Impacts of public policy on the rebound effect of green heating services.

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Acknowledgements

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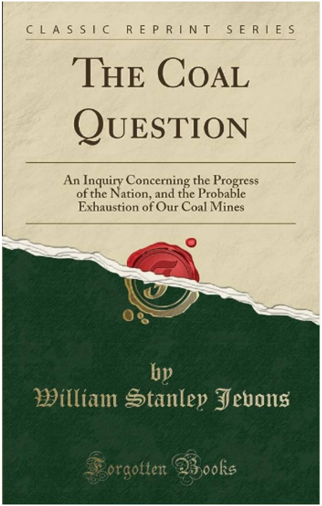
Overview

Table of Contents

History of rebound

The economy of fuel is the secret of the steam engine;... Whatever, therefore increase the efficiency of coal, and to diminish the cost of its use, direct tends to augment the value of the steam engine and to enlarge the field of its operations... Every improvement of the (steam) engine, when affected, does but accelerate new the consumption of coal...



Introduction

Definition

After the progress of the household heating system, less energy is required to produce the same thermal comfort - *ceteris paribus*. The fall of unit cost leads to increased consumption (Berkhout, Muskens, and Velthuijsen, 2000).

- No problem if: Low emission + externalities + rate (Gillingham, Kotchen, et al., 2013)
- Magnitude of Rebound effects:
  1. Direct + Indirect: 36-43% (Marvin et al., 2023)
  2. Economic scale: Substantial, $< 100\%$ (Gillingham, Rapson, and Wagner, 2016)
- Can we apply to renewable energy?
  - Compared fossil fuel: Less heating productivity but cleaner.
  - Direct + Indirect: 0-60%
  - Mechanism: Moral licensing, pro-environmental effort.

In the context of heating services

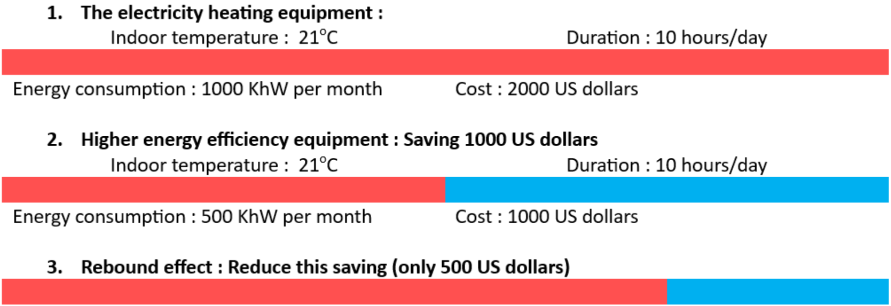


Figure: The rebound effect in the context of heating service

$$\text{Rebound effect} = \frac{\text{Potential saving - Actual saving}}{\text{Potential saving}} \quad (1)$$

Theoretical Framework

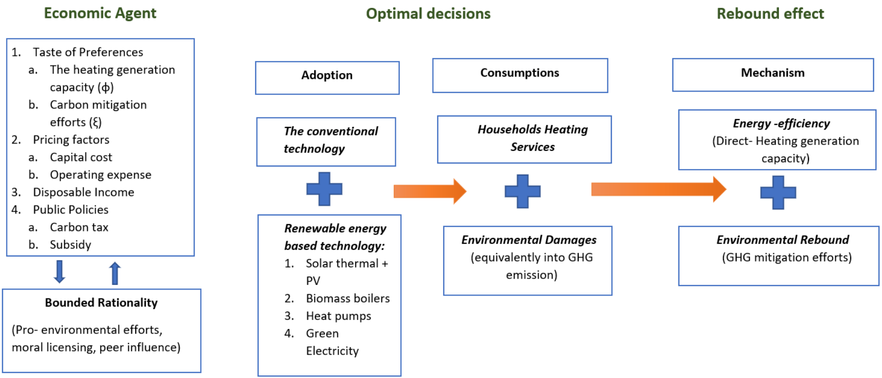


Figure: The chain of household's decision making.

Table of Contents

Model

Extending the model of Dorner, 2019, Chan and Gillingham, 2015 and Borenstein, 2015, we build a new model:

- x is No of heating services.
- d is the aggregate env. damages.
- ϕ Heating generation capacity.
- ε GHG mitigation effort.
- f_1 No of grid-based power.
- f_2 No of renewable fuel.
- p_1 unit price of power grid.
- p_2 unit price of renewables.
- $w + S$ Income and subsidy.
- τ the carbon tax.

$$x = f_1 + \phi f_2 \tag{2}$$

$$d = f_1 + \frac{1}{\varepsilon} f_2 \tag{3}$$

$$w + S \geq (p_1 + \tau) f_1 + p_2 f_2 \tag{4}$$

$$f_1 = \frac{-x}{\phi\varepsilon - 1} + \frac{d\phi\varepsilon}{\phi\varepsilon - 1} \tag{5}$$

$$f_2 = \frac{x\varepsilon}{\phi\varepsilon - 1} - \frac{d\varepsilon}{\phi\varepsilon - 1} \tag{6}$$

Model: Key assumptions

Two characteristics of Residental heating technology based on renewable energy RET:

Assumption 1 (Heating generation capacity)

Given the heating generation capacity for conventional sources (ϕ) is unchanged and equal to 1, this productivity of renewables is less than that of fossil fuel ($\phi \leq 1$)

The counter-example:
The green electricity: $\phi = 1$ - Heat pump: $\phi = 3$

Assumption 2 (GHG Mitigation efforts)

The environmental/ecological damages of renewable energy are converted into the common human GHG, and its environmental damages are $\frac{1}{\varepsilon}$ where ε is the mitigation effort and larger than 1.

Note: Each low-carbon source has a different ε.

Model: Key assumptions

Assumption 3 (Pricing)

The nominal price of renewable energy is higher than the conventional source's price ($p_2 > p_1$).

The extreme case:
The unit production cost of off-shore or solar electricity sometimes are lower than the grid-based source, but reconsider:

- Investment.
- Operating cost.
- The retail price is an average cost.
- Annual contracts and fixed price.

Model

The heating services and environmental damages can be substituted into the budget constrain and giving the optimization below:

$$\underset{\{x,d\}}{\text{Maximize}} \quad \mathbb{U}(x,d)$$

subject to

$$x \underbrace{\frac{p_2 - \frac{p_1+\tau}{\varepsilon}}{\phi - \frac{1}{\varepsilon}}}_{P_x} + d \underbrace{\frac{\phi(p_1+\tau) - p_2}{\phi - \frac{1}{\varepsilon}}}_{P_d} \leq w + S$$

P_x, P_d are implicit prices of heating services and pollution.

- Depends on the type of RET $(\phi - \frac{1}{\varepsilon})$.
- Tax on energy.

Table of Contents

Adoption: a single-fuel system

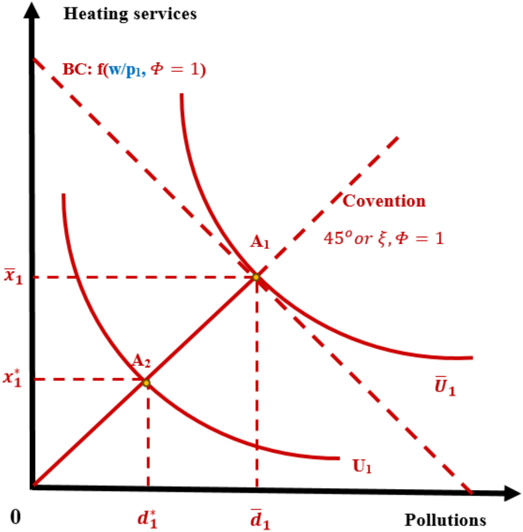


Figure: The chain of household's decision making.

Adoption: a hybrid-fuel system

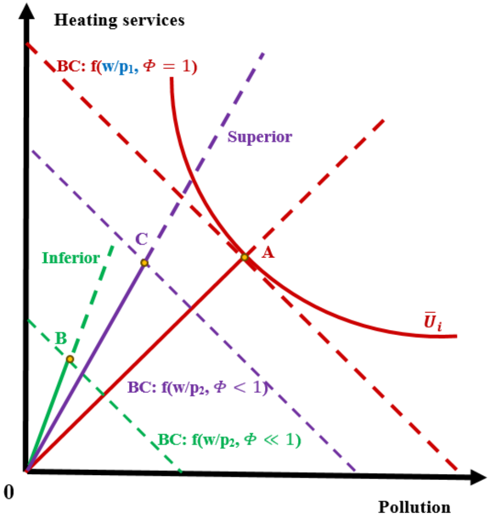


Figure: Two types of RET system.

1. $x = f_1 + \phi f_2$
2. $d = f_1 + \frac{1}{\varepsilon} f_2$
3. $\frac{x}{d} = 1 + \frac{f_2(\phi - \frac{1}{\varepsilon})}{f_1 + \frac{f_2}{\varepsilon}}$
4. $\frac{\partial(x/d)}{\partial\phi}, \frac{\partial(x/d)}{\partial\varepsilon} > 0$
5. $\frac{\partial P_x}{\partial\phi}, \frac{\partial P_x}{\partial\varepsilon} < 0$
6. $\frac{\partial P_d}{\partial\phi}, \frac{\partial P_d}{\partial\varepsilon} > 0$

Table of Contents

Findings - Rebounds

1. Direct rebound effect: Extra usage of heating services after the RET progress.

$$RE_x = \sum RE_{x_{\phi,\varepsilon}} = \underbrace{\%_x^{f_1^*} \% \tau \eta_{\phi,\varepsilon}^{f_1^*}}_{\text{Conventional}} + \underbrace{\%_x^{f_2^*} \left[1 + \eta_{\phi,\varepsilon}^{f_2^*} \left(1 - \frac{p_2}{\phi(p_1 + \tau)}\right)\right]}_{\text{Renewable}}$$

- $\eta_{\phi,\varepsilon}^{f_1^*} < 0$ - The cross elasticity, but it is positive
- $\eta_{\phi,\varepsilon}^{f_2^*} > 0$ - The price elasticity.
- The income elasticity: shifting and concavity (Mori, Yepez-Garcia, and Macedo, 2022).

Back-to-envelope calculation

Table: The estimation of the direct rebound effect*

	Control	**Green E**	**Solar_w**	**Solar_s**	**Biomass**	**Pump**
$p_1 + \tau$	0.154	0.154	0.154	0.154	0.154	0.154
p_2	0	0.1545	0.067	0.067	0.1533	0.1542
$\%\tau$	0.6	0.6	0.6	0.6	0.6	0.6
ϕ	1	1	0.1	0.7	0.6	3
$\eta^{f_1}_{\phi,\varepsilon}$	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%
$\eta^{f_2}_{\phi,\varepsilon}$	1%	50%	50%	50%	50%	50%
$\%f_2$	0%	50%	50%	50%	50%	50%
RE_{f_1}	**0.96%**	**0.48%**	**0.48%**	**0.48%**	**0.48%**	**0.48%**
RE_{f_2}	**0%**	**50%**	**-34%**	**59%**	**34%**	**67%**
RE_x	**1.0%**	**50.4%**	**-33.3%**	**59.9%**	**34.0%**	**67.1%**

2 Environmental rebound effect*

$$RE_d = \sum RE_{d_{\phi,\varepsilon}} = \underbrace{\%_d^{f_1^*} \% \tau \eta_{\phi,\varepsilon}^{f_1^*}}_{\text{Conventional}} + \underbrace{\%_d^{f_2^*} \left[\eta_{\phi,\varepsilon}^{f_2^*} \left(1 - \frac{\varepsilon p_2}{p_1 + \tau} \right) - 1 \right]}_{\text{Renewable}}$$

- $\%_d^{f_1^*, f_2^*} > 0$ - The share emission between fuels.
- $\% \tau > 0$- The tax share on the conventional price.
- $\eta_{\phi,\varepsilon}^{f_1^*} < 0$ - The cross elasticity
- $\eta_{\phi,\varepsilon}^{f_2^*} > 0$ - The price elasticity.

Rebound effects after the RET transition*

Remind: Less efficiency ($\phi < 0$), but also lower emission ($\varepsilon > 1$)

$$
\begin{aligned}
RE_T =& RE_{x_\varepsilon} - RE_{x_\phi} + RE_{d_\varepsilon} - RE_{d_\phi} \\
=& \%\tau(\%_x^{f_1^*} + \%_d^{f_1^*}) \underbrace{(\eta_\phi^{f_1^*} - \eta_\varepsilon^{f_1^*})}_{\eta_1} - (\%_d^{f_2^*} + \%_x^{f_2^*}) \\
& + \underbrace{(\eta_\phi^{f_2^*} - \eta_\varepsilon^{f_2^*})}_{\eta_2} \left[\%_d^{f_2^*} \left(\frac{\varepsilon p_2}{p_1 + \tau} - 1 \right) + \%_x^{f_2^*} \left(\frac{p_2}{\phi(p_1 + \tau)} - 1 \right) \right]
\end{aligned}
$$

- η_1: The gross tech elasticity of demand for conventional fuel.
- η_2: The gross tech elasticity of demand for renewable energy.

Two special cases:

- Green electricity: $RE_T = RE_\varepsilon$
- Heat pump: $RE_T = RE_\phi + RE_\varepsilon$

Table of Contents

Optimal tax

We use the multi-objective optimizations by the weighted method to achieve the adoption rate and lower rebounds.

