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

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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**.

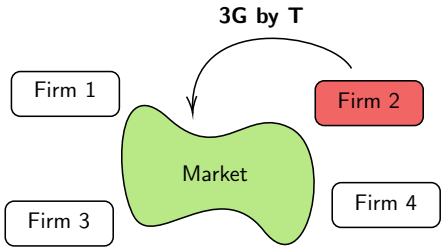
Provision of fixed and **mobile** telecom services regulated everywhere

- Why?
  - Positive welfare 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, ...



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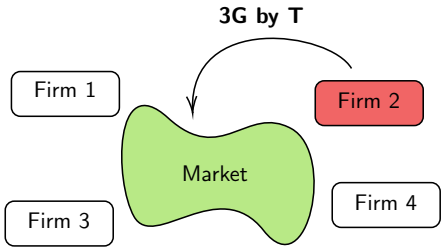

Trade-off

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

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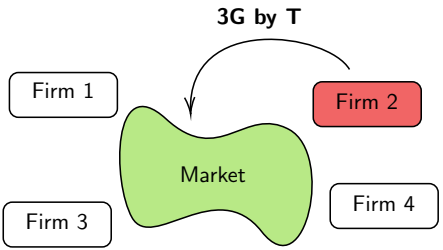


Trade-off

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?

Challenges

- Regulation is universal: no unregulated markets to compare with regulated ones.
- Welfare and counterfactual questions require a model.

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.
- **Counterfactuals**
  - Coverage Requirements vs. No regulation.
  - Subsidy auction (approximate).

Results

Regulation $\Rightarrow$ 3G roll-out **1.06 years faster** (avg.)

- Heterogeneity across municipalities: $p10 = 0.21$, $p90 = 2.44$.
- Spillover to 4G: 0.41 years faster rollout.
  - Probability of delay in 4G non-negligible: 6.25%.

Equilibrium effects *almost always* lead to delay.

- Quantitatively small.

Cost imposed on firms: **7.79%** reduction in aggregate profits.

- Incidence: 84.9% on regulated firms, mostly inactive ones.
- 15.1% on unregulated firms due to tougher competition.

Subsidy auction (approximate)

- Costs 30.36% of **CRs**' aggregate cost [553.43 vs. 1822.82 million BRL]
- Essentially **zero** difference in the speed of 3G 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), Igami (2017), Schmidt-Dengler (2024)

- 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), Hidalgo and Sovinsky (2023), Elliott, Houngbonon, Ivaldi, and Scott (2025)

- Empirical model of regulated build-out.

Data

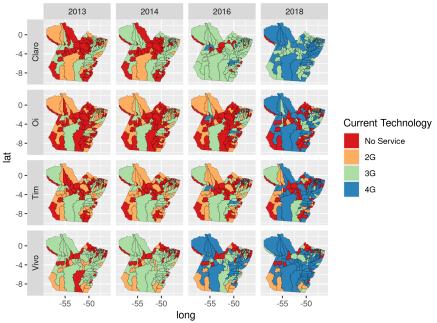


Figure: Technology availability in the state of Pará

- 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**.

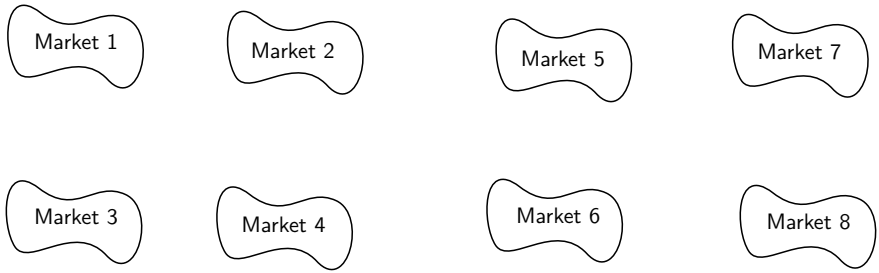
Four large carriers with national licenses.

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

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

- 3,461 municipalities.
  - Pop $\leq$ 30,000, mostly rural. Requirements map.
- Regulation deadline varies.
- For profit functions: all of Brazil.
- For counterfactuals: municipalities with Dec 2019 and April 2016 deadlines (1872).

