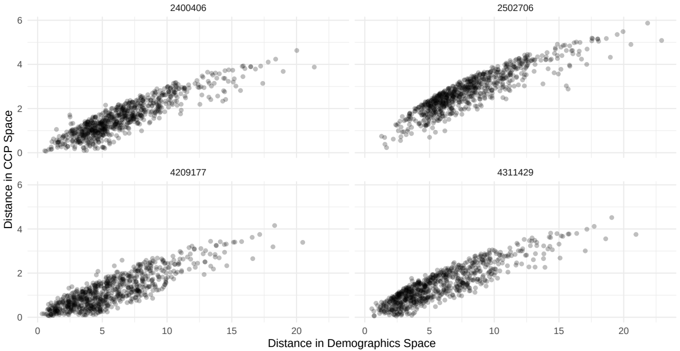


Figure: Equilibrium continuity

- φ: compare *regulated* and *unregulated* firms.
- $c(a, s_f, z_m; \theta)$: compare munics of different size conditional on state and CV.

Identification and Estimation: Dynamic Parameters

A **NPL fixed point** (Aguirregabiria and Mira (2007)) is a pair $(\tilde{\theta}, \{\tilde{P}^m\}_m)$ that satisfies

(i) $\tilde{\theta} = \text{argmax}_\theta \sum_{m,f,t} \ln \Psi_m(a_{mft}|t, \boldsymbol{s}_{mt}; \theta, \tilde{P}^m)$

(ii) $\tilde{P}^m = \Psi_m(\tilde{P}^m, \tilde{\theta})$ for all m

The set of NPL fixed points is non-empty; it need not be a singleton.

The **NPL estimator** is the NPL fixed point with the maximum value of the pseudo-likelihood.

Estimation Results – Dynamic Parameters

Entry Costs Median = 8.40 million BRL. p5 = 6.66 M, p95 = 11.09 M.

Cost of Non-Compliance $\hat{\varphi} = 400$k BRL. 4.76% of the median entry cost.

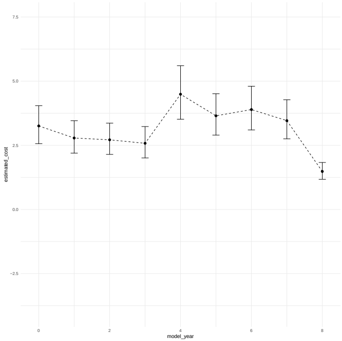


Figure: Cost of 3G Introduction

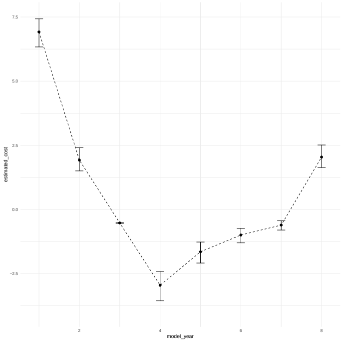


Figure: Cost of 4G Introduction

Results: Probability of 3G+ Without Regulation

Q: Would there be service in the absence of regulation?

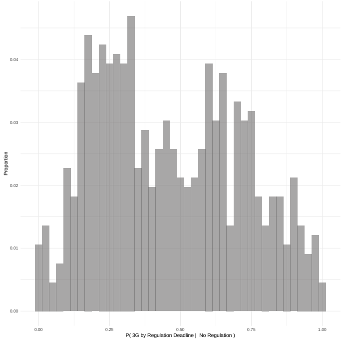


Figure: $\mathbb{P}(3G)$ – April 2016 Deadline

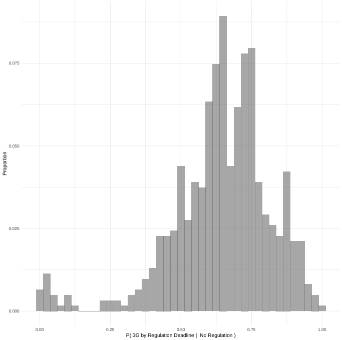


Figure: $\mathbb{P}(3G)$ – December 2019 Deadline

Results: Status quo vs. No Regulation, 3G

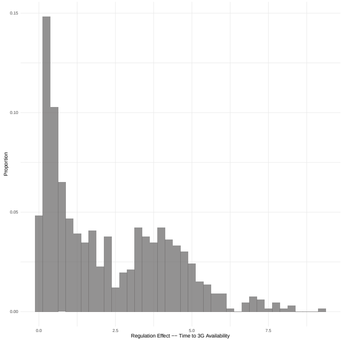


Figure: Regulation Effect – April 2016 Deadline

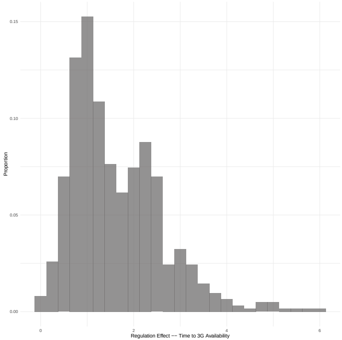


Figure: Regulation Effect – December 2019 Deadline

Avg. effect: 1.96 years. p10 = 0.32, p90 = 4.33. Distribution. Explaining heterogeneity.

