Heterogeneous effects of waste pricing policies

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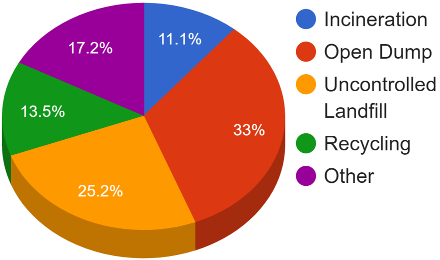
Motivation

- Waste management is one of the most expensive and polluting municipal services (5% global GHG, World Bank)
- Global household waste disposal:



$\Rightarrow$ Cake expected to grow by 70% by 2050

Environmental & economic sustainability:
How to reduce overall cake and increase recycling?

Pay-As-You-Throw waste policies

- Many countries use 'Pay-As-You-Throw' (PAYT) charging households per bag, can, or kg of **non-recyclable waste** (EPA and EEA priority)

Pay per bag.

- **Unit** (vs. fixed) **fees** aim to boost recycling and waste avoidance

How do households actually respond to waste prices?

Research questions

- What drives effects on non-recyclable waste? Recycling/waste avoidance
- Many challenges to evaluating PAYT policies:
  - Cities introducing PAYT differ by, e.g., the adopted price level, waste management costs, household waste habits and characteristics
  - Policy effects likely not homogeneous: price-specific (same reactions at any price level?) and covariate-specific (same time opportunity costs?)

$\Rightarrow$ **Which factors drive differences in policy effects?**

- Fear of cost increases keeps cities from adoption: no evidence on social costs

$\Rightarrow$ **Are waste prices socially desirable?**

This paper

1. Estimates **municipal-level causal effects of prices** on waste quantities (price elasticities), and analyzes **effect heterogeneity**
    - New panel dataset of Italian cities (3,600 of which 200 PAYT cities)
        - large variation of prices (e.g. one bag in Trento $\sim$ € 3 vs. € 1 in Mantua) and covariates (90) observed over 6 years
    - Machine learning as data-driven way to detect relevant heterogeneity in causal effects by observables (even a large number)
        - kernel matching estimator robust to confounding and self-selection (R-learning generalized random forests)

2. Estimates **social cost savings** for each municipality
    - Multiply estimated effects on non-recyclable and recyclable waste (kg)
    - with avoided pollution costs and municipal management costs (€ /kg)

Preview of results

Using high-dimensional data and forest-based approach shows:

At low prices: Evidence of nudge effects

- Significant reductions in overall waste and increases in recycling
- Rather constant elasticities independently on socio-economic factors

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Social benefits for most municipalities within three years

- driven by overall waste reductions (additional recycling is costly!)
- on average €30 per person, up to €170

Data

Unique panel 2010-2015 on $\sim$ 3,600 Italian municipalities with 90 observables

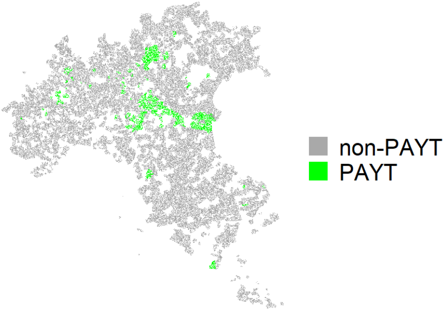
- **Waste generation and management costs**, source: National Environmental Protection Agency (ISPRA) ▸ Details
- **Prices**, source: list of treated from ISPRA, data collection directly from municipalities and indirectly from balance sheets
- **Socio-economic and geographic characteristics**, source: National Institute of Statistics (ISTAT) and web-scraping comuni-italiani.it
- **Waste treatment sites**, source: web-scraping the EU Pollution Release and Transfer Register (E-PRTR)
- **Waste environmental costs**, source: Kinnaman et al., 2014
- **Political variables**, source: Ministry of the Interior, upon request

