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**Geography versus income:
the heterogeneous effects of carbon taxation**

**Charles Labrousse
Yann Perdereau**

JEL Codes: C61, E37, E62, H23, H30, Q43, Q48, Q58, R11, R13.

Keywords: Carbon taxes ; Energy ; Fiscal policy ; Emissions ; Macroeconomic effects ; Inequalities ; Geography.



Geography versus income: the heterogeneous effects of carbon taxation

Charles Labrousse* and Yann Perdereau†

February 16, 2024

Abstract

Redistributive effects of carbon taxation are key for its political acceptability. We build a dynamic equilibrium model incorporating heterogeneity in wealth, income and living areas. Energy serves as both a household consumption good and a firm intermediate input. We position our model as a comprehensive policy toolkit, extendable to diverse countries and several environmental policies. Using calibrated French micro data, we evaluate the redistributive effects of carbon taxation and obtain three key results. First, geography is more important than income to assess the distributive effects of carbon taxation, as rural households bear more substantial losses. Second, the carbon tax on households is regressive, while the carbon tax on firms may be progressive. Third, it is possible to achieve welfare increase and emission reduction through appropriate recycling of carbon policy, but a trade-off between equity and efficiency emerges if we want to reduce the rural-urban gap.

JEL classification – C61, E37, E62, H23, H30, Q43, Q48, Q58, R11, R13

Keywords – Carbon taxes, energy, fiscal policy, emissions, macroeconomic effects, inequalities, geography

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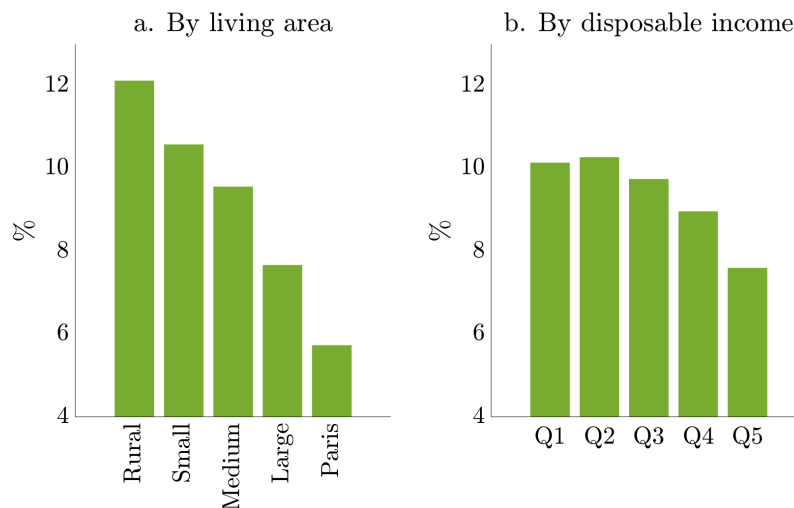
Introduction

Carbon taxes reduce emissions, but they induce strong distributional costs, as energy represents a larger share of consumption for poor and rural households. These regressive effects are likely to reduce the political acceptability of carbon taxation, as shown in [Douenne and Fabre \(2020\)](#), and illustrated in France with the Yellow Vests protest and the subsequent carbon tax freezing.

Therefore, a socially acceptable carbon taxation design should account for its distributive effects. A trade-off emerges between equity and (climate) efficiency, as redistributing carbon tax revenue towards poor and rural households will likely increase emissions. In this paper, we use a dynamic general equilibrium model with rich household heterogeneity to assess the distributive effects of carbon taxation, and we consider different revenue-recycling scenarios. The main features of our model, and the associated findings, can be put into three categories.

First, **geography is more important than income to assess the distributive effects of carbon taxation**. [Cronin et al. \(2019\)](#) for the U.S. and [Douenne \(2020\)](#) in the French context, find that most of energy consumption heterogeneity, and therefore winners and losers of carbon taxation, lie within income classes. As shown in [Figure 1](#) using French micro data, the energy share in total consumption expenditures varies more across living areas than across income levels. Rural areas inhabitants tend to have higher incompressible energy needs related to transport and heating systems, while urban households benefit from public transportation and live in smaller housing. The vertical heterogeneity is less relevant, as rich households tend to have bigger houses and travel more, mitigating the decline of their energy share compared to poor households.

Figure 1: Energy share in total consumption



We use the [Aiyagari \(1994\)](#) framework to introduce vertical heterogeneity related to income and wealth, and we add several household types with different incompressible energy consumption to take into account the horizontal heterogeneity related to living area. We find that in the absence of targeted transfers, carbon taxation hits disproportionately more rural households (with a consumption equivalent equal to -5.8% after the carbon tax increase, against -3.2% for urban households), and is mildly flat across income groups (-4.8% for low income and -4.3% for top income).

Second, **taxing households is much more regressive than taxing firms**. In our model, energy is both a consumption good for households, and an intermediate input in production for firms, hence we have two carbon taxes. Our mechanisms are closely related to the classical [Diamond and Mirrlees \(1971\)](#) optimal result. Taxing households' energy consumption is regressive, because of the nonhomotheticity of energy consumption. Therefore, poor and rural households are disproportionately hit by the policy. However, taxing firms' energy consumption distorts their optimal input allocation, reducing activity incomes. Those who rely more on labor incomes are more affected than poor people living mostly from public transfers. Those with a higher share of financial income are less affected because taxing firms' emissions reduces the income risk and reallocates towards a more capital intensive sector.

Third, **it is possible to reduce emissions and make the policy progressive with respect to income**. Uniform lump-sum rebate of carbon tax revenue allows to reduce CO₂ emissions by 18%, while increasing general welfare and reducing income inequality. However, this uniform transfer widens the rural-urban gap: compensating the loss for rural households implies a trade-off between equity and climate efficiency, as they have a high marginal propensity to consume energy. We quantify this trade-off, and propose different redistribution scenarios with targeted transfers. Moreover, we show that the optimal utilitarian scenario is to make a transfer contingent to both income and location (with a consumption equivalent of $+4.5\%$, against $+2.7\%$ for uniform transfers), but this creates much more losers (45% against 10%).

Our paper contributes to the literature assessing the distributive effects of carbon taxation. A first strand of the literature is based on *micro-simulations*, as [Cronin et al. \(2019\)](#) for the U.S. and [Douenne \(2020\)](#) in the French context, and generally concludes that carbon taxes, when put on final consumption, are regressive. Our findings on the households carbon tax are similar, but we use a general equilibrium model to take into account the firm intermediate input part of the carbon tax.

As highlighted in [Metcalf \(2023\)](#), carbon taxes also yield “source side” effects. Therefore, a second part of the literature relies on *Computable General Equilibrium*

(CGE) models. [Rausch et al. \(2011\)](#) and [Goulder et al. \(2019\)](#) conclude that the progressivity of source-side effects tends to offset the regressive use-side effects in the U.S., while [Ravigné et al. \(2022\)](#) estimates that the overall effect is still regressive. We also compare the “use-side” and “source-side” effects of the tax, but our income and wealth distribution is endogenous, based on idiosyncratic income risks.

