WORKING PAPER

n°2024-12

Macroeconomic Risk Chair
SCOR-PSE

Geography Versus Income: The Heterogeneous Effects of Carbon Taxation

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Macroeconomic risk

Executive Summary

Carbon taxes stand among the most effective instruments for mitigating greenhouse gas emissions. However, they induce strong distributional costs, as energy represents a larger share of expenditures for low-income and rural households. These distributional effects are likely to reduce the political acceptability of carbon taxation, as shown in France with the Yellow Vests protest and the subsequent carbon tax freezing. These asymmetric costs, and the lack of political acceptability that follows, pose a significant risk to the green transition. Therefore, a socially acceptable carbon taxation design should account for its redistributive effects.

In this working paper, Charles Labrousse and Yann Perdereau develop a dynamic general equilibrium model with both income and geographic heterogeneities, to capture that energy expenditures heavily depends on living area and revenue. Both imported fossil energy and locally produced cleaner energy are consumed as a non-homothetic final good by households and an intermediate input by firms. The model is precisely calibrated using French micro data, to match the energy bundle composition within each income quintile and living area. A gradual, permanent increase in carbon taxes on fossil energy used by firms and households is simulated, possibly at different rates. The model computes the aggregate and distributional welfare costs associated with this transition, considering various revenue-recycling policies.

The paper's results highlight the distributive and political risks associated with the green transition. Firstly, geography outweighs income or wealth in determining the distributive effects of carbon taxation. While the fiscal burden is relatively evenly distributed across income quintiles, it varies significantly across living areas. Rural households bear approximately twice the cost of urban households due to their higher incompressible energy needs.

Secondly, taxing households' emissions is considerably more regressive than taxing emissions from firms. Taxing households' energy consumption is regressive, because of the non-homotheticity of energy consumption, disproportionately affecting low-income and rural households. Conversely, taxing firms' energy consumption reduces both capital and labor income, affecting high-income households to a greater extent. Thirdly, it is possible to reduce emissions and make the policy progressive with respect to income. A 250 €/tCO2 carbon tax with a uniform lump-sum rebate reduces CO2 emissions by 18% per year, while enhancing overall welfare and reducing income inequality. However, this uniform transfer widens the rural-urban gap. Compensating for the loss experienced by rural households through targeted transfers entails a trade-off between equity and climate efficiency, as rural households exhibit a higher marginal propensity to consume energy. Compensating rural households is welfare-improving but comes with a 6% increase in total emissions compared to the uniform lump sum transfer.

In conclusion, the paper contributes to understanding the political risks associated with the green transition and proposes a more equitable and socially acceptable framework for carbon taxation. The paper argues that targeted transfers are crucial for communication and political acceptability. These transfers explicitly distinguish carbon tax revenue from government budget, clarifying that the tax aims to alter behavior rather than finance public deficits. Finally, this research emphasizes the paramount importance of geography in comprehending the aggregate and distributional effects of carbon taxes, hence suggesting that future carbon tax designs should take geographical factors into account.

Geography versus income: the heterogeneous effects of carbon taxation

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March 22, 2024

Abstract

Distributive effects of carbon taxation are key for its political acceptability. We introduce geographical heterogeneity into a calibrated dynamic general equilibrium heterogeneous-agent model, where energy is both a consumption good and an intermediate input. We evaluate the aggregate and distributive effects of carbon taxation and obtain three key results. Firstly, geography outweighs income in determining the distributive effects of carbon taxation, as rural households bear larger welfare losses. Secondly, taxing households' direct emissions is regressive, while taxing firms' direct emissions is progressive. Thirdly, we quantify the aggregate and distributive effects of various revenue-recycling policies that implement targeted transfers. We find that it is possible to reduce emissions and mitigate political risks associated with the green transition.