Selecting Markets



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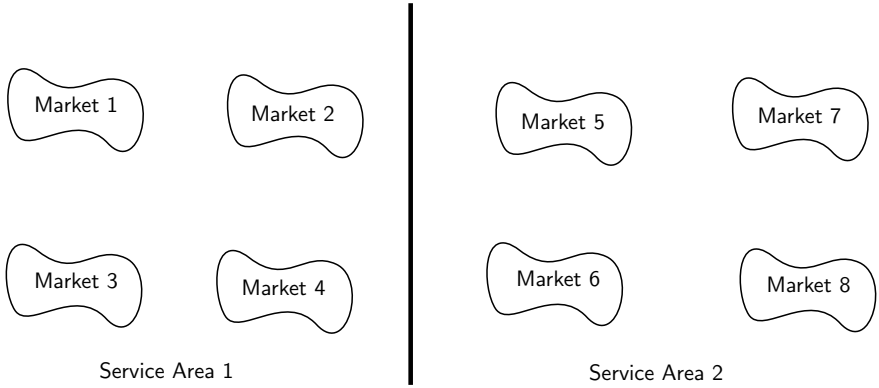

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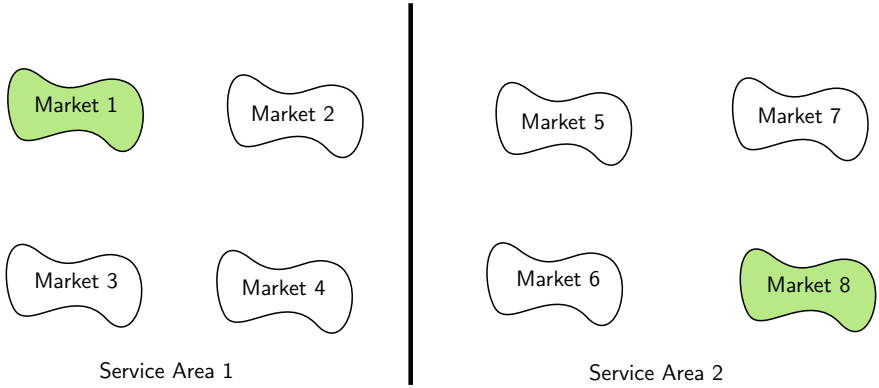

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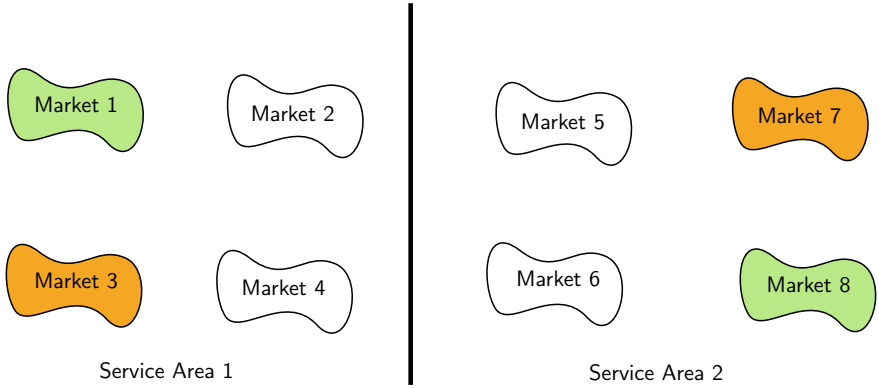

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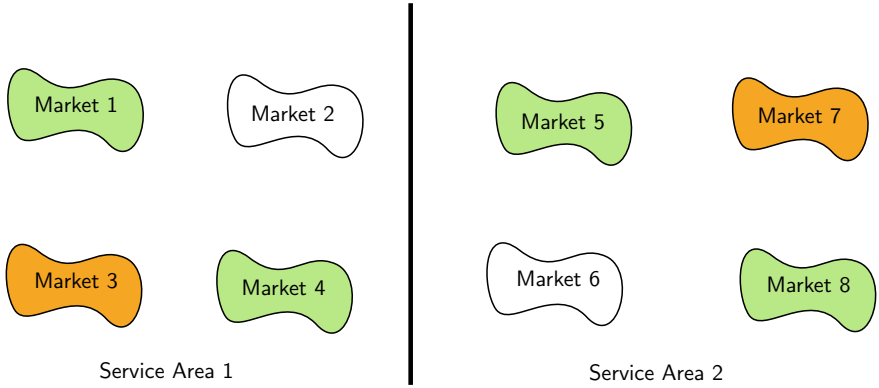

