Energy Efficiency and Household Behavior: The Rebound Effect in the Residential Sector

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Residential Energy Consumption

- Residential sector: 40% of total energy consumption in EU
- Introduction of Energy Efficiency Policies
  - Building codes
  - Subsidies for energy efficiency improvements
  - Financial instruments
- Policy expectation: an increase in efficiency leads to an equal amount of energy saving

Rebound effect

- Improved efficiency$\rightarrow$ reduced cost $\rightarrow$ increased demand

  This demand increase is referred to as the rebound effect, as it offsets the reduction in energy demand that results from an increase in efficiency. Example: Car travel

- Formal definition: Elasticity of the demand for a particular energy service with respect to efficiency

Research question

- What is the magnitude of the rebound effect for residential heating?

Literature: Rebound Effect in residential heating

- Estimates are ranging from 15% to %60
- Methodological problems
  - Use of "Price elasticity" instead of "Efficiency elasticity"
  - Incomplete measures of activity change (thermostat setting?)
  - Small sample size
  - Sample selection bias
  - Measurement error in engineering predictions
  - Heterogeneity

Panel Data

- Number of dwellings (households): 560,000

- Energy Labels (Issued in 2011 and 2012)
- Actual gas consumption (2008-2011)
- Household characteristics (2008-2011)
- Dwelling characteristics

Variables

- Annual Actual Gas Consumption (CBS)
- Predicted Gas Consumption (AgentschapNL)

Control Variables:

- Dwelling Characteristics (AgentschapNL)
  - House type/size, Construction year, Province
- Household Characteristics (CBS)
  - Size, Age, Gender, Income, Tenure, Employment status
- Dwellings without label (NVM)
  - Number of dwellings (households): 120,000