Results: Status quo vs. No Regulation, 4G

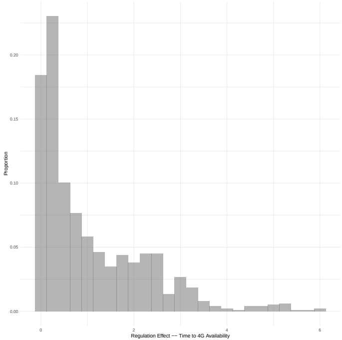


Figure: Regulation Effect – April 2016 Deadline

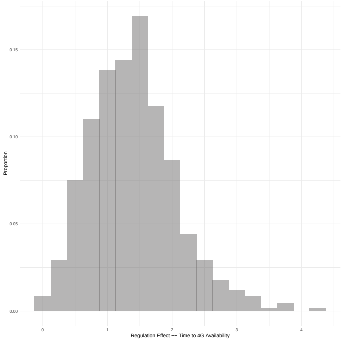
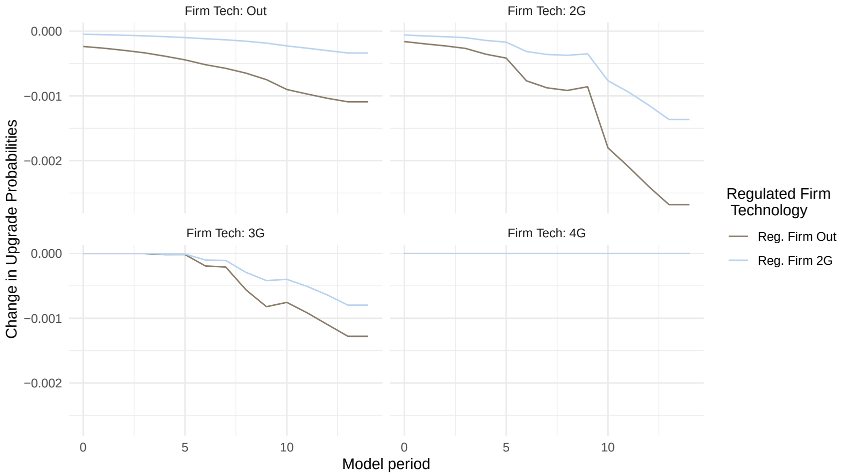


Figure: Regulation Effect – December 2019 Deadline

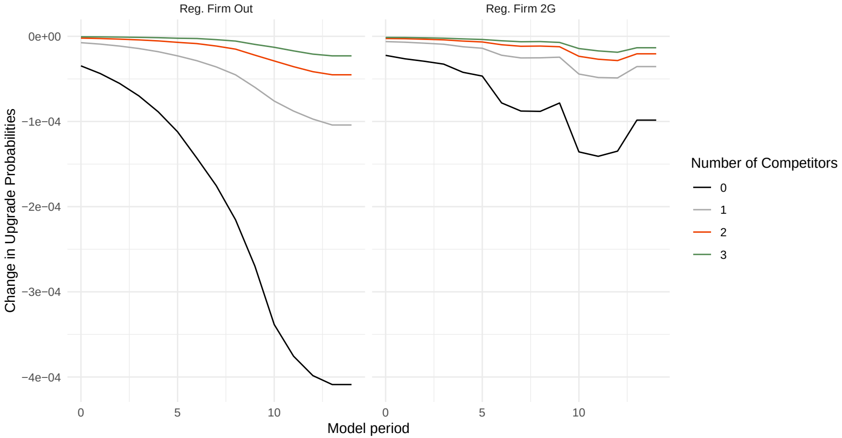
Avg. effect: 1.20 years. p10 = 0.11, p90 = 2.46.

- Negative effects for 1.5% of markets.