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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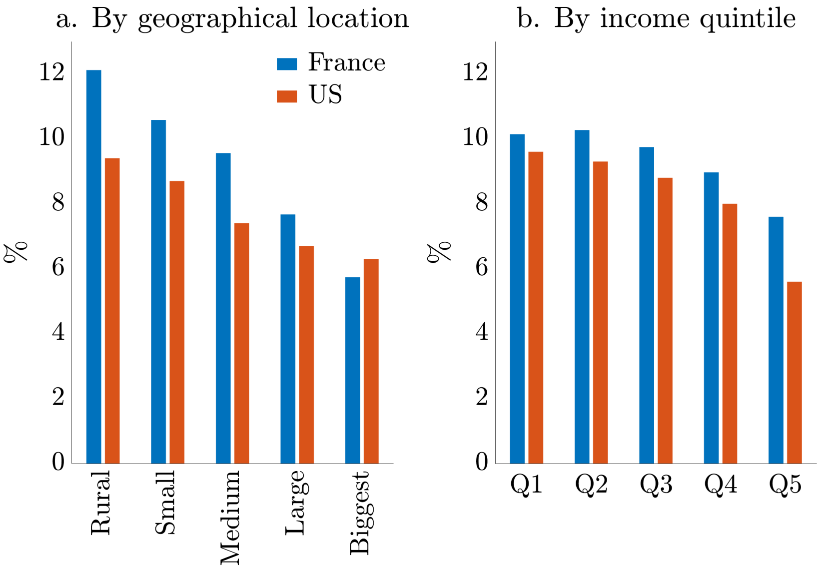
We are deeply grateful to Axelle Ferriere and Katheline Schubert for their help since the beginning of this project. We also thank for their precious advice: Barbara Annicchiarico, Adrien Auclert, Tobias Broer, Mireille Chiroleu-Assouline, Thomas Douenne, Eustache Elina, Adrien Fabre, Mouez Fodha, Stephie Fried, François Langot, Martí Mestieri, Gilbert Metcalf, Mar Reguant, Fabien Tripier, and seminar participants at conferences and seminars for their helpful comments. Finally, we thank organizers and participants of the French General Secretary for Ecological Planning (SGPE).

1 Introduction

Carbon taxes reduce emissions but induce strong distributional costs, as energy represents a larger share of consumption for low-income and rural households. These distributive effects are likely to reduce the political acceptability of carbon taxation, as illustrated in France with the Yellow Vests protest and the subsequent carbon tax freezing. Consequently, designing socially acceptable carbon taxes requires careful consideration of its distributional impacts. While existing literature has predominantly focused on the "rich versus poor" dimension of the energy transition burden, the geographical heterogeneity of energy consumption patterns remains a crucial feature. As depicted in Figure 1 for U.S. and French micro data[1], energy expenditure shares greatly vary across living areas. Rural areas communities are characterised by higher incompressible energy needs related to transportation and heating, while urban households benefit from public transportation and live in smaller housing units.

Figure 1: Energy share in total expenditure


a. By geographical location
b. By income quintile

In this paper, we emphasize the importance of geographical constraints in analysing both aggregate and distributive effects of carbon taxes. We introduce living area heterogeneity and energy consumption within a heterogeneous agent dynamic general equilibrium model. By adding household types with different incompressible energy consumption levels to the Aiyagari (1994) framework with idiosyncratic productivity shocks, we capture the rich heterogeneity in energy use across households. We use the model to compute both aggregate and distributive effects of carbon taxes, modelled as taxes on

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[1] See Appendix A.1 for more detail on data sources and classifications.

energy use. Our multi-sector model also allows to study the general equilibrium effect of these taxes. Finally, we consider different revenue-recycling scenarios and propose a design for an efficient and socially acceptable carbon taxation framework. Our analysis yields three key findings.

Firstly, **geography outweighs income or wealth in determining the distributive effects of carbon taxation**. We consider a gradual increase in the carbon tax reaching 250 euros per ton of CO_2 in 2030, and compute the welfare change along the transition, measured in consumption equivalent (CE) terms. As energy is a non-homothetic good, it weighs more in low-income households' expenditures, so that the first income quintile experiences a welfare drop of -6.3% CE after the tax increase, against -5.0% for the fifth income quintile. However, the gradient associated to the living area heterogeneity is stronger. Rural households, featuring high incompressible energy needs, experience a welfare decrease by -7.3%, against -4.0% for households living in largest cities.

