Geography versus Income: The Heterogeneous Effects of Carbon Taxation

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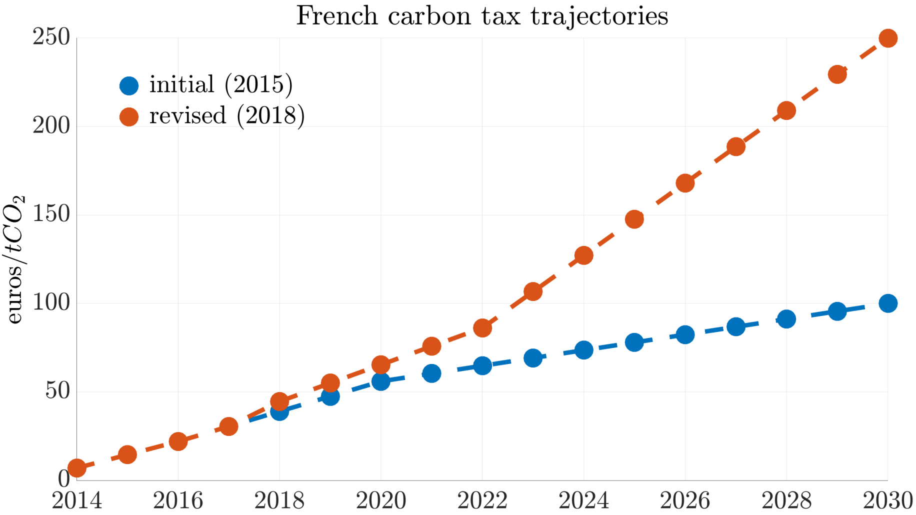
What we do

- We build a model to deal with fiscal policies related to energy
- Allows to assess both aggregate and distributive effects
- In this paper, we focus on carbon taxation

Motivation: social acceptability



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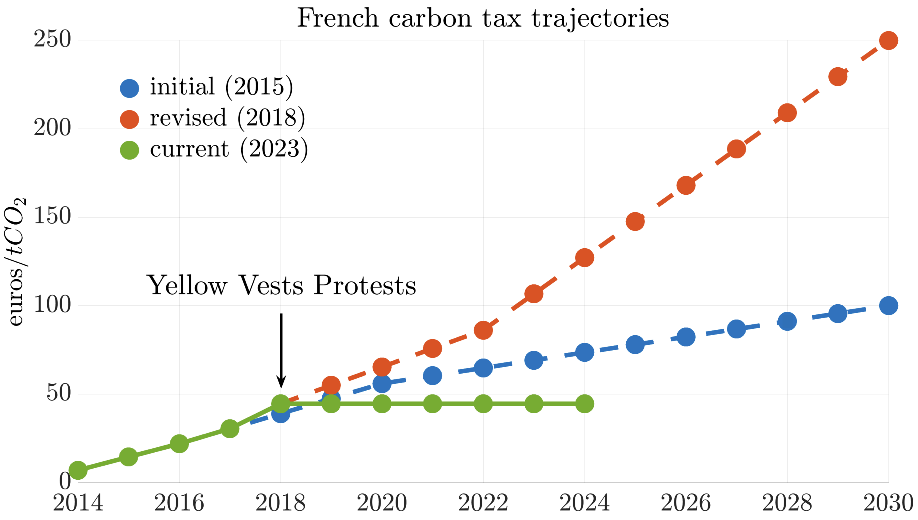
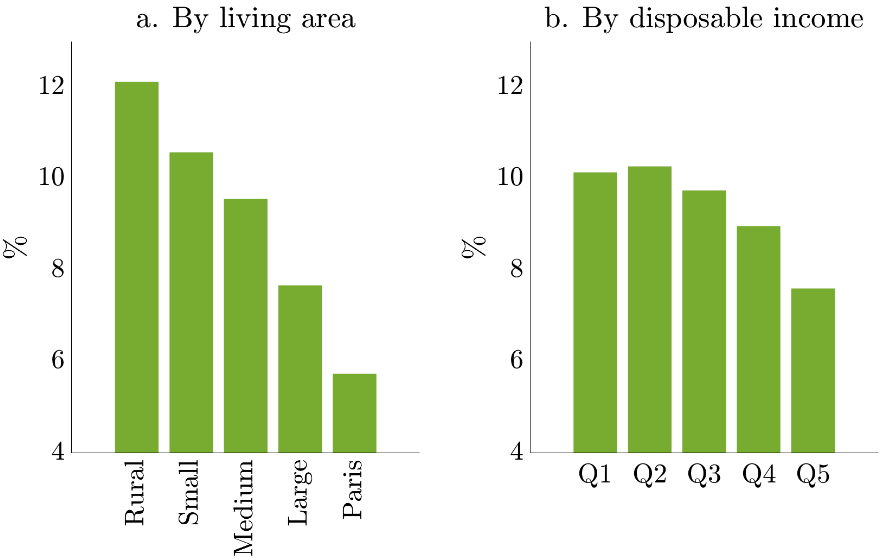


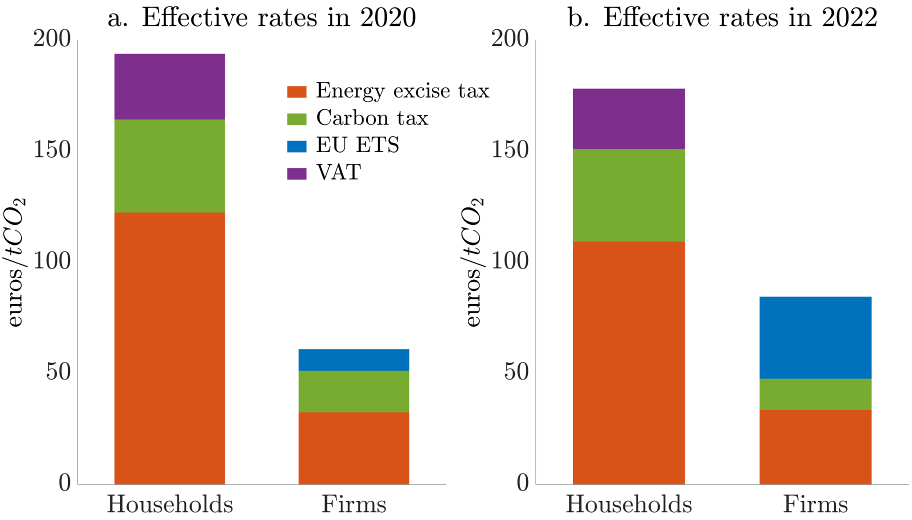
Literature Review

	Our contribution
i. Distributive effects of carbon taxes: Static microsimulations Cronin et al. (2019), Douenne (2020) CGE-micro models Rausch et al. (2011), Mathur and Morris (2014), Goulder et al. (2019), Ravigné et al. (2022)	• We build on Aiyagari (1994) • Dynamic general equilibrium model • Endogenous income distribution
ii. HANK and energy/climate: Fried (2018), Fried et al. (2018), Auclert et al. (forth.), Benmir and Roman (2022), Langot et al. (2023),	• Non-homothetic preferences and geographical energy needs • Permanent tax on hhs vs. firms
iii. GE effects of carbon taxes: Metcalf (2019), Barrage (2020), Känzig (2023)	• Imperfect capital markets • Targeted transfers