Results: Changes to Policy Functions, Unregulated Firms ☠



Results: Changes to Policy Functions, Regulated Firms ☠



Results: Equilibrium Effects, 3G

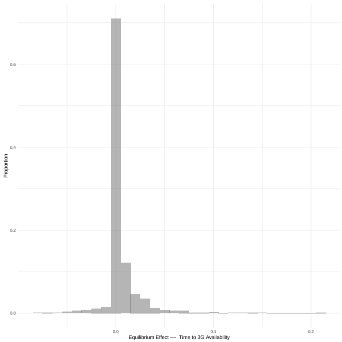


Figure: Equilibrium Effect – 3G

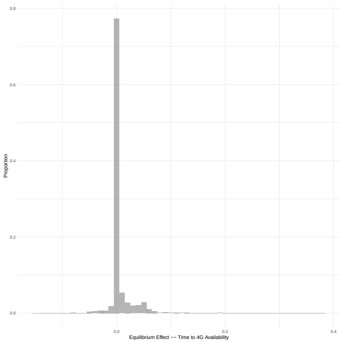


Figure: Equilibrium Effect – 4G

Results: Regulation Cost

$$\sum_m \sum_f \left(V_{fm}(\boldsymbol{s}_0, t = 0, \varphi = 0) - V_{fm}(\boldsymbol{s}_0, t = 0, \varphi = \hat{\varphi}) \right)$$

Aggregate cost: 1.89 billion BRL, **14.6%** of profits without regulation.

Table: Regulation Cost Incidence

Regulated	Firm State	Total Cost	Average Cost	Percentage of Total Cost
No	Out	15.04	0.00	0.80
No	2G	98.59	0.08	5.22
No	3G	37.54	0.09	1.99
Yes	Out	1,141.90	2.63	60.43
Yes	2G	596.68	0.49	31.57

(Approximate) Subsidy Auction

A large fraction of the costs is due to regulating inactive firms.

- Suggests inefficient selection.

Q: What is the minimum transfer required for some firm to be willing to be regulated?

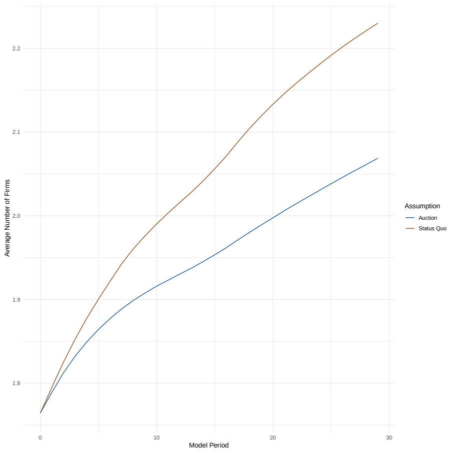
- Willigness to accept a transfer depends on payoffs when others are regulated.
- Approximate by minimum regulation cost relative to *no regulation*.

Results

- The regulated firm differs from the minimum cost firm in 53% of the markets.
- Aggregate transfer: **621.75 M BRL**, 32.75% of the total cost of **CRs**.
- **Same effect** on rollout.
  - Time to 3G+: auction 0.007 years slower on average.
  - Time to 4G: auction 0.09 years faster on average.
- **Cost**: encourages deployment by incumbents relative to **CRs**, reduces competition.

(Approximate) Subsidy Auction

The cost of a subsidy auction: **reduced competition**.



(Approximate) Subsidy Auction

Could $\boldsymbol{\Delta CS}$ overturn the cost reduction?

- The estimated model enables a suggestive calculation.

- **Assume**: $CS(N+1) - CS(N) = \gamma$ for all $N \geq 0$.
- $\Delta CS \geq \Delta\text{Cost}$ iff

$$\gamma \geq \frac{\Delta\text{Cost}}{\sum_m \text{Pop}_m \sum_{t\geq 0} \beta^t (N_{mt}^{SQ} - N_{mt}^{Auction})} \Rightarrow \gamma \geq 48.60\text{BRL}$$

  - **Conservative bound**, because
    - (i) Even with symmetry expect $\frac{\partial^2 CS(N)}{\partial N^2} < 0$.
    - (ii) With asymmetric firms expect marginal entrant to less desirable for consumers.
- 48.60 BRL $\approx 2.4 \times$ Average expenditure
  - Economides, Seim, and Viard (2008): $\Delta CS = 2.5\%$ of consumer bill.

Conclusion

Current regulation

- Accelerated 3G roll-out by **2 years**, on average. Reduced firm profits by **14.6%**.

Subsidy Auction

- Same effect on roll-out.
- At **32.75%** of the cost.
- Negative competition effects
  - But unlikely to overturn cost reduction.