- The weight $\rho \in (0, 1)$ - The relative priority assigned to a object.
- All types of rebounds are treated equally.
- No of renewables is responsive to an energy tax.

$$\underset{\{\tau\}}{\text{Maximize}} \quad \mathbb{G}(\%_x^{f_2^*}, -RE_x) \equiv \rho\%_x^{f_2^*} - (1-\rho)RE_x$$

subject to

$$\%_d f_2^* \geq 0$$

$$\frac{\partial \mathbb{G}}{\partial \tau} = 0 \iff \frac{\partial \%_x f_2^*}{\partial \tau} = \frac{(1-\rho)\%_x f_2^* \frac{\partial RE_x}{\partial \tau}}{\rho + (\rho - 1)RE_x}$$

Findings - Optimal policy

where

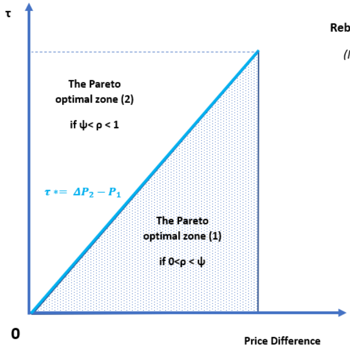
$$\frac{\partial RE_x}{\partial \tau} = \frac{p_1}{(p_1+\tau)^2}\eta_{\phi,\varepsilon}^{f_1^*} + \frac{\partial \text{‰}_x^{f_2^*}}{\partial \tau}\mathbb{A} + \text{‰}_x^{f_2^*}\frac{\partial \mathbb{A}}{\partial \tau} \tag{7}$$

As a result, the optimal tax rate is following:

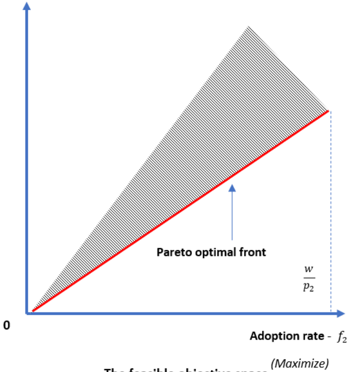
$$\begin{cases} \tau_x^* < \underbrace{\frac{\frac{\eta_{\phi,\varepsilon}^{f_2^*}}{\phi}p_2 - \left(\frac{2-\rho}{1-\rho} + \eta_{\phi,\varepsilon}^{f_2^*}\right)p_1}{\frac{2-\rho}{1-\rho} + \eta_{\phi,\varepsilon}^{f_2^*} - \eta_{\phi,\varepsilon}^{f_1^*}}}_{\Delta} & \text{for} \quad 0 < \rho < 1 - \frac{1}{\eta_{\phi,\varepsilon}^{f_2^*} - \eta_{\phi,\varepsilon}^{f_1^*} + 2} \\ \tau_x^* > \frac{\frac{\eta_{\phi,\varepsilon}^{f_2^*}}{\phi}p_2 - \left(\frac{2-\rho}{1-\rho} + \eta_{\phi,\varepsilon}^{f_2^*}\right)p_1}{\frac{2-\rho}{1-\rho} + \eta_{\phi,\varepsilon}^{f_2^*} - \eta_{\phi,\varepsilon}^{f_1^*}} & \text{for} \quad \frac{1}{\eta_{\phi,\varepsilon}^{f_2^*} - \eta_{\phi,\varepsilon}^{f_1^*} + 2} < \rho < 1 \end{cases} \tag{8}$$

When we change the policy preference:

$$\frac{\partial \Delta}{\partial \rho} = \left[\frac{\eta_{\phi,\varepsilon}^{f_2^*}}{\eta_{\phi,\varepsilon}^{f_1^*}} \frac{p_2}{p_1} - \phi \right] F\left(\rho, p_1, p_2, \eta_{\phi,\varepsilon}^{f_2^*}, \eta_{\phi,\varepsilon}^{f_2^*}, \phi\right)^{-2} > 0 \iff \frac{\eta_{\phi,\varepsilon}^{f_2^*}}{\eta_{\phi,\varepsilon}^{f_1^*}} \frac{p_2}{p_1} > \phi \tag{9}$$



The feasible decision space



The feasible objective space

Figure: The feasible decision on the energy tax.

Findings - Optimal policy

Repeatedly, we search for the optimal solution in the case of the environmental rebound effect. Policymakers face the problem following:

$$\underset{\{\tau\}}{\text{Maximize}} \quad \mathbb{H}(\%_d f_2^*, -RE_d) \equiv \rho\%_d f_2^* - (1-\rho)RE_d$$

subject to

$$\%_d f_2^* \geq 0$$

$$\mathbb{H} = \rho\%_d f_2^* + (\rho - 1)\left[\%\tau\eta_{\phi,\varepsilon}^{f_1^*} + \%_d^{f_2^*} \underbrace{\left[\eta_{\phi,\varepsilon}^{f_2^*}\left(1 - \frac{\varepsilon p_2}{p_1 + \tau}\right) - 1 - \%\tau\eta_{\phi,\varepsilon}^{f_1^*}\right]}_{\mathbb{B} < 0}\right]$$

$$\frac{\partial\mathbb{H}}{\partial\tau} = 0 \iff [\mathbb{B}(\rho - 1) + \rho]\frac{\partial\%_d^{f_2^*}}{\partial\tau} = \frac{(1-\rho)p_1\eta_{\phi,\varepsilon}^{f_1^*}}{(p_1+\tau)^2} + (1-\rho)\frac{\partial\mathbb{B}}{\partial\tau}$$

Findings - Optimal policy

In the case $\eta^{f_2^*}_{\phi,\varepsilon} > \eta^{f_1^*}_{\phi,\varepsilon}$, the optimal tax rate is the following is the optimal solution of Problem $\mathbb{H}$:

$$\begin{cases} \tau_x^* < \frac{\varepsilon \eta^{f_2^*}_{\phi,\varepsilon} p_2 - (\eta^{f_2^*}_{\phi,\varepsilon} - \frac{1}{1-\rho}) p_1}{\eta^{f_2^*}_{\phi,\varepsilon} - \eta^{f_1^*}_{\phi,\varepsilon} - \frac{1}{1-\rho}} & \text{for} \quad 0 < \rho < \underbrace{1 - \frac{1}{\eta^{f_2^*}_{\phi,\varepsilon} - \eta^{f_1^*}_{\phi,\varepsilon}}}_{\psi} \\ \tau_x^* > \frac{\varepsilon \eta^{f_2^*}_{\phi,\varepsilon} p_2 - (\eta^{f_2^*}_{\phi,\varepsilon} - \frac{1}{1-\rho}) p_1}{\eta^{f_2^*}_{\phi,\varepsilon} - \eta^{f_1^*}_{\phi,\varepsilon} - \frac{1}{1-\rho}} & \text{for} \quad 1 - \frac{1}{\eta^{f_2^*}_{\phi,\varepsilon} - \eta^{f_1^*}_{\phi,\varepsilon}} < \rho < 1 \end{cases} \tag{10}$$

In the case $\eta^{f_2^*}_{\phi,\varepsilon} < \eta^{f_1^*}_{\phi,\varepsilon}$, the optimal tax rate is the following:

$$\tau_d^* > \underbrace{\frac{\eta^{f_2^*}_{\phi,\varepsilon}(p_1 - \varepsilon p_2) - \frac{p_1}{1-\rho}}{\frac{1}{1-\rho} + \eta^{f_1^*}_{\phi,\varepsilon} - \eta^{f_2^*}_{\phi,\varepsilon}}}_{\Delta'}$$

Findings - Optimal policy

When we change the policy preference:

$$\frac{\partial \Delta'}{\partial \rho} = \left[\frac{\eta_{\phi,\varepsilon}^{f_2^*}}{\eta_{\phi,\varepsilon}^{f_1^*}} \frac{p_2}{p_1} \varepsilon - 1 \right] F'(\rho, p_1, p_2, \eta_{\phi,\varepsilon}^{f_2^*}, \eta_{\phi,\varepsilon}^{f_2^*}, \phi)^{-2} > 0 \iff \frac{\eta_{\phi,\varepsilon}^{f_2^*}}{\eta_{\phi,\varepsilon}^{f_1^*}} \frac{p_2}{p_1} > \frac{1}{\varepsilon} \tag{11}$$

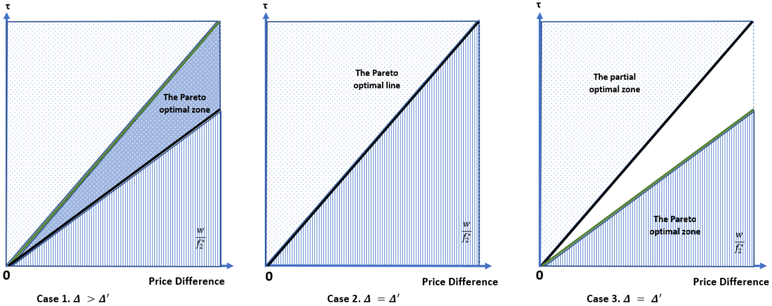


Figure: The feasible decision on the energy tax.

Table of Contents

Conclusion

1. All questions are answered.

Question 1: Adopting renewable energy

Matching with consumers' preferences and tax on energy.

Question 2: Does rebound effects exist?

Three positive types, increase in the quantity of renewable.

Question 3: How to gain everything?

Yes, well-designed tax scheme.

2. Alleys for future research:
   - Social or environmental preference.
   - Open economics with global pollution.
   - Revenue- neutral or deficit system
   - Subsidy allocation and RET promotion.

Merci beaucoup des vos gentilles attentions

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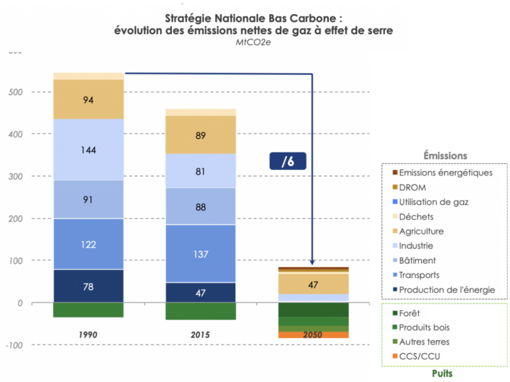
The effect of phasing-out energy inefficient dwellings from the rental market: a sorting demand model approach

Anna Creti, Gabrielle Fack, Edouard Civel, Daniel Herrera-Araujo

October 11, 2023

Building sector: 20% of GHG emssions in France



Plethora of initiatives to reduce Green House Gases

The breadth and scope of the initiatives are large, ranging from financial aids

- Tax credit for energy transition,
- Zero-interest eco-loans,
- Energy-saving certificates
- Reduced-rate VAT...

To information tools

- Energy Performance Certificates (what and where)

With limited success: About +65000 "global home improvements" in 2022. Objective: 35M homes for 2050.

Most recent: "command & control" phasing out energy inefficient dwellings from rental markets.

EPC prior to July 1^{th} 2021

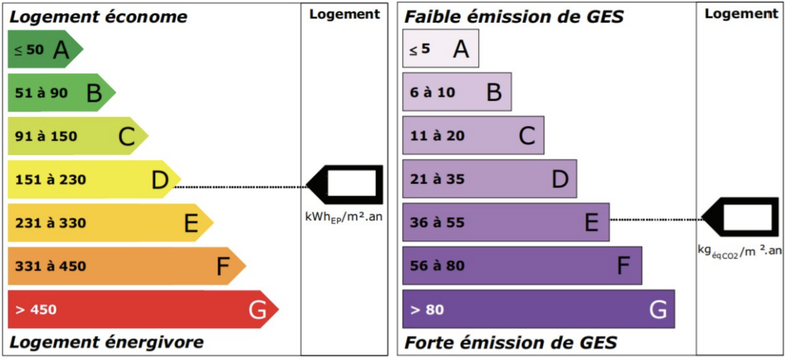


Figure: Thresholds values for EPC and GHG. Design prior to July 1, 2021

This paper in a nutshell

Research question:

What is the market impact from an elimination of the lowest energy classes?

How?

1. Estimate household preferences for energy efficiency
2. **Key modeling strategy:** structural sorting demand model
3. Data linking HH purchases and socio-demographics
4. Construction of policy relevant counterfactuals
5. **Many caveats:** focusing on selling market (for now!), choice set errors, EPC endogeneity, no supply side, just 5/95 departments...

Contribution

Green Premium: Cepedes-Lopez (2019); Civel (2019); A. de Ayala, I. Galarraga and J.V. Spadaro (2016); Brounen and Kok, 2011; Hyland et al. 2013; Fuerst et al., 2015; O.M. Jensen, A.R. Hansen, J. Kragh (2016); K.A. Kholodilin, A. Mense and C. Michelsen (2017).

Most of it hedonic models, unfit for non-marginal changes.

Sorting demand models : P. Bayer, R. McMillan and K. Rueben (2004); P.J. Barwick, S. Li, A.R. Waxman, J. Wu and T. Xia (2022); M. Almagro, E.T. Chyn and B.A. Stuart (2022)

Fit for welfare assessment allowing for partial equilibrium.

Setting - household utility

Let $i = 1, \ldots, I$ individuals participating in the market.

Each individual i considers a purchase from a set J^i of houses that are affordable give his wealth y_i, at period t

Let's define the indirect utility for an individual i that chooses housing unit j, located in neighborhood n, be:

$$\begin{aligned} U_{ijnt} \equiv U_{ih} &= V_{ijnt}(y_{it} - p_{jnt}, x_{jnt}) + \xi_{jnt} + \epsilon_{ijnt} \\ &= V_{ih}(y_{it} - p_h, x_h) + \xi_h + \epsilon_{ih} \end{aligned}$$

x_{jnt}: housing and neighborhood characteristics,
p_{jnt}: full price (transaction + expected cost of renovations),
ξ_{jnt} unobserved housing/neighborhood characteristics,
ϵ_{ijnt} idiosyncratic variation.

Setting - household utility contd'

A household chooses a housing type (h) if the utility from that type is at least as large as the utility from any other housing type ($h^{'}$). That is,

$$U_{ih} \geq U_{ih'} \ \forall \ h \neq h^{'}$$

A choice of a household depends on all the available choices and their characteristics. The probability of purchase for household i can be expressed as:

$$P_{ih} = f_h(D_i, \mathbf{x}, \mathbf{p}, \xi, \theta)$$

f_h: depends on the assumptions on ϵ,
θ: includes all the parameters of the model
the bold implies matrices containing all the relevant characteristics.

Setting - Aggregate demand and supply

Expected market demand for a specific housing type h is:

$$s_h^d(\mathbf{x}, \mathbf{p}, \xi, \theta) = \int f_h(D_i, \mathbf{x}, \mathbf{p}, \xi, \theta) g(D_i) d(D_i)$$

with g denoting the distribution function over the housing demographics.

Let s_h^s denote the aggregate exogenous supply share of house of type h exogenous supply of housing. The equilibrium is defined by:

$$s_h^s = s_h^d(\mathbf{x}, \mathbf{p}, \xi, \theta)$$

The equilibrium condition implies that the sample average choice is equal to the empirically observed share for each housing type.

The data - In a nutshell

1. **Transaction data** : Housing characteristics (price of transaction, time of transaction, structural characteristics...)
2. **Land use data**: Neighborhood characteristics/amenities that may influence the household choice.
3. **Fideli**: household composition and disposable income at a high level of spatial resolution.
4. **EPC dataset**: House energy and GHG labels

Consistency with the structural model: All data needs to be aggregated at the same h-level.

Defining the choice set

Household choose their location from a discrete set of housing alternatives

Location -n-

- Section-level analysis.
- A market is defined as a department.

House size -j-

- Divide by 33 and 66 percentile of mt2 distribution from transaction data
- HH composition may limit the range of homes considered

Time of purchase -t-

- 10 years into 2 periods.
- **A1**: New/old residents arrive/move exogenously and decide to purchase conditional date of arrival/moving.
- **A2**: preferences for observed characteristics are time-invariant.