Energy share in total consumption – US – +



τ_h versus τ_f – Effective carbon tax rates



Our results

1. Taxing households' direct emissions is regressive while taxing firms' direct emissions is progressive

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3. Targeting both poor and rural households mitigate welfare losses

A Heterogeneous Agents model (HA)

Our small open economy HA model with energy – +

Government

$$G + T = \tau^h F^h + \tau^f F^f$$

Households

$$u(c, l, e^h - \bar{e})$$

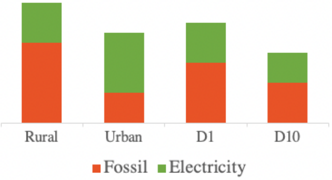
$$e^h = CES(F^h, N^h)$$

Firms

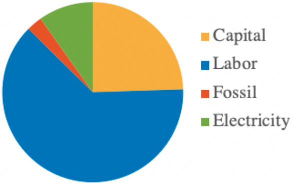
$$Y = f(k, l, e^f)$$

$$e^f = CES(F^f, N^f)$$

Energy share in total consumption



Cost shares of inputs



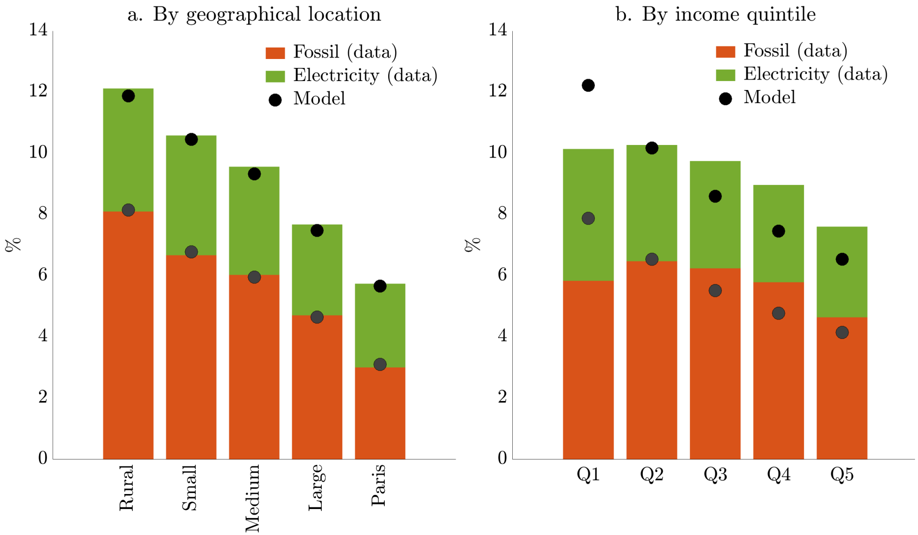
Fossil: imported from the rest of the world

Electricity

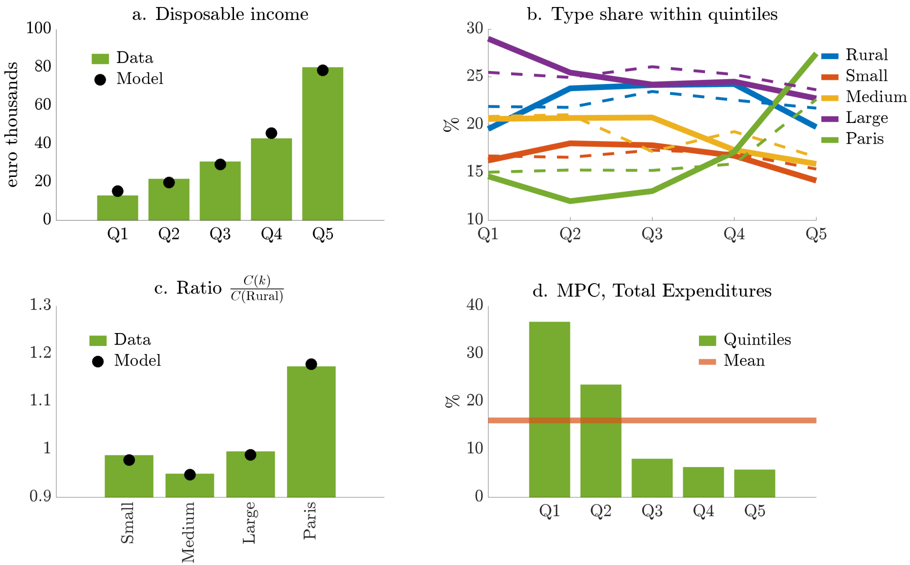
$N = f(k, l)$

Calibration: taking the model to the data

Energy share in total consumption – Insee BdF 2017



Inequalities in disposable income and consumption – +



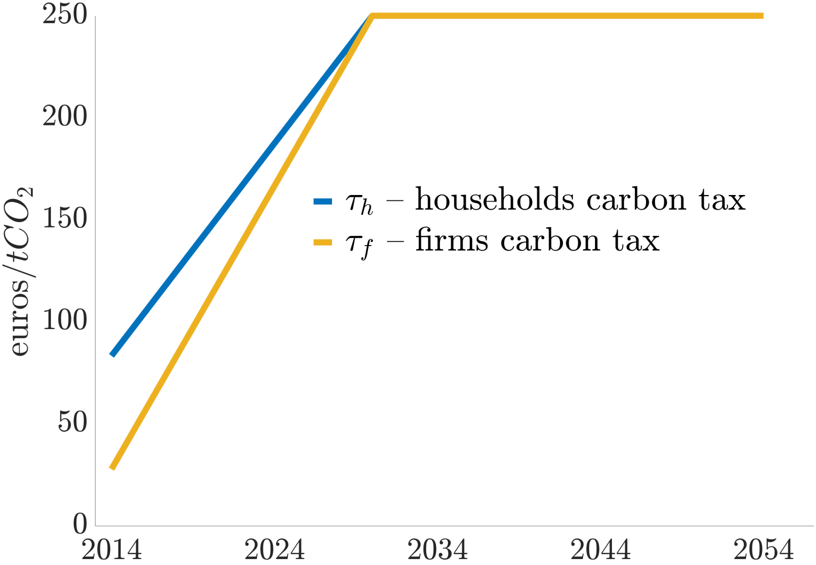
Macroeconomic targets – Other parameters

