Welfare trade-offs of energy-efficient homes: poverty, comfort, environment

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Homes emit 30% CO_2

THE EUROPEAN RENOVATION WAVE: ADDRESSING ENERGY POVERTY AND SOCIAL EXCLUSION

National fund needed to retrofit low-income homes in Australia

12 February 2024

AFFORDABILITY ACTION COUNCIL CANADA

Retrofit Reset: Prioritize Low-Income Households

NEWS BRIEF

Affordable Housing Gets Billions for Resilience Retrofits USA

HUD's Green Resilient and Retrofit Program, part of the Inflation Reduction Act, seeks to improve the efficiency and resilience of low-income housing.

CO2-emissions

Comfort

Poverty

Welfare trade-offs of subsidizing low-income heating efficiency retrofits

This paper quantifies **welfare effects of heating efficiency upgrades by income**: gas savings, comfort, environment

- Causal evidence for Netherlands from large quasi-experiment with 125K households
- Causal evidence on heterogeneity of effects by income
- Method to monetize comfort improvement
- Explicit modeling of drivers behind the heterogeneity in returns (computable consumer choice model)

JOURNAL ARTICLE

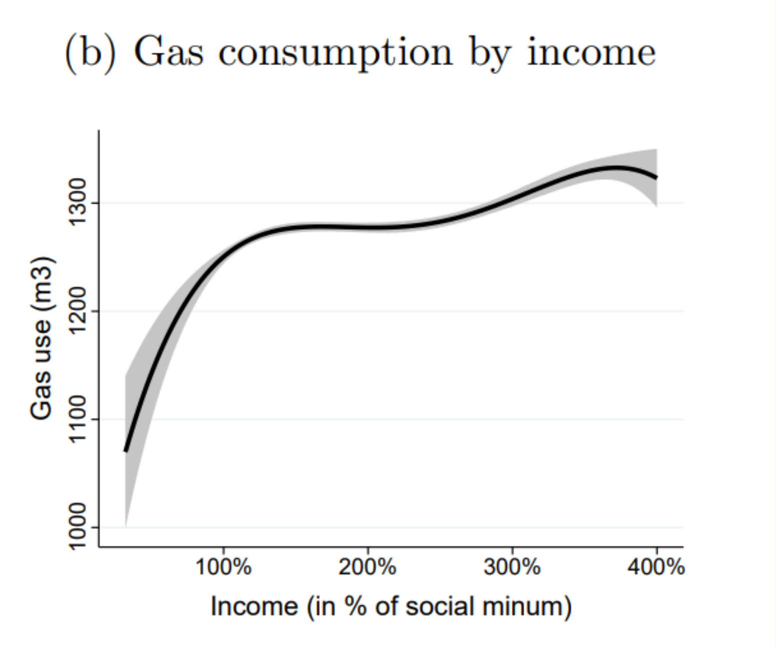
Do Energy Efficiency Investments Deliver? Evidence from the Weatherization Assistance Program*

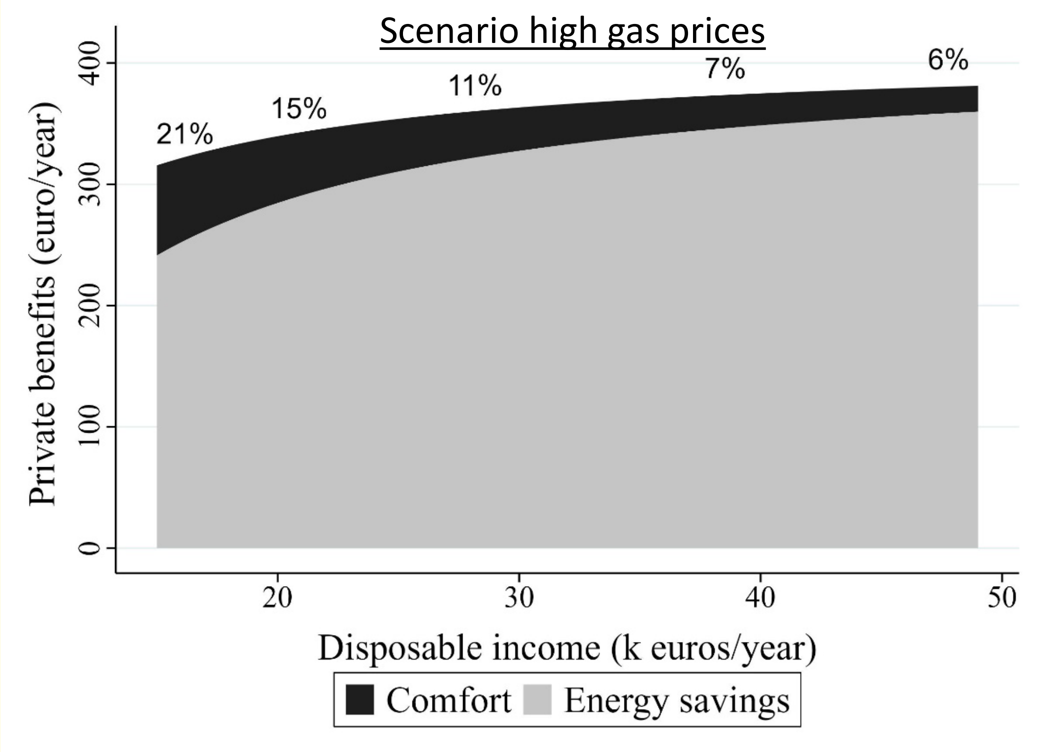
Meredith Fowlie, Michael Greenstone, Catherine Wolfram

The Quarterly Journal of Economics, Volume 133, Issue 3, August 2018, Pages 1597–1644,

Preview of results

We find:	**Poor (<=social minimum)**	**Mean income**
Gas savings	-16%	-22%





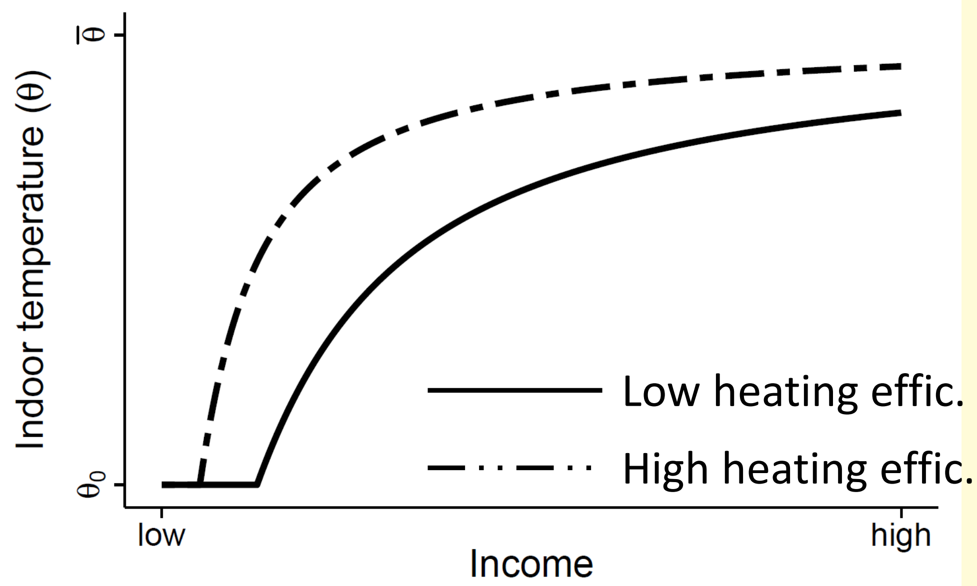
- For social minima up to 20% benefits come through comfort
- Positive NPV possible under high gas prices

