Pricing and Informality: Evidence from Energy Theft in Brazil

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Introduction

- Informality has a sizeable presence in the world economy.
  - The volume of international trade in counterfeit and pirated products amounted to as much as USD 464 billion in 2019 (source: OECD).
  - Labor force employed in the informal sector is 35 percent in Chile and 80 percent in Peru (Perry et al., 2007).

- Recent literature has studied this phenomenon, mostly focused on its impact on trade, labor markets and firm dynamics (Ulyssea 2018, Dix-Carneiro et al 2021, Finamor 2024).

- Less attention has been given to how informality affects firms' micro decisions, e.g. **pricing**.

Introduction

- Informal consumer markets can have an impact on firms' profits in two ways:
  1. Reduce the direct revenue (less paying customers).
  2. Increase costs for the firm, potentially passed-on to consumers.

- Examples:
  - Spotify/Netflix users sharing accounts with friends/family
  - Counterfeit goods
  - Software piracy
  - Theft (e.g. using and not paying for water, electricity, public transportation)

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Our paper focuses on the latter.

A toy model of pricing with informality

Firm problem is:

$$\pi(p) = (p - c)d(p)\sigma(p) - c\bar{d}(1 - \sigma(p)).$$

where:

- p : price paid by formal consumers.
- $\sigma(p)$: share of formal consumers as a function of price.
- $d(p)$: residual demand conditional on being formal.
- c : constant marginal cost.
- $\bar{d}$: demand of informal consumers (does not depend on price).

A toy model of pricing with informality

Then, the first order condition of the firm is

$$\underbrace{d(p)\sigma(p) + (p-c)d'(p)\sigma(p)}_{\text{(i) trad FOC}} + \underbrace{p\sigma'(p)d(p)}_{\text{(ii) evasion adj}} - \underbrace{c\sigma'(p)(d(p)-\bar{d})}_{\text{(iii) theft adj}} = 0$$

Note that:

(i) trad FOC: Exactly the same as faced by a traditional monopolist facing demand $d(p)$

(ii) evasion adj: Adjustment for the lost revenue from switchers betweem formal and informal status.

(iii) theft adj: Additional cost that informal consumers impose on the firm. Firm still faces the cost of supplying informal consumers.

Setting

We study this question in the context of electricity theft in Brazil.

Setting

Setting

Empirical Setting

Energy theft in the State of Rio de Janeiro, Brazil

- The utility firm that sells electricity in the state of Rio de Janeiro faces a large fraction of consumers that steal energy (in 2021 theft represented 54% of distributed energy).
- Consumers create ilegal connections between the formal electric grid and their homes to steal energy.
- The utility firm has costs with informality as it still needs to generate power to serve the consumers with the illegal connections. A fraction of these costs is then passed on to formal consumers through higher tariffs.

Research Questions

1. How does the possibility of theft affect optimal pricing decisions by firms?
2. What are the welfare effects from informality?
3. Can price discrimination be a useful tool to mitigate inefficiencies in this setting?

This paper

What do we do in this paper?

- Provide evidence of a causal link between pricing and the consumer decision to become informal.
  - We leverage a natural experiment from 2011 where the electricity prices increased exogenously and *permanently* to a subset of consumers.
- Estimate a structural model of consumer decisions using detailed micro data from the sector.
  - In this model consumers decide if they want to be formal or informal and then, conditional on that first decision, decide how much to consume.
- Leverage the structural model to simulate different pricing and informality scenarios for the firm in this market.

Findings

1. **Demand more elastic with informality:** The aggregate demand curve for electricity becomes significantly more elastic when accounting for the informality margin (-**0.39** vs -**0.24** without informality).

2. **Optimal Pricing:** Unregulated monopolist would price **10.4% higher** if theft was not possible.

3. **Price discrimination:** Current social tariff increases overall participation in the formal market while keeping firm profits constant.