Takeaways:

√ Regulation should **exploit competition in the market**

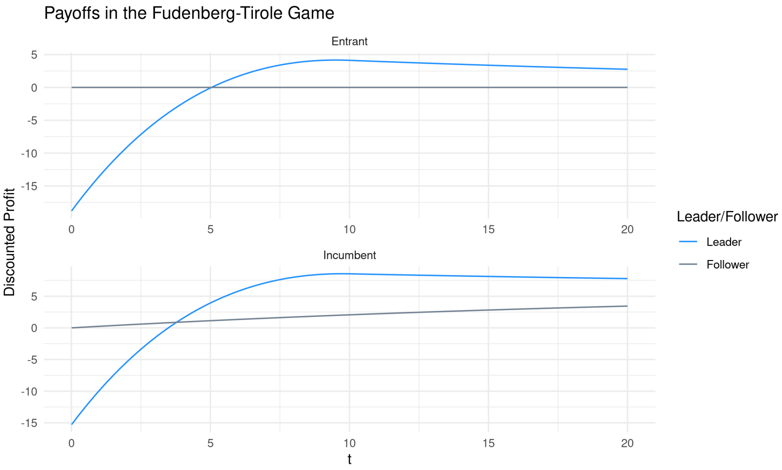
√ Potential commitment power of regulation.

√ Cross sectional data enables **quasi-stationarity**.

(A few of the) Topics I did not touch on

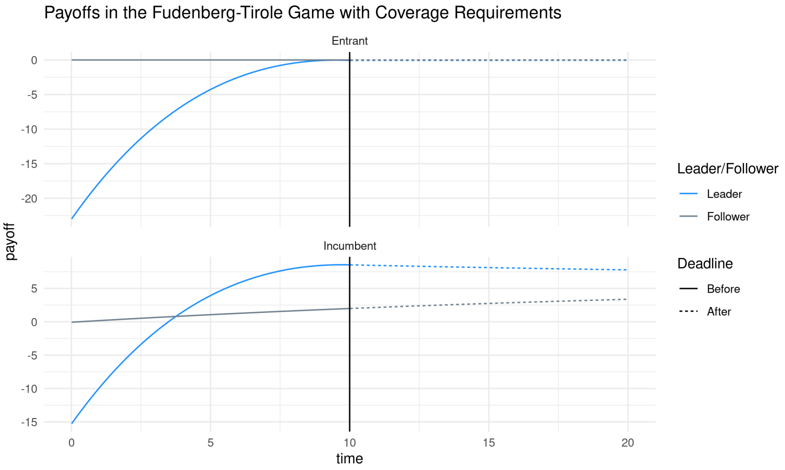
- Technology diffusion on a *network*; interdependent costs.
- Optimal regulation? Need p, q data. Consumer surplus vs. cost reductions.

Fudenberg-Tirole without Regulation

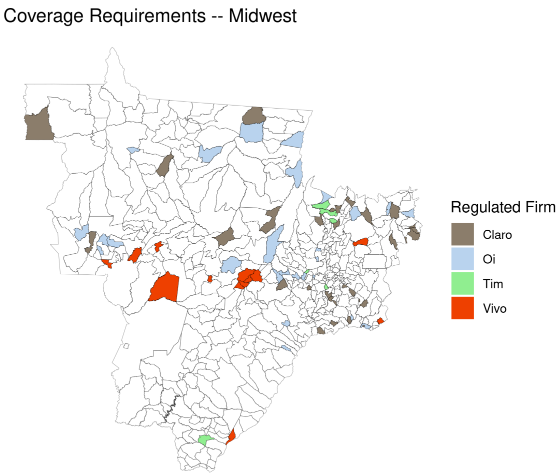


▸ Back to Intro.

Fudenberg-Tirole with Regulation



Map of Requirements – Midwest



▸ Back to institutions.

Testing for Selection on Service in Neighboring Municipalities

	Dependent variable:	
	Regulated	
	Logit	LPM
	(1)	(2)
2G Service	1.727***	0.237***
	(0.058)	(0.008)
3G Service	0.883***	0.194***
	(0.058)	(0.010)
2G Service Nb.	−0.240*	−0.018
	(0.125)	(0.016)
3G Service Nb.	−0.345***	−0.047***
	(0.052)	(0.008)
Constant	−2.104***	0.116***
	(0.117)	(0.015)
Observations	13,204	13,204
R^2		0.139
Adjusted R^2		0.139
Note:	*p<0.1; **p<0.05; ***p<0.01	

▸ Back to data.