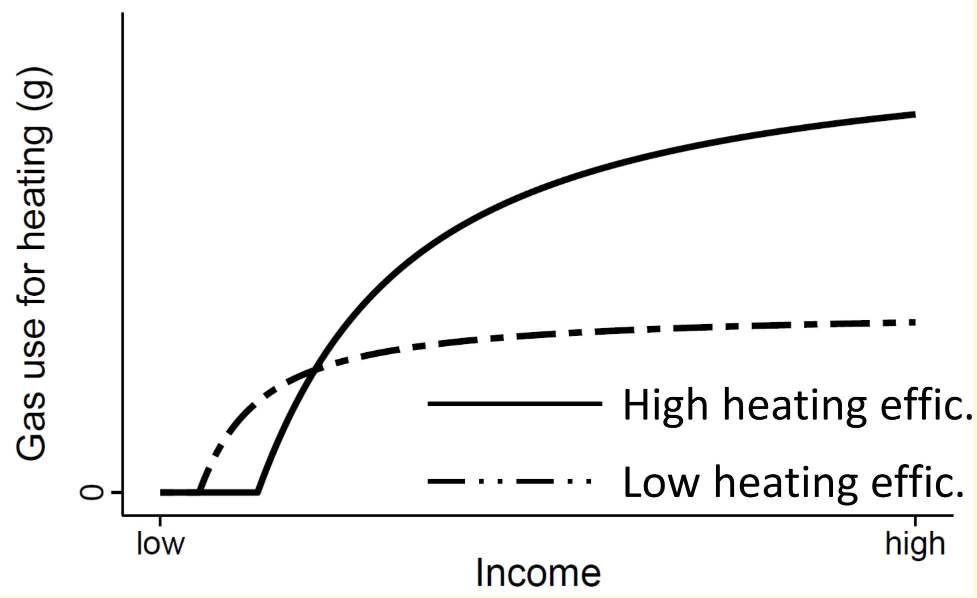
Outline rest of the talk

1) Microeconomic model
2) Institutions and data
3) Econometric identification
4) Results. Welfare

The results of this study are based on calculations using non-public microdata from Statistics Netherlands. We thank RVO for supporting the data access.
This work was supported by the Netherlands Organization for Scientific Research (NWO) grant 403.19.230.

1 Microeconomic model & Welfare





Household utility depends on
- thermal comfort
- normalized consumption good

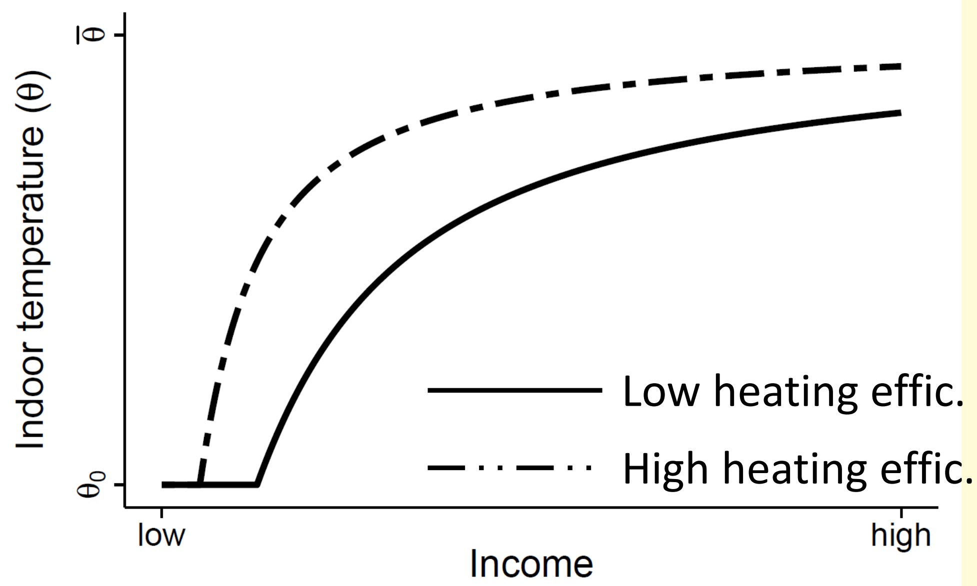
Comfort is produced from natural gas.

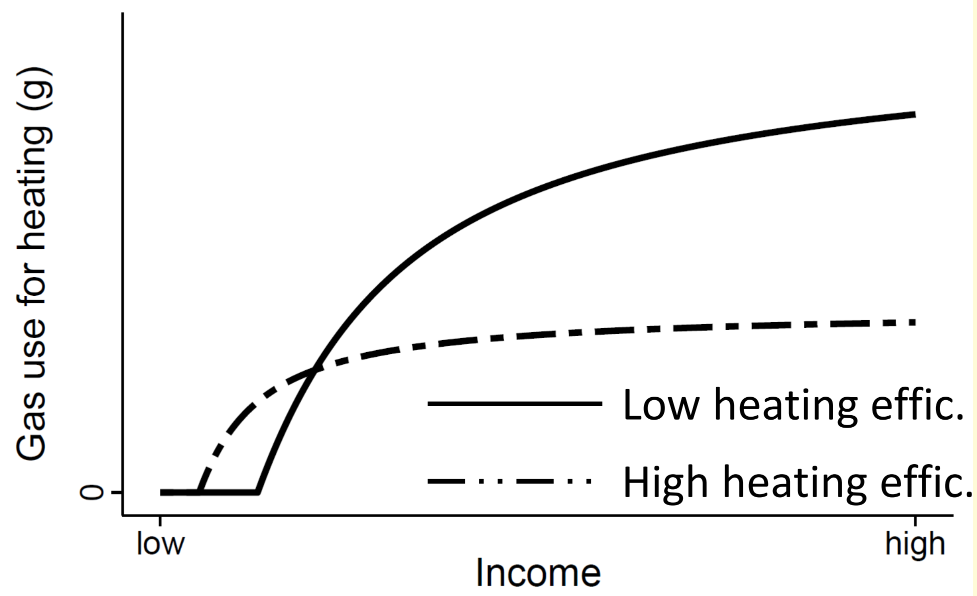
There is a satiety level of thermal comfort.