In this regards, we are closer to a third literature, based on modern *macroeconomic heterogeneous-agent models*. [Fried et al. \(2023\)](#) focuses on the optimal recycling of carbon tax revenue, allowing the government to use the carbon tax revenue to lower any existing tax; we focus on targeted transfers, as this option is often favored by government and clearer for citizens. [Benmir and Roman \(2022\)](#) investigates the distributional effects of the U.S. net-zero emissions target; [Känzig \(2023\)](#) focuses on the EU-ETS market; [Langot et al. \(2023\)](#) studies the tax-shield implemented in France in 2021. We build on these works by adding living areas heterogeneity through different incompressible energy consumption levels, producing a rich and realistic heterogeneity across households. This framework allows us to consider targeted transfers contingent on location or income, creating a variety of “equity-efficiency” trade-offs for the government. Compared to some of these papers, we also focus on a permanent increase in carbon tax rather than a temporary one, reflecting the fact that the carbon transition will shift the economy towards a new steady state.

Finally, we contribute to the literature comparing the taxation of firms (intermediate goods taxation) and consumers (final commodity taxation) going back to [Diamond and Mirrlees \(1971\)](#), in the the specific context of carbon taxation. In our heterogeneous-agent model framework, we obtain that taxing households is more regressive than taxing firms. Traditional mechanisms exposed in the literature to explain the distributive effects of carbon taxation: (i) income effects in [Rausch et al. \(2011\)](#), (ii) indexation of social income on prices in [Metcalf \(2019\)](#), (iii) use of multisector macroeconomic modelling in [Ohlendorf et al. \(2021\)](#), (iv) the crossed effect between subsidies for low-carbon technologies and a carbon tax in [Lamb et al. \(2020\)](#) or (v) indirect income effects in [Känzig \(2023\)](#).

The remainder of the paper is organized as follows. Section 1 presents our quantitative model. Section 2 discusses our calibration choices using French data. Section 3 presents the quantitative results. Finally, Section 4 concludes.

1 A quantitative Heterogeneous-Agent model

Our main focus is the distributive effect of carbon taxation, so we introduce a rich heterogeneity on the households side, with idiosyncratic productivity shocks leading to income and wealth heterogeneity, and different incompressible energy consumption levels by living areas. Our productive sector is composed of a electricity firm, a final good firm using fossil fuel and electricity as intermediate inputs, and an imported fossil energy. Finally, the fiscal authority has a complete set of instruments, and uses the carbon tax revenue either to increase public spending or to implement targeted transfers.

1.1 Households

The economy is populated by an infinite amount of households indexed by i that are heterogeneous in two dimensions. The “vertical” heterogeneity is related to the idiosyncratic productivity process z , creating a distribution for wealth and income. The “horizontal” heterogeneity is related to the living area, with 5 household types k ranking households from “rural” to “urban”, depending on the size of the city they live in. The living area determines the level of incompressible energy consumption $\bar{e}(k)$, the energy mix parameter $\gamma_h(k)$, and the mean and variance of the idiosyncratic productivity shock, so that the individual productivity is denoted $z_i(k)$.

Households maximize intertemporal utility, choosing consumption c , asset a , energy bundle e^h (composed of electricity N^h and fossil fuel F^h with the carbon tax τ^h), subject to their budget constraint, their idiosyncratic productivity process and a borrowing constraint. Each household i of type k solves the following problem:

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

subject to:

$$\Lambda_c^{\frac{1}{\sigma}} \left(\frac{c_{i,t}}{u_{i,t}^c} \right)^{\frac{\sigma-1}{\sigma}} + \Lambda_e^{\frac{1}{\sigma}} \left(\frac{e_{i,t}^h - \bar{e}(k)}{u_{i,t}^e} \right)^{\frac{\sigma-1}{\sigma}} = 1 \quad (1)$$

$$e^h = \left[(1 - \gamma_h(k))^{\frac{1}{\epsilon_h}} (N^h)^{\frac{\epsilon_h-1}{\epsilon_h}} + \gamma_h(k)^{\frac{1}{\epsilon_h}} (F^h)^{\frac{\epsilon_h-1}{\epsilon_h}} \right]^{\frac{\epsilon_h}{\epsilon_h-1}} \quad (2)$$

$$\underbrace{(1 + \tau^{\text{VAT}}) [c_{i,t} + p_t^N N_{i,t}^h + (p_t^F + \tau_t^h) F_{i,t}^h]}_{\text{Total consumption expenditures}} + \underbrace{a_{i,t+1} - a_{i,t}}_{\text{Savings}} = \underbrace{\Gamma(z_{i,t}(k) w_t l_t)}_{\text{Net labor income}} + \underbrace{(1 - \tau^k) r_t a_{i,t}}_{\text{Net capital income}} + \underbrace{T_{i,t}(k)}_{\text{Transfers}} \quad (3)$$

$$z_{i,t}(k) = e^{x_{i,t}(k)}, \quad x_{i,t}(k) = (1 - \rho_z)\mu_z(k) + \rho_z x_{i,t-1}(k) + \epsilon_{i,t}, \quad \epsilon_{i,t} \sim \mathcal{N}(0, \sigma_z(k)) \quad (4)$$

$$a_{i,t} \geq \underline{a} \quad (5)$$

Equation 1 implicitly defines utility following [Comin et al. \(2021\)](#), which is appealing for three reasons. First, it introduces a non-homotheticity for the energy consumption that does not vanish with income: energy represents a higher share of total consumption expenditure for poor households, and stays a non-homothetic good even for high income. Second, this utility function introduces an imperfect substitution between energy and other goods, with a constant elasticity of substitution. Third, we introduce an incompressible consumption level $\bar{e}(k)$ that differs across living areas, accounting for higher energy requirement in rural areas compared to urban areas.

Equation 2 is the energy bundle of the household. The elasticity of substitution between fossil fuel and electricity is determined by the parameter ϵ_h , and the energy mix depends on the living area with the parameter $\gamma_h(k)$.

Equation 3 is the budget constraint of the household, subject to 4 taxes. Good and energy consumptions are subject to a VAT tax at a rate τ^{VAT} . Fossil fuel with relative price p_t^F is subject to an excise tax τ^h . Labor income is taxed according to a progressive tax rule Γ defined later. Capital income is subject to a flat tax at rate τ^k . Finally, households receive transfer from the fiscal authority, that may be contingent to their productivity or their living area.

Equation 4 is the idiosyncratic productivity process. Productivity follows an AR(1) process with normally distributed shocks. We allow the mean μ_z and the variance σ_z to depend on the type k , which allows us to match the cross-distribution across income and living areas.