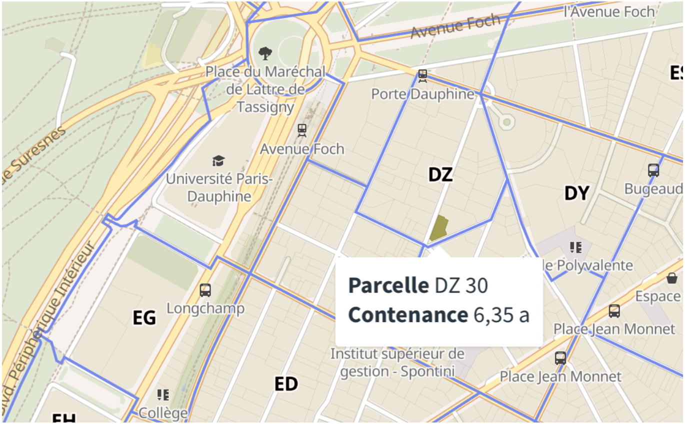
Defining the choice set - contd'

The combination of j, n and t makes the choices available to households, $-h$

Household level information:

- Demographics from Fideli
- Aggregated on the same unit as a neighborhood.
- Able to match at the parcel level
- Date of last mutation
- **Key input:** allows to better match choice set by limiting choices

A section in the "cadastre"



Econometric implementation

Let the indirect utility be re-written as:

$$
\begin{aligned}
V_{ih} &= \Theta_h + \Gamma_h^i + \epsilon_h^i \\
\Theta_h &= X_h \beta_X + N_{jt} \beta_N - \alpha p_h + \xi_h . \\
\Gamma_h^i &= X_h \Sigma_{XD} D_{it} + N_{jt} \Sigma_{ND} D_{it} ,
\end{aligned}
$$

Θ_h: mean preferences for housing units of type h
Γ_h^i : household heterogeneity as idiosyncratic deviations from mean preferences
X_h are observed housing characteristics,
N_{jt} are observed neighborhood characteristics,
ϵ_{ih} idiosyncratic variation.

Econometric implementation

Two-stage step estimation strategy

First step: Follows Berry (1994), uses a nested fixed point algorithm.

1a-step: recovers the fixed effects, Θ_h

1b-step: and recovers heterogeneity parameters Σ_{XD} and Σ_{ND}.

Second step: Uses a minimum distance estimator, similar to Nevo (2000)

recovers mean indirect utilities $(\beta_x, \beta_n, \alpha)$ from Δ_h.

Econometric implementation: First stage estimation

Assuming ϵ_{ih} follows a T1ED, then the probability for household i to choose type h is given by:

$$P_{ih}(\mathbf{X}, \mathbf{N}, D_i, \mathbf{p}_t, \xi; \theta) = \frac{\exp(\Theta_h + \Gamma_h^i)}{1 + \sum_{h' \in \mathcal{H}_i} \exp(\Theta_{h'} + \Gamma_{h'}^i)}.$$

The log-likelihood is

$$ll = \sum_i \sum_h Y_h^i \ln(P_{ih})$$

where Y_h^i equals 1 if an individual chooses a housing type h and 0 otherwise.

Behavior is consistent with a Nash sorting equilibria: location choice is consistent with all other households choice and set of observed market clearing prices

Econometric implementation: Second stage estimation

Second stage estimation decomposes the mean indirect utilities Δ_h into observable and unobservables.

Primary concern: unobserved attributes likely correlated with prices $\longrightarrow$ better locations likely command better prices $\longrightarrow$ need a suitable instrument for prices.

Instrument: Spatial structure of housing market.

- prices are a result of the equilibrating process that depends on housing types attributes from across the market.
- observed attributes of distant neighborhoods in the same market are correlated with local prices.
- unlikely that unobserved attributes are correlated with distant observed attributes.

Econometric implementation: second stage estimation

First, re-arrange mean utilities as:

$$\Theta_h - \alpha p_h = X_h \beta_X + N_{jt} \beta_N + \tilde{\xi}_h$$

Next, guess a plausible value for the price coefficient, α^*, and add additional regressors, $\tilde{N}_{jt}$, to the right hand side based on observed neighborhood characteristics located within 1, 2, 3, 4 and 5 KM.

All residual variation $\Theta_h - \alpha^* p_h$ depends on factors that originate beyond the 5-KM ring. Set $\tilde{\xi}_h = 0$ and solve for price, p_h^{iv}, that satisfies the market clearing condition:

$$s_h^s = \frac{\exp(\tilde{\Theta}_h + \hat{\Gamma}_{ih})}{\sum_{h'} \exp(\tilde{\Theta}_h' + \hat{\Gamma}_{ih'})}$$

where $\tilde{\Theta}_h = \alpha^* p_h^{iv} + \hat{\beta}_x x_h + \hat{\beta}_n \tilde{n}_{jt}$

Results – Mean coefficients – IV's work!

	(1) OLS estimation	(2) IV estimation
Price (in 2019 euros, in 1000's)	0.00277***	-2.822***
	(0.000823)	(0.957)
Rental value	-0.000625	0.404***
	(0.000566)	(0.142)
Living space (in 1000's mts2)	-3.806	1252***
	(2.320)	(410.6)
Neighborhood construction age (less 1km)	0.728*	-10.1
	(0.401)	(9.341)
Neighborhood transaction age (less 1km)	-1.508***	12.56
	(0.401)	(9.462)
Log((# of businesses wihtin 1km)	-0.273***	-2.322
	(0.102)	(2.581)
Log (# of buildings wihtin 1km)	1.237***	-0.894
	(0.125)	(2.481)
Observations	37,453	37,453
Commune FE	YES	YES
Year FE	YES	YES

Notes: This table reports the first set of estimates from the structural demand estimation. 5 Departments are used, and the geographical dimension is the track level. The dependent variable is equal to one when the individual is observed to select the alternative, and zero otherwise. The choice set of each individual consists of 50 alternatives: 1 the choice she selects + 49 random alternatives. The estimates are obtained using a two-step method approach All standard errors are clustered at the commune level. The weak IV test, with a value of 62.98, is the Kleibergen-Paap Wald F-statistic. *** p¡0.01, ** p¡0.05, * p¡0.1.

Results - Heterogeneity in preferences for EPC/GHG

	(1) OLS estimation	(2) IV estimation	Interaction with Log(Disposable income)
EPC class C	-0.728**	7.514	-0.66821***
	(0.306)	(7.873)	(0.194)
EPC class D	-0.511*	-9.401	-0.38618***
	(0.293)	(7.315)	(0.190)
EPC class E	0.0151	-25.76**	-0.31363***
	(0.284)	(10.35)	(0.188)
EPC class F	2.282***	-32.61***	-1.2278***
	(0.303)	(11.67)	(0.195)
EPC class G	1.199***	-35.65***	-0.59774***
	(0.342)	(13.81)	(0.204)
GHG class C	-3.419***	-1.262	0.24632***
	(0.159)	(3.172)	(0.073)
GHG class D	-2.634***	-12.08**	0.75359***
	(0.157)	(5.884)	(0.082)
GHG class E	-0.196	-17.65**	0.074142
	(0.185)	(7.143)	(0.073)
GHG class F	0.144	-21.19**	-0.052911
	(0.156)	(8.308)	(0.091)
GHG class G	-2.044***	-18.09**	0.24085**
	(0.193)	(7.258)	(0.108)
Commune FE	YES	YES	
Year FE	YES	YES	

Notes: The interaction terms are obtained in the first step, while the estimates in column (1) and (2) are obtained in the second step. Although we report just one set of interactions, the all regressions include interactions between demographic variables such as share of 1-person households, share of 5-person households and the disposable income, with garages and rental value variables. All standard errors are clustered at the commune level. The weak IV test, with a value of 62.98, is the Kleibergen-Paap Wald F-statistic. *** p¡0.01, ** p¡0.05, * p¡0.1.

Counterfactual - Phasing-out leads to sell

Under the (strong) assumption that owners of low-performing dwellings that are excluded of the rental market will sell, we evaluate the impact on prices in the sales market.

Our counterfactual evaluates the impact of three scenarios:

- (1) an increase 15% of the housing stock;
- (2) an increase 50% of the housing stock;
- (3) an increase 100% of the housing stock.

Counterfactuals – mechanics

The algorithm is as follows:

Step 1. Calculate s_h^d, the aggregate housing demand for house type h after the policy intervention. For the first iteration, use the observed equilibrium price.

Step 2. For each housing type, compare the aggregate demand, s_h^d, to the exogenously given supply, s_h^s, to determine if excess demand or supply exists.

Step 3. Increase (decrease) prices p_h for housing types with excess demand (supply).

Step 4. Repeat step 1 to 3 until aggregate demand equals supply.

Phasing-out decreases selling prices of F/G dwellings by +1.5%.

VARIABLES	(1) 15% increase	(2) 50% increase	(3) 100% increase
EPC class B	0.00238***	0.00835***	0.0165***
	(0.000396)	(0.00114)	(0.00195)
EPC class C	0.00250***	0.00864***	0.0169***
	(0.000124)	(0.000359)	(0.000614)
EPC class D	0.00262***	0.00910***	0.0179***
	(6.96e-05)	(0.000201)	(0.000343)
EPC class E	0.00283***	0.00993***	0.0196***
	(7.05e-05)	(0.000203)	(0.000348)
EPC class F	-0.0155***	-0.0432***	-0.0715***
	(0.000106)	(0.000306)	(0.000524)
EPC class G	-0.0174***	-0.0485***	-0.0801***
	(0.000189)	(0.000546)	(0.000935)
Observations	37,453	37,453	37,453
R-squared	0.595	0.592	0.590

Notes: Standard errors are in parenthesis. *** p¡0.01, ** p¡0.05, * p¡0.1.

To conclude – still a lot of work!

What do we want with our paper?

- Construct a structural model to the effects of phasing-out low energy efficiency households
- For now, we have that a decrease in prices after ad-hoc increase in # of dwellings. (Caution!)

Next steps

- Supply side: rental's decision to sell vs. upgrade energy efficiency.
- Demand for renting vs. buying:
  - Choice set?: consideration sets
  - Data: rental website (Chapelle et al., 2023).
- EPC : links with unobserved quality, instrument needed.

APPENDIX

Instrumenting for EPC using temperature and precipitation.

	Model 1	Model 2
Average temperature recorded daily for a station, divided by its sd (in °C)	0.0311***	0.0388***
	(0.00951)	(0.00993)
Maximum precipitation recorded daily for a station (in kg*m2)	-0.0156*	-0.0200**
	(0.00876)	(0.00846)
Log Living area (in log-m2)		0.275***
		(0.00766)
North facing bay area (in m2)		-1.70e-05
		(9.88e-05)
East-west facing bay area (in m2)		-0.000300
		(0.000223)
South facing bay area (in m2)		0.00102**
		(0.000475)
Floor area for heat loss (in m2)		-0.000428***
		(9.92e-05)
Surface area of opaque vertical walls (in m2)		-0.000144**
		(6.62e-05)
Constant	0.755***	-0.498***
	(0.0195)	(0.0381)
Observations	63,526	53,015
R-squared	0.210	0.273

Notes: Notes : Data on 5 departments and betwee 2016 and 2018. We are interested in transitions from class E to D and from class F to E of the EPC. The dependent variable equals 1 when the energy consumption is fairly close to the discontinuity threshold between 2 energy classes and when it is below this threshold. Model 1 and Model 2 include only houses. We removed multi-family dwellings from the sample. All regressions include commune FE, date of diagnosis visit FE, diagnostician FE, method of estimation FE, year of construction FE and building type FE. All standard errors are clustered at the commune level. Robust standard errors in parentheses. *** p¡0.01, ** p¡0.05, * p¡0.1

Setting - household utility and choice set

A household chooses a housing type (h) if the utility from that type is at least as large as the utility from any other housing type ($h^{'}$). That is,

$$U_{ih} \geq U_{ih'} \;\; \forall \text{ h} \neq h^{'}$$

A choice of a household depends on her available choices and their characteristics.

- Some houses may afford to purchase and rent
- Others will only be able to rent
- Not all households will compare all alternatives (search costs)

Setting - household utility and choice set

Let the consideration technology, ϕ_{ih}, describe the effectiveness of inclusion of alternative h within a household's choice set.

$$\phi_{ih} = \frac{\exp(\gamma_h + \lambda_{ih})}{1 + \exp(\gamma_h + \lambda_{ih})}$$

γ_h: characteristics increasing likelihood to all households
λ_{ih}: Individual-specific characteristics, capturing budgetary constraints, opportunity costs

Main advantage: models search and financial considerations in a reduced-form. Widely used in the literature.

Household individual demand

The unconditional probability of individual i choosing alternative h, P_{ih}, is given by:

$$P_{ih} = \sum_{s \in S^h} \frac{\exp(V_{ih})}{\sum_{d \in s} \exp(V_{ih_r})} \times \prod_{l \in s} \phi_{il} \prod_{k \notin s} (1 - \phi_{ik})$$

S^h: collection all possible choice sets including alternative h
Choice probability conditional on choice set s
Probability for individual i of having choice set s

Supply: landlords (and owners)

Two-step decision

1. Investment on energy efficiency: High ($\overline{x}_h$) vs. Low ($\underline{x}_h$)
2. Decide whether to rent or to sell

Profits from renting

$$\pi_{lr}(x_h) = r_h * \left(\sum_i P_{ih_{r(x)}} \right) - c_l(x_h)$$

Profits from selling

$$\pi_{lp}(x_h) = p_h * \left(\sum_i P_{ih_{p(x)}} \right) - c_l(x_h)$$

Supply: landlords (and owners)

Let L be the number of landlords, then

$$
\begin{aligned}
N^r_{\overline{x}_h} &= \sum_{l\in L} \mathbb{1}\left(\pi_{lr}(\overline{x}_h) \geq \max(\pi_{lr}(\overline{x}_h), \pi_{lp}(\overline{x}_h), \pi_{lr}(\underline{x}_h), \pi_{lp}(\underline{x}_h))\right) \\
N^p_{\overline{x}_h} &= \sum_{l\in L} \mathbb{1}\left(\pi_{lp}(\overline{x}_h) \geq \max(\pi_{lr}(\overline{x}_h), \pi_{lp}(\overline{x}_h), \pi_{lr}(\underline{x}_h), \pi_{lp}(\underline{x}_h))\right) \\
N^r_{\underline{x}_h} &= \sum_{l\in L} \mathbb{1}\left(\pi_{lr}(\underline{x}_h) \geq \max(\pi_{lr}(\overline{x}_h), \pi_{lp}(\overline{x}_h), \pi_{lr}(\underline{x}_h), \pi_{lp}(\underline{x}_h))\right) \\
N^p_{\underline{x}_h} &= \sum_{l\in L} \mathbb{1}\left(\pi_{lp}(\underline{x}_h) \geq \max(\pi_{lr}(\overline{x}_h), \pi_{lp}(\overline{x}_h), \pi_{lr}(\underline{x}_h), \pi_{lp}(\underline{x}_h))\right) \\
N^s_h &= N^p_{\underline{x}_h} + N^r_{\underline{x}_h} + N^p_{\overline{x}_h} + N^r_{\overline{x}_h}
\end{aligned}
$$

Boosting Sluggish Climate Policy: Endogenous Substitution, Learning, and Energy Efficiency Improvements

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CEC Annual Conference, 11-12 October 2023

CER-ETH
Center of Economic Research
at ETH Zurich

Our paper on two slides

Challenge: Current climate policies are lagging behind necessary action (IPCC 2023) $\Rightarrow$ How to accelerate the low-carbon transition?