▸ All deconfounders

Obs. 19,976		Mean	Sd	Min	P50	Max
Treatment:	PAYT price in € /L ▸ by year	0.08	0.05	0.01	0.08	0.18
Outcomes:	Recycling Waste (RW) kg p.c.	238.7	85.62	13.13	237.4	828.5
	Unsorted Waste (UW) kg p.c.	220.4	120.7	21.62	185.6	1016.4
	Total Waste (TW=RW+UW)	459.1	127.9	107.6	438.6	1594.1
Costs:	RW unit costs per kg	0.18	0.12	0.001	0.16	2.24
	UW unit costs per kg	0.29	0.19	0.001	0.24	4.40
	RW costs p.c.	40.99	22.62	0.11	39.81	327.4
	UW costs p.c.	53.29	33.70	0.11	45.51	682.8
Covariates:	Income p.c. (x 1,000€)	13.89	2.28	4.66	13.79	45.62
	Pop. share with college deg.	0.09	0.03	0.03	0.09	0.18
	Pop. share aged >65	0.23	0.05	0.05	0.22	0.51
	Housing density (x 100m^2)	2.30	0.27	1.28	2.31	3.27
	Pol. particip. (voter turnout)	0.68	0.10	0.01	0.71	0.91
	Mayor's age	51.99	10.47	21	52	87
	Mayor's years of office	1.85	1.38	0.00	2.00	8.00
	Pop. (x 1,000 inh.)	7.42	34.02	0.03	2.69	1345.8
	Pop. density (x km^2)	332.9	571.0	1.33	142.5	7765.5
	Urban (dummy)	0.39	0.49	0.00	0.00	1.00
	(...up to 90 covariates)	$(\cdots)$	$(\cdots)$	$(\cdots)$	$(\cdots)$	$(\cdots)$

Treated (PAYT) and Never-treated (non-PAYT)

- Treated (2012-15, $t = 1, 2, 3$): 1,7 M people in 194 PAYT cities
- Data allows predictions for 26 M people (45% pop.) in $\sim$ 3,400 cities



- Sources of (staggered) PAYT adoption: Distance to other treated, landfill/incinerator, pre-policy waste/cost levels, income, etc. Stats

Excluded: treated<2012 (no 2^{nd}order lags), South (no treated), outliers, mergers.

Generalized random forests (Athey et al., 2019)

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- Use **tree** to partition X space into binary (Left; Right) partitions
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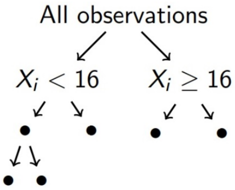

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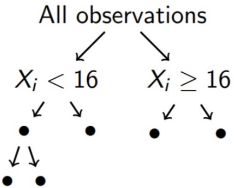


- Use **forest** to calculate a weighted set of neighbors for each x
  - **Random subsampling** reduces X dimension and decorrelates trees
- Estimate $\hat{\delta}(x)$ by regressing (weighted) waste outcomes on prices of the neighbor units

Consistency Variance

Identification strategy

Neyman-Rubin potential outcome framework

Potential outcomes for municipality i (in t, omitted):

- Characteristics $X_i = x$ may determine both P_i and $Y_i = Y_i(P_i)$
- Define a set of potential outcomes $Y_i(p)$ for $p \in \mathcal{P} = [0, p_{max}]$

- Unconfounded Conditional Average Treatment Effect (CATE): $\Delta(x) = \mathbb{E}\left[Y_i(p) - Y_i(0)|X_i = x\right]$ u.a. $Y_i(p) \perp\!\!\!\perp P_i|X_i \; \forall p \in \mathcal{P}$

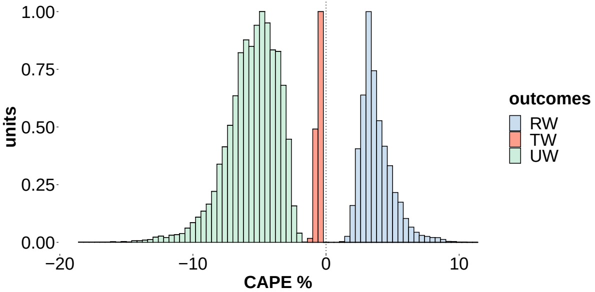
- Unconfounded Conditional Average Price Effect (CAPE): $\delta(x) = \frac{\partial \mathbb{E}[Y_i(p)|X_i=x]}{\partial p}$ u.a. above

- Self-selection: How to control for the confounding impact of X on P? Residual-on-residual regression / R-learning in high dimension Details

Ass.: ignorability + no interference + overlap (Imbens, 2000).