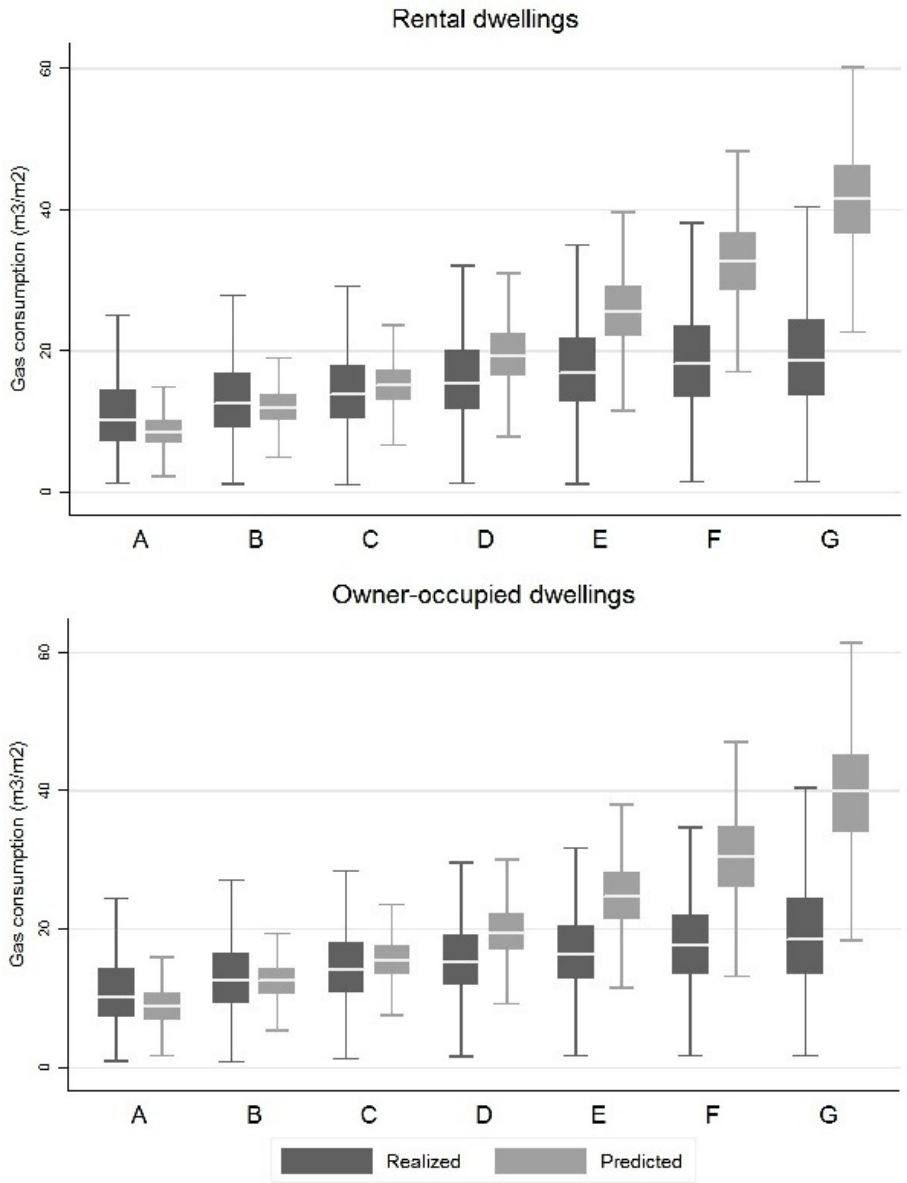
Descriptive Statistics-1

Number of Observations	Rental (With Label) *519,512*		Owner-Occupied (With Label) *43,498*		Owner-Occupied (Without Label) *122,119*	
Variables	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
Actual Gas Consumption (m^3)	1,245	(526)	1,588	(665)	1,573	(632)
Predicted Gas Consumption (m^3)	1,492	(624)	1,887	(759)		
Actual Gas Consumption (m^3/m^2)	15.7	(7.1)	15.3	(6.2)		
Predicted Gas Consumption (m^3/m^2)	18.7	(8.1)	18.2	(7.1)		
Size (m^2)	82.2	(21.6)	106.7	(34.7)		
Label:						
Label-A (EI<1.06)	0.02		0.03			
Label-B (1.05<EI<1.31)	0.16		0.17			
Label-C (1.30<EI<1.61)	0.33		0.32			
Label-D (1.60<EI<2.01)	0.25		0.24			
Label-E (2.00<EI<2.41)	0.14		0.14			
Label-F (2.40<EI<2.91)	0.07		0.08			
Label-G (2.90<EI)	0.03		0.02			
Dwelling Type:						
Apartment	0.49		0.27		0.21	
Semi-detached	0.32		0.21		0.32	
Corner	0.19		0.32		0.32	
Detached	0.00		0.20		0.15	