Dynamic perspective: We analyze three endogenous, empirically relevant mechanisms that may amplify current policies

- Endogenous substitution elasticity between clean & dirty energy
- Learning effects for renewables (wind and solar)
- Energy efficiency improvements via intentional investments

Our paper on two slides

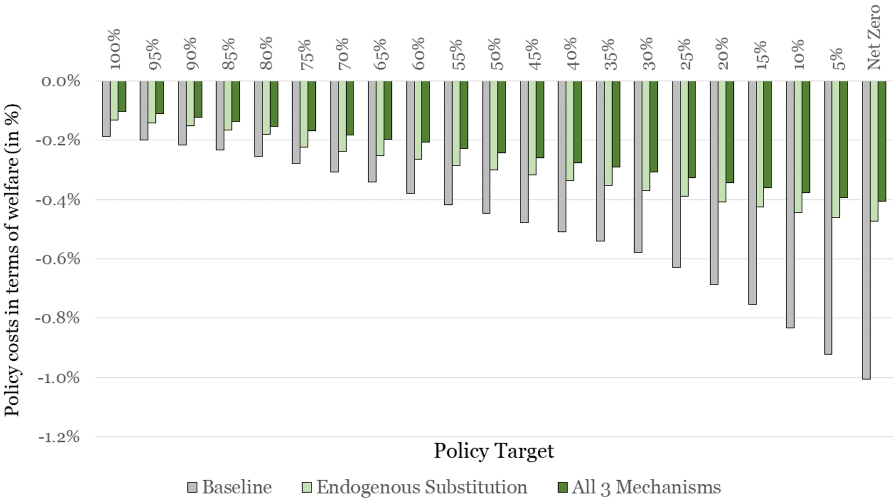
Methodology:

- We use a CGE model with endogeneous growth dynamics (CITE)
- We study the 3 mechanisms on an example of the Swiss economy

Two Key Findings:

- Policy can amplify these endogenous channels, which in turn accelerate the low-carbon transition
- Disregarding these dynamic mechanisms may lead to overestimated economic costs of climate change mitigation

Key Result: Policy costs



Related Literature

Endogenous substitution:

- Constant & exogenous elasticity of substitution is the dominant theoretical approach
- Studies distinguishing between high & low substitution elasticity generate markedly different policy recommendations (e.g. Acemoglu et al. 2012)
- Empirical evidence suggests that elasticity of substitution varies with time and clean energy share (e.g. Papageorgiou et al. 2017 and Jo & Miftakhova 2022)

Learning effects:

- Learning-by-doing in the low-carbon transition (e.g. Kalkuhl et al. 2012 and Mattauch et al. 2015)
- Empirical evidence: Higher learning potential for renewables (as compared to dirty technologies) (e.g. Dechezlepretre et al. 2014 and Rubin et al. 2015)

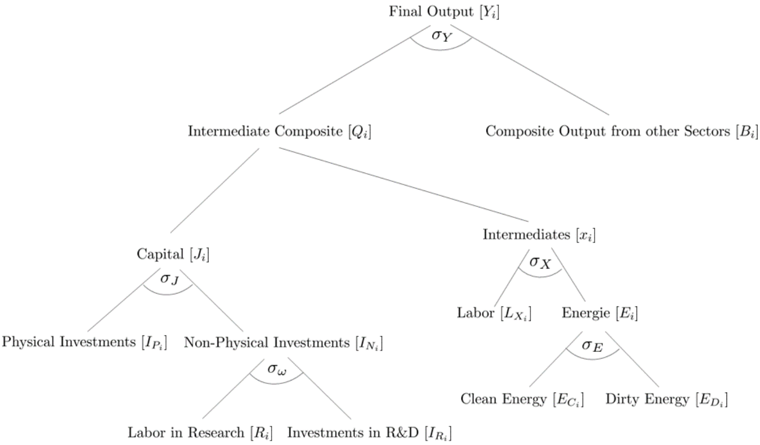
Energy efficiency improvements:

- Induced Innovation (Hicks 1932) & DTC literature (e.g. Acemoglu et al. 2012)
- Empirical evidence suggests that environmental policy spurs innovation in energy efficiency (e.g. Popp 2002 and Bretschger 2015)

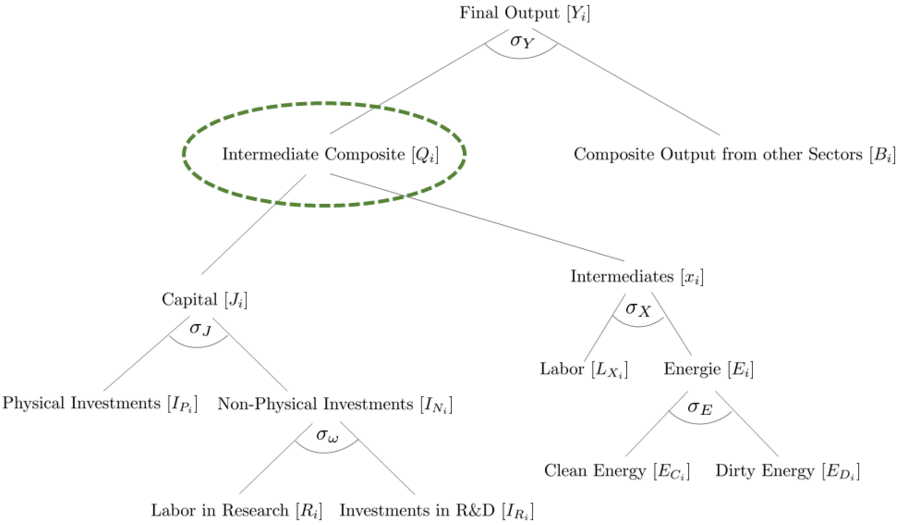
CITE Model

- Top-down, dynamic CGE model (Bretschger et al. 2011)
- Economic growth is endogenized: intentional investments in R&D determine the growth rate of each sector and the economy
- Calibrated to represent the Swiss economy
- Representative infinitely-lived agent maximises CIES utility
- The economy has 18 sectors:
  - 10 non-energy sectors (e.g. industry sectors)
  - 3 fossil energy sectors (e.g. oil)
  - 5 clean energy sectors (e.g. solar)

CITE: Structure



Intermediate Composite



Gains from Specialization

Endogenous growth dynamics based on gains of specialization (Romer 1990) in production of intermediates (Dixit-Stiglitz 1977):

$$Q_i = \left[\int_{j=0}^{J_{i,t}} x_{i,j,t}^{\kappa} dj \right]^{\frac{1}{\kappa}}, \quad \kappa \in (0,1). \tag{1}$$

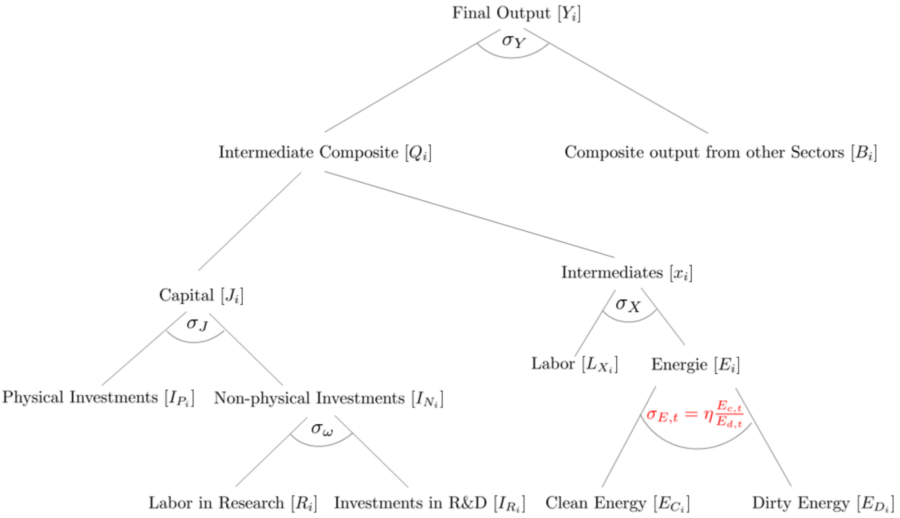
⇒ The sectors are able to grow due to gains of specialization and even without growth of the inputs in production.

Scenarios

Baseline:

- Analysis spans 25 years - from 2025-2050
- Nuclear phase-out by 2035
- NET/CSS technology available starting at 2035
- Carbon tax (according to a carbon target)

Endogenous Substitutability



Feedback mechanisms: Endogenous Substitution

Elasticity of substitution between clean & dirty energy determines the feasibility and ease of energy transition in macroeconomic frameworks

Empirical Evidence: Elasticity of substitution varies with time and clean energy share (Jo & Miftakhova 2022) CES Estimation

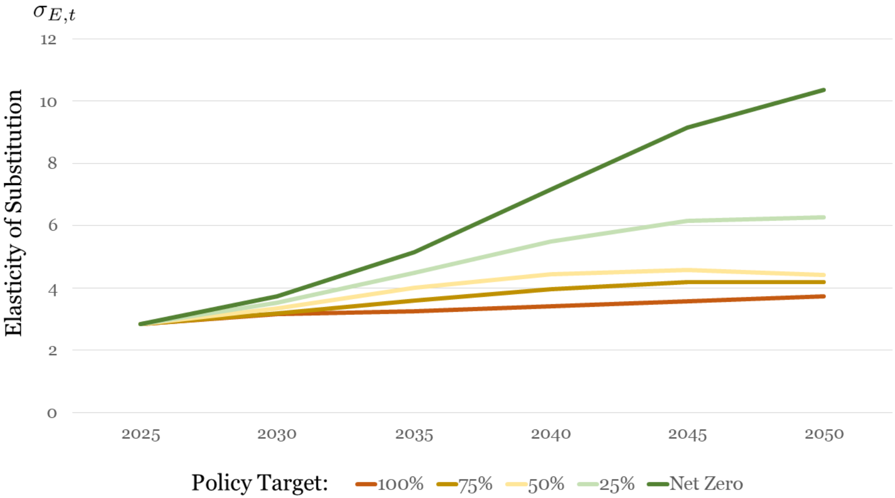
Main Idea: Endogenous elasticity of substitution between clean and dirty energy

$$E_i = \left[\phi_i E_{C,i}^{\frac{\sigma_{E,t}-1}{\sigma_{E,t}}} + (1-\phi_i) E_{D,i}^{\frac{\sigma_{E,t}-1}{\sigma_{E,t}}} \right]^{\frac{\sigma_{E,t}}{\sigma_{E,t}-1}}, \tag{2}$$

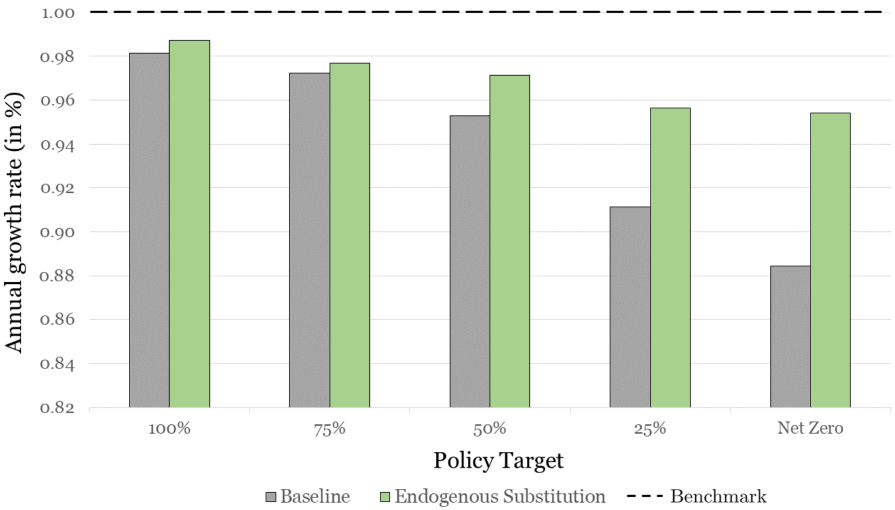
$$\sigma_{E,t} = \eta \frac{E_{C,t}}{E_{D,t}}, \tag{3}$$

where $\eta = 3.076$ is estimated from the data (Jo & Miftakhova 2022).