Secondly, **taxing households' direct emissions is regressive, while taxing firms' direct emissions is progressive**. In our model, energy is both a consumption good for households, and an intermediate input used by firms, hence we have two carbon taxes. Taxing fossil energy consumed directly by households hits mostly low-income people, due to the non-homotheticity of energy, and rural households, due to higher energy needs and a more fossil-intensive energy-mix. Therefore, taxing direct households' emissions is regressive, with a welfare change equal to -2.5% CE for the first income quintile against -1.6% for the fifth. Conversely, taxing fossil energy used as an intermediate input by firms is progressive. As in Diamond and Mirrlees (1971), intermediate input taxation distorts firms' optimal input allocation, reducing activity incomes. Households with higher labor and capital income shares are more affected than low-income households, for whom public transfers represent a higher income share. When increasing only the tax on firms' emissions, welfare losses reach -1.8% for low-income households (Q1) against -2.1% for high-income ones (Q5).

Thirdly, we find it possible **to reduce emissions while addressing political risks associated with the green transition**. We allow the government to use the carbon tax revenue to increase public spending, which is our benchmark scenario, or lump-sum transfers, either uniformly across households, or targeted towards rural or poor. While increasing public spending achieves the best reduction in emission because they are less energy intensive, it is dominated by transfer policies in terms of welfare. Indeed, our favorite lum-sum transfer scenario, targeting both low-income and rural households, increases aggregate welfare by 5.4% CE, but emissions increase by 0.8% each year with respect to our benchmark scenario, implying a stock of emissions 50%

larger over 50 years. This scenario allows to mitigate political risks associated with carbon taxation frameworks. However, we also quantify that our favorite transfer policy makes more losers in big cities and high income groups than uniform transfers, while the latter concentrates losers among rural households.

Our paper contributes to the literature assessing the distributive effects of climate policies in general equilibrium models. First, we emphasize the importance of geographical heterogeneity. Second, we consider general equilibrium effects. Third, we distinguish between taxes on households' energy consumption and taxes on firms' intermediate energy inputs. We then broadly relate to two strands of the literature: the distributive effects of carbon taxation, and the general equilibrium effects of carbon taxes.

The literature on the *distributive effects of carbon taxation* analyzes the heterogeneous fiscal incidence of energy taxes across households, using micro-simulation, Computable General Equilibrium (CGE) or heterogeneous-agent general equilibrium models. Based on micro-simulations, Cronin et al. (2019) for the U.S. and Douenne (2020) in the French context, conclude that carbon taxes, as a share of consumption, are regressive, and that most of the heterogeneity lies within income quantiles. We confirm these findings for the households carbon tax, adding a firm carbon tax within a general equilibrium set-up. Within the CGE literature, Rausch et al. (2011) and Goulder et al. (2019) conclude that the progressivity of source-side effects offsets the regressive use-side effects in the U.S., while Ravigné et al. (2022) estimates that the overall effect is still regressive in France. Compared to these papers, our income and wealth distribution is endogenous, based on idiosyncratic income risks, and we introduce a horizontal heterogeneity related to living areas. In this regard, we are closer to the heterogeneous-agent general equilibrium model. Fried et al. (2023) focuses on the optimal recycling of carbon tax revenue in a life-cycle model, allowing the government to use the carbon tax revenue to lower any existing tax. In this paper, 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, with a role for inflation and monetary policy. As them, we find that transfers are a powerful tool to mitigate the cost of energy transition. We depart from their framework by considering a tax on households, while they focus on energy consumed by firms. Langot et al. (2023) studies the tax-shield implemented in France in 2021. We focus on carbon taxes, adding living areas heterogeneity, producing a rich and realistic households heterogeneity in energy use. Moreover, we 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.

In this paper, we also emphasize the importance of *general equilibrium effects* to assess the aggregate and distributive effects of carbon taxation. As highlighted in Rausch et al. (2011), “source-side” effects may dominate “use-side” effects: the change in relative factor price and income may create more distortions than the substitution effects for the households. Due to the heterogeneous exposure of households to various types of income, these source-side effects are likely to modify the distributive effects associated to the carbon tax. Metcalf (2023) explains that “the conventional view that a carbon tax is regressive needs to be re-examined given the importance of source-side impacts”. We follow this idea and decompose our results between taxes on firms’ direct emissions and taxes on households’ direct emissions. A general equilibrium framework is also needed to compare the different carbon tax revenue-recycling scenario. Barrage (2020) shows that considering existing distortionary taxes is necessary to compute the optimal carbon tax. We add an important distortion to their framework: the incomplete financial market, which makes lump-sum transfers welfare-improving, as they allow agents to self-insure against idiosyncratic productivity shocks. Känzig (2023) shows that indirect effects matter for the distributive impact of carbon taxation, as poor households work in sectors more strongly hit by demand shocks triggered by carbon tax increases. We analyze these indirect effects by proposing a three-sector model, where clean energy is produced locally, fossil energy is imported, and the final good sector uses both clean and fossil energy, creating a reallocation between energy sectors. Finally, Metcalf (2019) shows that carbon tax may be progressive as they distort activity income while transfer income are indexed: we obtain the same result in our experiment for the increase in energy tax on firms only.