Finally, **Equation 5** is the borrowing constraint leading to imperfect capital markets. Households cannot borrow more than $-\underline{a}$, so that some agents will be constrained and “hand-to-mouths”, resulting in high marginal propensity to consume.

1.2 Three-sector model

1.2.1 Goods & Services sector

Consumption good y is consumed by households (c), government (G) or foreigners (X_t), or invested by the energy firm (I_e) or the final good firm (I_y). The consumption good is produced competitively using labor l_y , capital k_y and energy bundle e_y (composed of electricity N^y and fossil fuel F^y with the carbon tax τ^f), according to the following program:

$$\max_{\{l_y, k_y, e_y, F^y, N^y, y\}} \Pi_y = y - (r + \delta)k_y - wl_y - (p^F + \tau^f)F^y - p^N N^y$$

such that

$$y = \left[(1 - \omega_y)^{\frac{1}{\sigma_y}} (k_y^\alpha l_y^{1-\alpha})^{\frac{\sigma_y-1}{\sigma_y}} + \omega_y^{\frac{1}{\sigma_y}} (e^y)^{\frac{\sigma_y-1}{\sigma_y}} \right]^{\frac{\sigma_y}{\sigma_y-1}}$$

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

Hassler et al. (2021) points toward a very low short-run substitutability between energy and other inputs once the technology factors have been chosen. This motivates our choice for a CES production function. Moreover, we assume constant return to scale since Lafrogne-Joussier et al. (2023) finds a full pass-through of positive energy price shocks on French firm microdata. Finally, the energy used by the firm is a bundle of electricity and fossil fuel, with an elasticity of substitution governed by the parameter ϵ_y .

1.2.2 Electricity sector

Electricity N in our model is a consumption good for households (N^h) and an intermediary input for firms (N^y). We assume electricity is produced competitively using labor l_N , capital k_N and fossil fuel F_N , according to the following program:

$$\max_{\{l_N, k_N, F_N, N\}} \Pi_N = p_N N - (r + \delta)k_N - w l_N - (p^F + \tau^f)F_N$$

such that

$$N = l_N^\eta k_N^\zeta F_N^{1-\eta-\zeta}$$

As explained in Section 2, we calibrate l_N and F_N to be very small, reflecting the fact that energy production is capital-intensive and is a small share of the total labor force and total fossil consumption.

1.2.3 Fossil fuel sector and the rest of the world

Fossil fuel F is imported from the rest of the world, at a fixed price p_F . The rest of the world uses this revenue to import goods and services X from the domestic economic. The budget constraint of the rest of the world is then:

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

1.3 State

The fiscal authority gets revenue from taxes on labor income, capital income, consumption, and carbon taxation. It uses its revenue to fund lump-sum transfers (T), public

spending (G) and public debt repayment ($r_t \bar{d}$). Denoting the aggregation $x_t = \int_0^1 x_{i,t} di$ for $x \in \{a, c, e^h\}$, the government has the following budget constraint:

$$T_t + G_t + r_t \bar{d} = \int_0^1 [z_{i,t} w_t l_t - \Gamma(z_{i,t} w_t l)] di + \tau^k r_t a_t + \tau^{\text{VAT}} (c_t + p_t^N N_t^h + p_t^F F_t^h) + \underbrace{\tau_t^h (1 + \tau^{\text{VAT}}) F_t^h + \tau_t^f (F_t^y + F_t^N)}_{\text{Carbon tax revenue}}$$

Following [Heathcote et al. \(2017\)](#), we assume a progressive labor tax of the form:

$$\Gamma(zwl) = \lambda(zwl)^{1-\tau}$$

Apart for the carbon tax revenue, the budget constraint clears with G_t . However, the carbon tax revenue can be separately allocated either to finance an increase in public spending, or to fund lump-sum transfers towards households, possibly contingent on income and location. We explore these different scenarios in Section 3.

1.4 Market clearing conditions and equilibrium

Finally, to close the model, we have the following market clearing conditions:

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

Households' savings are invested in capital in both sectors and in public debt, and labor supply is also allocated within both sectors. By no-arbitrage, we only have one wage and one interest rate in the model. The G&S production (y_t) is consumed by households (c_t), government (G_t) or foreigners (X_t), or invested by firms ($I_{e,t}, I_{y,t}$). Electricity N_t is consumed as intermediate inputs by firms (N_t^f), or as a commodity good by households (N_t^h).

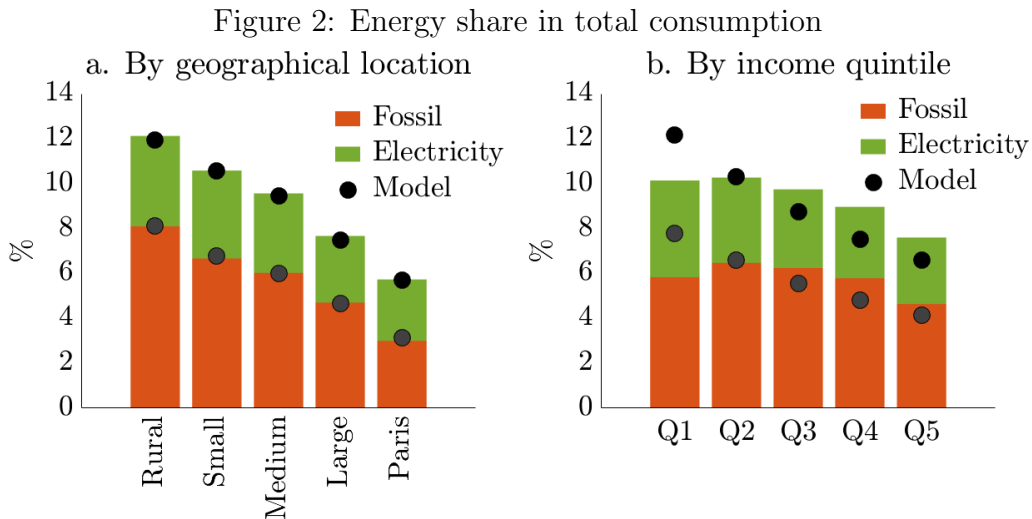
An equilibrium in this economy is defined as paths for households decisions $\{c_t, N_t^h, F_t^h, l_t, a_t\}_t$, G&S firm decisions $\{y_t, l_{y,t}, k_{y,t}, F_t^y, N_t^y\}_t$, electricity firm decision $\{N_t, l_{N,t}, k_{N,t}, F_t^N\}_t$, relative prices $\{r_t, w_t, p_t^N\}_t$, fiscal policies $\{\tau_t^h, \tau_t^f\}_t$, public expenditures $\{T_t, G_t\}_t$, and aggregate quantities, such that, for every period t , (i) households and firms maximize their objective functions taking as given equilibrium prices and taxes, (ii) the government budget constraint holds, and (iii) all markets clear.