——— Dwelling with low heating efficiency

— · · — · · Dwelling with high heating efficiency

Microeconomic model & Welfare





Dwelling with low heating efficiency (solid line)
Dwelling with high heating efficiency (dash-dot line)

$$V(q,w) \stackrel{\text{def}}{=} u(x^*(q,w), \theta^*(q,w)),$$

Indirect utility V

$$V(q_H, w - CV) = V(q_L, w).$$

Compensating variation CV

Increase in consumption

Increase in thermal comfort

Use quasi-experimental evaluation to fit the parameters

2 Institutions: quasi-experiment – home upgrade – change in gas use

2012: covenant Social Housing Sector – Housing Associations

aim to move to average energy label B in 2021

2016: still 1.6M (out of 2.5M) dwellings to go

2017-19: Quasi-experiment

-Retrofit assignment piggybacks on planned maintenance,

conditional on homes qualifying for retrofit.

-No self-selection. Tenants within a complex may not opt out.

Administrative data on dwellings and people. 125K households in 8 years

Conditional random assignment

Treatment:
- Single family dwelling
- Household lives in house 1yr before & 1yr after retrofit

Control:
- Single family dwelling
- Built before 1993
- Energy label CDEFG
- Household did not move

Treatment and control balanced on personal charact.

Treatment and control balanced on energy use, after controlling for observable housing covariates (p-value 0.35)

Table 1: Balance between treatment and control groups at baseline

	Mean treatment	Mean control
Panel A: Socio-economics		
No. persons	2.13	2.09
No. children	0.63	0.58
No. seniors	0.51	0.51
Income (k euroyear)	26.63	27.43
Education high (0/1)	0.10	0.10
Migration background foreign (0/1)	0.22	0.20
Below 100% social min. (0/1)	0.03	0.03
Below 130% social min. (0/1)	0.27	0.26
Below 150% social min. (0/1)	0.38	0.37
Panel B: House characteristics		
Surface (m^2)	94.79	94.27
Constr. Period 1906-1939 (0/1)	0.06	0.07
Constr. Period 1940-1965 (0/1)	0.53	0.30
Constr. Period 1966-1976 (0/1)	0.38	0.32
Constr. Period 1977-1992 (0/1)	0.03	0.31
Energy label EFG (0/1)	0.45	0.26
Panel C: Residualized energy use		
Electricity	−0.03	0.00
Gas	−0.00	0.00
No. houses/households	13409.00	110891.00

3 Empirical model: OLS (2way fixed effect)

Run also with Callaway&StAnna; Sun&Abraham

i is dwelling/household, t is year 2014..21, g is log(gas.usage)

$$g_{it} = R_{it}\,\alpha + X_{it}\,\delta + \gamma_i + \varphi_t + u_{it}$$

$$g_{it} = R_{it}(\alpha + \beta_j S_{ijt}) + X_{it}\,\delta + \gamma_i + \varphi_t + u_{it}$$

R is incidence of retrofit

S is retrofit size modifier

X are time-variant dwelling/household characteristics

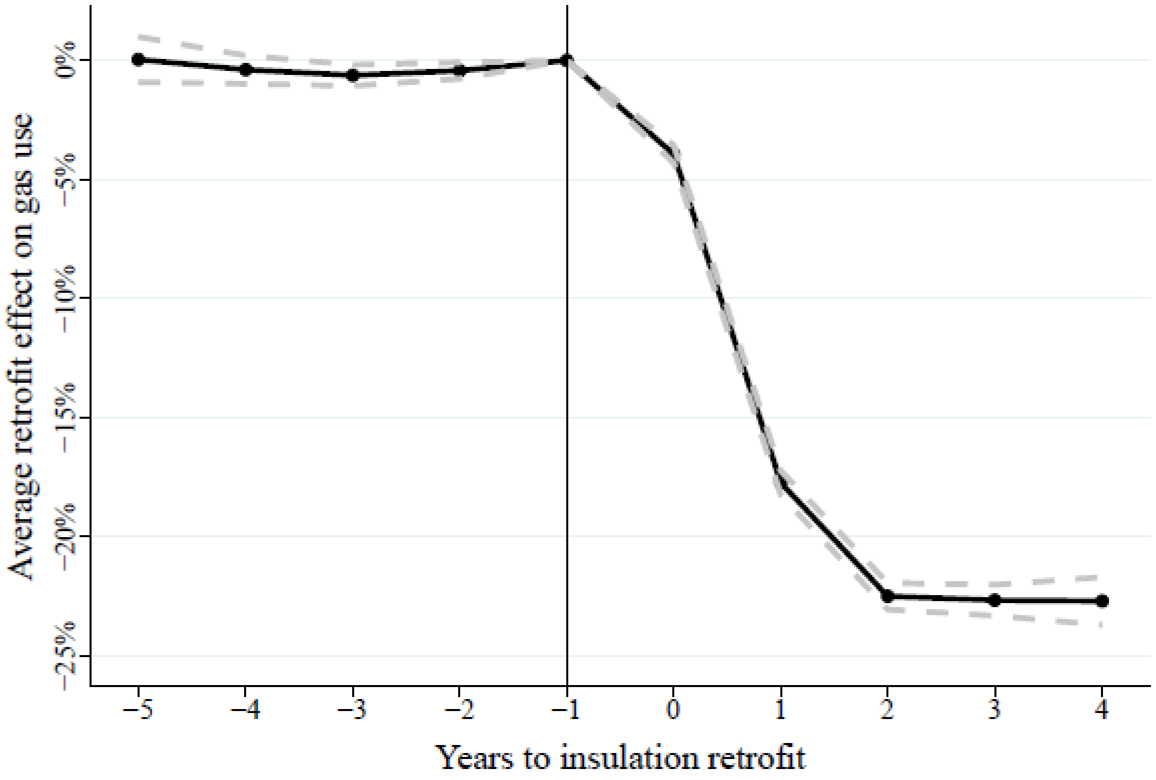
γ_i are dwelling fixed effects

φ_t are year fixed effects

u_{it} is error term (clustered by household)

4 Results OLS Event study

Figure 5: Gas savings from heating efficiency upgrade: event study by year



Notes: Plotted values are the coefficients of the interaction effect of the treatment indicator with the year-to-retrofit, see Equation (11). Year -1 (vertical line) is the last pre-retrofit year. The dashed lines represent the 95% confidence interval. Standard errors are clustered at household level.