Roadmap

1. Literature
2. Institutional Details
3. Data and descriptives
4. Empirical Model
5. Counterfactual Results

Literature

- Informality in consumer markets: Qian (2014), Qian, Gong & Chen (2014), Lu, Wang &I Bendle (2019), Li, Liao & Xie (2021)
- Consumer Demand for Electricity: Dubin and McFadden (1984), Reiss and White (2005), McRae (2015), McRae and Meeks (2016), Costa and Gerard (2018), Cahana, Fabra, Reguant & Wang (2022), among others.
- Demand Estimation for Illicit Products: Jacobi and Sovinsky (2016), Galenianos and Gavazza (2017)
- Electricity theft: Smith (2004), Min and Golden (2014)

Institutional Details

Why should we care?

Table 1 — Electricity Losses Worldwide by Income Group

Quartile	Lowest	Lower middle	Upper middle	Highest
Elec. Losses (%)	22.8	16.2	9.6	6.1

Source: World Bank (2020)

- Electricity theft is prevalent in much of the developing world
- It is forecasted that by 2035 the energy demand in the developing world will be twice that of the developed world (Wolfram et al., 2012)

Institutional details

- Brazil is one of ten largest countries in electricity consumption worldwide
- Potential effects from informality in this market:
  - Less reliable grids
  - Energy waste
  - Higher tariffs
  - Personal injuries

Institutional details

Social tariff and 2011 rule change

- Some customers have access to a *social tariff*, which gives them discounted rates over the regular tariff.

Consumption bracket	**Discount**
Up to 30 kWh/month	65%
From 31 to 100 kWh/month	40%
From 101 to 220 kWh/month	10%
Above 220 kWh/month	No discount

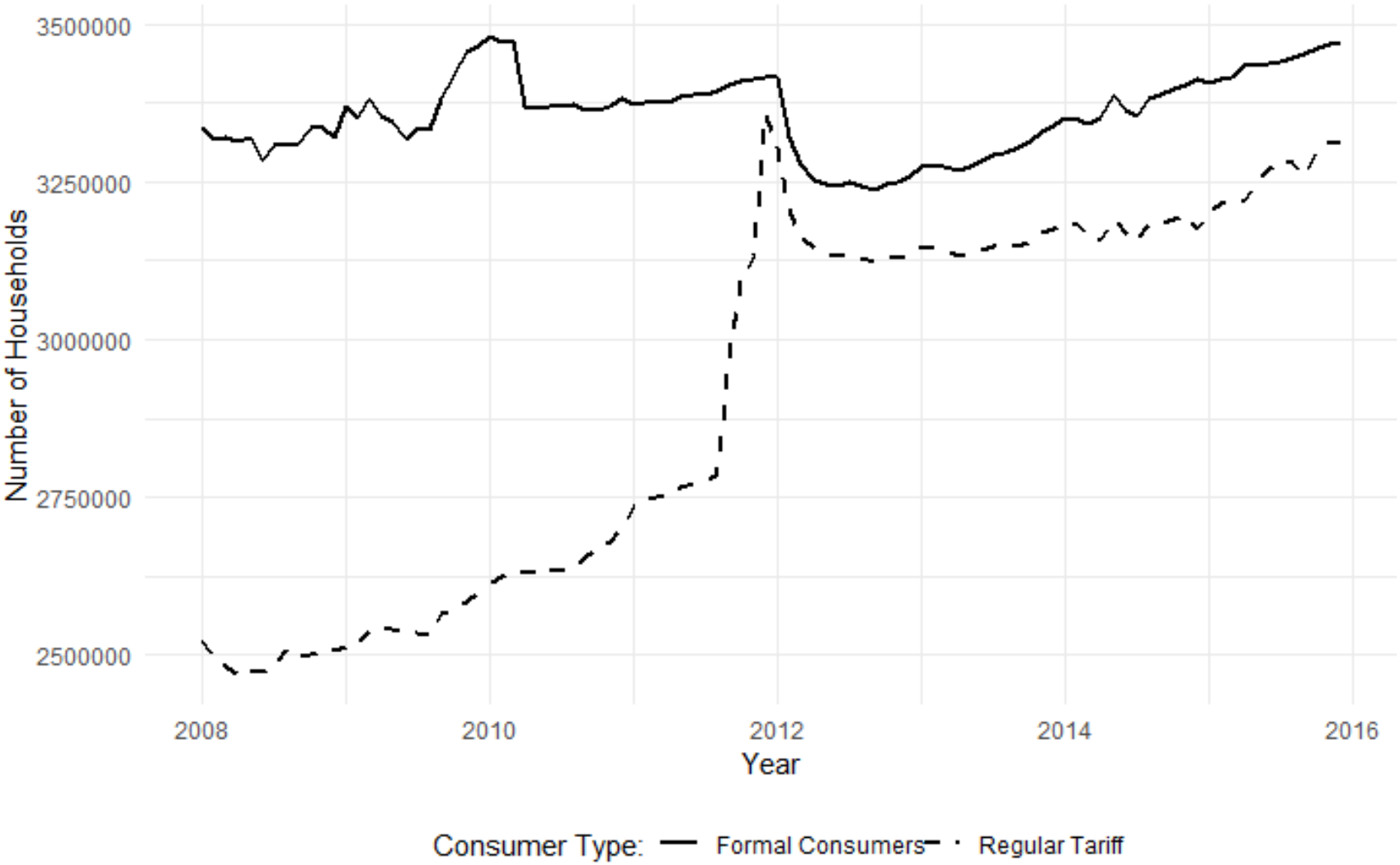
- The rules to have access to the *social tariff* changed.
  - In 2010 and before, every household with consumption below 80 kWh/month had automatic access. Above that limit, low income proof was required.
  - From 2011 onwards, everyone has to submit proof of low income in order to qualify for the social tariff.