2 Calibration on French macro and micro data

As this paper assesses the distributive effects of carbon taxation, the main point of the calibration is to reproduce the energy mix used by households and firms in France, with a special focus on the consumption heterogeneity related to living area and income. The complete calibration is summarized in Appendix A.

2.1 Households

Energy consumption: first, we need to fit the energy consumption heterogeneity both between and within income quantiles. We use $\bar{e}(k)$ to match the average energy share in each city types, and $\gamma(k)$ to have the right energy mix, as shown in Figure 2.a. We use Λ_e to match the average energy share in Paris, and ϵ_e is used to fit the nonhomotheticity in energy consumption (Figure 2.b).



Note: share of fossil fuel $[(p^F + \tau^h)F^h]$ and electricity $[p^N N^h]$ in total consumption expenditures $[c + (p^F + \tau^h)F^h + p^N N^h]$, by geographical location (Panel a) or disposable income quintile (Panel b).

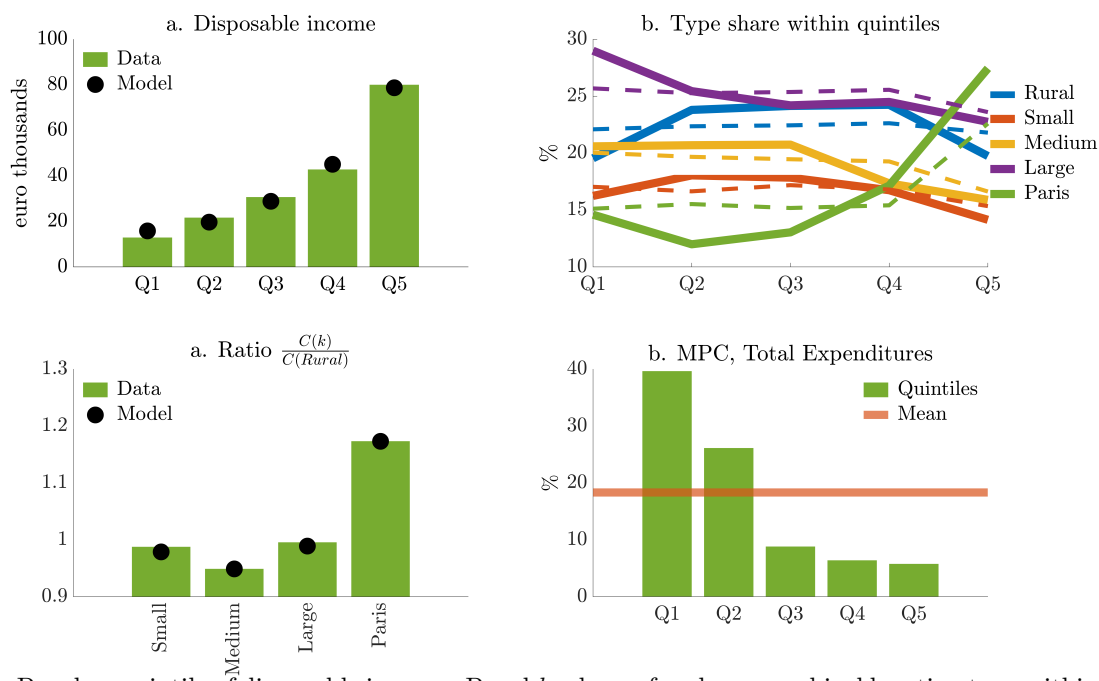
Source: BdF 2017 Insee survey.

We estimate σ , the elasticity of substitution between energy and G&S consumption, using National Accounts longitudinal data from Insee (Insee 2022 – NA), ranging from 1959 to 2021. Our regressions are described in Appendix A.3. We get $\hat{\sigma} = 0.26$, significant at the 1% threshold. Thus, we consider energy consumption as a substitute rather than as a complement to other consumption goods. Finally, we set the elasticity of substitution between fossil fuel and electricity to $\epsilon_h = 0.2$ because we focus on the upper bound effect of carbon taxation.

Income process: as changes in transfer, labor and capital incomes account for

a large part of the distributive effects of carbon taxation, we calibrate carefully the distribution of each type of income. We fit the disposable income distribution¹ (Figure 3.a), using the AR(1) persistence parameter ρ that we set equal for all types. We use the mean of the idiosyncratic productivity process for each type $\mu_z(k)$ to match the ratio of total consumption between types (Figure 3.c), and the variance $\sigma_z(k)$ to match the proportion of each geographical location type within each disposable income quintile (Figure 3.b). Our model recovers that high- and low-income households are concentrated in largest cities. We do not target the MPC, but as shown in Figure 3.d, we obtain an average MPC of 18%, which is in the range of empirical estimates, and is closed to Kaplan et al. (2018).

Figure 3: Consumption across areas and MPCs across income quintiles



Notes: Panel *a*: quintile of disposable income. Panel *b*: share of each geographical location type within each quintile in data (solid lines) and in the model (dashed lines). Panel *c*: average consumption of each types relative to rural households. Panel *d*: MPC out of liquid wealth by quintile of disposable income.

Sources: Panel *a*: RPM 2021 Insee survey. Panel *b* and *c*: BdF 2017 Insee survey.

Other parameters: we set the annual discount factor β to match the French capital to income ratio from Piketty and Zucman (2014) when excluding public debt and housing: $\frac{a}{GDP} = 2$. The borrowing constraint is set at $\bar{a} = 0$.

¹from the 2021 Insee survey “Revenus et patrimoine des ménages” (RPM 2021)

2.2 Firms

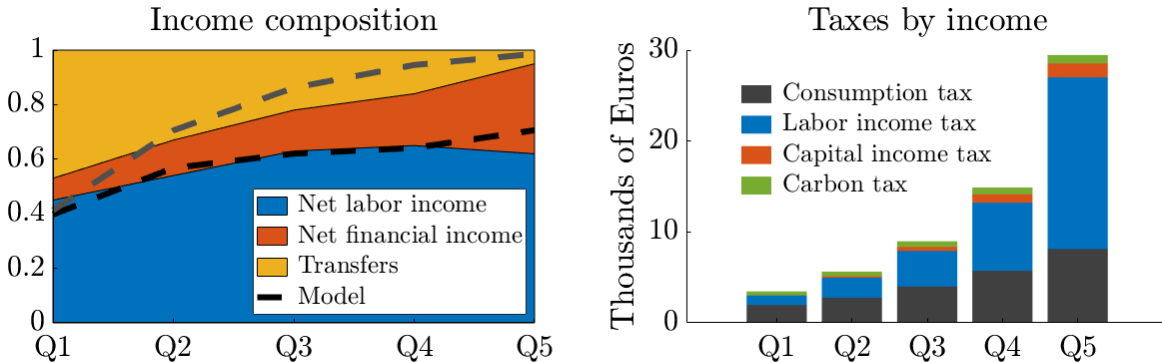
Goods and services firm: the energy share is set to $\omega_y = 0.43$ to account for the fact that the G&S sector represents 60% of total energy. The elasticity of substitution between energy and the capital-labor bundle is set to $\sigma_y = 0.4$ following [Artus and Peyroux \(1981\)](#) and [Hassler et al. \(2021\)](#). The capital share is set to $\alpha = 0.2$ to match the share of labor revenue $\frac{wl}{\text{GDP}} = 65\%$ following [Cette et al. \(2019\)](#). The share of fossil fuel in the policy mix is set to $\gamma_y = 0.22$ such that the G&S firm accounts for 59% of the total fossil fuel. We set the elasticity of substitution between fossil fuel and electricity to $\epsilon_y = 0.2$, as discussed above. Finally, the depreciation rate is set to $\delta = 11.28\%$ like in [Auray et al. \(2022\)](#).