OLS results by income

Table 3: Effects of retrofits for poor households

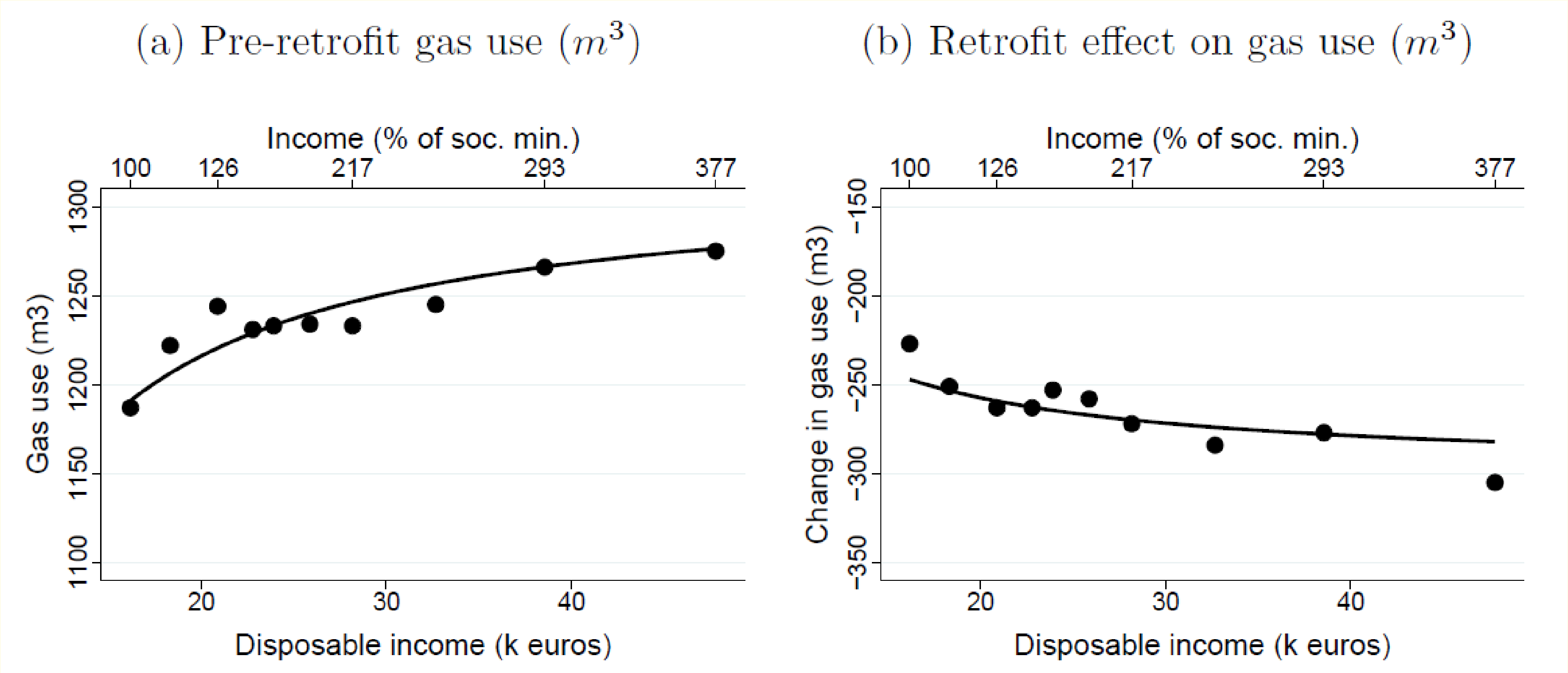
	Baseline
Retrofit (year $\geq$ 2)	-0.218 (0.003)***
$\times$ Below 100% soc.min.	0.062 (0.016)***
$\times$ Below 130% soc.min.	0.025 (0.006)***
$\times$ Below 150% soc.min.	0.018 (0.006)***

Notes: The table shows estimates of Equation (12) for 5 separate regressions. Coefficients reported are two-way interactions. The symbol $\times$ indicates an effect as compared to the reference level (non-poor). The dependent variable is log of gas. Each regression includes controls, household fixed-effects and year fixed-effects. The sample size is 13409 treated and 110891 control units. Standard errors in parentheses are clustered at household level. Statistical significance: $^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.

Social minimum (soc.min.): minimal amount one needs in order to cover basic personal needs

Results are robust to various sensitivity checks

5 Welfare analysis: fitting the parameters of utility function



How we fit parameters?

For the whole income distribution, fit model outcomes to

- Observed gas usage
- Quasi-experimental gas savings

Parameters estimated using NLS

Which parameters:

- home energy efficiency q (before and after retrofit)
- natural home temperature θ_0
- satiation temperature $\bar{\theta}$
- substitution parameter σ

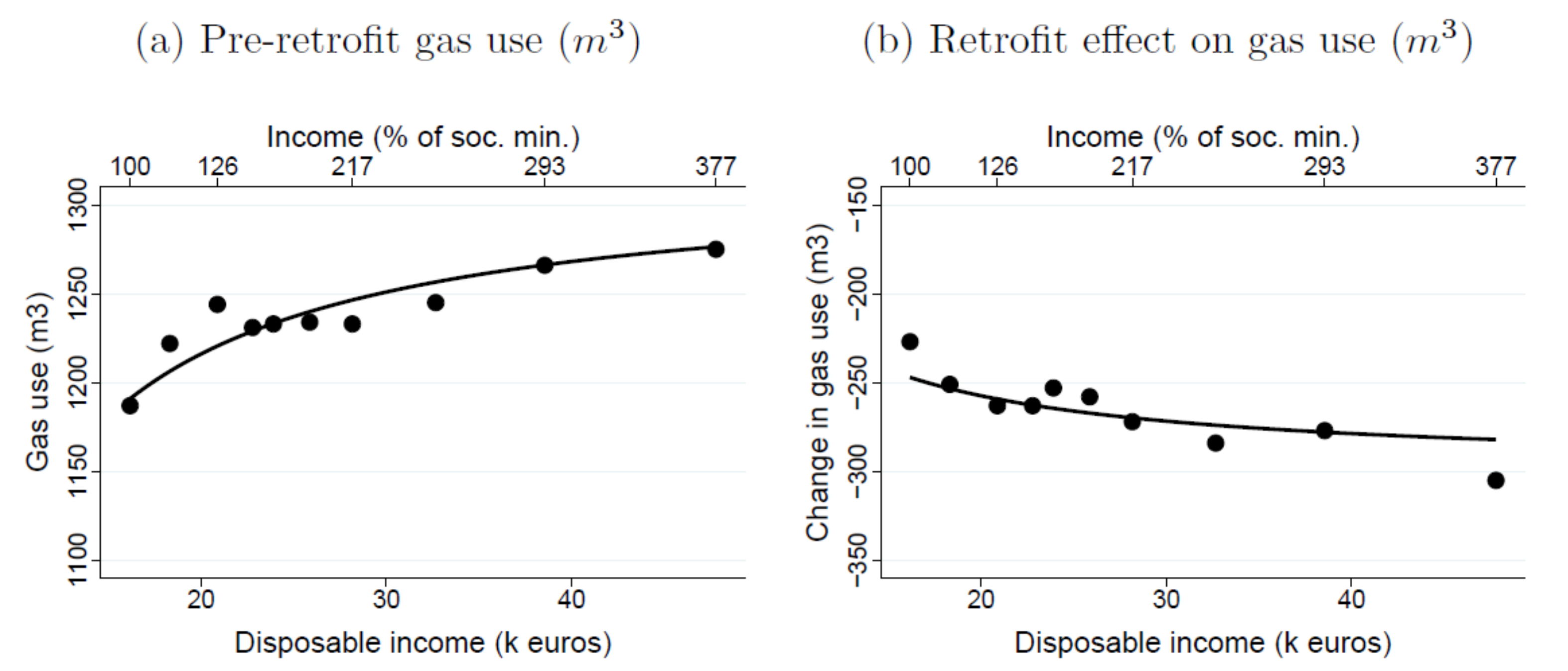
$$u(x, \theta) = \left(x^{\frac{\sigma - 1}{\sigma}} + ((2\bar{\theta} - \theta)\theta)^{\frac{\sigma - 1}{\sigma}} \right)^{\frac{\sigma}{\sigma - 1}}$$

$$\theta = \theta_0 + qg \qquad x + \frac{p_q}{q}(\theta - \theta_0) = w.$$

(x consumption good, θ home temperature, g gas use and p gas price)