Table: Empirical targets vs Model results

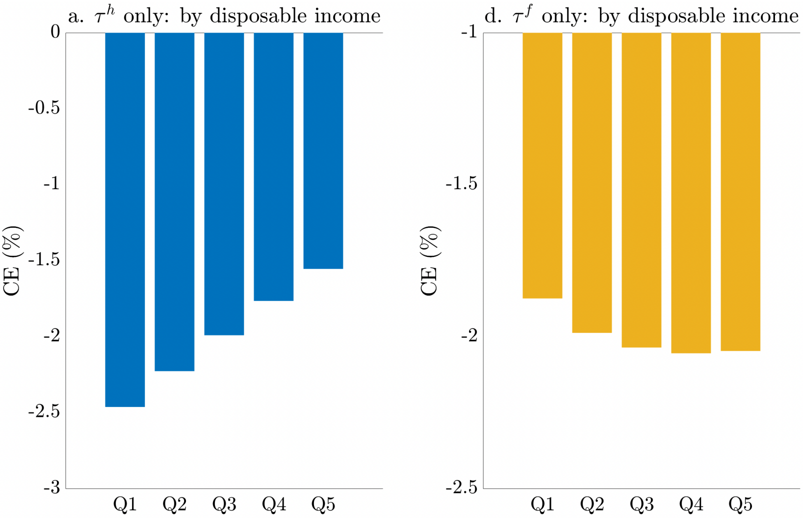
	Model	Target	Parameter	Value	Sources & notes
a/GDP	260%	250%	β	0.92	Piketty and Zucman (2014)
I_N/I	2%	2.3%	η	0.11	Insee 2023 – EAE
wl/GDP	63.1%	65%	α	0.28	Cette et al. (2019)
E_y/E	60.6%	60%	ω_y	0.43	PLF 2023 appendix
F_y/F	58.5%	59%	γ_y	0.33	PLF 2023 appendix
$p^F F/\mathrm{GDP}$	3.6%	2%	p^F	0.1	PLF 2023 appendix
I/GDP	13%	10%	δ	5.1%	Insee 2022 – NA
SB/GDP	41%	45%	λ	0.75	Ferriere et al. (2023)
G/GDP	29.3%	29%	$\bar{T}$	0.3	Auray et al. (2022)
R^c/SB	6.7%	7%	τ^f	0.012	PLF 2023
Elasticity of substitution c-e_h			σ	0.2	Estimation of σ
Elasticity of substitution KL-e_y			σ_y	0.2	Authors' choice
Elasticity of substitution N-F			ϵ_h, ϵ_y	0.2	Authors' choice

Quantitative results

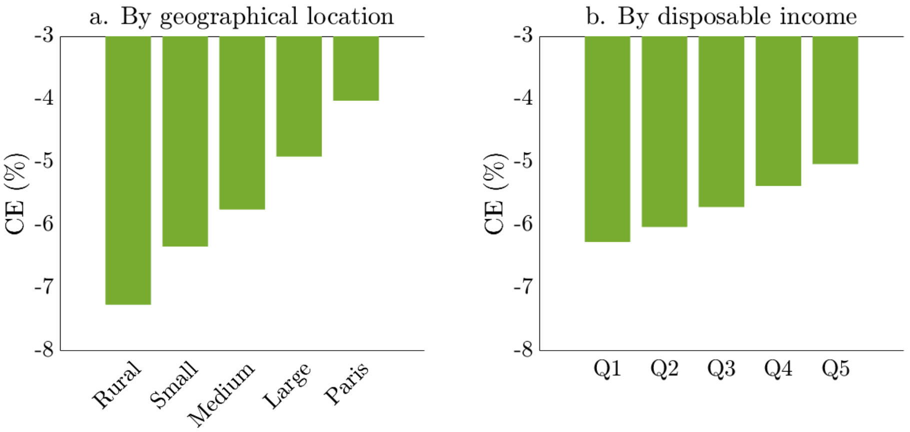
Experiment: permanent increase in carbon taxes