Data

- (formal) Household level data
  - Monthly consumption
  - Tariff type (regular vs social)
  - Installed capacity
- Prices
  - Monthly. Source: ANEEL
  - Prices are a function of qt consumed and status (social vs regular)
- Demographics (for all households)
  - Income, Household size, Crime status
  - Different Sources: 2010 and 2022 Census, Fogo Cruzado Institute

Change in social tariff rules

Consumers respond to higher prices by migrating to the informal sector



[migration to informality]

Structural model

Overview

- Households i choice problem has two parts:

    1. **Discrete choice (extensive margin)**: formal consumption ($j = 0$) or informal/theft ($j = 1$).

    2. **Continuous choice electricity demand (intensive margin)**: how much to consume based on the previous decision.

Structural model

Electricity demand (intensive margin)

Utility function is quasi-linear, depending on the consumption of electricity q and a numeraire good:

$$v_{it}(q, p) = \theta_{it} q^{\frac{\xi - 1}{\xi}} - pq$$

- **Formal consumption:** Demand curve with constant elasticity ξ, allowing for individual demand shifters:

$$\log(q_{it}) = \gamma_i + \gamma_t + \xi \log(p_{it}) + \nu_{it},$$

  where p_{it} is the average individual price.

- **Informal consumption:** Under informality the price is zero and consumption is only bounded by capacity constraint $\bar{q}_{it}$.