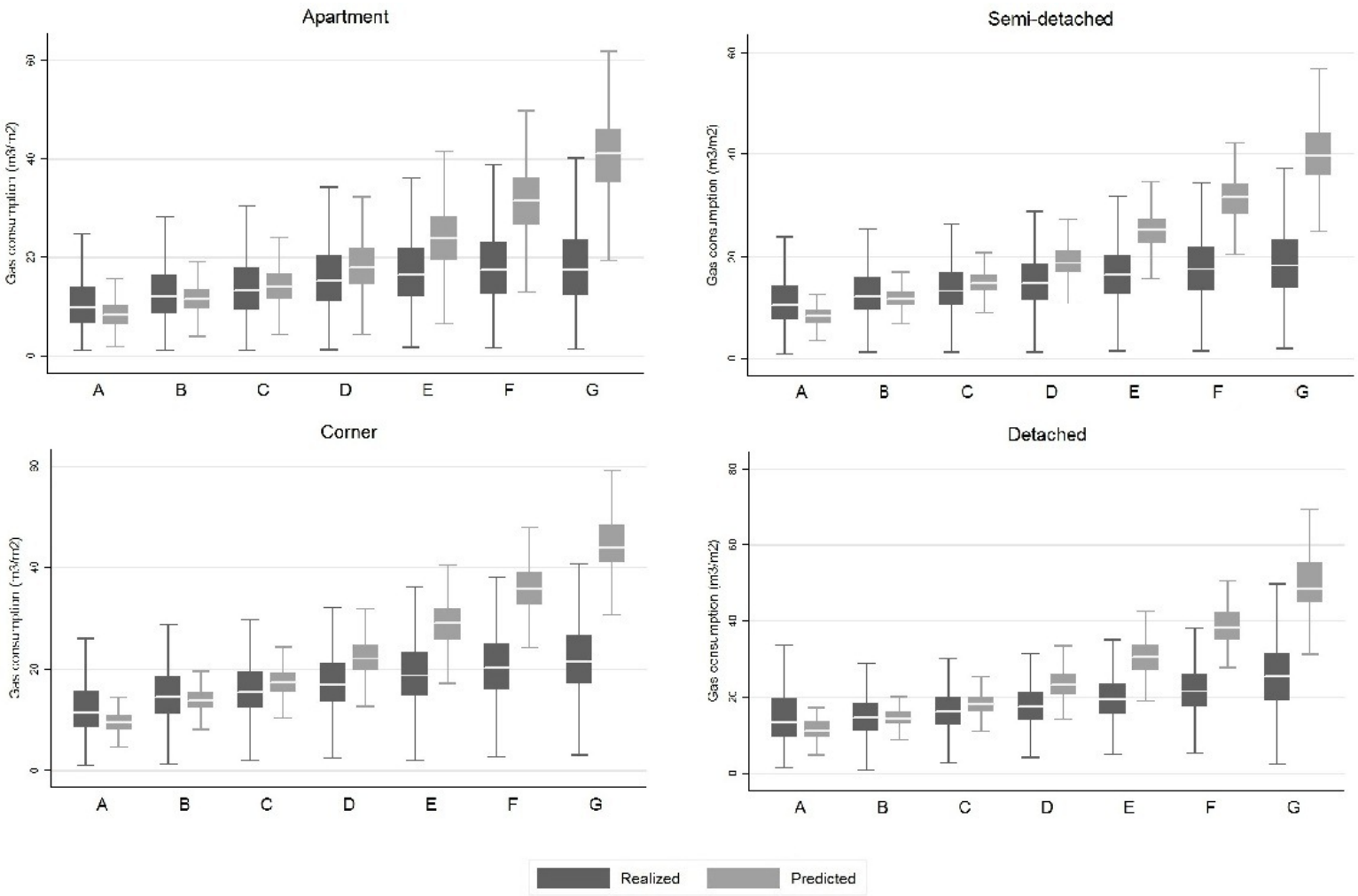
Descriptive Statistics-2

Number of Observations	Rental (With Label) *519,512*		Owner-Occupied (With Label) *43,498*		Owner-Occupied (Without Label) *122,119*	
Variables	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
Construction Period:						
1900-1929	0.07		0.10		0.12	
1930-1944	0.03		0.08		0.09	
1945-1959	0.17		0.14		0.08	
1960-1969	0.20		0.19		0.15	
1970-1979	0.19		0.25		0.17	
1980-1989	0.20		0.12		0.14	
1990-1999	0.11		0.09		0.16	
>2000	0.03		0.03		0.09	
Household Characteristics:						
Number of Household Members	1.91	(1.12)	2.36	(1.21)	2.28	(1.21)
Number of Elderly (Age>64)	0.46	(0.68)	0.29	(0.62)	0.31	(0.61)
Number of Children (<18)	0.34	(0.78)	0.50	(0.89)	0.53	(0.91)
Number of Females in Household	1.01	(0.74)	1.16	(0.77)	1.13	(0.79)
Number of Working Household Members	0.84	(0.94)	1.48	(0.99)	1.35	(0.96)
Household Annual Net Income (1000 Euro)	23.8	(11.5)	36.9	(17.1)	37.3	(26.2)
Household Wealth (1000 Euro)	22.6	(91.6)	177.8	(393.8)	191.3	(531.5)
Share of Households Receiving Rent Subsidy	0.41					