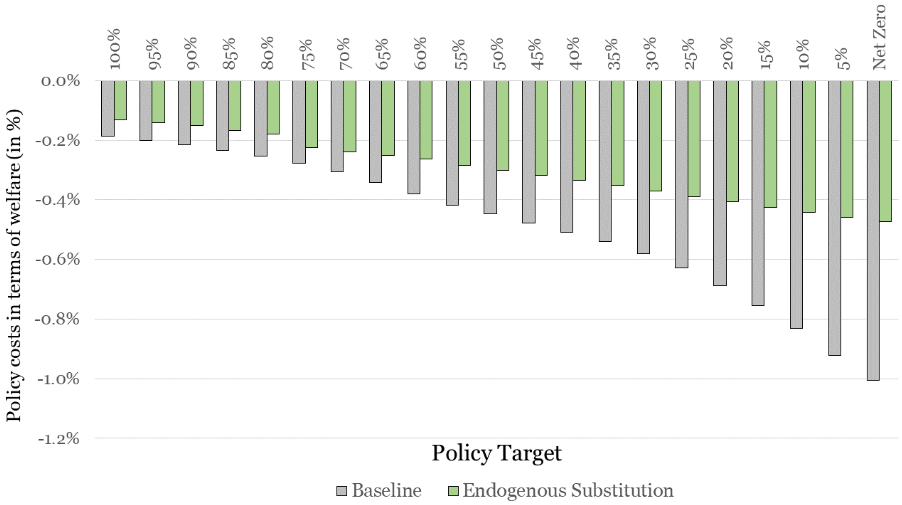
Results: Elasticity of substitution



Results: Economy's annual growth rate



Results: Policy costs



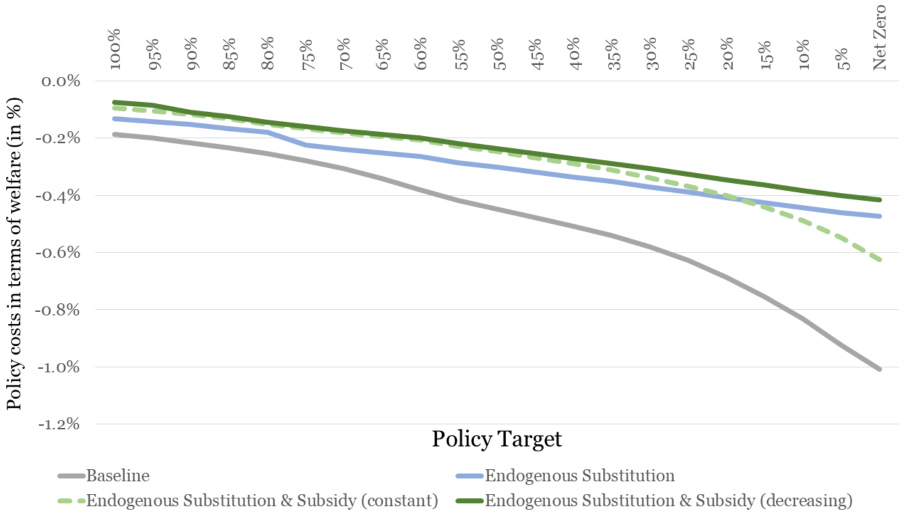
Clean Output Subsidy

⇒ Increasing clean energy share entails positive spillover effects that further facilitates the low-carbon transition

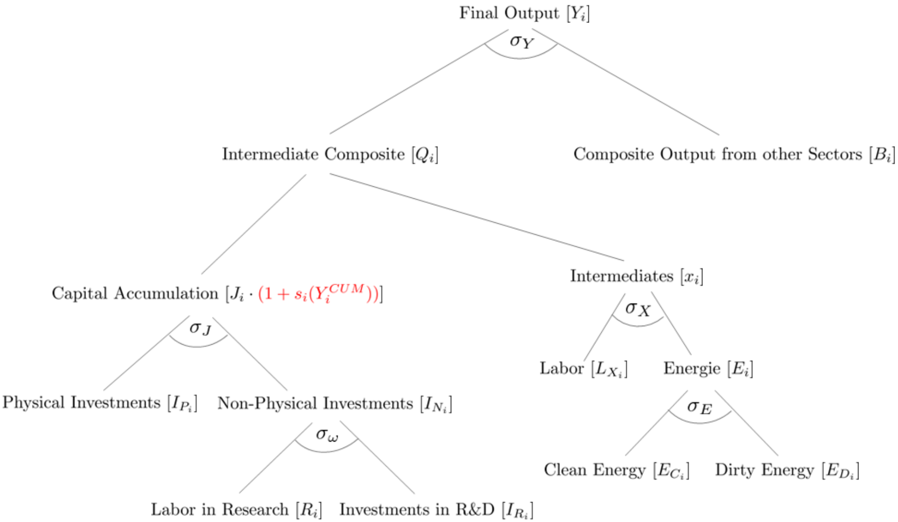
We consider two output subsidy profiles $[(1+\tau_{c,t})E_{c,t}]$:

- Constant subsidy profile: 30% from 2025 to 2050
- Decreasing subsidy profile: From 30% in 2025 to 5% in 2050

Results: Policy costs with subsidy



Learning effect for wind and solar



Feedback Effects: Learning Effects

Empirical Evidence: The costs of renewable technologies decrease with cumulative installed capacity (e.g. Rubin et al. 2015)

Main Idea: Investment efficiency increases endogenously Circle

$$J_{i,t+1} = (1 + s_{i,t}) \left[\gamma_N I_{P,i,t}^{\frac{\sigma_N - 1}{\sigma_N}} + (1 - \gamma_N) I_{N,i,t}^{\frac{\sigma_N - 1}{\sigma_N}} \right]^{\frac{\sigma_N}{\sigma_N - 1}} + (1 - \delta_t) J_{i,t},$$

where the learning factor $s_{i,t}$ depends on excess cumulative output

$$s_{i,t} = \frac{\beta}{1 + \left(\frac{\omega}{x_t} \right)^{\gamma}}, \quad \text{with} \quad x_t = \max \left[0, \frac{Y_{i,t}^{CUM} - \bar{Y}_{i,t}^{CUM}}{\bar{Y}_{i,t}^{CUM}} \right]$$

⇒ Output expansion in the wind and solar sectors entails positive spillover effects that may further accelerate the low-carbon transition

Policy circle

Calibration

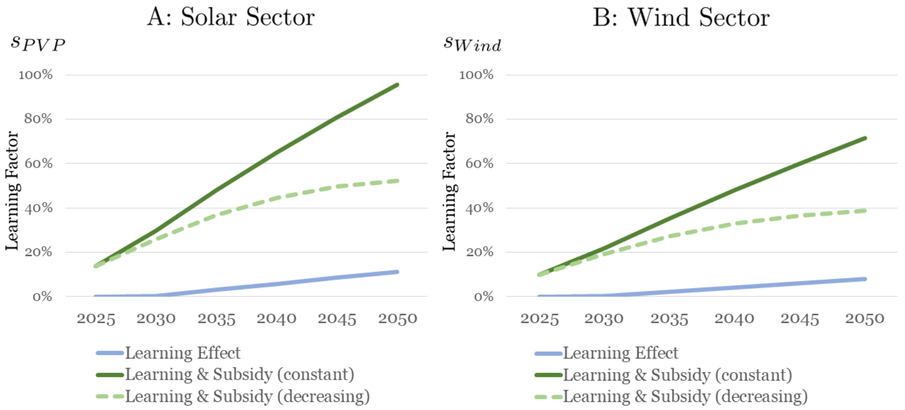
- This function is widely used in energy economic models (e.g. Mattauch et al. 2015; Kahlkuhl et al. 2012; Kverndokk and Rosendahl 2007; Fischer and Newell 2008)

$$s_{i,t} = \frac{\beta}{1 + \left(\frac{\omega}{x_t}\right)^{\gamma}}$$

- Parameters β, ω and γ are based on Mattauch et al. (2015):

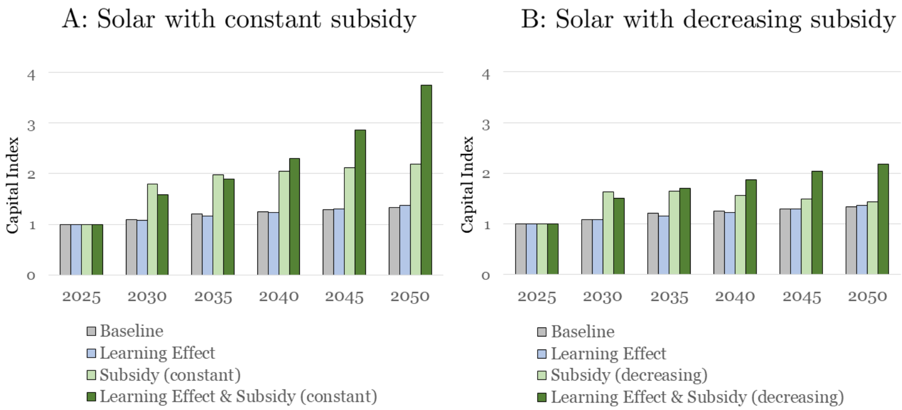
Parameters:	PVP:	Wind:
Maximal productivity β:	9	7
Scaling parameter ω:	250	250
Curvature of learning curve γ:	0.2	0.27

Learning Effect

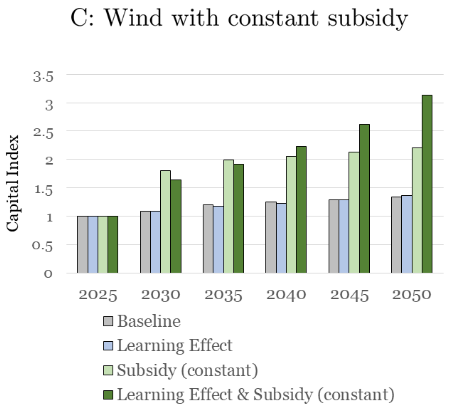


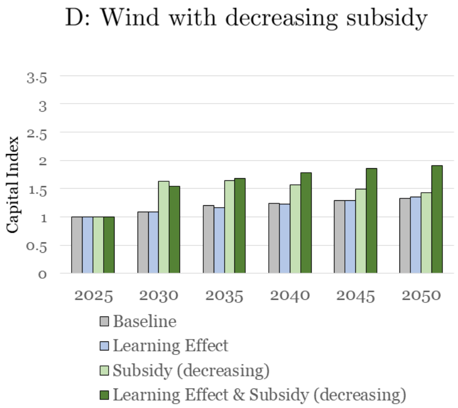
$\Rightarrow$ Key result: Policy can stimulate learning (huge synergy effects)

Capital Index: PVP



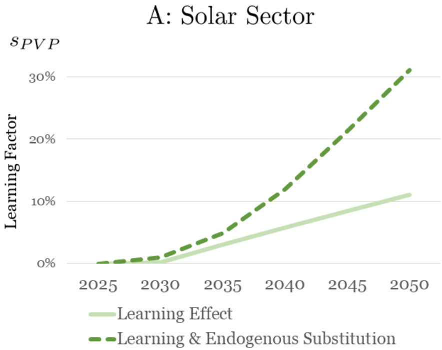
⇒ Key result: Policy stimulates capital accumulation (synergy effects)
— also with decreasing subsidy profile

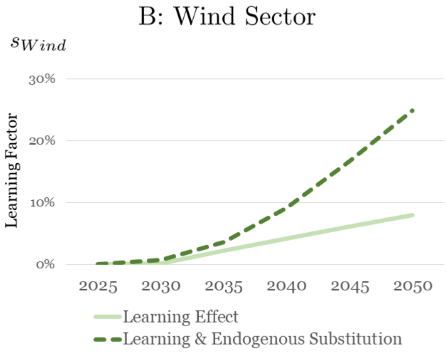




$\Rightarrow$ Key result: Policy stimulates capital accumulation (synergy effects) — also with decreasing subsidy profile

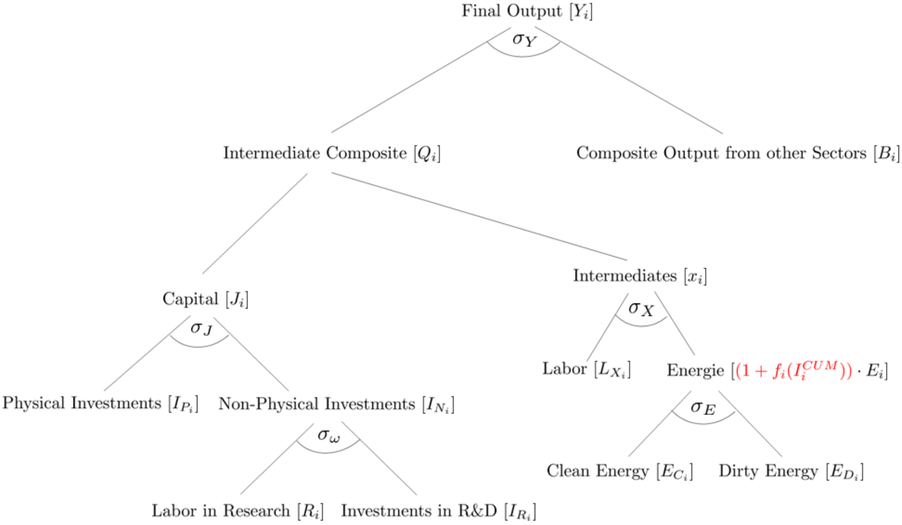
Synergie Effects





→ Key result: Synergy effects between endogenous substitutability and learning

Energy efficiency improvement



Feedback Effects: Energy Efficiency Improvements

Empirical Evidence: Environmental policy spurs innovation in energy efficiency (Jaffe and Palmer 1997; Popp 2002; Bretschger 2015)

Main Idea: Energy efficiency in non-energy sectors increases endogenously with excess sectoral R&D investments:

$$X_{i,t} = \left[\nu_i L_{i,t}^{\frac{\sigma_x - 1}{\sigma_x}} + (1 - \nu_i) \left[\left(1 + f_{i,t}\right) E_{i,t} \right]^{\frac{\sigma_x - 1}{\sigma_x}} \right]^{\frac{\sigma_x}{\sigma_x - 1}}, \tag{4}$$

$$f_{i,t} = \max \left[0, k_i \cdot \frac{I_{i,t}^{CUM} - \bar{I}_{i,t}^{CUM}}{\bar{I}_{i,t}^{CUM}} \right], \tag{5}$$

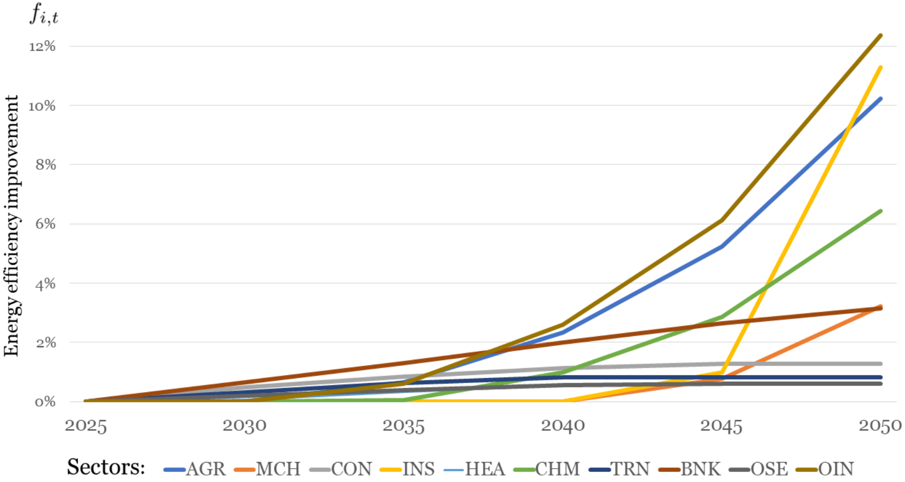
where k_i is a sector-specific parameter for the intensity of energy efficiency improvements