Welfare analysis: validation

1. Visual inspection

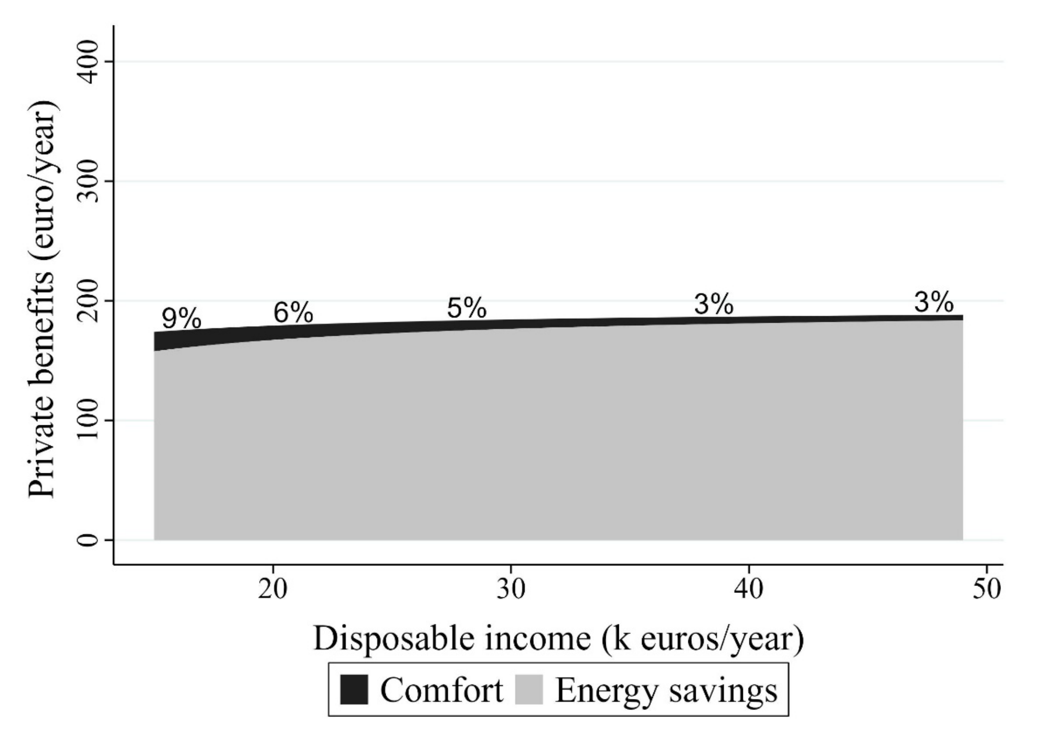


2. Compare model outcomes to existing empirical estimates

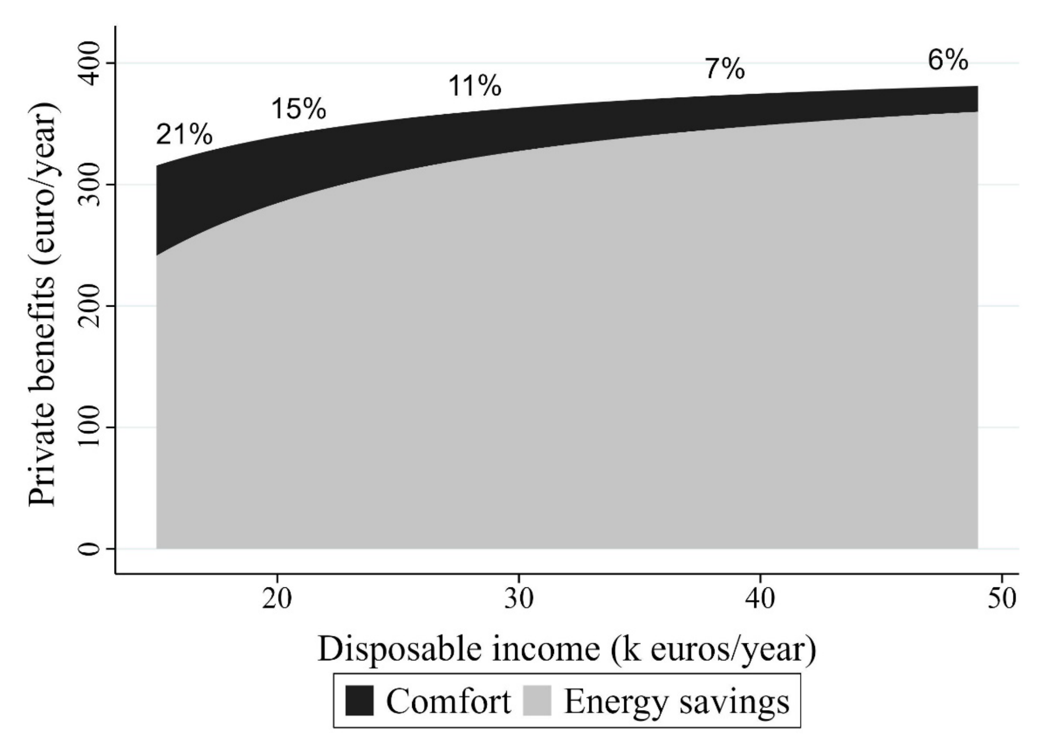
Estimate	Values from calibrated model	Empirical literature
Indoor temperature increase	0.1 to 0.6 degrees	Fisk et al. (2020)
Price elasticity of gas	-0.04 to -0.27	Asche et al. (2008)
Rebound effect (2016 prices)	5%	Christensen et al. (2023)

Welfare analysis: private benefits

Low gas prices (2016)



High gas prices (2022)



- Poorest households spend up to 20% of retrofit benefit into additional comfort
- NPV : negative under low gas prices, positive under high gas prices (reference retrofit of 7K euro incl. VAT)