Predicted versus Actual Gas consumption



Predicted versus Actual Gas consumption



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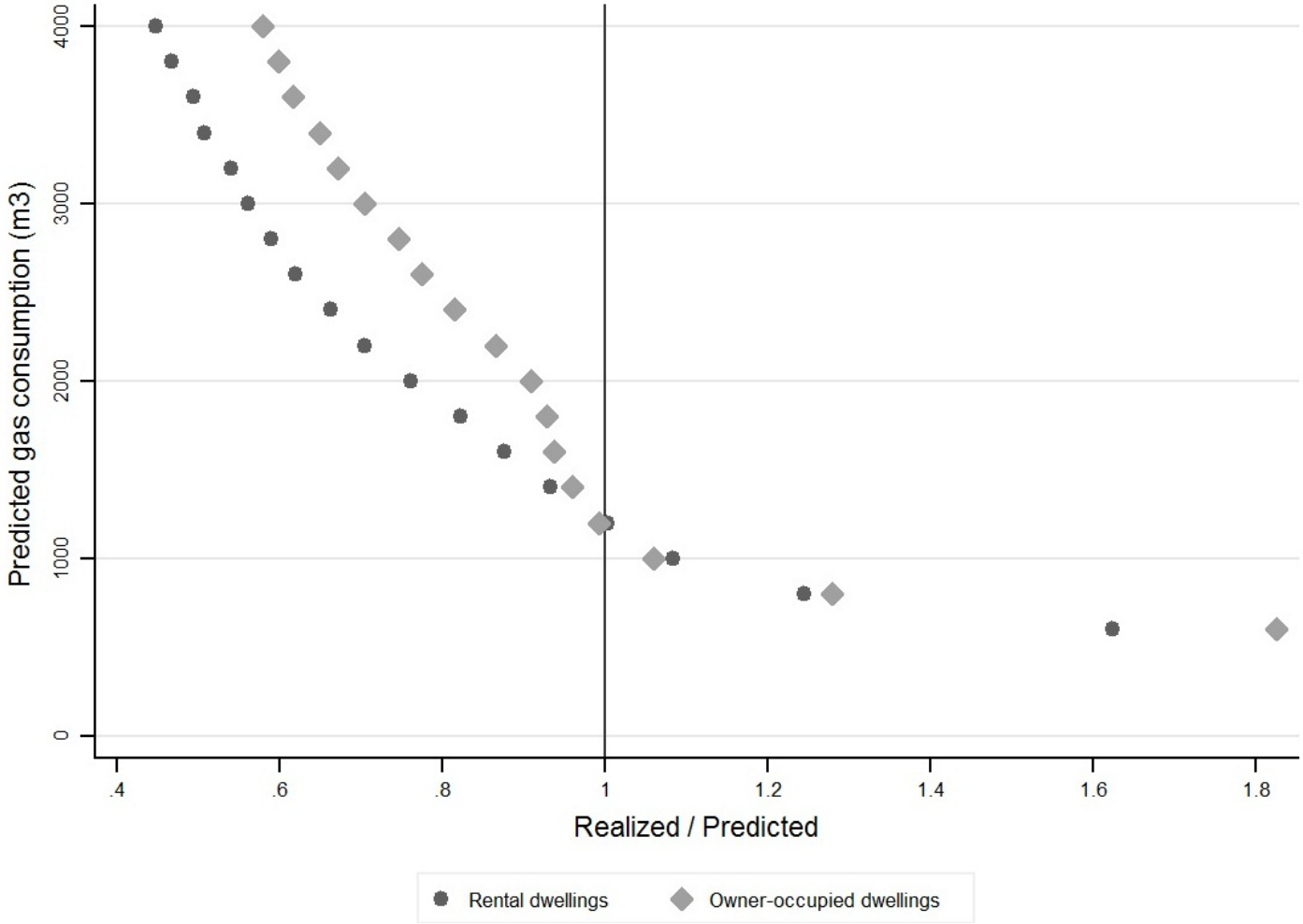

Rebound Effect

$$\tau_G = \frac{\partial ln(H)}{\partial ln(\mu_H)} \tag{1}$$

$$\mu_H = \frac{H_r}{G^*}, H = H_r \frac{G^a}{G^*} \tag{2}$$

$$\tau_H = 1 - \frac{\partial ln(G^a)}{\partial ln(G^*)} \tag{3}$$

- τ_G : Rebound effect
- H : Heating demand (combination of temperature, heating duration, and share of heated area)
- μ_H : Efficiency of the dwelling
- H_r : Reference heating level
- G^* : Predicted gas consumption for reference heating level
- G^a : Actual gas consumption