Structural model

Discrete choice (extensive margin)

The utility conditional on formality status is

$$u_{ijt} = \begin{cases} \beta\psi_{i0t}(q_{it}(p_{it})) + x_{it}'\gamma + \eta_t + \varepsilon_{i0t} & \text{for formal } j = 0 \\ \beta\psi_{i1t}(\bar{q}_{it}) + \varepsilon_{i1t} & \text{for informal } j = 1 \end{cases}$$

where

- ε_{ijt} is the usual e.v. shock
- x_{it} are covariates that affect one´s propensity to be formal (e.g. income, living in a crime dominated area, etc)
- η_t is an unobserved shifter

The choice between formal ($j = 0$) or informal ($j = 1$) has a logit structure:

$$\mathbb{P}_{i,t}(\textit{formal}) = \frac{\exp(\beta(\psi_{i0t}(p_{it}) - \psi_{i1t}) + x_{it}'\gamma + \eta_t)}{1 + \exp(\beta(\psi_{i0t}(p_{it}) - \psi_{i1t}) + x_{it}'\gamma + \eta_t)}$$

Estimation

We estimate the model in two steps.

- **First**, we use monthly consumption data at the household level to estimate the parameters of the demand for electricity, conditional on being formal. This means that we estimate by OLS the following regression:

$$\log(q_{it}) = \gamma_i + \gamma_{m(t)} + \gamma_{y(t)} + \xi \log(p_{it}) + \nu_{it} \tag{1}$$

- We can now use the model to compute:
  - The $ (net) utility of formal consumption for different price points, i.e., ψ_{i0t}
  - The utility of consumption under informality ($\psi_{i1t}(\bar{q})$), where $\bar{q}$ is recovered directly from our theft data at the feeder level.

Estimation

- **Second**, we estimate the parameters behind the decision to be formal or informal (β, γ, η_0), using the expression:

$$\mathbb{P}_{lt}(formal) = \int_{i \in I} \frac{\exp\left(\beta(\psi_0 - \psi_{1,i}) + \gamma X_{ijt} + \eta_0\right)}{1 + \exp\left(\beta(\psi_0 - \psi_{1,i}) + \gamma X_{ijt} + \eta_0\right)} dF(i) \qquad (2)$$

- Specifically, parameters are chosen to match the following moments, directly observed in our data:
  - **[A]** The observed total change in the number of formal consumers before and after the 2011 natural experiment - *identifies* β
  - **[B]** Cross-feeder variation in the share of formal consumers - *identifies* γ

Estimation

In progress:

1. Address potential price endogeneity
   - Use price flags as instrumental variables in the quantity regression

2. Address potential selection bias (we only observe quantity for formal consumers)
   - Use the control function approach in the discrete-continuous demand literature (Dubin and McFadden (1984))

Results

Electricity demand (intensive margin)

$$\log(q_{it}) = \gamma_i + \gamma_{m(t)} + \gamma_{y(t)} + \xi \log(p_{it}) + \nu_{it},$$

	(1)	(2)	(3)	(4)
ξ	-0.198	-0.160	-0.0904	-0.2676
	(0.002)	(0.002)	(0.0029)	(0.0020)
IC (capacity)		1.329	4.617	0.6517
		(0.0020)	(0.0028)	(0.0008)
Month FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Social Tariff FE	Yes	Yes	Yes	Yes
Building FE	Yes	Yes	Yes	Yes
Capacity Heterogeneity	No	No	$<$ Median IC	$>$ Median IC
Observations (MM)	230	230	38	42
R-squared	0.21762	0.53961	0.56413	0.60508