Welfare analysis: environmental outcomes

Table 6: Program effects and private benefits, by income

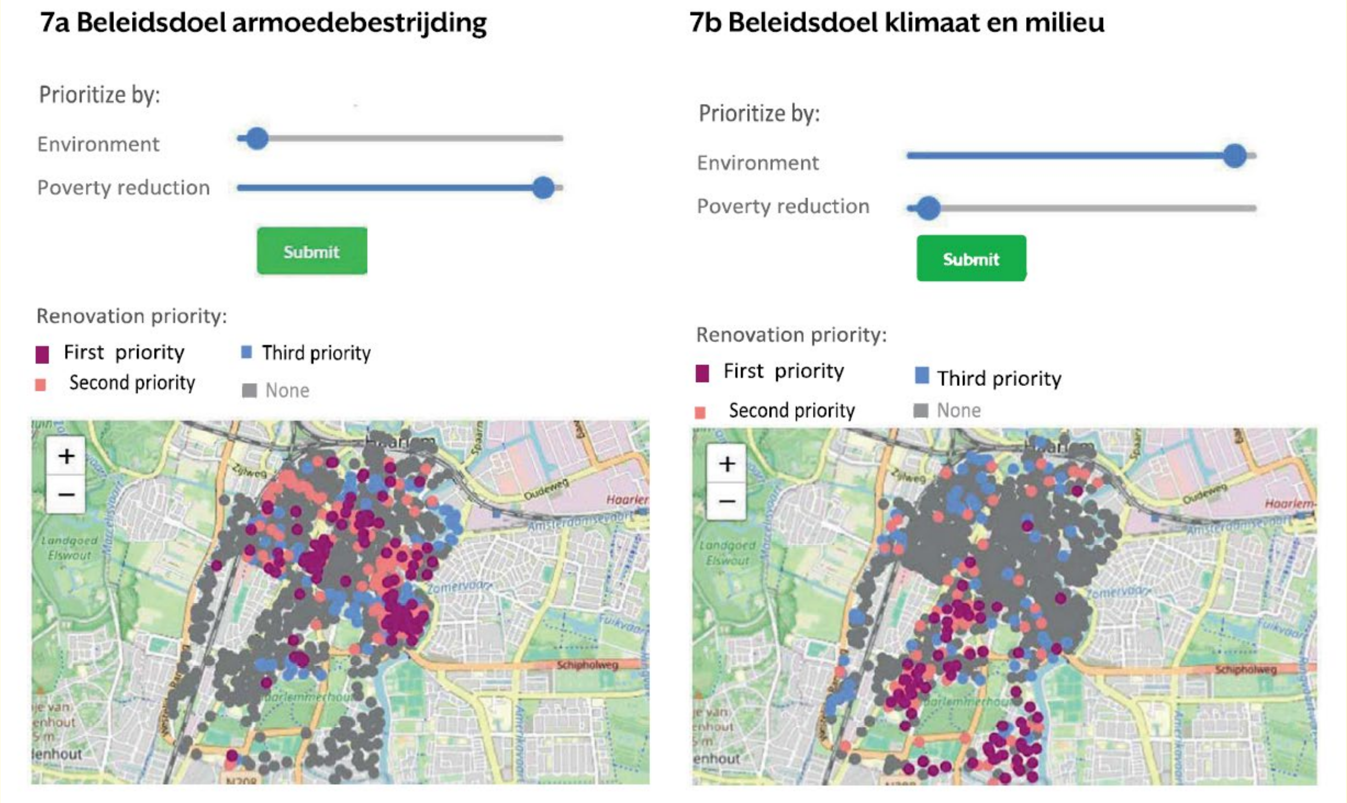
Income	Private and external effects			Private benefits (euro)			
	Δ Temp.	Δ Gas	ΔCO_2	Slutsky valuation			Hicksian val.
	°C	m^3	kg	$-\Delta^S$	$-\Delta^S_\theta$	$-\Delta^S_x$	CV
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
In prices 2016 (0.65 euro/m^3)							
low	0.30	-245	-439	175	15	159	177
average	0.19	-265	-474	182	10	172	183
high	0.10	-280	-501	187	5	182	188
In prices 2022 (1.36 euro/m^3)							
low	0.65	-182	-326	320	71	249	329
average	0.41	-225	-402	352	45	307	358
high	0.22	-258	-463	377	24	353	381

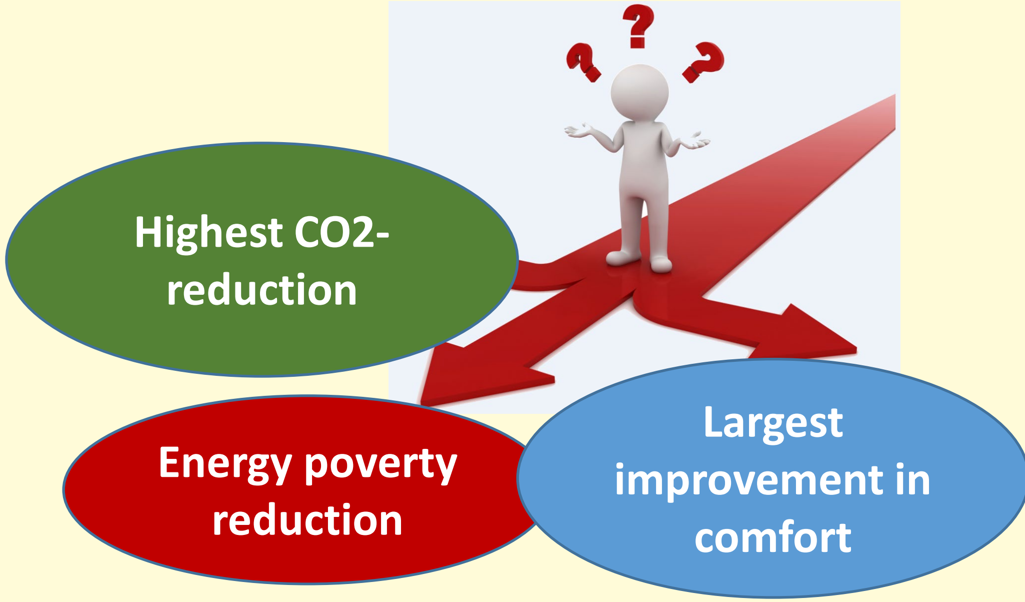
50% of the gas price is excise duty
→ Tax Pigouvian?

Excise seems an effective instrument to increase private returns to energy-efficient homes.

6 Conclusion and further steps. See also bel-tue.nl

- Poverty improvement with home upgrades comes at the cost of environmental benefits
- Positive return if natural gas prices stay high





Next: Effects insulation on health; Effects of electrification on energy use; Large language models

Models and identification: causal forest yields heterogeneity range

Wager and Athey, 2018, Tibshirani, 2022

Can predict causal effect of retrofits, for each individual house! We use this to identify the highest savers.