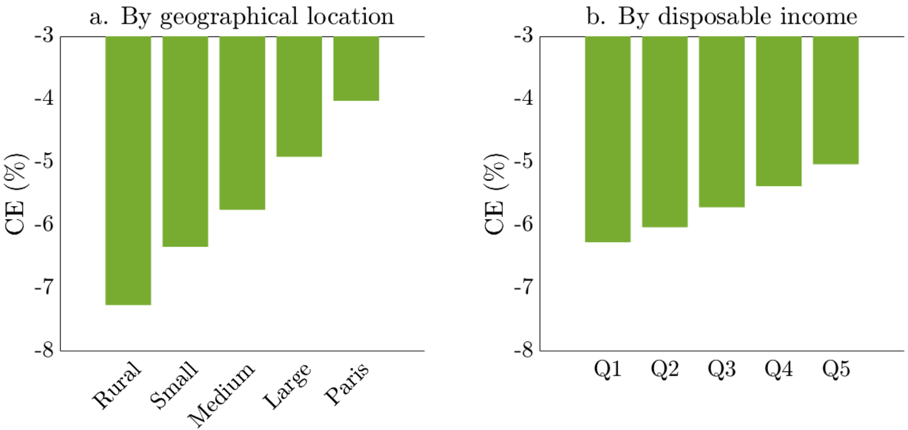
τ_h is regressive, τ_f is progressive



Overall, geography is more important than income – CE formula



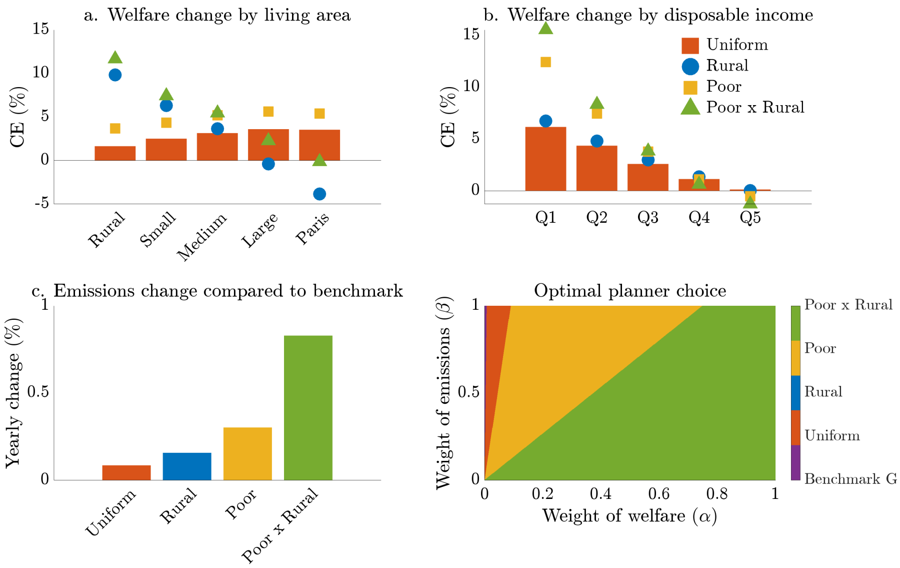
Overall, geography is more important than income – CE formula



We compute the R^2 of $CE_i = \alpha + \beta X_i + u_i$ for $X_i \in \{\bar{e}_i, \text{inc}_i, \text{wealth}_i\}$:

- geographical location explains 77% of CE lossses variability
- while income only explains 12% and wealth 16%

What if we redistribute?



Target $\bar{E}$ – Transition

A political trade-off between rural and largest cities

Benchmark scenario: -5.7% CE and 100% losers.

Table: **Share of losers (%)**

	Uniform	Poor	Poor x rural
Q1	0	0	0
Q2	0	0	1
Q3	0	0	15
Q4	8	19	47
Q5	39	81	91
Rural	27	31	12
Small	13	24	20
Medium	4	16	27
Large	1	14	39
Paris	2	14	58
All	10	20	31
Welfare (% CE)	2.9	4.8	5.4

Conclusion

1. τ_h is progressive when τ_f is regressive
2. Geography is more important than income
3. Targeting both poor and rural households mitigate welfare losses, but there is a political choice to be made between rural and largest cities

Thank you !

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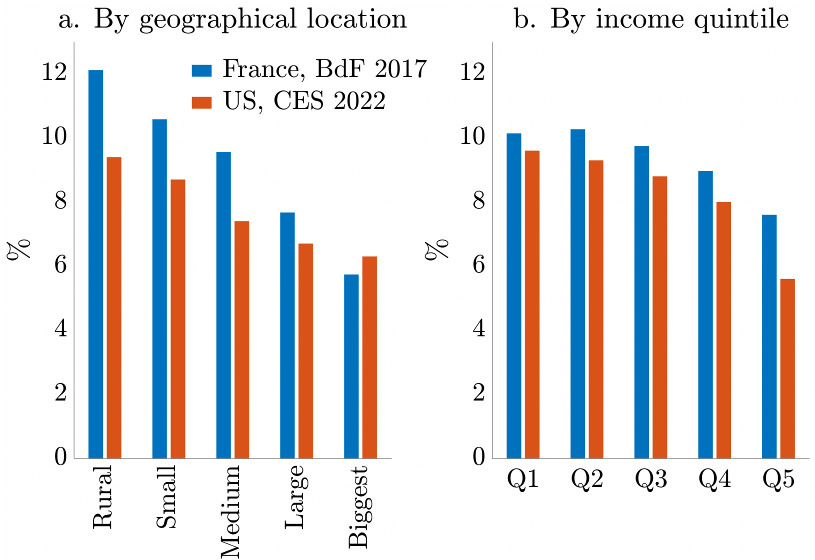
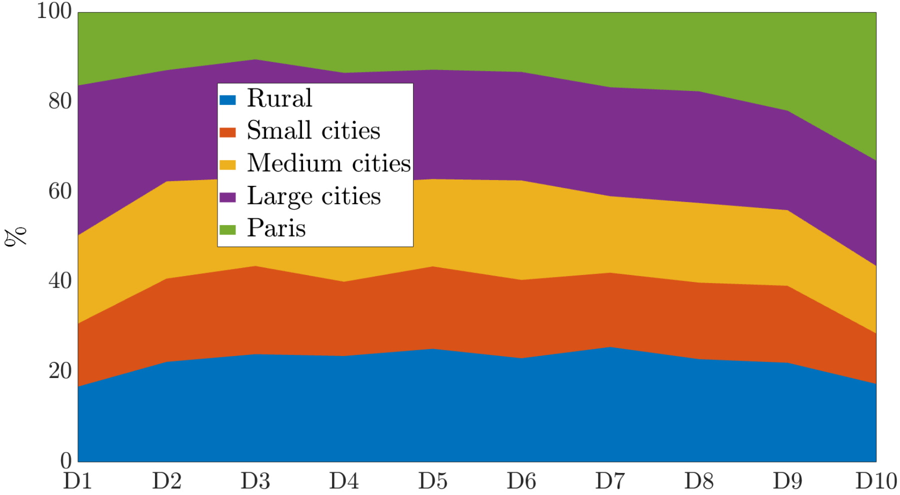
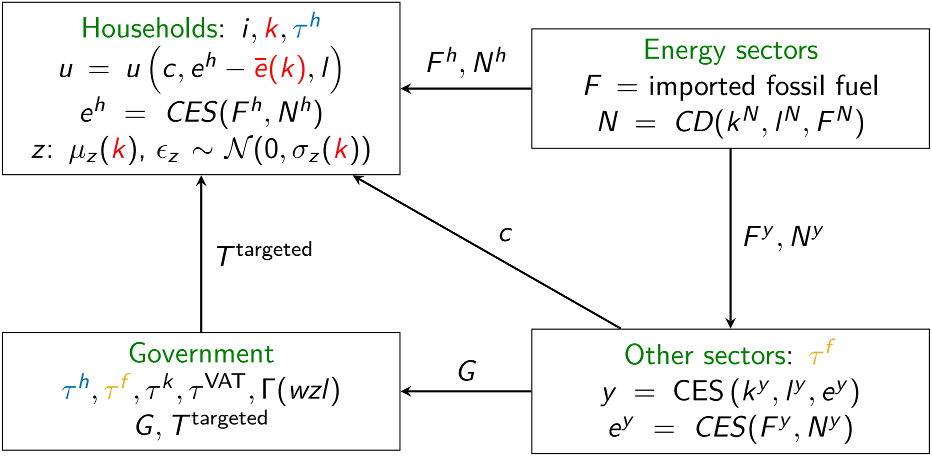
Energy share in total consumption – Return