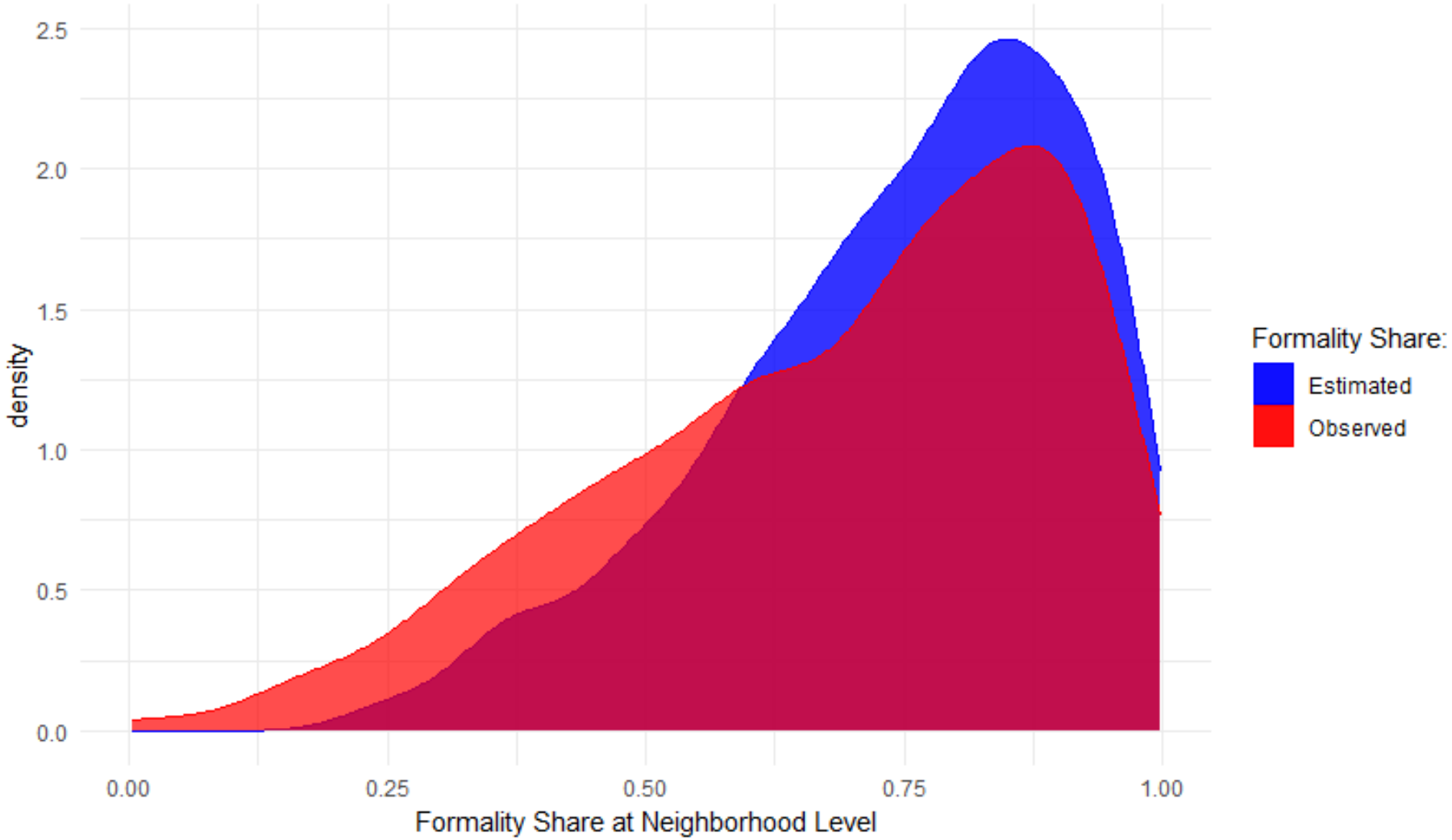
Results

Discrete choice (extensive margin)

	(1)	(2)
β	0.041	0.041
	(0.008)	(0.008)
η	6.7814	-7.562
	(1.193)	(1.591)
Log(income)		0.568
		(0.1913)
Traffic		-0.782
		(0.130)
Militia		-0.624
		(0.126)
Dispute		-0.407
		(0.156)
Avg IC		0.036
		(0.003)
Controls: hh size, density, illiteracy	No	Yes
Spatial heterogeneity	N/A	Neighborhood
Observations		788