Calibration

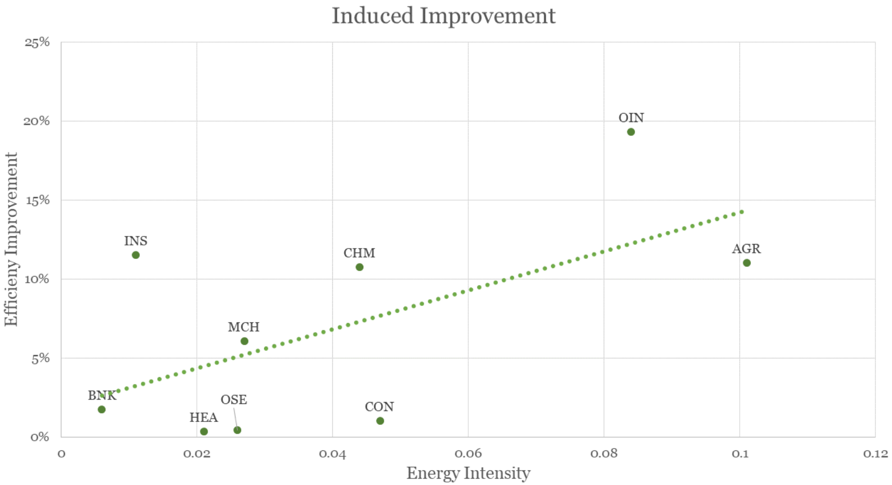
For the parameter k_i, we use the values from Bhadbhade et al. (2020) and Bhadbhade et al. (2021) for the Swiss economy:

Sector:	k_i (p.a.)
Machinery industry (MCH):	1.4%
Chemical industry (CHM):	1.4%
Other industry (OIN):	1.4%
Construction (CON):	1.4%
Agriculture (AGR):	1.7%
Other Services (OSE):	1%
Health (HEA):	2%
Banking & financial services (BNK):	1%
Transport (TRN):	2%
Insurance (INS):	2%

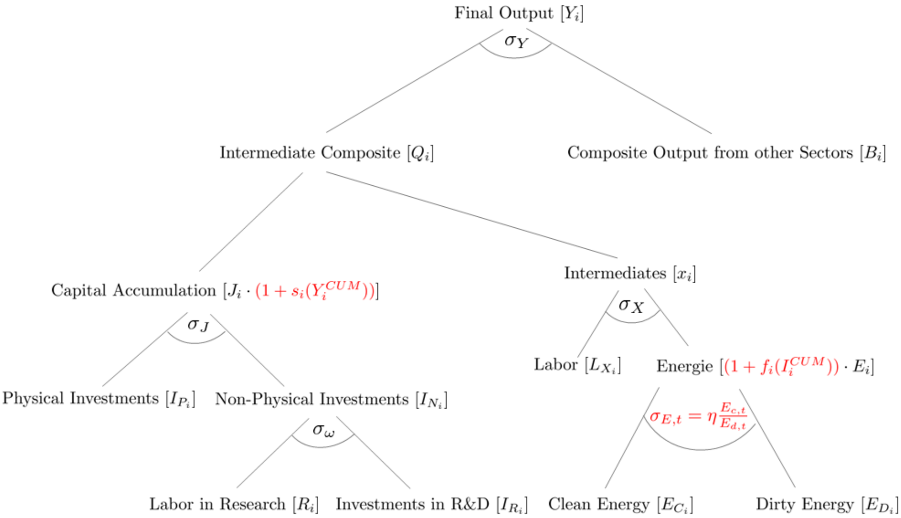
Results


$f_{i,t}$
Energy efficiency improvement
12%
10%
8%
6%
4%
2%
0%
2025
2030
2035
2040
2045
2050
Sectors:
AGR
MCH
CON
INS
HEA
CHM
TRN
BNK
OSE
OIN

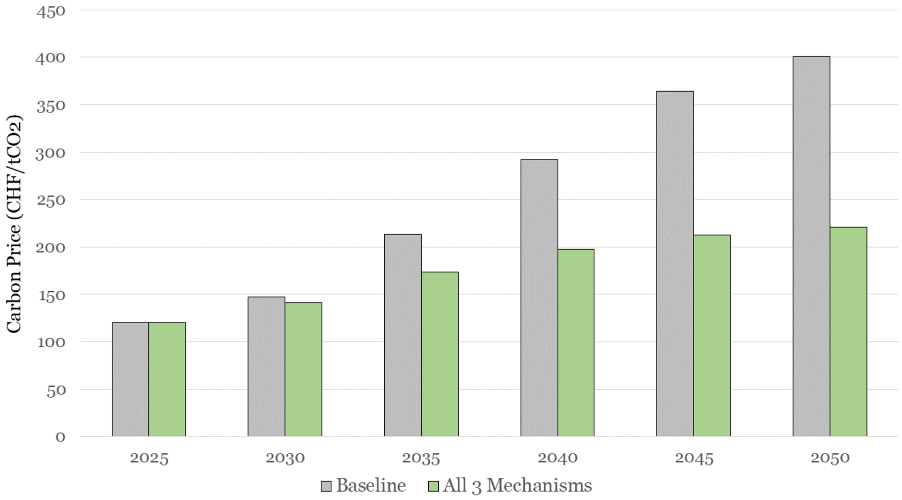
Results


Induced Improvement
25%
20%
15%
10%
5%
0%
Efficieny Improvement
OIN
INS
CHM
AGR
MCH
BNK
OSE
HEA
CON
0
0.02
0.04
0.06
0.08
0.1
0.12
Energy Intensity

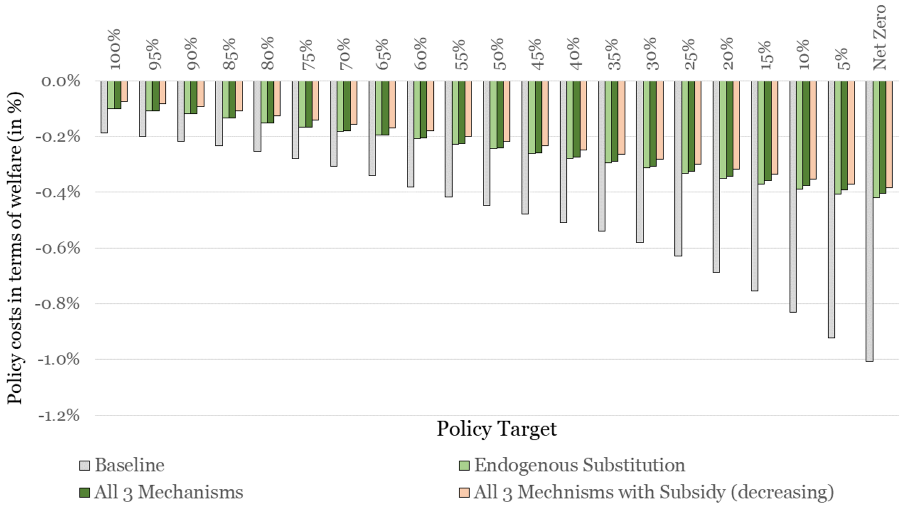
Putting it all together



Putting it all together: Carbon Price



Putting it all together: Policy costs



Conclusion

- We study three empirically relevant feedback channels that evolve endogenously during decarbonization
- Taking these endogenous feedback dynamics into account leads to substantially lower economic costs of climate change mitigation
- Climate policy can amplify or even trigger these feedback effects, thereby boosting the transition to a low carbon economy

Thank you!

CITE Model Structure

Consumption

Representative infinitely-lived agent allocates income between consumption and investment in accordance with intertemporal utility maximization (CIES utility):

$$U = \left[\sum_{t=0}^{\infty} \left(\frac{1}{1+\rho} \right)^t C_t^{1-\theta} \right]^{\frac{1}{1-\theta}} \tag{6}$$

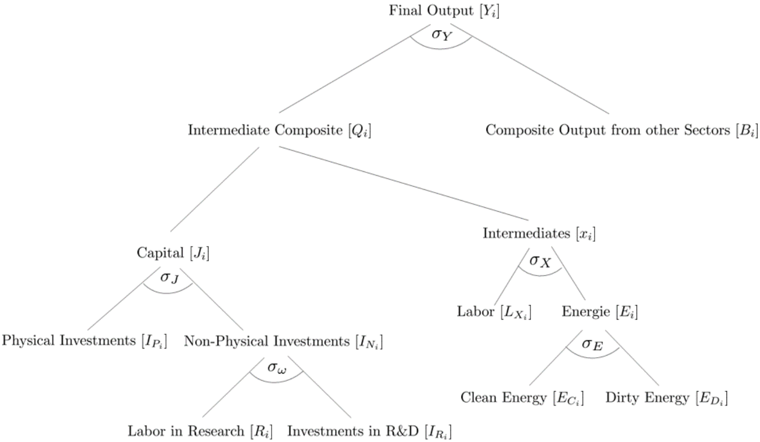
This yields the usual Keynes–Ramsey rule for consumption growth

Consumption C includes a final good composite D and (directly consumed) energy E:

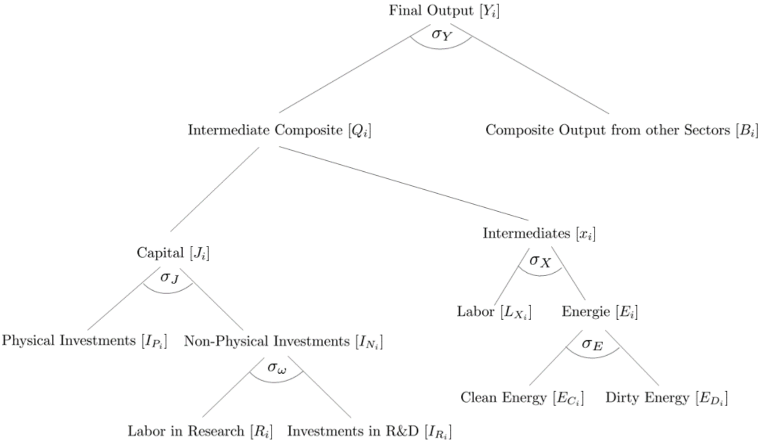
$$C = \left[(1-\zeta) D^{\frac{\psi-1}{\psi}} + \zeta E^{\frac{\psi-1}{\psi}} \right]^{\frac{\psi}{\psi-1}} \tag{7}$$

The final good composite D includes the output of the regular sectors

CITE: Structure

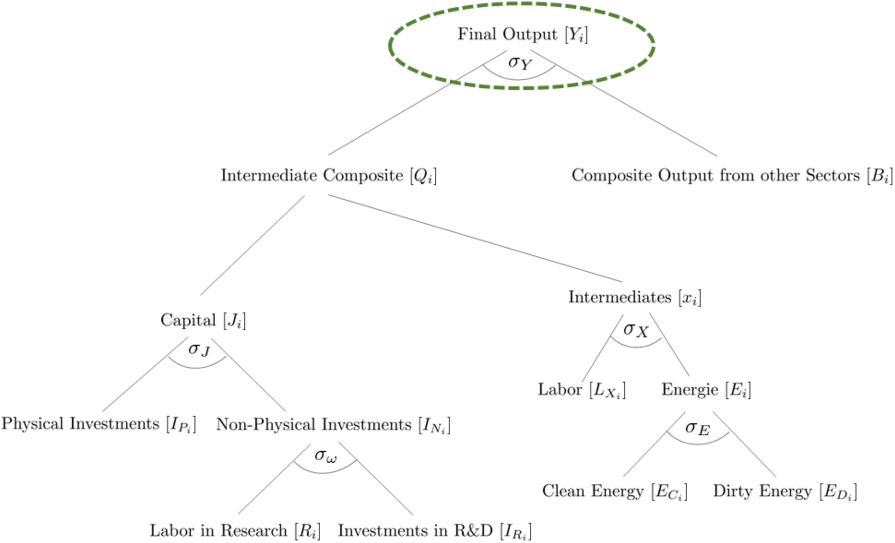


CITE: Structure



Each sector can grow 1) by devoting more resources (labor & clean energy) to production of intermediates x_i or 2) by expanding the number of intermediates, J_i, via intentional investment

Final Output



Final Output

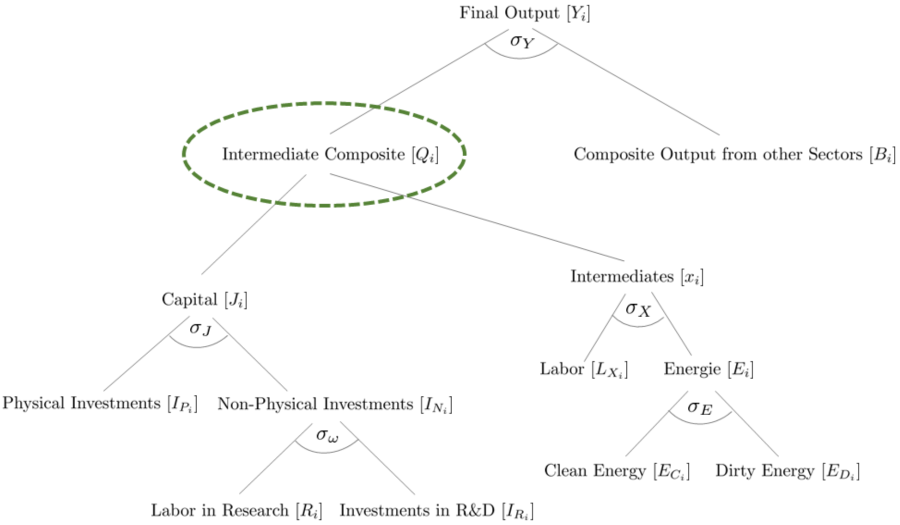
At the top level, final good Y_i is produced with a CES production function (under perfect competition):

$$Y_i = \left[\alpha_i Q_i^{\frac{\sigma_Y - 1}{\sigma_Y}} + (1 - \alpha_i) B_i^{\frac{\sigma_Y - 1}{\sigma_Y}} \right]^{\frac{\sigma_Y}{\sigma_Y - 1}} \tag{8}$$

- B_i: input from all other non-energy sectors
- Q_i: sector-specific intermediate composite
- α_i: sector-specific share parameter
- σ_Y: sector-specific (constant) elasticity of substitution

B_i (output from the other sectors) contains the underlying input–output structure of the economy, i.e. the intersectoral linkages

Intermediate Composite



Intermediate Composite

Intermediates are aggregated into sector-specific composite Q_i via Dixit-Stiglitz (1977) production function (perfect competition):

$$Q_i = \left[\int_{j=0}^{J_i} x_{ij}^{\kappa} dj \right]^{\frac{1}{\kappa}} \tag{9}$$

- $\kappa \in (0, 1)$: measure of substitutability between intermediate goods

Intermediate Composite

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- $\kappa \in (0,1)$: measure of substitutability between intermediate goods

The number of varieties in each sector J_i is determined by its level of capital which is accumulated from investments:

$$J_{i,t+1} = \left[\gamma_i I_{P,i,t}^{\frac{\sigma_J - 1}{\sigma_J}} + (1-\gamma_i) I_{N,i,t}^{\frac{\sigma_J - 1}{\sigma_J}} \right]^{\frac{\sigma_J}{\sigma_J - 1}} + (1-\delta) J_{i,t} \tag{10}$$

- I_P: Physical investment (e.g. machinery)
- I_N: Non-physical investment (e.g. patents or blueprints)
- δ: Capital depreciation rate

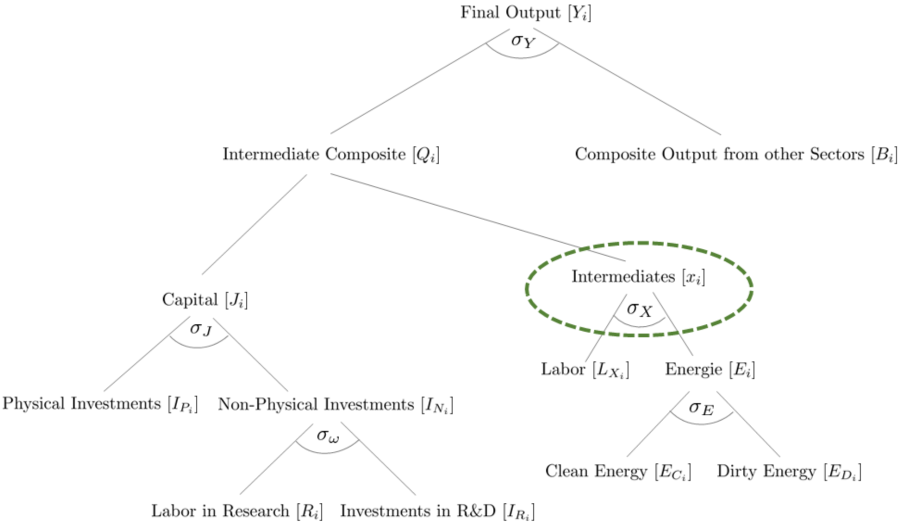
Research Nesting

Non-physical investments (I_N) are effectuated by labor in research R_i, and non-labor inputs in R&D, I_{R_i}:

$$I_{N,i} = \left[\beta_i R_i^{\frac{\sigma_\omega - 1}{\sigma_\omega}} + (1 - \beta_i) I_{R,i}^{\frac{\sigma_\omega - 1}{\sigma_\omega}} \right]^{\frac{\sigma_\omega}{\sigma_\omega - 1}} \tag{11}$$

with β_i denoting the share parameter and σ_ω representing the elasticity of substitution between R_i and $I_{R,i}$.