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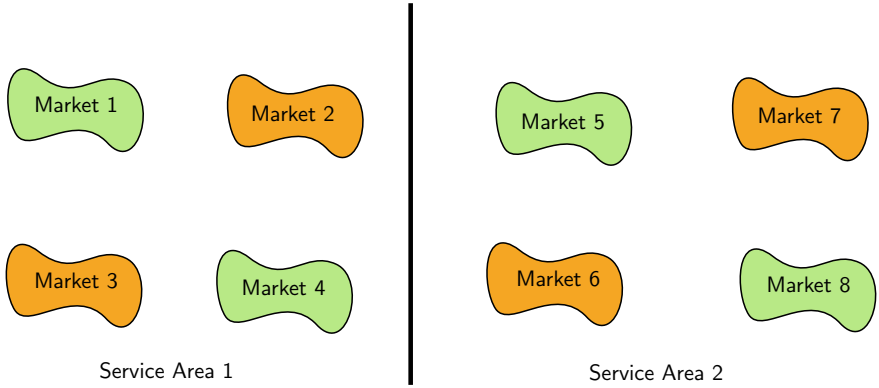
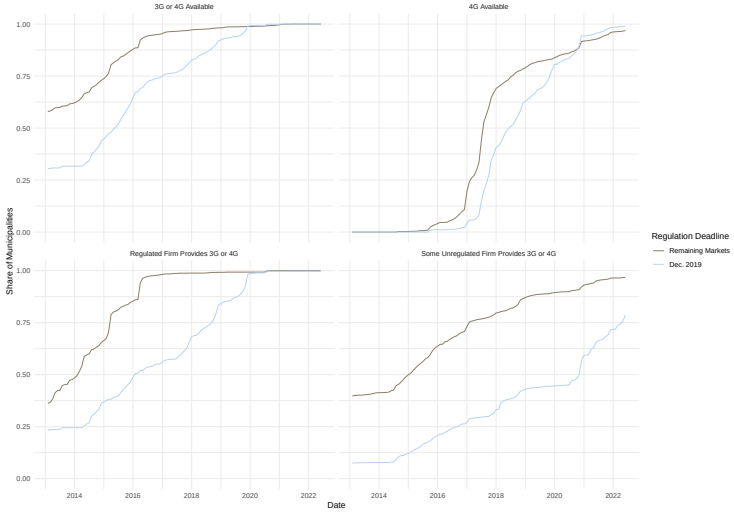


- Selection?
  - Service in the municipality: accounted for in the model.
  - Service in neighboring municipalities. Fail to reject H_0 no selection ▸ No selection.
  - Model features rich firm heterogeneity.

Data – Patterns of Adoption



- Non-compliance happens in **4.53%** of markets.

Data – Regulation Effects

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

Columns: subsamples conditional on firm's technology.

	Out	2G	3G
Regulated	0.116	0.161	−0.039
	(0.008)	(0.009)	(0.005)
Regulated Competitor - Out	−0.014	−0.005	−0.041
	(0.003)	(0.007)	(0.009)
Regulated Competitor - 2G	0.001	−0.021	−0.064
	(0.005)	(0.004)	(0.007)
Group FE	Yes	Yes	Yes
$\bar{Y}$	0.031	0.075	0.083
Num. obs.	108221	55708	57679

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 technologies $g \leq s_f$.
- 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.

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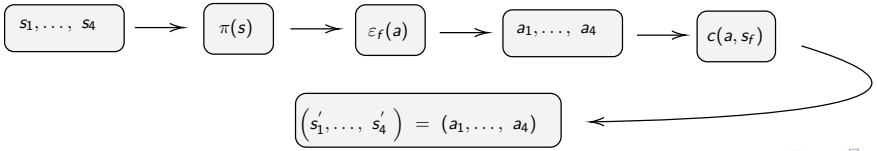
Timing within a period:



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:

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

where

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

- $\varepsilon_{fmt}(a) \overset{\text{iid}}{\sim} T1EV$.
- z_{fmt}: municipality area, deployment share in nearby unregulated markets.

Model – Flow Profits

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

$$\pi_{fmt}(\boldsymbol{s}_{mt}) = \sum_{g \in s_{fmt}} \sum_{i} \mathbf{1}\{j_i = (f, g)\} e_{it}$$

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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 j_i conditional on x_i.

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Specification of $\mu_{fgt}(\boldsymbol{s}_{mt}, x_i)$: Nested logit.

- Nesting at the **technology** level.
- Mean utility includes
  - → Technology-year FEs
  - → State-carrier FEs
  - → Interactions of Tech-Year dummies with population density and income.

▸ Dynamics of technology market shares.

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Specification of $\mathbb{E}[e_{it} \mid x_i]$: Log-linear, including

- State $*$ urban/rural FEs.
- Household size.

▸ Expenditure log-linearity in the data.

Model – Solution Concept

Assumption. Parameters stabilize at a known date T_θ.

Quasi-Stationary Markov Perfect Equilibria (QS-MPE):

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

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Note. 2nd source of non-stationarity: **regulation** itself.