Results

Model Fit



Results

Demand elasticity decomposition

Decomposing the elasticities:

$$\xi_{Total} = \xi_d + \xi_\sigma$$

	ξ_{Total}	ξ_d	ξ_σ
ξ_x	-0.39	-0.24	-0.15
ξ_x/ξ_{Total}	1.00	0.62	0.38

Counterfactuals

Optimal pricing

Toy model's FOC of the **monopolist** problem with evasion and theft adjustment:

$$\underbrace{d(p)\sigma(p) + (p-c)d'(p)\sigma(p)}_{\text{trad FOC}} + \underbrace{p\sigma'(p)d(p)}_{\text{evasion adj}} - \underbrace{c\sigma'(p)(d(p)-\bar{d})}_{\text{theft adj}} = 0$$

	Price	ΔPrice
Status-quo (evasion adj + theft adj)	1.42	-
No informality (no theft adj)	1.45	2.4%
No informality (no evasion + no theft adj)	1.57	10.4%

Counterfactuals

- Tho counterfactual scenarios (no theft, no social tariff) $\times$ two price regimes (fixed prices and constant profits).

Panel A: Holding baseline prices constant			
	Baseline	No Theft	No Social Tariff
	(1)	(2)	(3)
Share formal	0.809	1.000	0.805
Mass formal low income	0.052	0.063	0.048
Regular price (R$ / kWh)	0.405	0.405	0.405
Revenue (in MM R$)	190.1	213.6	192.3
Profit (in MM R$)	91.6	126.4	94.1
Panel B: Adjusting prices to keep profit constant			
	Baseline	No Theft	No Social Tariff
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Share formal	0.809	1.000	0.808
Mass formal low income	0.052	0.063	0.048
Regular price (R$ / kWh)	0.405	0.33	0.397
Revenue (in MM R$)	190.1	182.6	193.9
Profit (in MM R$)	91.6	91.6	91.6

Counterfactuals

- Eliminating theft would increase profits by 40% (if prices remain constant), but would allow a 17.7% reduction if prices adjusted to keep profits constant.

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Counterfactuals

- Current price discrimination scheme (social tariff) increases formal participation even if keeping the firm profit constant.

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Conclusion

In this paper, we...

- Study how informal consumer markets affect firms´ pricing decisions.
- Provide evidence of a formal link between pricing and consumer decisions to be formal or not.
- Set up a structural model where consumers optimally choose the informality margin and consumption, which we estimate with rich data from the electricity sector.
- Find that pricing decisions substantially change in the presence of informality (40% of total demand elasticity from extensive margin)

THANK YOU !!