Production of Intermediate Varieties



Production of Intermediate Varieties

At bottom level, intermediate goods $x_{i,j}$ are produced by monopolistic firms using labor L_i and energy E_i as inputs:

$$x_{i,j} = \left[\nu_i L_i^{\frac{\sigma_x - 1}{\sigma_x}} + (1 - \nu_i) E_i^{\frac{\sigma_x - 1}{\sigma_x}} \right]^{\frac{\sigma_x}{\sigma_x - 1}} . \tag{12}$$

Production of Intermediate Varieties

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$$x_{i,j} = \left[\nu_i L_i^{\frac{\sigma_x - 1}{\sigma_x}} + (1 - \nu_i) E_i^{\frac{\sigma_x - 1}{\sigma_x}} \right]^{\frac{\sigma_x}{\sigma_x - 1}} . \tag{12}$$

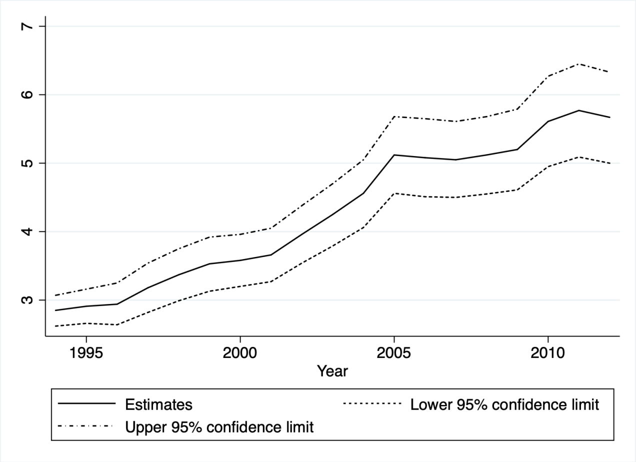
The energy aggregate required for intermediates' production is made out of clean (E_C) and fossil (E_D) energy:

$$E_i = \left[\phi_i E_{C,i}^{\frac{\sigma_E - 1}{\sigma_E}} + (1 - \phi_i) E_{D,i}^{\frac{\sigma_E - 1}{\sigma_E}} \right]^{\frac{\sigma_E}{\sigma_E - 1}} . \tag{13}$$

⇒ Important Parameter: σ_E denotes the elasticity of substitution between clean & dirty energy

Feedback Channels: Dynamic Substitutability

Dynamic Substitutability: Empirical Evidence



Elasticity of Substitution is dynamic and increases as the share of clean energy rises (Jo and Miftakhova 2022) back

Dynamic Substitutability I

- **Energy transition** from fossil fuels to renewables is a key component of a successful policy to halt global warming.
- The **degree of substitutability** between clean and dirty energy determines the potential speed and scope for the transition.
- The substitutability **may change over time** as technology and infrastructure for the use of renewables advances.
- Macroeconomic models that inform policy-making assume the substitutability between clean and dirty inputs to be **constant**.

We challenge the assumption of the constant substitution elasticity between clean and dirty inputs by

- ➢ empirically motivating its endogenous nature and,
- ➢ numerically examining the implications for climate policy.

Dynamic Substitutability II

Estimation of elasticity

- difficult to identify due to implicit connection with technical change (Diamond et al. 1978)
- several strategies for estimation in the literature (Papageorgiou et al. 2017; Baccianti 2019 and Jo 2020)

Limitation of the conventional CES form

- CES adopted mostly for practical convenience (Turnovsky 2008)
- limited in capturing large-scale energy transitions (Carrara and Marangoni 2017; Kaya et al. 2017)
- studies that distinguish between high and low elasticity of substitution generate markedly different policy recommendations (Acemoglu et al. 2012; Golosov et al. 2014; Van den Bijgaart, 2017; Greaker et al. 2018; Hart 2019)
- increasing profile for substitutability resembles its constant-high-value scenario (Mattauch et al. 2015)

The role of σ in numerical analysis

- Numerical studies on environmental policies treat this parameter as **exogenous and constant** over time and thus overlook its potential positive feedback mechanism.
- Taking this **dynamics** into account could substantially impact the outcome for the policies by **further facilitating** the transition to clean energy.

$\Rrightarrow$ To quantify this impact, we implement an **endogenous** elasticity of substitution between clean and dirty inputs in a dynamic computable general equilibrium model of endogenous growth.

Feedback Channels: Learning Effect

Gains from specialization

Capital accumulation

Higher productivity of inputs

Higher output level

$$J_{i,t+1} = \left[\gamma_i I_{P,i,t}^{\frac{\sigma_J-1}{\sigma_J}} + (1-\gamma_i) I_{N,i,t}^{\frac{\sigma_J-1}{\sigma_J}}\right]^{\frac{\sigma_J}{\sigma_J-1}} + (1-\delta) J_{i,t}$$

$$Q_i = \left[\int_{j=0}^{J_{i,t}} x_{i,j,t}^{\kappa}\right]^{\frac{1}{\kappa}} = J_{i,t}^{\frac{1-\kappa}{\kappa}} X_{i,t}$$

$$Y_{i,t} = \left[\alpha_i Q_{i,t}^{\frac{\sigma_Y-1}{\sigma_Y}} + (1-\alpha_i) B_{i,t}^{\frac{\sigma_Y-1}{\sigma_Y}}\right]^{\frac{\sigma_Y}{\sigma_Y-1}}$$

Higher output level

For solar and wind: higher investment efficiency

(Enhanced) Capital accumulation

$$Y_{i,t} = \left[\alpha_i Q_{i,t}^{\frac{\sigma_Y-1}{\sigma_Y}} + (1-\alpha_i) B_{i,t}^{\frac{\sigma_Y-1}{\sigma_Y}}\right]^{\frac{\sigma_Y}{\sigma_Y-1}}$$

$$s_{i,t} = \frac{\beta}{1+\left(\frac{\omega}{x_t}\right)^{\gamma}}, \quad \text{and}$$

$$x_t = \max\left[0, \frac{Y_{i,t}^{CUM} - \bar{Y}_{i,t}^{CUM}}{\bar{Y}_{i,t}^{CUM}}\right]$$

$$J_{i,t+1} = (1 + s_{i,t}) \left[\gamma_i I_{P,i,t}^{\frac{\sigma_J-1}{\sigma_J}} + (1-\gamma_i) I_{N,i,t}^{\frac{\sigma_J-1}{\sigma_J}}\right]^{\frac{\sigma_J}{\sigma_J-1}} + (1-\delta) J_{i,t}$$

Learning effects

back

Clean Output Subsidy

Gains from specialization

Capital accumulation → Higher productivity of inputs → Higher output level

$$J_{i,t+1} = \left[\gamma_i I_{P,i,t}^{\frac{\sigma_J - 1}{\sigma_J}} + (1-\gamma_i) I_{N,i,t}^{\frac{\sigma_J - 1}{\sigma_J}}\right]^{\frac{\sigma_J}{\sigma_J - 1}} + (1-\delta) J_{i,t}$$

$$Q_i = \left[\int_{j=0}^{J_{i,t}} x_{i,j,t}^{\kappa}\right]^{\frac{1}{\kappa}} = J_{i,t}^{\frac{1-\kappa}{\kappa}} X_{i,t}$$

$$Y_{i,t} = \left[\alpha_i Q_{i,t}^{\frac{\sigma_Y - 1}{\sigma_Y}} + (1-\alpha_i) B_{i,t}^{\frac{\sigma_Y - 1}{\sigma_Y}}\right]^{\frac{\sigma_Y}{\sigma_Y - 1}}$$

(Enhanced) Capital accumulation ← For solar and wind: higher investment efficiency ← Higher output level

$$J_{i,t+1} = (1 + s_{i,t}) \left[\gamma_i I_{P,i,t}^{\frac{\sigma_J - 1}{\sigma_J}} + (1-\gamma_i) I_{N,i,t}^{\frac{\sigma_J - 1}{\sigma_J}}\right]^{\frac{\sigma_J}{\sigma_J - 1}} + (1-\delta) J_{i,t}$$

$$s_{i,t} = \frac{\beta}{1+\left(\frac{\omega}{x_t}\right)^{\gamma}}, \quad \text{and}$$

$$Y_{i,t}(1+\tau_{c,i}) = \left[\alpha_i Q_{i,t}^{\frac{\sigma_Y - 1}{\sigma_Y}} + (1-\alpha_i) B_{i,t}^{\frac{\sigma_Y - 1}{\sigma_Y}}\right]^{\frac{\sigma_Y}{\sigma_Y - 1}}$$

$$x_t = \max\left[0, \frac{Y_{i,t}^{CUM}(1+\tau_{c,i}) - \bar{Y}_{i,t}^{CUM}}{\bar{Y}_{i,t}^{CUM}}\right]$$

Learning effects

back

Feedback Channels: Energy Efficiency Improvements

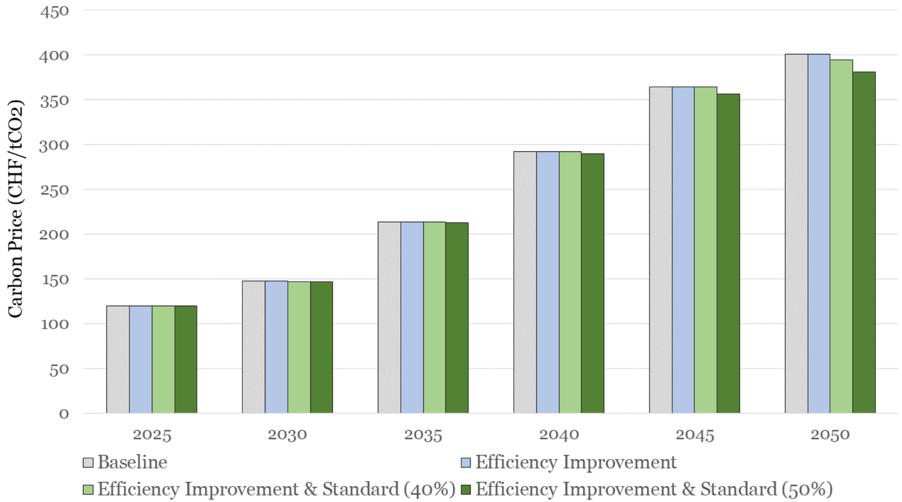
Efficiency Standards

⇒ Investments thus entail positive spillover effects that may further accelerate the low-carbon transition

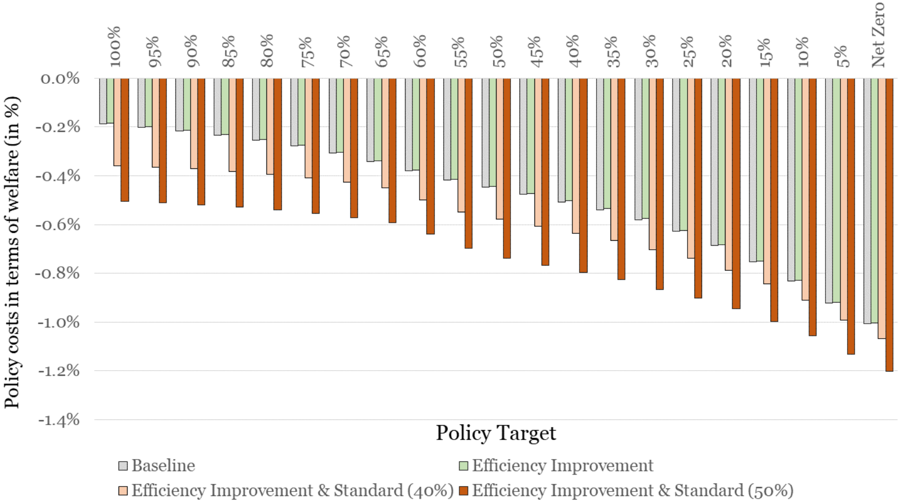
Efficiency standard: 40%-50% reduction in energy consumption by 2050 in

- Transportation sector
- Construction sector

Results: Carbon price



Results: Policy costs



The EU Fit-for-55 climate action: a distributive analysis for Italy

CEC Annual Conference 2023

Presenter: Benedetta Mina
Co-authors: Valeria Costantini, Chiara Martini, Mariangela Zoli

Dauphine-PSL University

October 11, 2023

Motivation

- The **Fit-for-55 package** is a set of proposals to revise and update EU climate legislation to ensure that EU policies are in line with climate goals: **55%** CO2 emission reduction in 2030 w.r.t. 1990.
  - Reform of the EU ETS
  - Revision of the Energy Taxation Directive
  - *Potential impact on commodity prices in all sectors*
- Concerns on regressivity of climate policies (Mirlees, A. 2011):
  - Consumption shares
  - Substitution possibilities

Aim of our work

- Evaluate the distributive impact of price changes due to climate policies with a specific focus on Italy
- Price changes are simulated with a recursive-dynamic CGE model and are coherent with EU climate targets

1. we consider policy-driven changes in relative prices for the whole consumption structure
2. by estimating a demand system, we can capture both channels through which price changes may affect households of different income levels
3. we provide a monetary quantification of the welfare losses caused by climate policies and find that the revenue generated by the same policies is sufficient to compensate households

Literature

The empirical literature yields ambiguous results.