- Resolves prior to T_θ.

QS-MPE

- Accommodates non-stationarity and retains dynamics.
  - In contrast with finite-horizon approaches.
- Enables the use of tools for stationary environments.

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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:

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

Can form moment conditions

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

IV for λ: $f(\text{Population}_{2010})$

▸ Number of Regulated Firms vs. Population

Estimation: Static Parameters

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

If $|c|$ is "large", then

$$\sigma_{jct} \approx \sum_{m \in c} \omega_m \int \sigma_{jmt}(\boldsymbol{s_{mt}}, \boldsymbol{v_{mt}}, \boldsymbol{\xi_{c(m)t}}, \boldsymbol{\eta_{mt}}; \theta) \, \mathrm{d}F(\boldsymbol{\eta_{mt}})$$

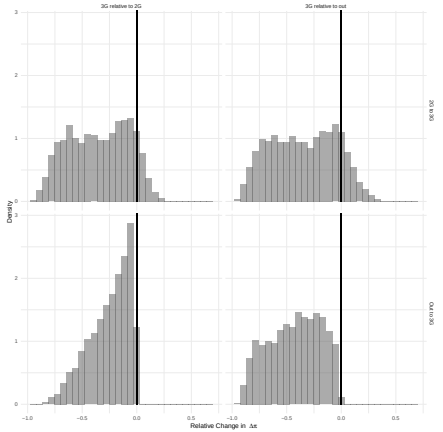
Use equation above to solve for $\xi_{jct}(\theta)$. Form MCs

$$\mathbb{E}[\xi_{jct}(\theta) Z^2_{jct}] = 0$$

Z^2_{jct}: weighted-averages of muni characteristics included in v_{jmt}.

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.

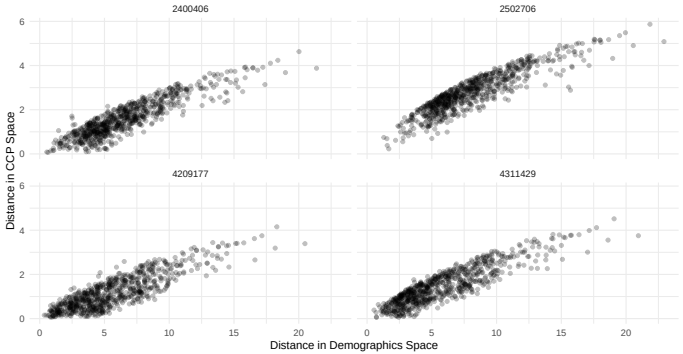


Figure: Equilibrium continuity

- φ: compare *regulated* and *unregulated* firms.
- **Estimation**: Aguirregabiria and Mira (2007), adapted to m-specific P^m. ▸ AM details.

Estimation Results – Dynamic Parameters

Entry Costs Median = 7.03 million BRL. p5 = 5.44 M, p95 = 9.52 M.

Cost of Non-Compliance $\hat{\varphi} = 1.35$ million BRL. 19.14% of the median entry cost.

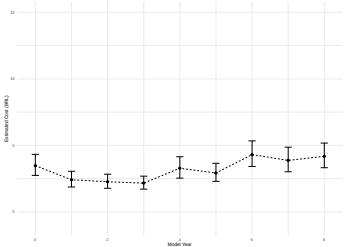


Figure: Cost of 3G Introduction

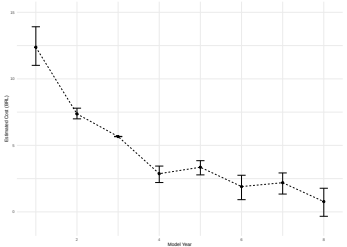


Figure: Cost of 4G Introduction

Counterfactuals: Overview

- Measuring the effect of regulation on the roll-out speed of 3G/4G.
  - Equilibrium effects.
  - Computing the cost of regulation and its incidence.
  - Subsidy auction.