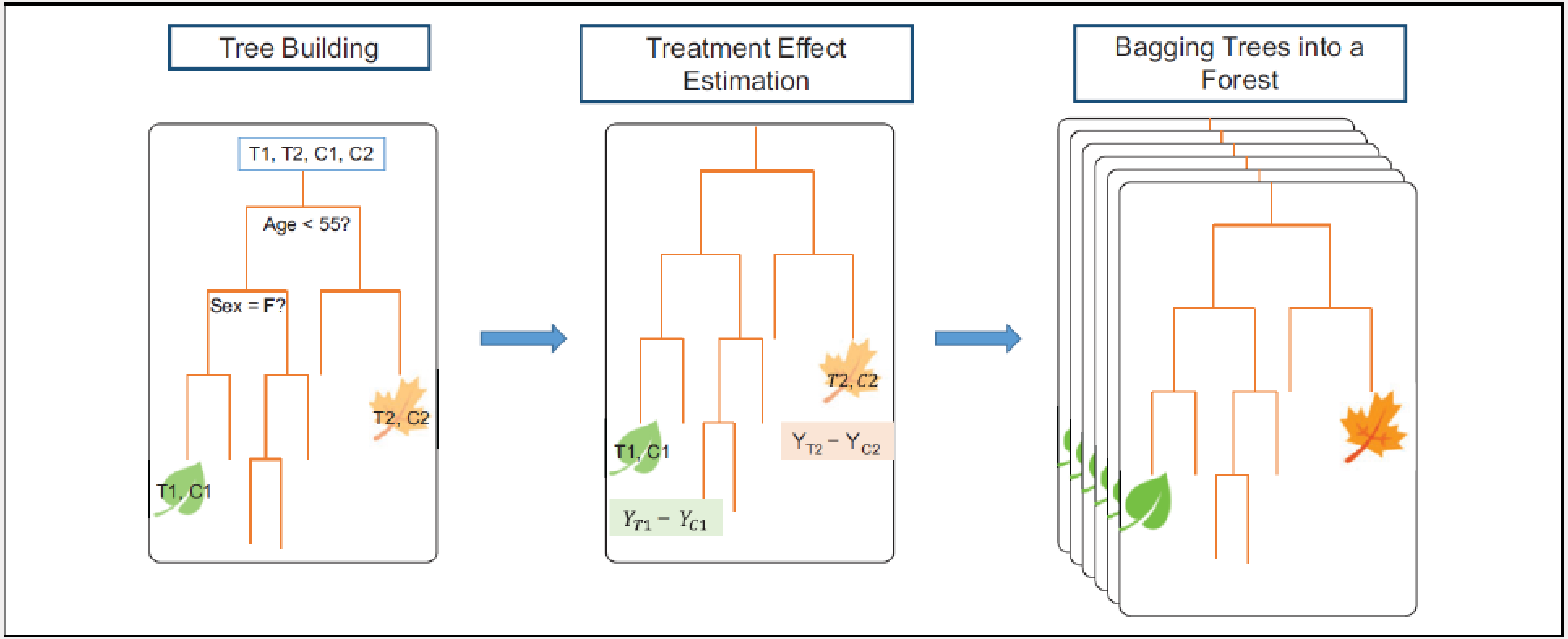


Figure: Guo et al. 2021

OLS average results

Table 2: Average effects of insulation retrofit on gas consumption

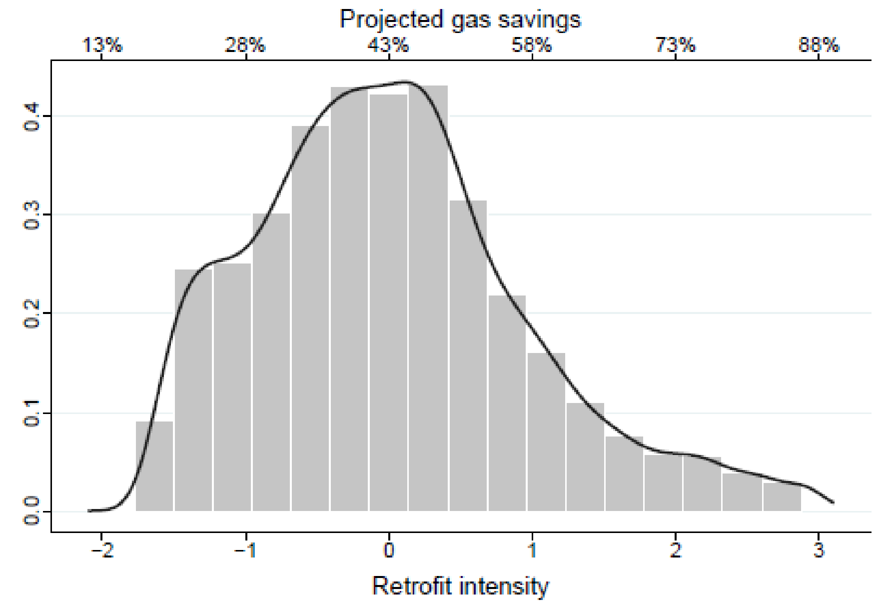
Dependent: log of yearly natural gas use	(1)	(2)	(3)	(4)
Retrofit (year $\geq$ 2)	-0.149***	-0.228***	-0.228***	-0.218***
	(0.004)	(0.003)	(0.004)	(0.003)
Retrofit (year $\geq$ 2) $\times$ Retrofit index	-0.058***	-0.077***	-0.100***	-0.078***
	(0.004)	(0.003)	(0.004)	(0.003)
No. obs.	963459	963459	959073	959073
No. treatment houses	13409	13409	13409	13409
No. control houses	110891	110891	110891	110891
R^2 Adj.	0.021	0.822	0.144	0.826
Year fixed-effect	X	X	X	X
Household fixed-effect		X		X
Controls			X	X

Possible identification concerns

General

- Retrofit intensity varies and may be endogenous (dwellings with worse energy efficiency get larger retrofits)
  - → Retrofit intensity not correlated to household covariates, only housing covariates
  - → Include retrofit size as a covariate: linear, but also flexible higher order polynomial,
  - → Run separate regressions by dwelling segment & by type/size of retrofit
- People self-select by moving
  - → Do not find evidence
- Problems due to staggered treatment
  - → Run with Callaway&StAnna; Sun&Abraham

Figure 4: Distribution of retrofit intensity



Behavioural mechanisms: substitution?

