The Effect of Energy Efficiency Obligations on Residential Energy Use: Empirical Evidence from France

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Buildings Energy efficiency

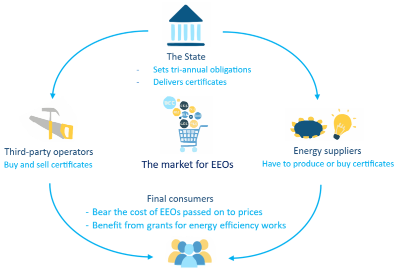
- **Let's start with energy demand.**
- In France, a recent government report indicates that 72% of the investment needed to meet the 2030 target should be devoted to energy-efficient building renovation (Pisani Ferry, Mahfouz, 2023).

Heat-pump installation

Insulation

Energy Efficiency Obligation Schemes (EEOs)

- A widespread instrument: 24 States in the US, 16 Member States in the EU + the UK, China, etc.
- The French program *Certificats d'Economies d'Energie*, CEE herafter, is the largest EEOs in Europe $\simeq$ 4 bln EUR/yr.
- The program implemented to comply with the EU Energy Efficiency Directive (2012/27/EU)
  - A 1.5 % reduction in annual energy sales over the period 2014-2020



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- Certificates are tradable (white certificates)

What we do

Questions

- What is the impact of 1 kWh of *projected* savings on residential gas and electricity use?
- Does France comply with the Energy Efficiency Directive?
- What is the implied CO2 marginal abatement cost?

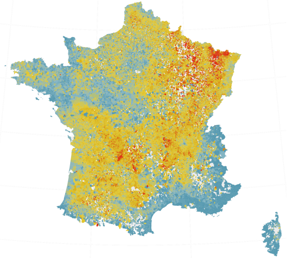
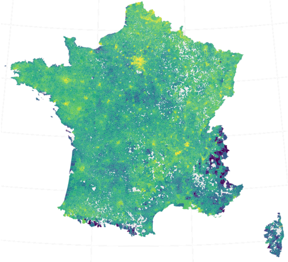
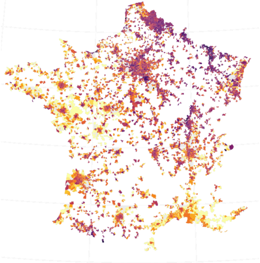
Approach

- An IV-DiD analysis relying on data on 2,523 municipalities over the period 2018-2020.
  - 3.8 million people

Results

1. 1 kWh of projected savings decreases gas and electricity use by 0.29 kWh
2. The implied CO2 abatement cost is €410/tCO_2e, way above the EU-ETS price

Municipal-level data for > 30K French municipalities

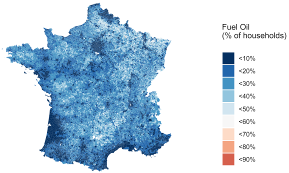




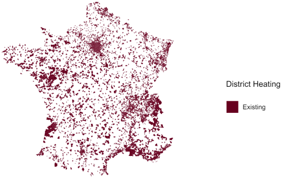
Over the period 2018-2020:

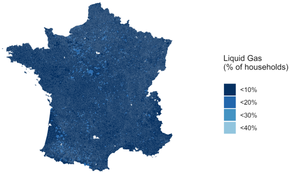
- 3.1 millions retrofit works
  - The number of certificates granted for each investment
- Yearly residential electricity & gas consumption
- Share of electricity & gas in the residential energy mix
- Determinants of energy use
  - Heating Degree Days, population, median income

Estimation sample

- No information on the use of fuel oil, district hearing, and liquid gas
- We restrict the sample to 2,523 municipalities with no district heating and where liquid gas and fuel oil is the heating source in less than 10% of the housing units







Descriptive statistics

	Estimation sample (N = 2,523)		Mainland France (N = 34,868)	
	Mean	SD	Mean	SD
Panel A: Energy use				
Electricity (kWh)	3,092.386	943.88	3,168.284	830.544
Gas (kWh)	1,921.821	1,808.872	745.262	1,384.025
Panel B: Retrofit works				
Certificates (kWhc)	5,778.82	3,242.75	7,164.31	5,818.714
Projected annual savings (kWh)	199.791	137.366	261.359	239.588
Panel C: Demographics				
Population	1,497	1,587	1,991	8,262
Median income (EUR/yr)	22,394.885	3,700.173	21,833.585	3,692.437