Conditional average price effects (CAPE)

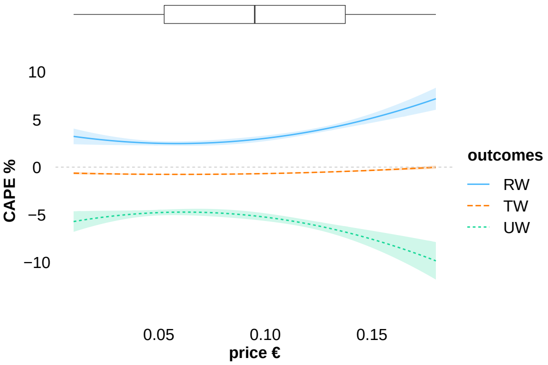
- CAPE: % change in waste quantity for a 1 cent price increase
- Indirect effects: ↑ recycling (large) and waste avoidance (small) ◂ Model



- All estimates are statistically different from zero (p-values<0.01)
- Hypothesis of no heterogeneity rejected for all outcomes ▸ Tests

CAPE heterogeneity across price levels (ceteris paribus)

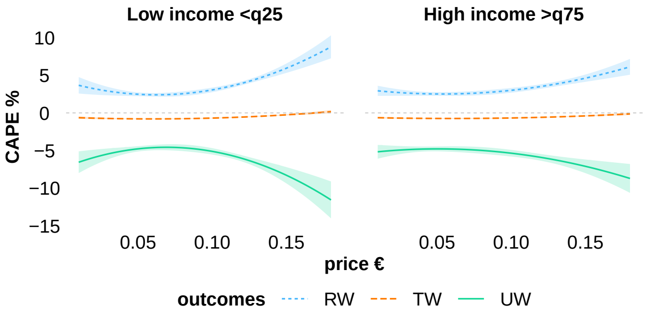
- Linear projection of CAPE onto prices and relevant regressors



- Constant effects at low prices vs. increasing effects at high prices
- Effects largely driven by recycling, especially at high prices
- Higher recycling is associated to lower waste avoidance ▸ Plot

Income effects

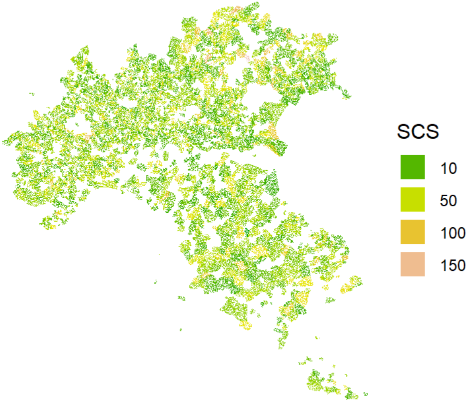
- No signif. income effects at low prices: **symbolic prices/nudges**
- **Income effects explain reactions at high prices only**
- Low-income cities are on average 1 pp more elastic



Effects of waste habits

Social cost savings

Figure: Predicted Social Costs Savings (SCS) in € p.c. after three years of adoption if all municipalities were to implement PAYT.



Conclusion

Using high-dimensional data and forest-based approach shows:

PAYT causal effects are heterogeneous across municipalities

- even low prices (nudges) are effective: + recycling and - overall waste
- income effects reveal PAYT is not regressive policy
- direct application to understand which municipalities benefit the most

Welfare benefits within three years for virtually all cities

- driven by overall waste reductions (additional recycling is costly!)

Final implication

- may help municipalities to overcome their hesitation in adopting PAYT

Thank you!

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