Results: Probability of 3G+ Without Regulation

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

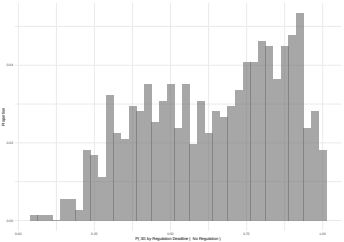


Figure: $\mathbb{P}(3G)$ – April 2016 Deadline

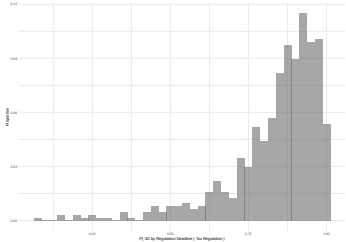


Figure: $\mathbb{P}(3G)$ – December 2019 Deadline

Results: Status quo vs. No Regulation, 3G

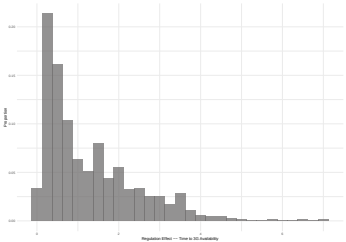


Figure: Regulation Effect – April 2016 Deadline

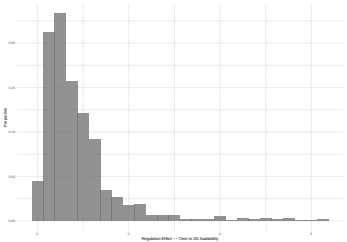
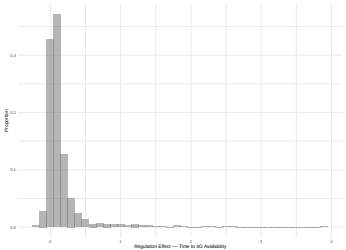


Figure: Regulation Effect – December 2019 Deadline

Avg. effect: 1.06 years. p10 = 0.21, p90 = 2.44. Distribution. Explaining heterogeneity.

Results: Status quo vs. No Regulation, 4G



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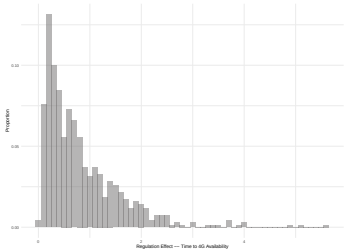


Figure: Regulation Effect – December 2019 Deadline

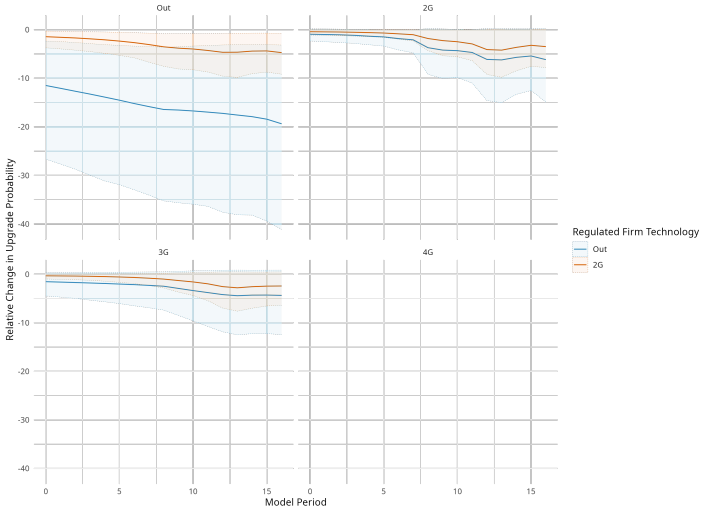
Avg. effect: 0.41 years. p10 = 0.01, p90 = 1.21.

- Negative effects for 6.25% of markets.

Counterfactuals: Overview

- Measuring the effect of regulation on the roll-out speed of 3G/4G.
- Equilibrium effects.
- Computing the cost of regulation and its incidence.
- Subsidy auction.

Results: Changes to Policy Functions, Unregulated Firms



▸ Changes to Policy Functions, Regulated Firms.

Results: Equilibrium Effects, 3G

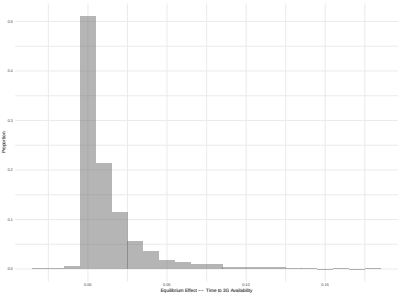


Figure: Equilibrium Effect – 3G

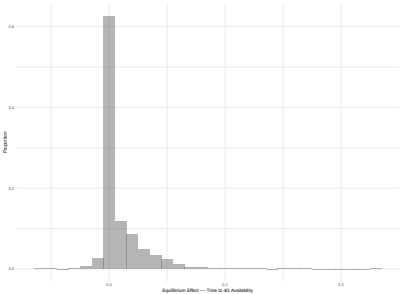


Figure: Equilibrium Effect – 4G

- Overall effect on speed of 3G roll-out is *small*.
- Effect on other outcomes need not be small.
  - E.g., policy functions above show that some firms choose not to enter.
  - One can place an upper bound on regulatory deterrence by initializing simulations at $\boldsymbol{s} = \mathbf{0}$.