Income tails live in big cities – Return



Our small open economy HA model with energy – Return



Households – Aiyagari (1994) set-up – Return – +

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4. geographical heterogeneity of energy needs: $\bar{e}(k)$

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2. imperfect substitution between electricity and fossil fuel: ϵ_h
3. non-homothetic energy demand: Comin et al. (2021)
4. geographical heterogeneity of energy needs: $\bar{e}(k)$
5. geographical heterogeneity of income processes: $z_i(k)$

Firms – Goods & Services sectors – Return

- Final good y (numeraire): produced using capital, labor and energy

$$\max_{\{y,k^y,l^y,F^y,N^y\}} \Pi^y = y - (r+\delta)k^y - wl^y - (p^F + \tau^f)F^y - p^N N^y$$

$$\text{such that } y = \left[(1-\omega_y)^{\frac{1}{\sigma_y}} \left((k^y)^{\alpha}(l^y)^{1-\alpha}\right)^{\frac{\sigma_y-1}{\sigma_y}} + \omega_y^{\frac{1}{\sigma_y}} (e^y)^{\frac{\sigma_y-1}{\sigma_y}}\right]^{\frac{\sigma_y}{\sigma_y-1}}$$

$$\text{and } e^y = \left[(1-\gamma_y)^{\frac{1}{\epsilon_y}} (N^y)^{\frac{\epsilon_y-1}{\epsilon_y}} + \gamma_y^{\frac{1}{\epsilon_y}} (F^y)^{\frac{\epsilon_y-1}{\epsilon_y}}\right]^{\frac{\epsilon_y}{\epsilon_y-1}}$$

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$$\text{and } e^y = \left[(1-\gamma_y)^{\frac{1}{\epsilon_y}} (N^y)^{\frac{\epsilon_y-1}{\epsilon_y}} + \gamma_y^{\frac{1}{\epsilon_y}} (F^y)^{\frac{\epsilon_y-1}{\epsilon_y}}\right]^{\frac{\epsilon_y}{\epsilon_y-1}}$$

- Casey (2024): Cobb-Douglas overestimates emissions adjustments
- Hassler et al. (2021): σ_y should be close to 0 in short-run
- Papageorgiou et al. (2017): ϵ_y close to 2 in long-run
- Lafrogne - Joussier et al. (2023): 100% passthrough of positive energy-driven cost shocks

Firms – Energy sectors – Return

- Electricity sector N: produced using capital, labor and fossil fuel

$$\max_{\{N, k^N, l^N, F^N\}} \Pi^N = p^N N - (r+\delta)k^N - wl^N - (p^F + \tau^f)F^N$$

$$\text{such that } N = (l^N)^{\eta}(k^N)^{\zeta}(F^N)^{1-\eta-\zeta}$$

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- Fossil fuel sector F
  - imported from the rest of the world at a fixed price p^F.
  - the rest of the world uses the fossil fuel revenue $p^F(F^Y + F^N + F^h)$ to import goods and services X from the domestic economic:

$$X = p^F(F^Y + F^N + F^h)$$

Government – Return

$$
\begin{aligned}
T_t^{\text{targeted}} + G_t + r_t \bar{d} = & \int_0^1 \left(z_{i,t} w_t l_{i,t} - \Gamma\left(z_{i,t} w_t l_{i,t}\right)\right) di \\
& + \tau^{\text{VAT}} \int_0^1 \left(c_{i,t} + p_t^N N_{i,t}^h + p_t^F F_{i,t}^h\right) \mathrm{d}i \\
& + \tau^k r_t \int_0^1 a_{i,t} \mathrm{d}i \\
& + \tau^h (1 + \tau^{\text{VAT}}) \int_0^1 F_{i,t}^h \mathrm{d}i + \tau^f \left(F_t^y + F_t^N\right)
\end{aligned}
$$

- following Heathcote et al. (2017), we assume: $\Gamma(x) = \lambda x^{1-\tau}$
- Benchmark scenario: carbon tax revenue used in G
- We then allow for targeted transfers

Households: utility function à la Comin et al. (2021)

Aiyagari (1994) with 5 living areas

- Each household i of type k solves the following problem:

$$\max_{\{e^h_{i,t}, c_{i,t}, a_{i,t}, l_{i,t}\}_{t=0}^{+\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{u_{i,t}^{1-\theta} - 1}{1-\theta} - \phi \frac{l_{i,t}^{1+\nu}}{1+\nu} \right\}$$

such that

$$\Lambda_c^{\frac{1}{\sigma}} \left(\frac{c_{i,t}}{u_{i,t}^{\epsilon_c}} \right)^{\frac{\sigma-1}{\sigma}} + \Lambda_e^{\frac{1}{\sigma}} \left(\frac{e^h_{i,t} - \bar{e}(k)}{u_{i,t}^{\epsilon_e}} \right)^{\frac{\sigma-1}{\sigma}} = 1$$

$$e^h_{i,t} = \left[(1-\gamma_h(k))^{\frac{1}{\epsilon_h}} (N^h_{i,t})^{\frac{\epsilon_h - 1}{\epsilon_h}} + \gamma_h(k)^{\frac{1}{\epsilon_h}} (F^h_{i,t})^{\frac{\epsilon_h-1}{\epsilon_h}} \right]^{\frac{\epsilon_h}{\epsilon_h - 1}}$$

- c and e^h are imperfect substitutes: σ
- $\bar{e}(k) > 0$ exacerbates the non-homotheticity
- Robustness with CES and Alder et al. (2022)

Households: budget constraint and earning processes

Budget constraint:

$$\underbrace{(1+\tau^{\text{VAT}})\left[c_{i,t}+p_t^N N_{i,t}^h+(p_t^F+\tau_t^h)F_{i,t}^h\right]}_{\text{Total consumption expenditures}}+\underbrace{a_{i,t+1}-a_{i,t}}_{\text{Savings}}$$
$$=\underbrace{\Gamma(z_{i,t}(k)w_t l_{i,t})}_{\text{Net labor income}}+\underbrace{(1-\tau^k)r_t a_{i,t}}_{\text{Net capital income}}+\underbrace{T_{i,t}(k)}_{\text{Transfers}}$$