Empirical strategy

1. First-Difference (FD) regression of residential energy use $Y_{i,t}$ in municipality i in year t on:
   - $X_{i,t}$: projected savings
   - $H_{i,t}$: Heating Degree Days (HDD)
   - $W_{i,t}$: Population & Income

$$\Delta Y_{i,t} = \beta \Delta X_{i,t} + \delta \Delta H_{i,t} + \lambda \Delta W_{i,t} + \Delta u_{i,t}$$

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2. $\Delta X_{i,t}$ is **endogeneous**: energy efficiency investments are correlated with unobserved municipality shocks $\Delta u_{i,t}$ which also affect energy use $\Delta Y_{i,t}$. Example: green preferences ⇒ downward bias, i.e. overestimation .

Shift-share (Bartik) instrument

- For each investment, we know the type of energy efficiency solutions subsidized (e.g., heat-pumps, wall insulation).
- Let $\alpha_{i,s,t}$ denote the share of projected energy savings achieved through investments of type s in municipality i in year t and $\Delta X_{s,t}$, the national first-differenced projected energy savings from investments of type s in year t

- Our instrument for $\Delta X_{i,t}$ is then:

$$\Delta Z_{i,t} = \sum_{s=1}^{S} \alpha_{i,s,t_0} \Delta X_{s,t}$$

where t_0 is a pre-sample period. 2016 in our case

Instrument validity

$$\Delta Z_{i,t} = \sum_{s=1}^{S} \alpha_{i,s,t_0} \Delta X_{s,t}$$

1. **Relevance.** The initial shares α_{i,s,t_0} predict $\alpha_{i,s,t}$

$\rightarrow$ A high share of heat-pumps in 2016 in a municipality increases the local heat-pump market growth over 2018-2020 (e.g. local learning-by-doing)

2. **Exogeneity.** The initial shares α_{i,s,t_0} do not correlate with *changes* in energy use in year t through other channels than energy efficiency investments. True?

Non-CEE investments

- In practice, some investments are made without CEE support and those are unobserved. Our second stage equation thus rewrites:

$$\Delta Y_{i,t} = \beta^{2SLS}\, \Delta \widehat{X}_{i,t} + \delta_2\, \Delta H_{i,t} + \lambda_2\, \Delta W_{i,t} + \phi \Delta R_{i,t} + \Delta \varepsilon_{i,t}$$

where $\Delta R_{i,t}$ represents the energy savings achieved through unobserved investments, while $\Delta \varepsilon_{i,t}$ encompasses other unobserved within-municipality dynamics.

$\Rightarrow$ Two questions: $\mathrm{Cov}(Z_{i,t}, \epsilon_{i,t}) = 0$? $\mathrm{Cov}(Z_{i,t}, \Delta R_{i,t}) = 0$?

$\mathrm{Cov}(Z_{i,t}, \epsilon_{i,t}) = 0$

- The estimation of the Rotemberg weights (Goldsmith-Pinkham et al. 2020) indicate that identification is mainly based on a comparison between locations with higher or lower shares of roof insulation.
- Hence, will the fact that your neighbors opted for roof insulation instead of installing a heat pump when retrofitting their home 3 years ago correlate with changes in your electricity or gas consumption?
- We believe not $\Rightarrow \mathrm{Cov}(Z_{i,t}, \epsilon_{i,t}) = 0$
    - Two different markets, strong policy shocks in 2018 and 2019 in the EE market ("Coup de Pouce")

$\mathrm{Cov}(\Delta Z_{i,t}, \Delta R_{i,t}) \neq 0$

- Non-CEE and CEE retrofits respond to similar determinants $\Rightarrow$ β^{2SLS} is biased
- Good news. We know the sign of the bias
- As $Z_{i,t}$ is also positively correlated with $\Delta R_{i,t}$, β^{2SLS} estimates the **maximum** effect of CEE works on energy use:

$$\beta^{2SLS} = \beta + \phi \times \frac{Cov(\Delta R_{i,t}, Z_{i,t})}{Cov(\Delta X_{i,t}, Z_{i,t})} \quad \Rightarrow \quad \beta^{2SLS} < \beta.$$

$$\{< 0\} + \{< 0\} \times \{> 0\}$$

Results

	OLS-FD	2SLS-FD
Expected Savings	-0.425***	
	(0.074)	
Fitted Expected Savings		-0.290*
		(0.118)
Log. of Pop.	1326512.125***	1301123.027***
	(195046.089)	(200548.038)
Median income	10.560+	9.510
	(6.138)	(6.355)
Rel. HDD	335.729***	354.932***
	(43.282)	(38.299)
Num.Obs.	4444	4444
R2	0.062	0.057
R2 Adj.	0.061	0.056
F-test (1st stage)		432.717