Counterfactuals: Overview

- Measuring the effect of regulation on the roll-out speed of 3G/4G.
- Equilibrium effects.
- Computing the cost of regulation and its incidence.
- Subsidy auction.

Results: Regulation Cost

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

Aggregate cost: 1822.82 million BRL, **7.79%** of profits without regulation.

Table: Regulation Cost Incidence

Regulated	Firm State	Total Cost	Average Cost	Percentage of Total Cost
No	Out	61.51	0.02	3.37
No	2G	143.26	0.10	7.86
No	3G	70.50	0.12	3.87
Yes	Out	962.91	1.69	52.83
Yes	2G	584.63	0.45	32.07

Counterfactuals: Overview

- Measuring the effect of regulation on the roll-out speed of 3G/4G.
- Equilibrium effects.
- Computing the cost of regulation and its incidence.
- Subsidy auction.

(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?

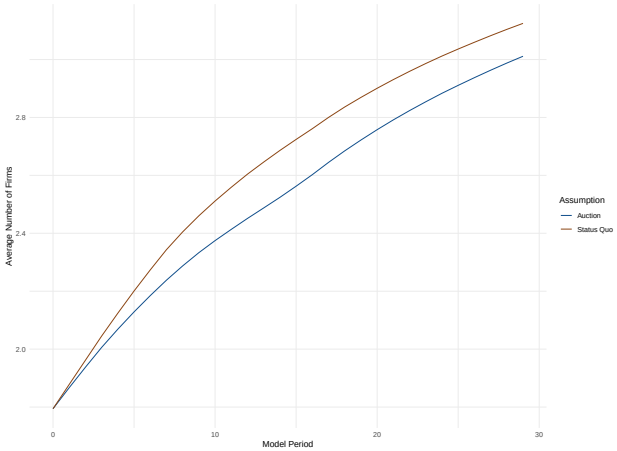
- Willigness to accept a transfer depends on payoffs when others are regulated.
- Approximate by minimum regulation cost relative to *no regulation*.

Results

- The regulated firm differs from the minimum cost firm in 57.96% of the markets.
- Aggregate transfer: **553.43 million BRL**, 30.36% of the total cost of **CRs**.
- **Very similar effect** on rollout speed.
  - Time to 3G+ (4G): auction 0.03 (-0.16) slower 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 ΔCS overturn the cost reduction?

- Let $\gamma := \Delta CS$ due to marginal entrant.
  - **Assume** it is constant.
- Aggregate $\Delta CS \geq \Delta$Cost iff

$$\gamma \geq \frac{\Delta \text{Cost}}{\sum_m \text{Pop}_m \sum_{t \geq 0} \beta^t (N_{mt}^{SQ} - N_{mt}^{Auction})} \Rightarrow \gamma \geq 37.02 \text{ BRL}$$

  - **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 be less desirable for consumers.
- 37.02 BRL $\approx 2.69 \times$ Average expenditure
  - Bourreau, Sun, and Verboven (2021): $\Delta CS = 7.7\%$ of industry sales.
  - Economides, Seim, and Viard (2008): $\Delta CS = 2.5\%$ of consumer bill.

Conclusion

Current regulation

- Accelerated 3G roll-out by **1.06**, on average. Reduced firm profits by **7.79%**.

Subsidy Auction

- Same effect on roll-out speed.
- At 30.36% of the cost.
- Negative competition effects
  - But unlikely to overturn cost reduction.

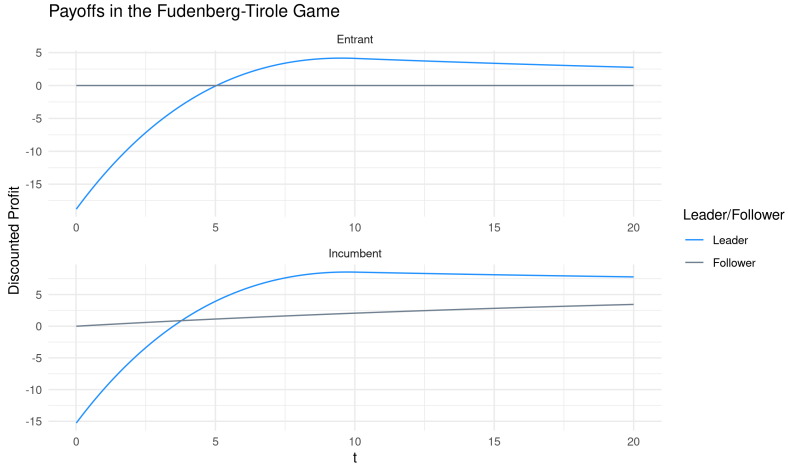
Takeaways:

√ Potential **commitment power of regulation**.
√ **Subsidy auctions** can substantially reduce the cost of universal service.
√ Non-stationary dynamic games can be handled with **quasi-stationarity**.