Households: budget constraint and earning processes

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$$=\underbrace{\Gamma(z_{i,t}(k)w_t l_{i,t})}_{\text{Net labor income}}+\underbrace{(1-\tau^k)r_t a_{i,t}}_{\text{Net capital income}}+\underbrace{T_{i,t}(k)}_{\text{Transfers}}$$

Earning process for type k:

$$z_{i,t}(k)=e^{x_{i,t}(k)},\ x_{i,t}(k)=(1-\rho_z)\mu_z(k)+\rho_z x_{i,t-1}(k)+\epsilon_{i,t}$$
$$\epsilon_{i,t}\sim\mathcal{N}(0,\sigma_z(k))$$

Borrowing constraint:

$$a_{i,t}\geq \underline{a}$$

Return

All markets clear – Return

$$
\begin{cases}
\int_0^1 a_{i,t} \mathrm{d}i = k_{e,t} + k_{y,t} + \bar{d} & \text{(Savings)} \\
\int_i z_{i,t} l_{i,t} \mathrm{d}i = l_y + l_N & \text{(Labor)} \\
y_t = \int_0^1 c_{i,t} \mathrm{d}i + I_{e,t} + I_{y,t} + G_t + X_t & \text{(G\&S)} \\
N_t = N_t^y + \int_0^1 N_{i,t}^h \mathrm{d}i & \text{(Electricity)} \\
F_t = F_t^y + F_t^N + \int_0^1 F_{i,t}^h \mathrm{d}i & \text{(Fossil)}
\end{cases}
$$

Bellman equation – Return

The Bellman equation of the problem is defined as:

$$V(a, z, k) = \max_{\{c, e^h, a', l\}} \left\{ \frac{\left[u(c, e^h)\right]^{1-\theta} - 1}{1-\theta} - \phi \frac{l^{1+\psi}}{1+\psi} + \beta \mathbb{E}_{z'} \left[V(a', z', k) | z \right] \right\}$$

Households: CES Stone-Geary utility function – Return

- Each household i of type k solves the following problem:

$$\max_{\{e^h_{i,t}, c_{i,t}, a_{i,t}, l_{i,t}, N_{i,t}, F_{i,t}\}_{t=0}^{+\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{u_{i,t}^{1-\theta} - 1}{1-\theta} - \phi \frac{l_{i,t}^{1+\nu}}{1+\nu} \right\}$$

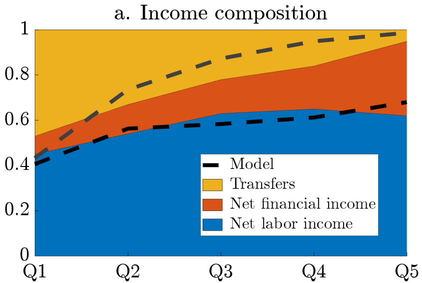
such that

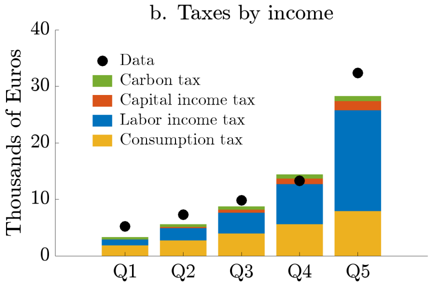
$$u_{i,t} = \left[(1-\omega)^{\frac{1}{\sigma}} (c_{i,t})^{\frac{\sigma-1}{\sigma}} + \omega^{\frac{1}{\sigma}} (e^h_{i,t} - \bar{e})^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}$$

$$e^h_{i,t} = \left[(1-\gamma_h(k))^{\frac{1}{\epsilon_h}} (N^h_{i,t})^{\frac{\epsilon_h-1}{\epsilon_h}} + \gamma_h(k)^{\frac{1}{\epsilon_h}} (F^h_{i,t})^{\frac{\epsilon_h-1}{\epsilon_h}} \right]^{\frac{\epsilon_h}{\epsilon_h-1}}$$

- $\bar{e}(k) > 0$ implies non-homothetic preferences

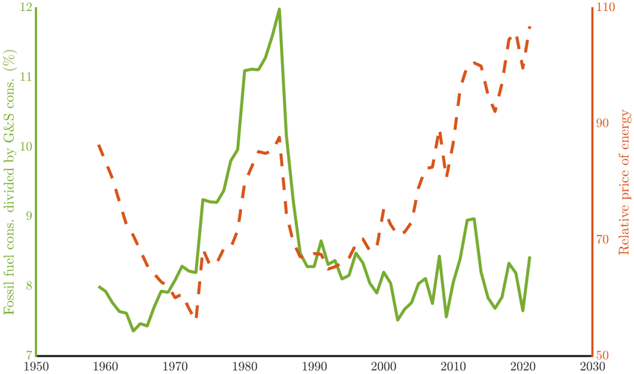
Income composition and taxes– Return





e^h and c are imperfect substitutes: $\hat{\sigma} = 0.2$ $(**)$ – Return

$$\text{Comin et al. (2021)} \implies \frac{\partial \ln(c/(e^h - \bar{e}))}{\partial \ln(p^e + \tau^h)} = \sigma$$



Rk: 1960-1990 period: $\hat{\sigma} = 0.28$ $(**)$, 1990-2021 period: $\hat{\sigma} = 0.08$

Calibration – Parameters – Return

Table: Households

Paramètres	Valeur	Note
β	0.92	$\frac{a}{\text{GDP}}$ de Piketty and Zucman (2014)
θ	1	IES $= 1$ like in Kaplan et al. (2018)
ϕ	1	Labor disutility normalization
$1/\nu$	3	Ferriere et al. (2023)
σ	0.26	Estimation of σ, NA 2022
Λ_e	0.155	Mean energy share, BdF 2017
ϵ_e	0.8	Comin et al. (2021) non-homotheticity
ϵ_h	0.2	Authors' choice
$\Gamma_h(k)$	[0.17, 0.25, 0.19, 0.17, 0.22]	Population in each type, Douenne (2020)
$\gamma_h(k)$	[0.60, 0.67, 0.69, 0.70, 0.73]	Mean fossil fuel consumption, BdF 2017
$\bar{e}(k)$	[0.0, 0.11, 0.22, 0.29, 0.39]	Energy share across types, BdF 2017
ρ_z	0.9725	Income inequality, RPM 2018
$\mu_z(k)$	[0, -0.09, -0.11, -0.08, -0.08]	Average consumption, BdF 2017
$\sigma_z(k)$	[0.34, 0.31, 0.3, 0.3, 0.305]	Douenne (2020)
$\underline{a}$	0	Authors' choice