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Clustered standard errors at the municipality level

- **1 kWh of projected savings** associated with at best **-0.290 kWh** in residential electricity and gas use

Impact on gas and electricity

	Electricity	Natural Gas
Fitted Expected Savings	0.037	-0.327**
	(0.031)	(0.113)
Log. of Pop.	574511.194***	726611.834***
	(82407.164)	(172205.221)
Median income	6.742*	2.768
	(2.791)	(5.481)
Rel. HDD	-102.965***	457.897***
	(21.949)	(29.313)
Num.Obs.	4444	4444
R2	0.014	0.093
R2 Adj.	0.013	0.092
F-test (1st stage)	432.717	432.717

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Clustered standard errors at the municipality level

- Energy savings mostly achieved through a decrease in gas consumption

Discussion

- The energy performance gap is at least 71%. Very wide, including in comparison with foreign programs.
- Why ? Program design?
  - No energy audits or ex post work quality inspections.
  - The flexibility given to competing obligated parties to select retrofits leads them to support the cheapest. Cheap investments can be of poor quality.
  - Competition between obligated firms exacerbates energy retrofit market failures.
- Projected savings are used by the government to report on compliance with the Energy Efficiency Directive.
  - Reported compliance rate: 114% for the period 2014-2021
- The effect on annual residential energy use is a 1.04% reduction, well below the -1.5% target of the Energy Efficiency Directive.

Estimating the marginal CO2 abatement cost

- We know the certificate price, which captures the cost of saving energy through the program
  - Transaction costs + the cost of the subsidy for the obligated parties
  - The level of subsidy reflects the costs and benefits for the energy user when making energy efficiency investments, including monetary and non-monetary costs and benefits (comfort, improved health, the inconvenience caused by the work, etc.).

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- The CO2 marginal abatement cost is then

$$\underset{(EUR/kWh)}{\text{CEE spot price}} \times \underset{(TWh)}{\text{projected savings}} \times \mathbf{0.29} \times \underset{(t.CO_2eq./TWh)}{\text{emission factor}}$$

$\Rightarrow$ **410 [300-660] EUR/tCO_2**

- **Very high. The cost efficiency of the program is clearly problematic**

Robustness checks

	Fuel Oil	Liq. Gas	SEM 10km	SEM 20km
Fitted Expected Savings	-0.256+	-0.277*	-0.290*	-0.290+
	(0.147)	(0.130)	(0.122)	(0.166)
Log. of Pop.	1236128.462***	1282066.021***	1301123.027***	1301123.027***
	(230670.484)	(214488.543)	(218408.119)	(272436.213)
Median income	10.503	8.386	9.510	9.510
	(7.762)	(6.923)	(6.402)	(6.482)
Rel. HDD	401.311***	390.187***	354.932***	354.932***
	(45.612)	(40.107)	(56.280)	(80.401)
Num.Obs.	3541	4134	4444	4444
R2	0.053	0.058	0.057	0.057
R2 Adj.	0.052	0.057	0.056	0.056
F-test (1st stage)	322.866	365.715	432.717	432.717

$+$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Clustered standard errors at the municipality level (1-2) / Spatial Error Model (3-4)

$\Rightarrow$ Results are **robust** to:

1. fuel switching out of fuel oil and liquid gas (1) & (2)
2. spatial correlation of the error term (3) & (4)

Conclusion

- A program design which seeks to promote cost-effectiveness
- Does not seem to work because of asymmetry information on quality in the energy efficiency markets
- The benefits and costs of investing in energy efficiency are not limited to the difference between discounted energy savings and the cost of the investment. We need to take into account transaction costs and non-monetary benefits (e.g. comfort)