Empirical Model

$$ln(G^a_{it}) = \beta_0 + \beta_1 ln(G^p_{it}) + \sum_{j=2}^{j} \beta_j Z_{jit} + \alpha_i + \varepsilon_{it} \quad (4)$$

$$\tau_G = 1 - \frac{\partial ln(G^a)}{\partial ln(G^p)} = 1 - \beta_1 \quad (5)$$

- G^a: Log of Actual Gas Consumption
- G^p: Log of Predicted Gas Consumption
- Z : Control variables
- t : Time dummies
- α : Household specific effects

Pooled OLS Estimations

	(1) Rental	(2) Owner-Occupied	(3) Rental	(4) Owner-Occupied
Log (Predicted Gas Consumption)	0.485***	0.589***	0.441***	0.528***
	[0.001]	[0.003]	[0.001]	[0.003]
Number of Household Members			0.118***	0.132***
			[0.001]	[0.005]
Number of Household Members^2			-0.012***	-0.014***
			[0.000]	[0.001]
Number of Children (<18)			-0.009***	0.001
			[0.001]	[0.003]
Number of Elderly (Age>64)			0.031***	0.049***
			[0.001]	[0.003]
Number of Female			0.037***	0.016***
			[0.001]	[0.003]
All Household Members Are Working (1=yes)			-0.060***	-0.042***
			[0.001]	[0.003]
Log (Household Income)			0.054***	0.075***
			[0.001]	[0.003]
Receiving Rent Subsidy (1=yes)			-0.032***	
			[0.001]	
Province Dummy	Yes	Yes	Yes	Yes
Year Dummy	Yes	Yes	Yes	Yes
Constant	3.725***	3.038***	3.295***	2.481***
	[0.006]	[0.026]	[0.012]	[0.039]
R^2	0.210	0.361	0.255	0.402
Number of observations	1,664,113	87,282	1,664,113	87,282
Number of dwellings	519,512	43,498	519,512	43,498

Measurement Error in Engineering Predictions

- Random measurement error in "Predicted Gas Use"

$$G^p = G^* e \tag{6}$$

- Instrument for "Predicted Gas Use": Construction year of the dwelling (Dummy variable)

Pooled OLS-IV Estimations

	(1) Rental	(2) Owner-Occupied
Log (Predicted Gas Consumption)	0.587***	0.733***
	[0.001]	[0.007]
R^2	0.239	0.375
R^2 (First stage regression)	0.225	0.256
Number of observations	1,664,113	87,282
Number of dwellings	519,512	43,498

Endogeneity

Problems with OLS

- Unobserved household characteristics that affect both the actual gas consumption and thermal quality of the dwelling
- energy-efficient households sort into energy-efficient dwellings

Control for household-specific effects

- Moving households: The address change generates a variation in theoretical gas consumption due to the change of the characteristics of the dwelling in which the household resides

Random&Fixed-Effects (IV) Estimations

	Random-Effects Model		Fixed-Effects Model	
	(1) Rental	(2) Owner-occupied	(3) Rental	(4) Owner-occupied
Log (Predicted Gas Consumption)	0.582*** [0.002]	0.722*** [0.009]	0.584*** [0.011]	0.663*** [0.051]
R^2	0.209	0.355	0.165	0.243
R^2 (within)	0.032	0.017	0.024	0.021
R^2 (between)	0.222	0.357	0.176	0.249
Number of observations	1,664,113	87,282	994,804	44,876
Number of households	519,512	43,498	351,462	21,595

Heterogeneity: Different Wealth and Income Cohorts

Panel A: Wealth Cohorts (Owners)

	(1) 0-20%	(2) 20-40%	(3) 40-60%	(4) 60-80%	(5) 80-100%
Log (Predicted Gas Consumption)	0.602*** [0.021]	0.676*** [0.021]	0.724*** [0.018]	0.811*** [0.017]	0.811*** [0.019]
R^2	0.300	0.330	0.352	0.335	0.339
Number of observations	11,342	11,342	11,342	11,342	11,342

Panel B: Income Cohorts (Tenants)