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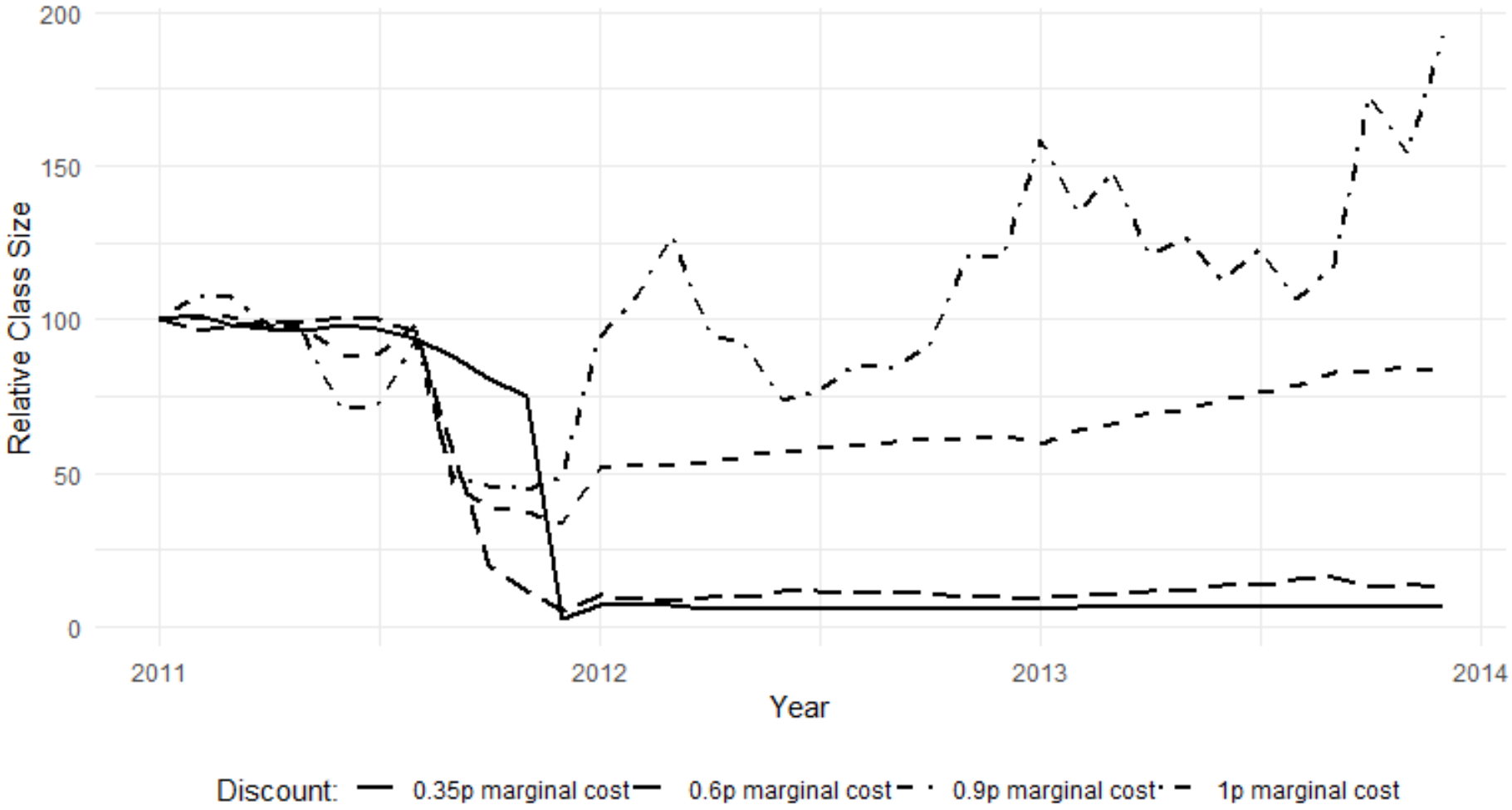
APPENDIX

Consumers respond to higher prices by migrating to the informal sector



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Estimation

Discrete choice (extensive margin)

Second step: Estimate formality parameters (β, γ), using the share of formal households at neighboorhood/date level:

$$\mathbb{P}_t(formal) = \sum_{i=1}^{N_{form}^T} \frac{\exp(\beta(\psi_{i0t}(p_{it}) - \psi_{i1t}) + x_{it}'\gamma + \eta_t)}{1 + \exp(\beta(\psi_{i0t}(p_{it}) - \psi_{i1t}) + x_{it}'\gamma + \eta_t)} w_{i,T}$$

- Sum above over formal consumer in our dataset, but need unconditional mean. Solution: re-weight by a factor $w_{i,T}$ informed by model and Bayes' rule:

$$\underbrace{\mathbb{P}[i|formal, T]}_{=\frac{1}{N_{form}^T}} = \frac{\mathbb{P}[formal|i, T]\overbrace{\mathbb{P}[i|T]}^{=w_{i,T}}}{\underbrace{\mathbb{P}[formal|T]}_{=\frac{N_{form}^T}{N}}} = \frac{\mathbb{P}[formal|i, T]w_{i,T}N}{N_{form}^T}.$$

Therefore we can express the unconditional weight at T as

$$w_{i,T} = \frac{1}{N \times \mathbb{P}[formal|i, T]}.$$

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