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

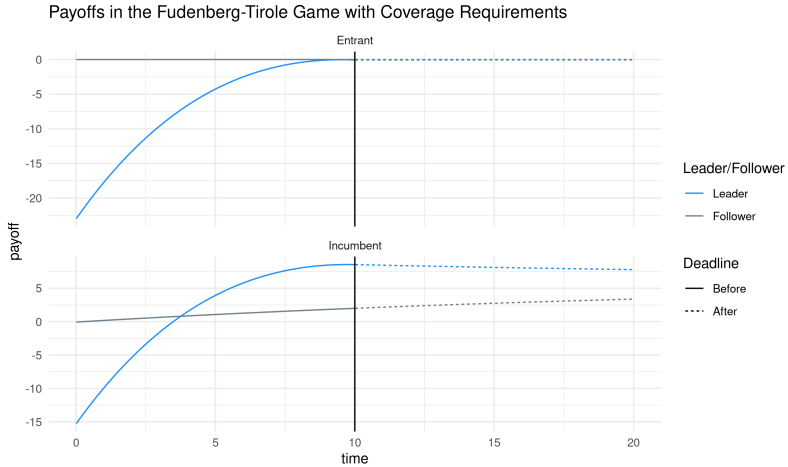
- Technology diffusion on a *network*; interdependent costs.
- Optimal regulation? Need p, q data. Consumer surplus vs. cost reductions.

Fudenberg-Tirole without Regulation

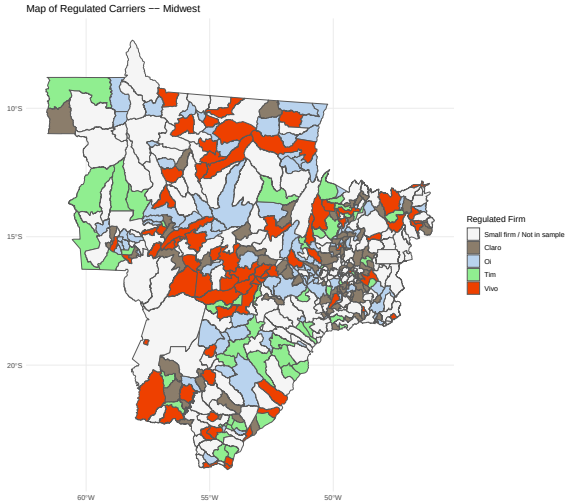


Back to Intro.

Fudenberg-Tirole with Regulation



Map of Requirements – Midwest

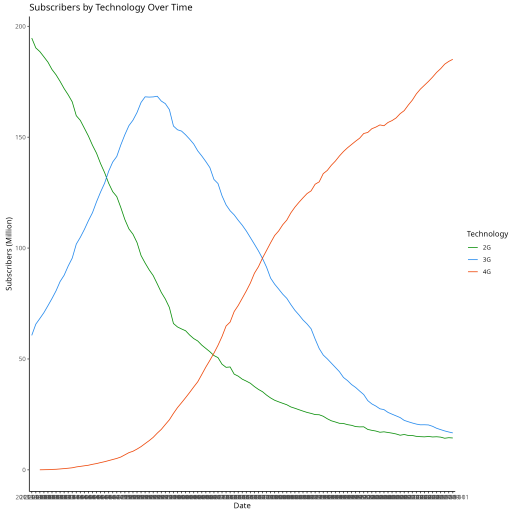


Testing for Selection on Service in Neighboring Municipalities

	Regulated
2G Service	0.307
	(0.069)
3G Service	0.194
	(0.078)
2G Service Nb.	0.005
	(0.020)
3G Service Nb.	−0.017
	(0.012)
Num. obs.	4020
R^2	0.512
Adj. R^2	0.488