Calibration – Parameters – Return

Table: Firms and State

Parameters	Value	Note
p^F	0.1	$\frac{p^F F}{GDP}$=2%
ω_y	0.43	$\frac{p^y E^y}{p^h E_h + p^y E^y + p^F F^N} = 60\%$
σ_y	0.2	Authors' choice, Hassler et al. (2021), Casey (2024)
α	0.28	$\frac{wl}{GDP}$ from Cette et al. (2019)
γ_y	0.33	$\frac{F_y}{F} = 59\%$
ϵ_y	0.2	Authors' choice, Papageorgiou et al. (2017)
η	0.11	$\frac{I_N}{I}$ =2%
ζ	0.886	$\frac{F_N}{F}$=1%
δ	5.1%	$\frac{I}{GDP}$ =10%
$\bar{T}$	0.3	$\frac{G}{Y} = 29\%$
$\bar{d}$	0	Authors' choice, realistic MPCs
τ	0.08	From Ferriere et al. (2023)
λ	0.75	From Ferriere et al. (2023)
τ^k	9.02%	Effective rate from Auray et al. (2022)
τ^{VAT}	22%	Effective VAT rate from Auray et al. (2022)

Welfare formula – Return

"Consumption equivalent" (CE) terms: permanent change in steady-state consumption that would make the household indifferent between the steady-state statu-quo forever and the carbon tax increase path.

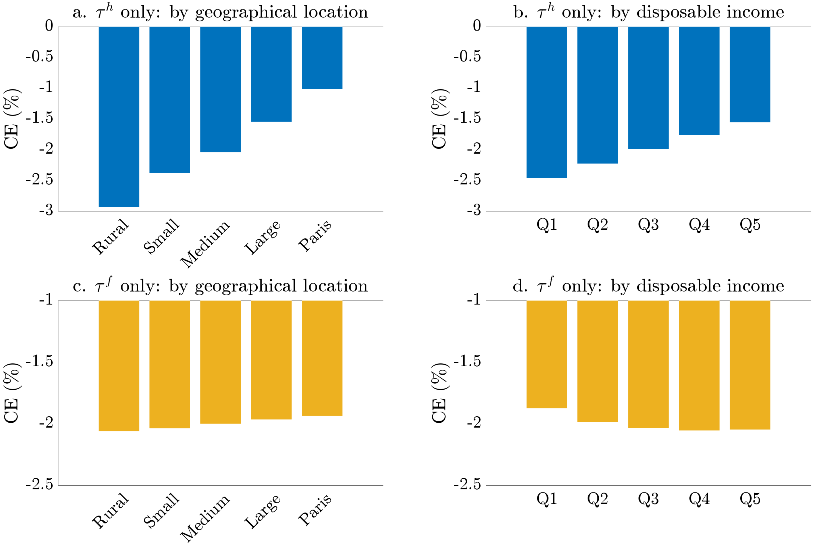
Formally, we compute for each initial wealth a_0 and productivity z_0:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{u_{i,t}(c^{\mathrm{SS}}(1+\mathrm{CE}), e_h^{\mathrm{SS}})^{1-\theta} - 1}{1-\theta} - \phi \frac{(l_{i,t}^{\mathrm{SS}})^{1+\nu}}{1+\nu} | a_0, z_0 \right\}$$

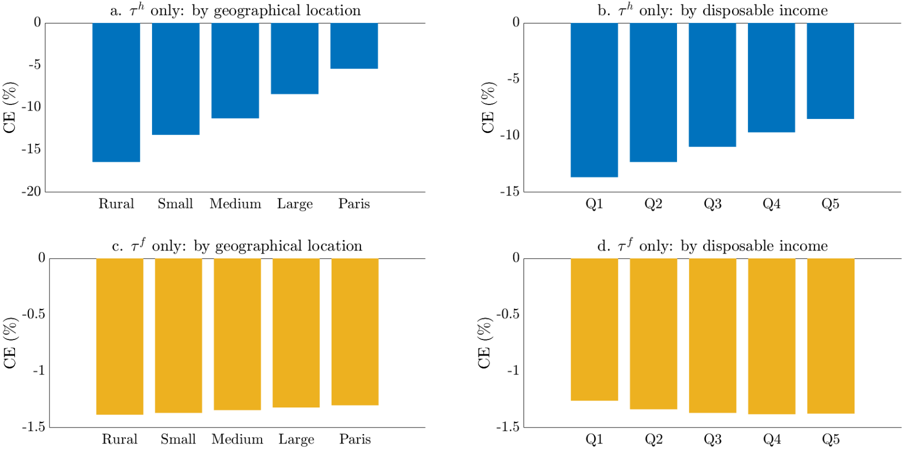
$$= \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{u_{i,t}(c^{\mathrm{carbon}}, e_h^{\mathrm{carbon}})^{1-\theta} - 1}{1-\theta} - \phi \frac{(l_{i,t}^{\mathrm{carbon}})^{1+\nu}}{1+\nu} | a_0, z_0 \right\}$$

with x^{SS} the path of the variable x without carbon tax increase, and x^{carbon} the path with the carbon tax increase and the new steady state.