Electricity firm: the electricity sector is capital intensive, so we set $\eta = 0.12$ to have $\frac{l_N}{l} = 2\%$ and $\zeta = 0.874$ to have $\frac{F_N}{F} = 1\%$. Finally, the exogenous price p^F of the imported fossil fuel is set such that fossil fuel imports account for 2% of the GDP.

2.3 Fiscal authority

We set lump-sum transfers according to the rule $T(z) = \frac{\bar{T}}{z} \left(\int_i \frac{1}{z_i} di \right)^{-1}$ to match the share of transfer in each disposable income quintile, as shown in Figure 4, left panel. We set the labor tax progressivity to $\tau = 0.1$ following [Auray et al. \(2022\)](#). The level of the tax λ is set such that public spending \bar{G} makes approximately 29% of GDP. Finally, we calibrate τ^h and τ^f initial levels so that energy taxes account for 3% of total government revenues². The resulting amount of tax paid by each households is shown in Figure 4, right panel.

Figure 4: Income composition and taxes by income quintile



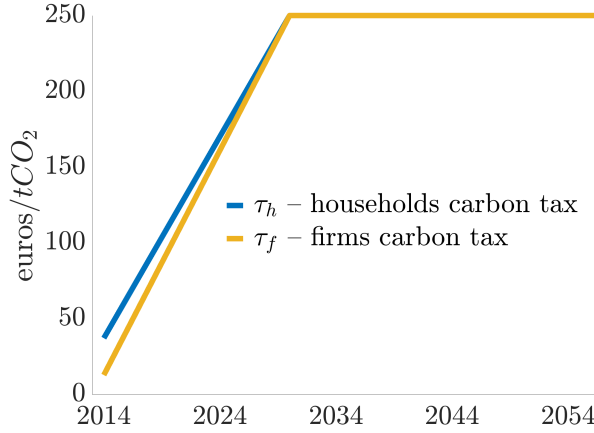
Notes: Panel *a*: composition of income in Insee 2018 data, and model fit. Panel *b*: taxes paid by households in the model.

²Additionally, we use the effective carbon tax estimates from the French Sustainable Development Agency (CGDD) to account for different energy mix and exemptions across households and firms. See Appendix A.2 for more details.

3 Quantitative results

Our main quantitative exercise implements an unanticipated, permanent increase in the carbon tax, following what should have happened in France between 2014 and 2030 after the [Quinet \(2019\)](#) report. This trajectory is plotted in Figure 5. After 2030, we keep the excise tax level unchanged at 250€/tCO₂. Initial taxes for households and firms are different, consistent with effective carbon taxes computations made by the French government³.

Figure 5: [Quinet \(2019\)](#) carbon tax shocks



In this section, our welfare results are presented in “consumption equivalent” term: we compute the change in steady-state consumption that would make the household indifferent between the steady-state statu-quo forever and the carbon tax increase path. Then we compute for each initial wealth a_0 and productivity z_0 the following equality:

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

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.

Finally, in subsection 3.1 and 3.2, we assume the government clears the budget constraint only by adjusting public spending, to isolate the distributive effects associated to carbon taxation. In 3.3, we consider alternative recycling scenarios for carbon

³See Appendix A.2. In our online Appendix, we perform the same increase in carbon taxes, but considering that the household-firm gap in effective carbon taxation rates will maintain over time.

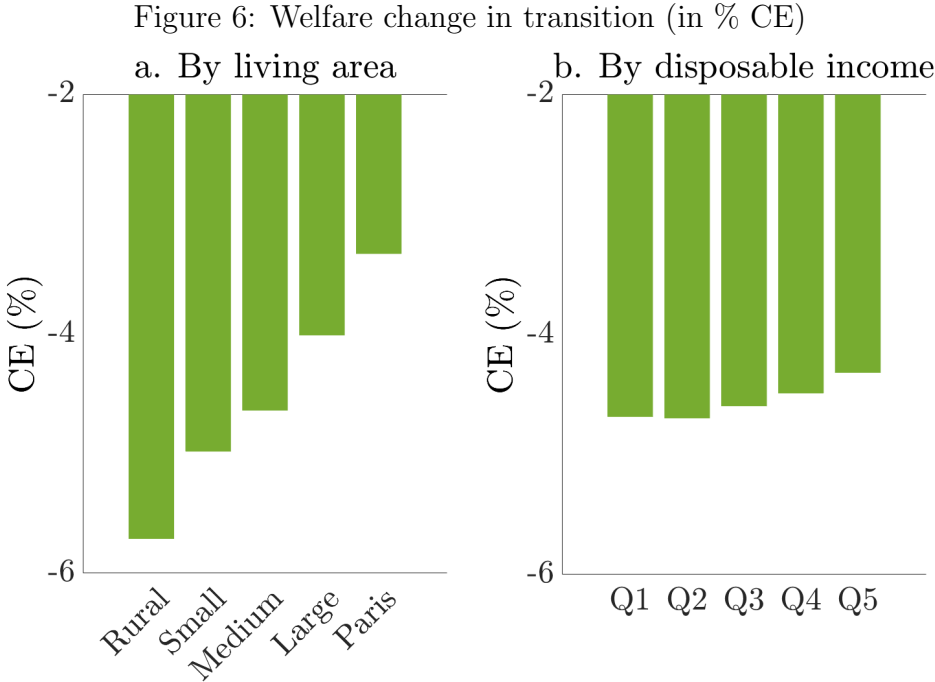
tax revenue, such as lump-sum transfer towards households, that may be contingent to income and location.

3.1 Geography trumps income

First, **rural households lose more than poor households** on average. In Figure 6, we find that the carbon tax is slightly regressive with respect to disposable income, but increases widely the rural-urban gap. In other words, geography trumps income to understand the distributive effects of carbon taxation, as the burden of the tax depends more on living area than on income.

On average, poorer households incur a slightly stronger loss (-4.8%) than top incomes (-4.3%). Indeed, the progressive distortion on labor and capital income, coming from the firms' carbon tax, mitigates the regressive effect of households' carbon tax, coming from the downward nonhomotheticity of energy consumption.