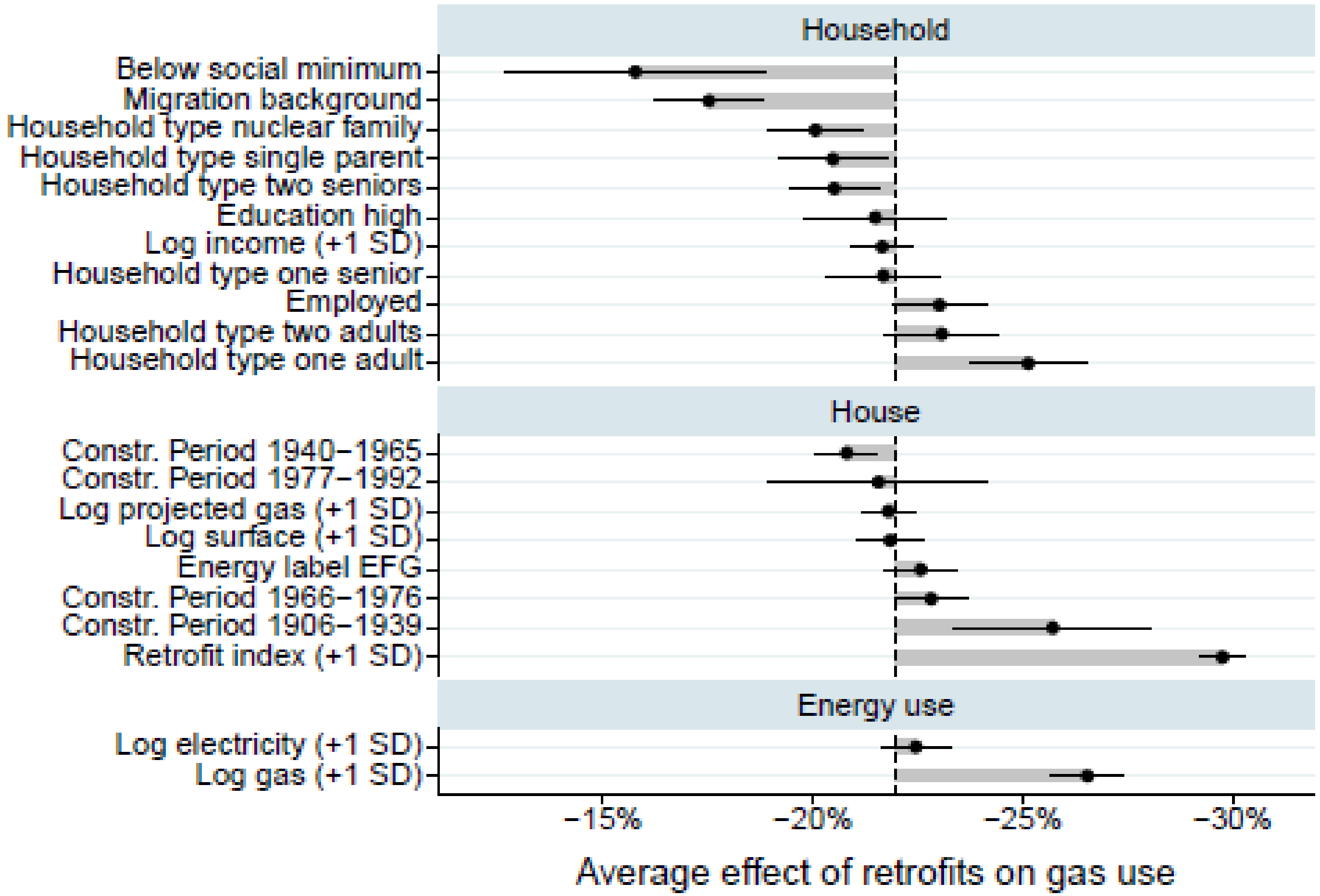
Table 4: Effects of retrofits on gas and electricity, by solar panel availability

	Dependent: log gas		Dependent: log electricity	
	No solar	Yes solar	No solar	Yes solar
Retrofit (year $\geq$ 2)	-0.223 (0.003)***	-0.237 (0.004)***	0.010 (0.004)***	-0.286 (0.007)***
$\times$ Below poverty line	-0.005 (0.015)	0.053 (0.014)***	0.059 (0.013)***	0.033 (0.028)
$\times$ Below 100% soc.min.	0.054 (0.019)***	0.063 (0.025)**	0.037 (0.022)*	0.037 (0.039)
$\times$ Below 130% soc.min.	0.013 (0.008)*	0.041 (0.009)***	0.014 (0.008)*	0.006 (0.016)
$\times$ Below 150% soc.min.	0.011 (0.007)	0.027 (0.008)***	0.010 (0.007)	-0.011 (0.015)

Notes: The table shows estimates of Equation (12) for 10 separate regressions. Coefficients reported are two- and three-way interactions. The symbol $\times$ indicates an effect as compared to the reference level (non-poor). The combination of the column and row name indicates the interaction (e.g. below poverty line $\times$ Yes solar). The dependent variable is log of gas or log of electricity. Each regression includes controls, household fixed-effects and year fixed-effects. The sample size is 13409 treated and 110891 control units. Standard errors in parentheses are clustered at household level. Statistical significance: $^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.

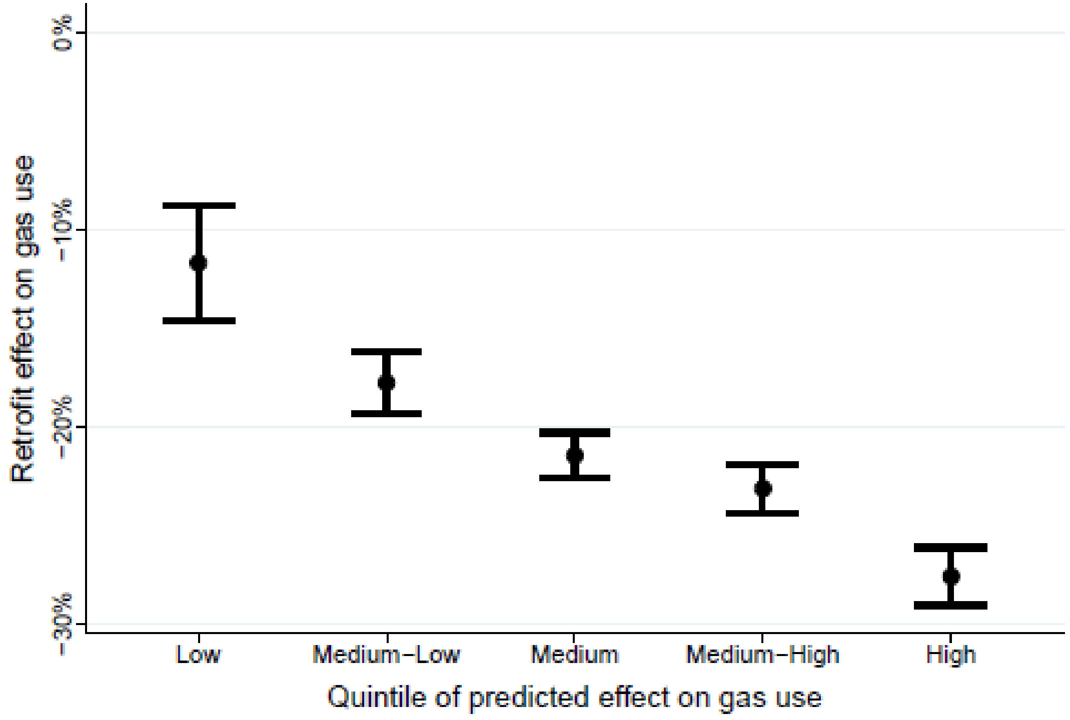
Range and sources of heterogeneity

Figure 6: Covariate importance in explaining gas savings



Range and sources of heterogeneity

Figure 7: Heterogeneity of retrofit effects: combination of causal forest and fixed effects panel regression



Notes: This figure reports coefficients from Equation (12) with $J = 5$. Coefficients are two-way interaction effects of the treatment with the causal forest quintile dummies. Bars indicate 95% confidence interval. Standard errors clustered at household level.