- Ohlendorf et al. 2021 (ERE), meta-analysis, overall regressivity.
- High-income countries:
  1. regressive direct effects (Pashardes, Pashourtidou, and Zachariadis 2014 EE, Tovar Reaños and Wölfing 2018 EE),
  2. progressive indirect effects (Labandeira, Labeaga, and Rodríguez 2009 EP).
- Italy: AIDS (Tiezzi 2005 EP), QUAIDS progressive direct effects (Martini 2009).

Methodology

Two steps:

1. We rely on results from a computable general equilibrium model (GDynEP) to simulate the effects on commodity prices of 3 policy scenarios:
   1.1 (P1: FF) the complete phase-out of fossil fuel subsidies + reinvestment of 50% of revenues in clean energy technologies (not compliant with EU2030 targets)
   1.2 (P2: CT) carbon pricing + reinvestment of 50% of revenues in clean energy technologies (62.35\$/tonCO2)
   1.3 (P3: FF+CT) simultaneous implementation of fossil fuels removal, carbon price and reinvestment of revenues (50.88\$/tonCO2).

   - price variations for final commodities in P1:FF are moderate (0.05 p.p. - 5.25 p.p.)
   - In P2:CT and P3:FF+CT scenarios most price indices increase: private transport and heating-related sectors are the most severely hit (15p.p.-80p.p.).

QUAIDS

2. Estimation of the Quadratic Almost Ideal Demand System (QUAIDS) of demand equations for 10 composite good classes (Banks, Blundell, and Lewbel 1997):

$$w_i = \alpha_i + \sum_{j=1}^{K} \gamma_{ij} \ln p_j + \beta_i \ln \left[\frac{m}{a(\mathbf{p})} \right] + \frac{\lambda_i}{b(\mathbf{p})} \left\{ \ln \left[\frac{m}{a(\mathbf{p})} \right] \right\}^2 \qquad (1)$$

$$\forall \quad i, j = 1...K$$

To account for observations with zero expenditure in the dependent variable we estimate the censored QUAIDS (Shonkwiler and Yen 1999's two-step procedure):

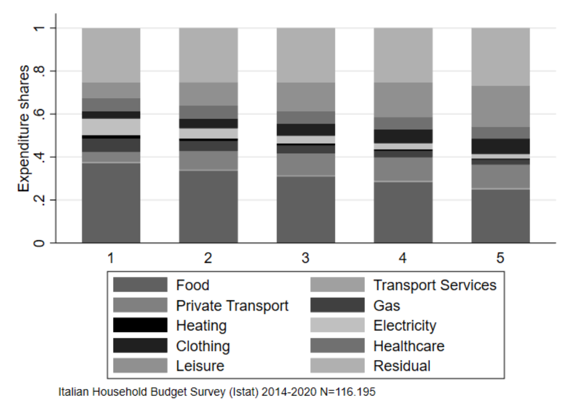
1. Estimation of the probability of having non-negative expenditures by a univariate probit for each composite good
2. The unconditional expected value of the expenditure share is obtained through the probit cumulative and density distribution functions.

Data

Italian Household Budget Survey (ISTAT) 2014-2020, N= 116.195

→ Go to CPI

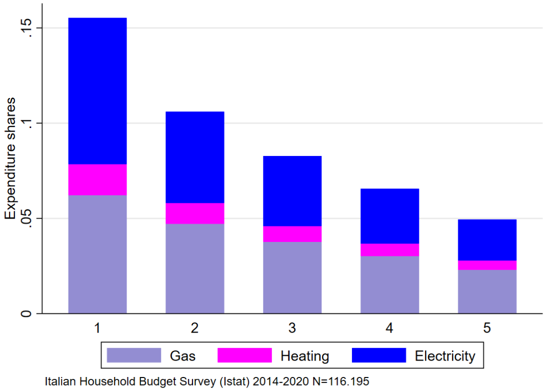
Figure: **Shares by total expenditure quintile**



Data

Italian Household Budget Survey (ISTAT) 2014-2020, N= 116.195

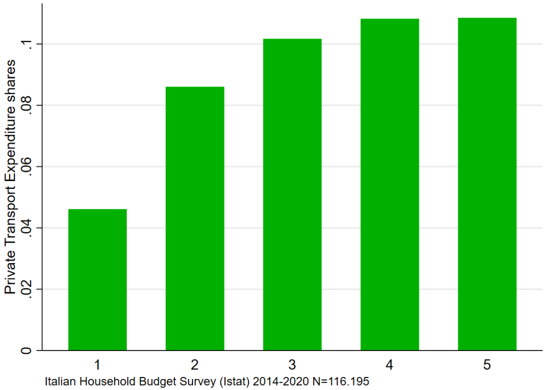
Figure: **Domestic energy shares by total expenditure quintile**



Data

Italian Household Budget Survey (ISTAT) 2014-2020, N= 116.195

Figure: **Private transport shares by total expenditure quintile**



Elasticities

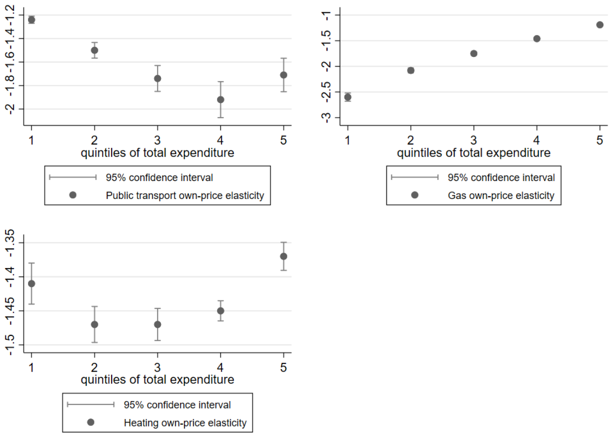
Table: **Own-price elasticities (e_{ii}) and expenditure elasticities (e_i)**

→ Go to Goodness of Fit

	e_{ii}	e_i
Food	-0.34	0.72
Public transport	-1.72	-0.17
Private transport	-0.60	1.58
Gas	-1.84	1.08
Other heating fuels	-1.50	0.62
Electricity	-1.27	0.26
Clothing	-1.63	1.20
Healthcare	-0.86	1.20
Leisure	-0.48	1.43
Residual	-0.53	0.97

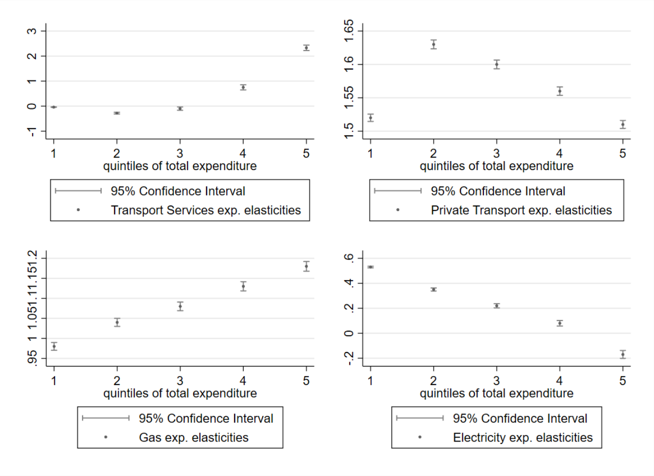
Elasticities by quintile

Figure: **Price elasticities by quintile**



Elasticities by quintile

Figure: **Expenditure elasticities by quintile**



Welfare measures

The welfare measure is the compensating variation (CV):

$$CV(\mathbf{p}^s) = m(u^0, \mathbf{p}^s) - m(u^0, \mathbf{p}^0) \tag{2}$$

where $m(u, \mathbf{p})$ is the cost function evaluated at different price vectors.
We simulate Eq. 2 with 3 different price vectors corresponding to the 3 different policy scenarios ($\mathbf{p}^s$, $s = 1, 2, 3$).
The burden of taxation is finally derived as:

$$\frac{B_i}{Y_i} = \frac{CV_i(\mathbf{p}^{BAU}) - CV_i(\mathbf{p}^s)}{Y_i} \tag{3}$$

Price variations

Table: **Price Variations from GTAP (pp)**

→ Go to aggregation details

	FF	CT	FF+CT
Food	0.05	0.13	0.06
Public transport	-1.20	1.75	2.35
Private transport	1.98	7.18	12.51
Gas	3.64	15.74	16.23
Heating	5.25	95.61	81.26
Electricity	-0.79	3.63	3.63
Clothing	0.18	-0.23	-0.35
Healthcare	0.08	-0.16	-0.20
Leisure	0.21	-0.27	-0.40
Residual	0.19	-0.26	-0.37

Overall welfare effects

Table: **Welfare losses**

	Policy 1		Policy 2		Policy 3	
q	$-CV(\mathbf{p}^1)$	$\frac{B_i}{Y_i}(\%)$	$-CV(\mathbf{p}^2)$	$\frac{B_i}{Y_i}(\%)$	$-CV(\mathbf{p}^3)$	$\frac{B_i}{Y_i}(\%)$
1	-9.85^{**}	-0.39	-17.16^{**}	-1.90	-18.42^{**}	-2.11
2	-19.75^{**}	-0.46	-32.00^{**}	-1.75	-35.87^{**}	-2.16
3	-29.07^{**}	-0.53	-48.87^{**}	-1.98	-55.87^{**}	-2.49
4	-40.82^{**}	-0.60	-73.70^{**}	-2.34	-85.36^{**}	-2.95
5	-60.65^{**}	-0.71	-127.35^{**}	-2.99	-148.76^{**}	-3.73
S	0.106**		0.128**		0.131**	
K	0.094**		0.107**		0.113**	

** 95% CI

Direct price effects

Table: **Kakwani Indices**

Scenarios	**Policy 1**	**Policy 2**	**Policy 3**
Overall	0.094**	0.107**	0.113**
Domestic energy	0.108**	0.093**	0.090**
Energy + Food (Direct)	0.097**	0.089**	0.088**
Indirect	0.092**	0.131**	0.129**

** 95% CI

Figure: **Progressivity Curves**

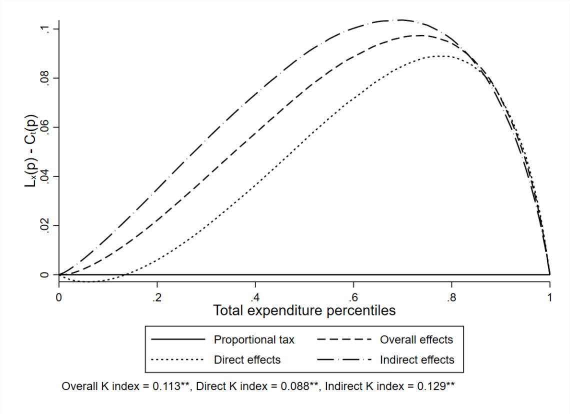


Figure: **Substitution effects**

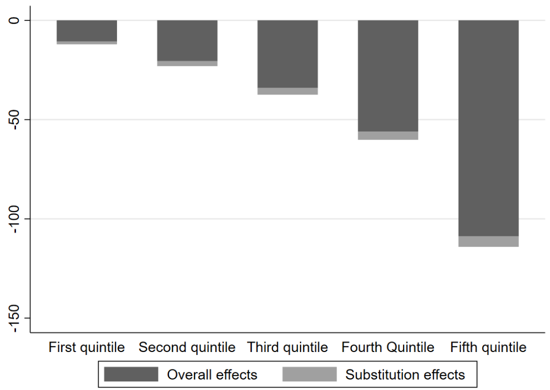
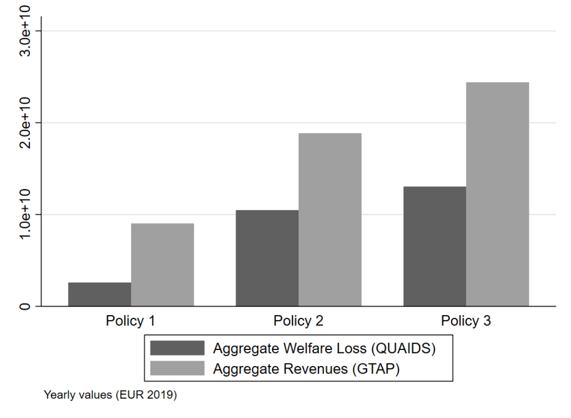


Figure: **Household compensations**



Conclusions

1. We provide an evaluation of the effects of climate policies coherent with the Fit-for-55 objectives in Italy;

2. We account for both direct and indirect price changes induced by climate policies;

3. By estimating a demand system we account also for substitution possibilities across consumption goods categories;

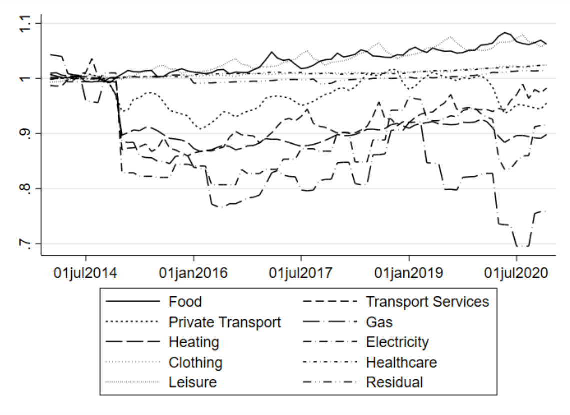
4. We find that all policy scenarios imply a welfare loss, that is mildly progressively distributed across the expenditure distribution;

5. We estimate the monetary value of annual households' compensations (10-13bn euro) and we show that they are always lower than the revenue directly or indirectly generated by climate policies.

Thank you

Prices (1/2)

CPI Italy 2014-2020 (Istat, January 2014=100)



Goodness-of-fit

Table: **Model specifications**

	Model 0	Model 1	Model 2	Model 3
Household size	No	Yes	Yes	Yes
Area of residence	No	No	Yes	Yes
Age of household head	No	No	No	Yes
Log-likelihood	2517370.8	2509325.9	2505247.7	2464677.8

Go back to slide

GTAP-QUAIDS aggregation

QUAIDS	N. GTAP sector	Description GTAP sector
Public transport	32	Road and railway transport
	34	Water transport
Private Transport	31	Oil products
Gas	28	Natural gas and LNG
Other heating fuels	26	Coal
	27	Oil crude
Electricity	29	Electricity from fossil fuels
	30	Electricity from renewables

Go back to slide