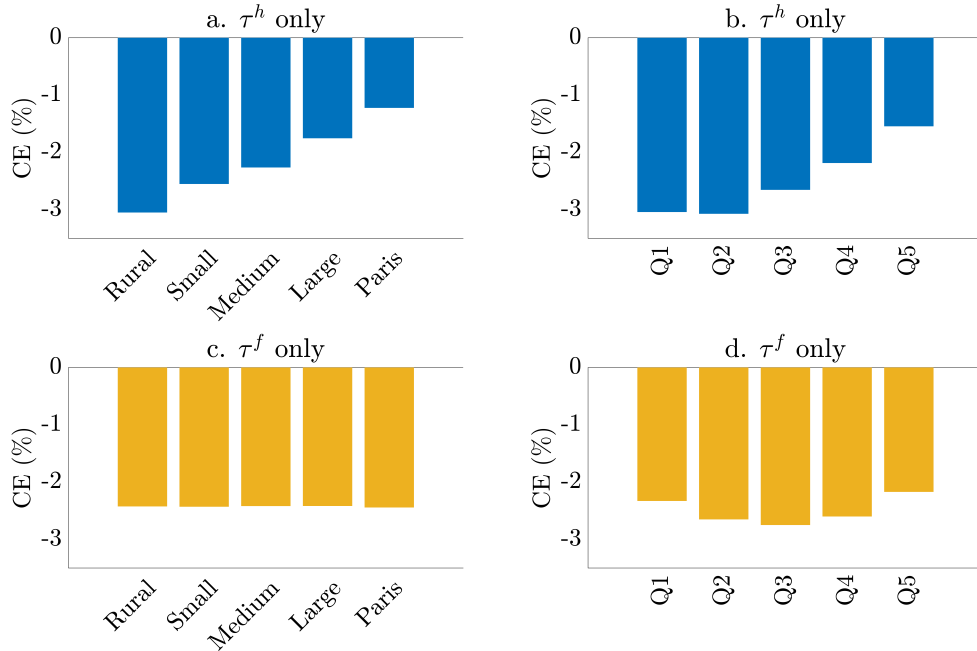
Rural households suffered from a 5.8% welfare loss while Parisian households' welfare only dropped by 3.2% . This is because the intermediate input tax is homogeneous across living areas while the final consumption tax affect disproportionately households with higher incompressible energy levels.



3.2 Taxing firms or households: a Diamond-Mirrless story

In this section, we focus on the distributive effects of taxing only households' energy consumption (final consumption tax, τ^h) or only firms' energy consumption (intermediate input tax, τ^f). Therefore, our story is closely related to the classical [Diamond and Mirrlees \(1971\)](#) paper. To provide a relevant comparison of the distributive effect of the two taxes, we calibrate the level of each tax such that they yield the same aggregate welfare loss (-2.5% CE). We conclude that **taxing households is regressive while taxing firms is rather progressive or flat**, as shown in Figure 7. Two main distortions of our model drive the result: the nonhomotheticity of energy consumption and the heterogeneous distribution of labor and capital income.

Figure 7: Welfare effects of carbon taxes by living area and by income



Notes: Panel *a* and *c* plots the effect on vertical and horizontal heterogeneity when increasing only the tax on households τ^h . Panel *b* and *d* show the same when raising only the tax on firms τ^f .

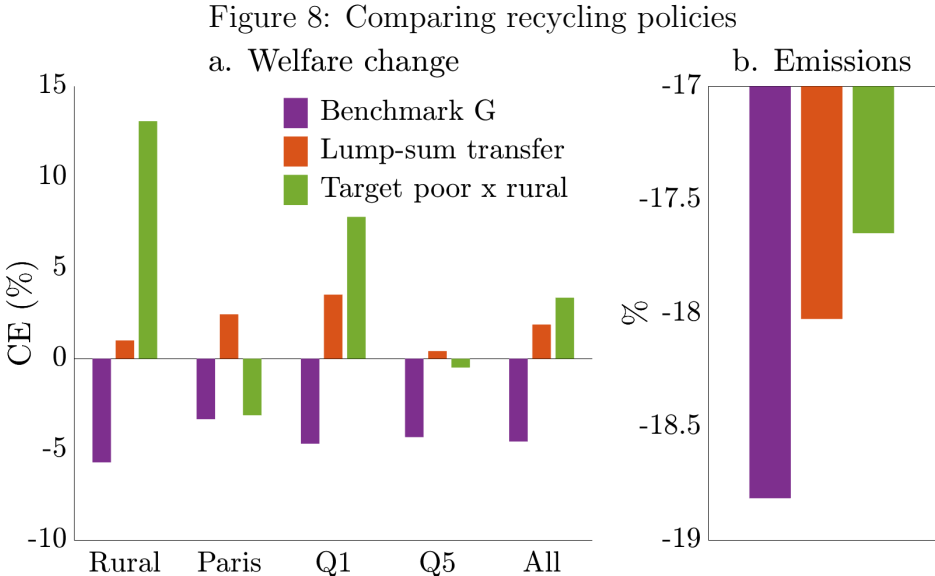
Taxing households' energy consumption is regressive because it affects disproportionately more households with a higher energy share in total consumption, *i.e.* poor and rural households. The household tax also reallocates resources from a capital intensive sector (energy) towards a more labor intensive sector (G&S). Therefore, capital income decreases and labor income raises after the tax. The borrowing constraint does not play a significant role at this point.

On the other hand, taxing firms' energy consumption is progressive. As in [Diamond and Mirrlees \(1971\)](#), it pulls away the economy from its technological productivity fron-

tier and reduces real wage and energy price. This affects disproportionately more rich households who earn capital and labor incomes, than low income households who rely on social transfers. Yet, the reallocation towards a capital intensive sector (electricity sector N) mitigates the loss at the top of the wealth distribution. Plus, the drop in activity incomes reduces the idiosyncratic risk for the top of the distribution⁴. Therefore, taxing firms hurts more the middle of the distribution (Q3) that holds a bigger labor income share, and is somewhat flat across geographical types.

3.3 The equity-efficiency trade-off of recycling policies

We have shown in subsection 3.1 that geography is more important than income to understand the losers of carbon taxation. Therefore, a natural question arises about the possibility to compensate these losses, using the carbon tax revenue, while preserving the positive effect of emissions reduction. In this section, we allow the government to use the carbon tax revenue to either (i) increase public spending (*Benchmark G*), (ii) increase uniform lump-sum transfers (*lump-sum transfer*), or (iii) implement targeted transfers toward low-skilled and rural households (*Target poor \times rural*). In Figure 8, we compare these three scenarios in the light of three objectives: optimizing households' welfare, reducing CO₂ emissions and minimizing the number of losers. Indeed, the aggregate welfare is not enough to deal with the political acceptability of the tax: if the redistribution increases total welfare by compensating the more affected households, but creates many little losers, the carbon taxation may still be rejected.