	(1) 0-20%	(2) 20-40%	(3) 40-60%	(4) 60-80%	(5) 80-100%
Log (Predicted Gas Consumption)	0.515*** [0.004]	0.597*** [0.003]	0.599*** [0.003]	0.625*** [0.003]	0.598*** [0.003]
R^2	0.169	0.213	0.245	0.243	0.243
Number of observations	332,299	332,225	332,275	332,284	332,305

Heterogeneity: Quantile Regression Estimates

Panel A: Sample of Owners					
	10^{th}	25^{th}	50^{th}	75^{th}	90^{th}
Log (Predicted Gas Consumption)	0.922*** [0.003]	0.826*** [0.002]	0.750*** [0.002]	0.644*** [0.002]	0.492*** [0.002]
Panel B: Sample of Tenants					
	10^{th}	25^{th}	50^{th}	75^{th}	90^{th}
Log (Predicted Gas Consumption)	0.699*** [0.003]	0.647*** [0.002]	0.599*** [0.002]	0.553*** [0.002]	0.494*** [0.002]

Quasi-Experimental Evidence

- In 2008, the Dutch government initiated a program named "Meer met Minder" (more with less), to stimulate energy efficiency improvements in the residential sector.
- Homeowners increasing the energy label of their dwelling by one or two categories received a premium of 300 or 750 EUR, respectively.

Quasi-Experimental Evidence

- Difference-in-differences (DID) approach.
  - Treatment group: 605 owner-occupied dwellings that benefited from the subsidy program in 2010.
  - Control group: 4,593 owner-occupied dwellings that did not apply to any of the energy efficiency subsidy programs during the period of the analysis.
  - Compare the realized savings with predicted savings between 2009 and 2011, the years just before and after the energy efficiency improvement.

Quasi-Experimental Evidence: Descriptive Statistics

Number of Observations	Treatment Group *605*			Control Group *4,593*		
Variables	2009	2011	%Change	2009	2011	%Change
Actual Gas Consumption (m^3)	2,318	1,766	-23.81	1,543	1,399	-9.33
Energy Index	2.34	1.52	-35.04	1.90	1.90	0.00
Size (m^2)	127.8			104.6		
Construction Year (Median)	1961			1970		
Number of Household Members	2.41			2.04		
Household Annual Net Income (1000 Euro)	40.1			33.9		
Household Wealth (1000 Euro)	285.8			80.3		

Quasi-Experimental Evidence: Empirical Model

$$\Delta ln(G_i) = \beta_0 + \beta_1 \Delta ln(EI_i) + \sum_{j=2}^{J} \beta_j \Delta Z_{ji} + \Delta \epsilon_i \quad (7)$$

- $\Delta ln(G_i)$: change in the logarithm of actual gas consumption from 2009 to 2011
- $\Delta ln(EI_i)$: change in logarithm of energy index
- ΔZ_{ji} : change in household characteristics

- In order to deal with measurement error bias, we apply an IV approach by using the assignment to treatment as an instrument for $\Delta ln(EI_i)$

Quasi-Experimental Evidence: Estimation Results

	(1) First-Diff.	(2) IV	(3) PSM-IV
Δ Log (Energy Index)	0.408*** [0.031]	0.445*** [0.032]	0.449*** [0.036]
R^2	0.034	0.034	0.032
Number of households	5,198	5,198	5,198

Quasi-Experimental Evidence

- Rebound effect is around 56 percent for the dwellings which applied to the subsidy.
  - Larger compared to the average estimate (27 percent).
  - This difference might be related to the heterogeneity of rebound effect based on the actual gas use intensity level.
  - Median actual gas consumption for the treatment group corresponds to the 80th quantile of actual gas consumption distribution in the full sample.
  - The rebound effect estimated for 90th quantile in the full sample is around 52 percent.

Conclusions

- Average rebound effect:
  - 27 percent for homeowners, and 41 percent for tenants
  - If the efficiency of an average dwelling is doubled, this will lead to a 59 percent energy reduction in rental dwellings and a 73 percent energy reduction in owner-occupied dwellings
- Heterogenous effects:
  - Rebound effect decreases as the wealth and income level increases
  - Rebound effect increases as the actual gas use intensity increases

Policy Implications

- Inaccurate estimations of the payback times for measures taken to improve the energy efficiency
- Achievability of the targets that have been set for primary energy as well as for reducing CO_2 emissions