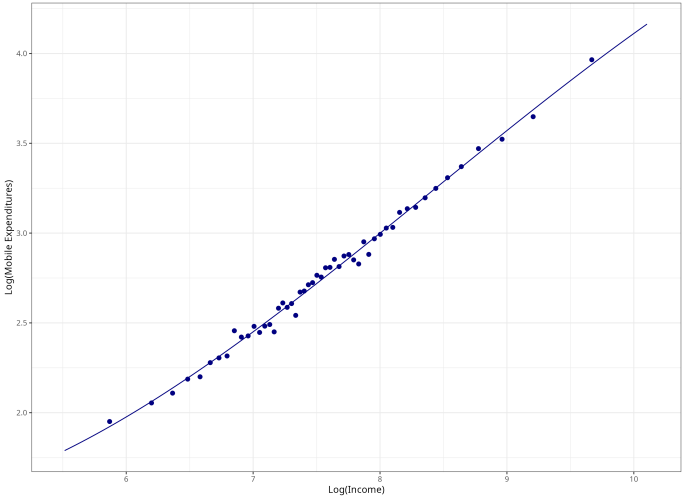
Back to *Selecting Markets.*

Dynamics of Technology Shares



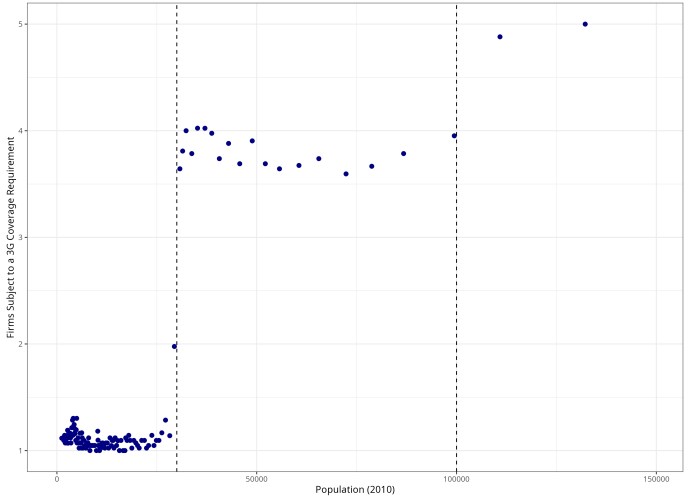
Back to *Flow Profits.*

Expenditure is Log-Linear in Income



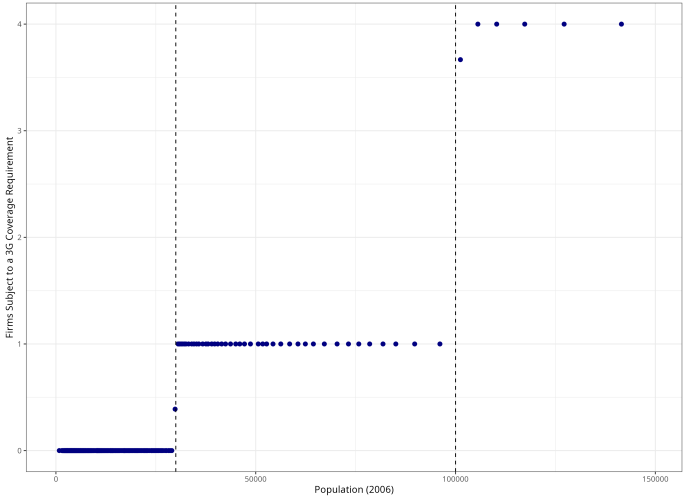
Back to *Flow Profits*.

Population Largely Determines the Number of Regulated Firms



Back to *Identification and Estimation*

Population Largely Determines the Number of Regulated Firms



Back to *Identification and Estimation*

Aguirregabiria and Mira (2007)

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.

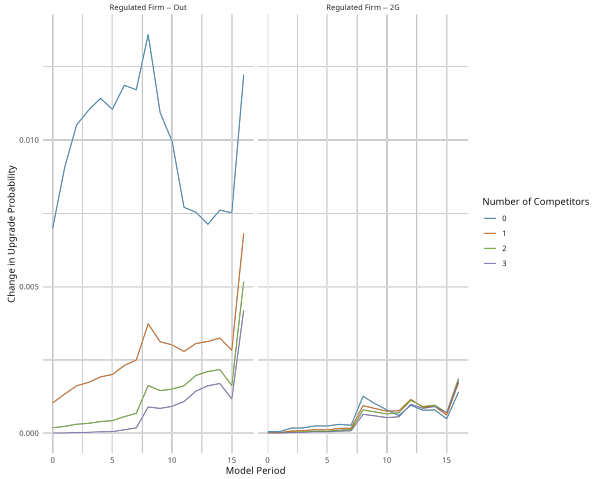
The **NPL estimator** is the NPL fixed point with the maximum value of the pseudo-likelihood.

Alternatives

- Dearing and Blevins (2019).
- Aguirregabiria and Marcoux (2021).

Back to *Identification and Estimation*.

Results: Changes to Policy Functions, Regulated Firms



- Competing effects: reduced preemption motive vs. strategic substitutability.

Back to *Changes to Policy Functions*.