⁴See Appendix B

While our benchmark increase in public spending was bad for welfare (as G does not enter the utility function), rebating the carbon tax revenues to households through lump-sum transfers is welfare enhancing. In our framework, lump-sum transfers mitigates the uninsured idiosyncratic risks. In other words, the borrowing constraint distortion is strong enough to offset the intermediate input tax distortion. Indeed, the share of losers drops from 100% in the *Benchmark G* scenario to 10% with the uniform transfer. Additionally, total emissions drop less than in *Benchmark G*. But the gap is not huge: lump-sum transfers, by mitigating idiosyncratic productivity risks, reduce labor supply and savings motives. Therefore, **it is possible to reduce both emissions and disposable income inequalities, and to increase aggregate welfare, at the same time.**

However, the “uniform transfer” scenario widens the rural-urban gap, and concentrates losers in rural areas. If we try to target this geographical heterogeneity, a trade-off arises. The bigger policy losers are rural households: a social planner may want to compensate these disproportionate losses through targeted transfers. As shown in Figure 8.a, this “poor and rural” transfer simultaneously reduces vertical and horizontal heterogeneity, and is the best scenario to increase aggregate welfare, which increases by 4.5% compared to 2.7% in the uniform scenario. However, emissions drop by less: -18% vs -17.6% . This is because targeted transfers reallocate resources towards households with high incompressible energy consumption levels. Furthermore, the share of losers bounce back with almost 45% of households losing from the policy. In this scenario, we have much more losers but those losers incur very little losses. They are now over-represented in large cities and uniformly distributed across disposable income groups.

All in all, **we show that there exists a dilemma between compensating rural households, reducing the number of losers to favor political acceptability, and reducing emissions.** Through uniform transfers, the government can achieve a high emissions reduction and increase welfare, at the cost of widening the urban-rural gap and concentrating the losers in rural areas. Targeted transfers allow to reach a higher aggregate welfare while compensating the rural households, but this also reduces the decline in emissions, and creates more small losers. It is left to the social planner to choose between these different objectives, taking into account that communication is key in the implementation of carbon taxation.

4 Conclusion

In this paper, we assess the distributive effects of carbon taxation with a quantitative heterogeneous-agent framework. While most of the literature has focused on income

heterogeneity, we highlight living areas heterogeneity, as households face higher incompressible energy consumption levels in rural areas. We simulate a linear 15-year increase in carbon tax, and first show that geography is more important than income to assess the distributive effects of carbon taxation. Second, as energy is both a final consumption good for households and an intermediate input for firms, we compare the distributive effects of taxing only consumers or firms. We find that households' carbon tax is regressive as it affects people with a high energy share, while firms' carbon tax is progressive as it reduces labor and capital incomes. Third, we show that there exists different ways to recycle the carbon tax revenue. A uniform transfer allows to reduce emissions and to increase welfare, but it widens the rural-urban gap, while a targeted transfer towards poor and rural households is more welfare-enhancing but reduces emissions by less and yields more losers among large cities.

We leave for future research the optimal carbon tax revenue recycling policy. We studied here polar scenarios for transfers, leaving aside the possibility to use the revenue to lower existing taxes or invest in the reduction of incompressible energy consumption. We yet believe that transfers are of primary importance for communication and political acceptability, as it explicitly separates the carbon tax revenue from the state budget, making clear that this tax aims at distorting behavior and not at financing public deficit. Finally, a possible research avenue would be to improve our geographical economy, allowing households to move across areas and to work on specific segmented local labor markets.

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A Complete calibration

A.1 Parameter values

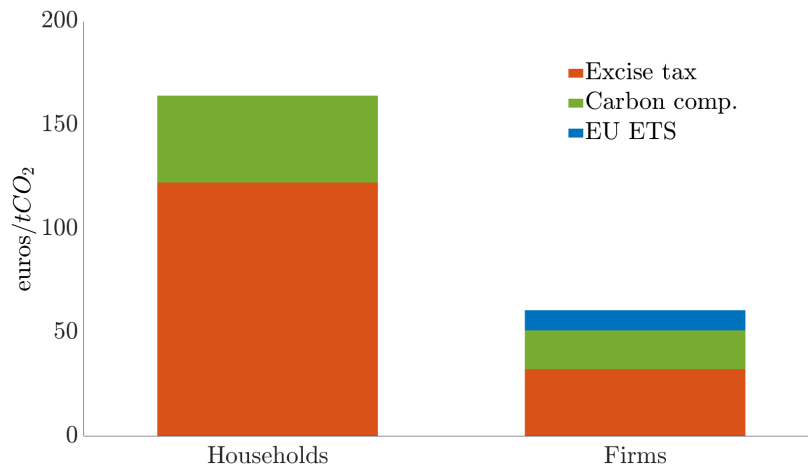
Table 1: Parameter values and steady-state targets.

Parameter	Description	Value	Notes
Households			
β	Discount factor	0.92	$\frac{a}{\text{GDP}} = 2$
θ	Intertemporal ES	1	Authors choice
$1/\psi$	Frisch elasticity	3	Lee (2021)
ϕ	Labor disutility	1	Normalization
σ	ES between c and e^h	0.26	Authors calculation
Λ_e	Energy share	0.155	$\frac{p_h e_h}{p_h e_h + c}$
ϵ_e	Non-homotheticity parameter	0.8	Energy share by disposable income
Λ_c, ϵ_c	Utility parameters	1	Normalization like in Comin et al. (2021)
$\gamma_h(k)$	Fossil share	[0.60, 0.67, 0.685, 0.695, 0.73]	$\frac{p_F F_h(k)}{p_F F_h(k) + p_N N_h(k)}$
ϵ_h	ES between F^h and N^h	0.2	Authors choice
$\Gamma(k)$	Living area share	[0.17, 0.25, 0.19, 0.17, 0.22]	Population in each type
$\bar{e}(k)$	Energy incompressible use	[0, 0.13, 0.27, 0.36, 0.48]	Energy share across types
ρ_z	Persistence z	0.9725	Income heterogeneity, aggregate
$\mu_z(k)$	Mean z	[0, -0.09, -0.11, -0.08, -0.08]	Average income for each type
$\sigma_z(k)$	Variance z	[0.34, 0.31, 0.3, 0.3, 0.305]	Heterogeneity within each type
\underline{a}	Borrowing constraint	0	Authors choice
Firms			
p^F	Price of fossil fuel	0.1	$\frac{p_F F}{\text{GDP}} = 2\%$
ω_y	Energy share	0.43	$\frac{p_y E_y}{p_h E_h + p_y E_y + p_F F_N} = 60\%$
σ_y	ES between e^y and (k, l)	0.2	Hassler et al. (2021), Artus and Peyroux (1981)
α	Capital share	0.2	$\frac{wl}{\text{GDP}}$ from Cette et al. (2019)
γ_y	Share of fossil in Y mix	0.22	$\frac{F_y}{F} = 59\%$
ϵ_y	ES between F^y and N^y	0.2	Authors choice
η	Labor share	0.11	$\frac{L_N}{l} = 2\%$
ζ	Capital share	0.886	$\frac{F_N}{F} = 1\%$
δ	Capital depreciation rate	11.28%	Auray et al. (2022)
Government			
\bar{T}	Transfers	0.3	$\frac{\bar{G}}{\bar{Y}} = 0.29$
\bar{d}	Public debt	0	Realistic MPCs
τ	Labor tax progressivity	0.08	From Ferriere et al. (2023)
λ	Labor tax level	0.75	From Ferriere et al. (2023)
τ^k	Effective corporate income tax	9.02%	Auray et al. (2022)
τ^{VAT}	VAT tax rate	20%	From PLF 2023