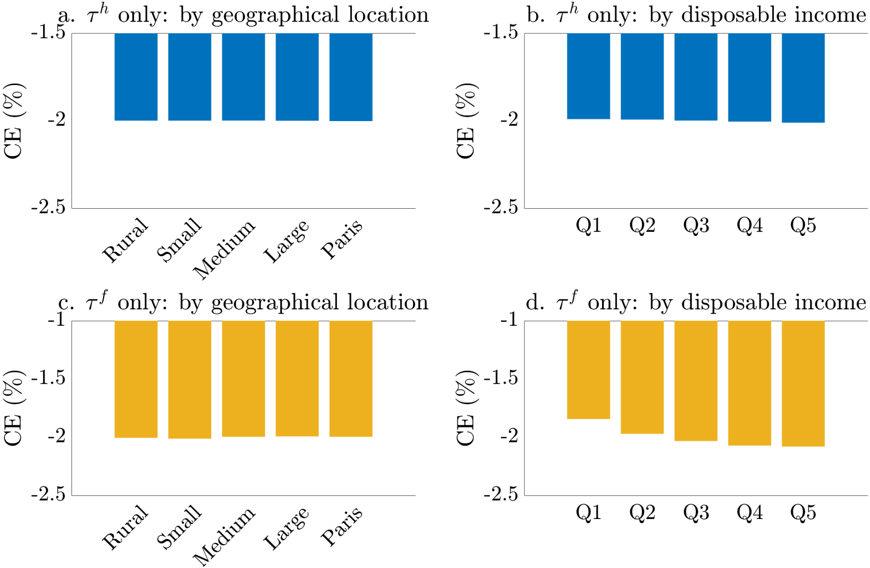
τ_h versus τ_f – Return



τ_h versus τ_f with a 10% emissions reduction target – Return



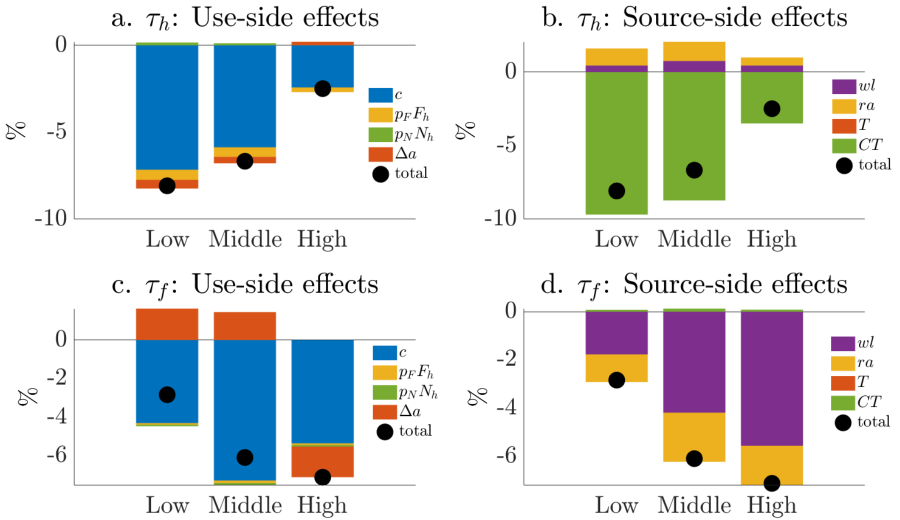
τ_h versus τ_f with homothetic preferences – Return



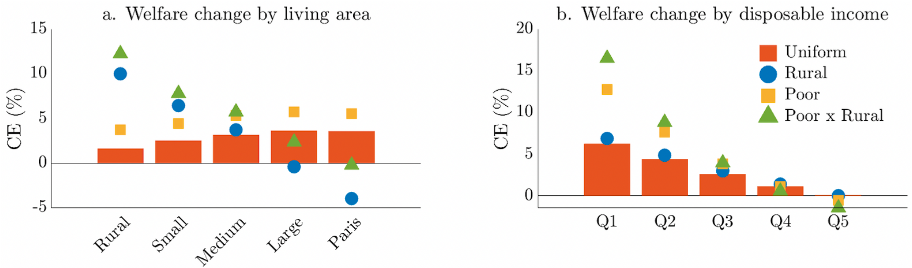
"use-side" vs. "source-side" decomposition – Return

- We use households' budget constraint to decompose between
  - "use-side" effects
  - "source-side" effects
- We get:

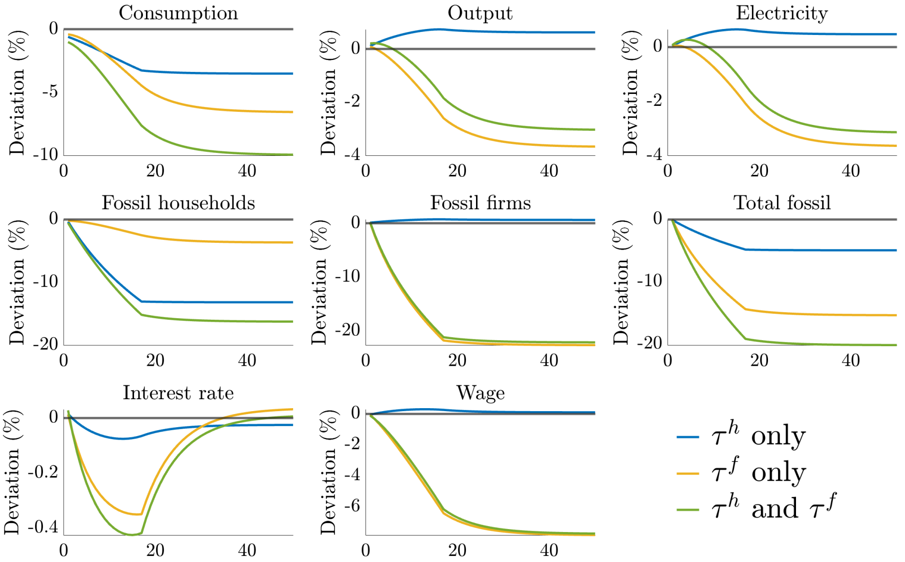
$$\underbrace{\frac{\partial c_i}{\partial \tau} + \frac{\partial p_i^h e_i^h}{\partial \tau} + \frac{\partial (a_i' - a_i)}{\partial \tau}}_{\text{Use-side effects}} = \underbrace{\frac{\partial \Gamma(z_i w l_i)}{\partial \tau} + \frac{\partial r^n a_i}{\partial \tau} + \frac{\partial T}{\partial \tau} - \frac{\partial f_i(\tau^h, \tau^{\text{VAT}})}{\partial \tau}}_{\text{Source-side effects}}$$


a. τ_h: Use-side effects
0
-5
-10
%
Low Middle High
c
$p_F F_h$
$p_N N_h$
Δa
total
b. τ_h: Source-side effects
0
-5
-10
%
Low Middle High
wl
ra
T
CT
total
c. τ_f: Use-side effects
0
-2
-4
-6
%
Low Middle High
c
$p_F F_h$
$p_N N_h$
Δa
total
d. τ_f: Source-side effects
0
-2
-4
-6
%
Low Middle High
wl
ra
T
CT
total

Recycling with a 17.5% reduction emissions target – Return



Transitional dynamics – Return



What if we redistribute the carbon tax revenue? – Return