A.2 Effective carbon taxes

In France, CO₂ emissions by firms and households are not taxed at the same level. There are three reasons for that. First, energy taxes vary across sectors, energy products and geographical location. Since firms and households do not have the same location, consumption basket or energy mix (households use more oil, especially gasoline, firms consume more electricity and gas), this leads to different effective tax rates. Fuels represent 49% of households' energy consumption when oil products only make 27% of firms' energy consumption. Second, some sectors are part of the European Union Emissions Trading System (EU ETS). This explains why CGDD computations of effective carbon tax rates vary a lot for firms. In 2020, effective carbon tax rate reached 60.8€/tCO₂ against 83.2€/tCO₂ in 2022. Plus, there exists multiple reduced rates and exemptions for firms. To calibrate the initial carbon tax rates for households and firms, we take 2018 estimates, implying an effective rate for households three times larger than for firms.

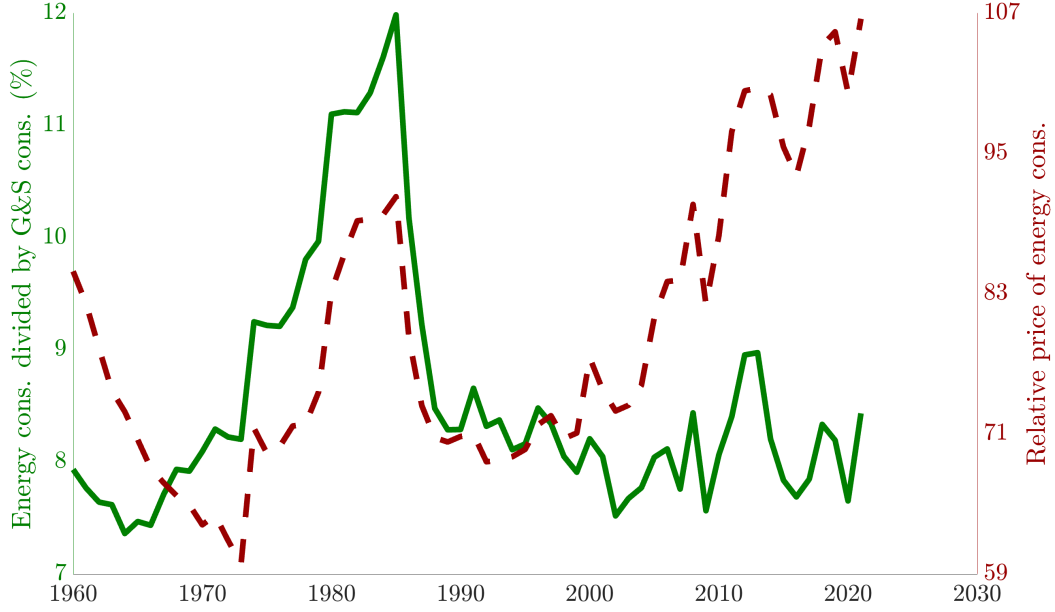
Figure 9: Effective carbon tax for France 2020



A.3 Household energy consumption: estimation of σ

In French longitudinal aggregate data taken from Insee 2022 national account, the consumption ratio comoves with the relative price of energy, see Figure 10. As explained in [Hassler et al. \(2021\)](#), if energy and G&S consumption were perfect substitutes, this would not happen. From the graph, we can isolate two periods. It seems that before 1990, the consumption ratio comoved more with p^e than after.

Figure 10: Effective carbon tax for France, CGDD computations



With [Comin et al. \(2021\)](#) preferences, we have that the elasticity of substitution between goods of different sectors is constant i.e.

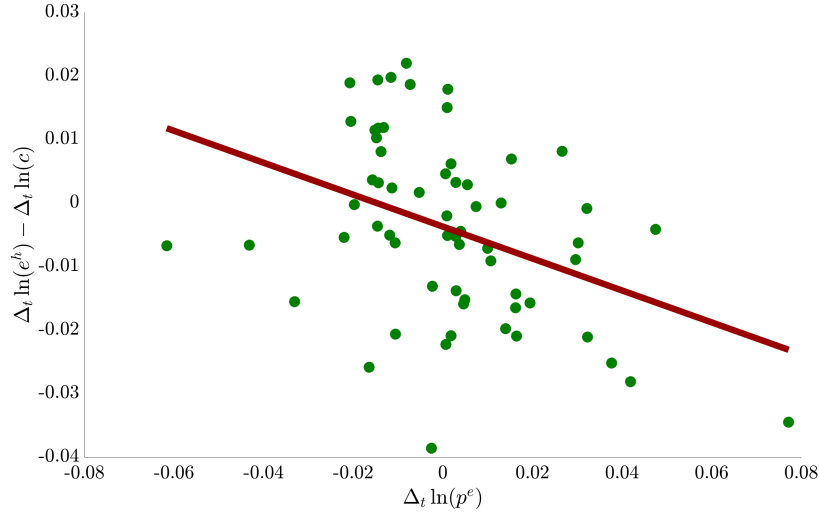
$$\frac{\partial \ln(c/(e^h - \bar{e}))}{\partial \ln(p_h)} = \sigma \quad (6)$$

Thus, we can estimate σ through the following equation:

$$\Delta \ln(e^h - \bar{e}) - \Delta \ln(c) = -\sigma \Delta \ln(p^e + \tau^h)$$

We finally get $\hat{\sigma} = 0.26192$, significant at the 1% level. Restricting our estimation to the 1960-1990 period, we get $\hat{\sigma} = 0.27242$, and taking only the 1990-2021 period we get $\hat{\sigma} = 0.2477$. Therefore, the households' elasticity of substitution between energy and other goods may be a structural parameter of the economy.

Figure 11: Effective carbon tax for France, CGDD computations



B Quantitative results – complements

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

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

Figure 12 shows this decomposition by productivity types for rural households. Top panels show what happens when you increase only τ^h while bottom ones deal with an increase of τ^f . The change in savings show how the borrowing constraint interact with the two carbon taxes.

Figure 12: Rural households