The remainder of the paper is organized as follows. Section 2 presents our quantitative model. Section 3 discusses our calibration choices using French data. Section 4 presents the quantitative results. Finally, Section 5 concludes.

2 A quantitative Heterogeneous-Agent model

Our main focus is the distributive effects of carbon taxation. Therefore, 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 final good producer using capital, labor, electricity and imported fossil fuel as intermediate inputs. Another representative firm produces electricity using capital labor and imported fuel. Finally, the fiscal authority has a complete set of instruments: a progressive labor income tax $\Gamma(.)$, a flat capital income tax τ^k, a VAT tax τ^{VAT} and carbon taxes $\{\tau_t^h, \tau_t^f\}_t$. The Government uses the carbon tax revenue either to increase public spending or to implement targeted transfers.

2.1 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 several 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[2]:

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

subject to:

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

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

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

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[2] Denoting a the assets, z the idiosyncratic productivity, the Bellman equation is defined as $V(a,z,k) = \max_{u,a',l} \left\{ \frac{u^{1-\theta}-1}{1-\theta} - \phi \frac{l^{1+\psi}}{1+\psi} + \beta \mathbb{E}_{z'} \left[V(a', z', k) | z \right] \right\}$, such that Equations (1) to (5) hold.

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

$$a_{i,t} \geq \underline{a} \tag{5}$$

Equation 1 implicitly defines utility following Comin et al. (2021), which is appealing for two 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 allows for imperfect substitution between energy and other goods, with a constant elasticity of substitution. On top of this utility function, we introduce an incompressible consumption level $\bar{e}(k)$ that differs across living areas, accounting for higher energy needs in rural areas compared to urban areas (lack of public transportation, less efficient transportation system, bigger houses...).

Equation 2 describes 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 defines the budget constraint of households, subject to four 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 $\Gamma(\cdot)$ defined later. Capital income is subject to a flat tax at rate τ^k. Finally, households receive lump-sum transfers 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** depicts 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", producing high marginal propensity to consume households at the bottom of the disposable income distribution.

2.2 Three-sector model

2.2.1 Goods & Services sector

Consumption good y is consumed by households (c), government (G) or foreigners (X), 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

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

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

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 using French firm microdata. Finally, the energy used by the firm is a bundle of electricity and fossil fuel, with an elasticity of subtitution governed by the parameter ϵ_y.

2.2.2 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:

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

such that

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

2.2.3 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:

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

This assumption allows us to focus on domestic general equilibrium effects, taking rest of the world dynamics neutral.

2.3 Fiscal authority

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 $x_t = \int_0^1 x_{i,t}\mathrm{d}i$ for $x \in \{a, c, e^h\}$, the government has the following budget constraint:

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

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 4.

2.4 Market clearing conditions and equilibrium

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

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

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) is consumed by households (c), government (G) or foreigners (X), or invested by firms (I^e, I^y). Electricity N is consumed as intermediate inputs by firms (N^y), or as a commodity good by households (N^h).

We define the equilibrium as paths for households decisions $\{c_t, N_t^h, F_t^h, l_t, a_t\}_t$, G&S firm decisions $\{y_t, l_t^y, k_t^y, F_t^y, N_t^y\}_t$, electricity firm decision $\{N_t, l_t^N, k_t^N, F_t^N\}_t$, relative prices $\{r_t, w_t, p_t^N\}_t$, fiscal policies $\{\Gamma(.), \tau^k, \tau^{\text{VAT}}, \tau_t^h, \tau_t^f\}_t$, 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.

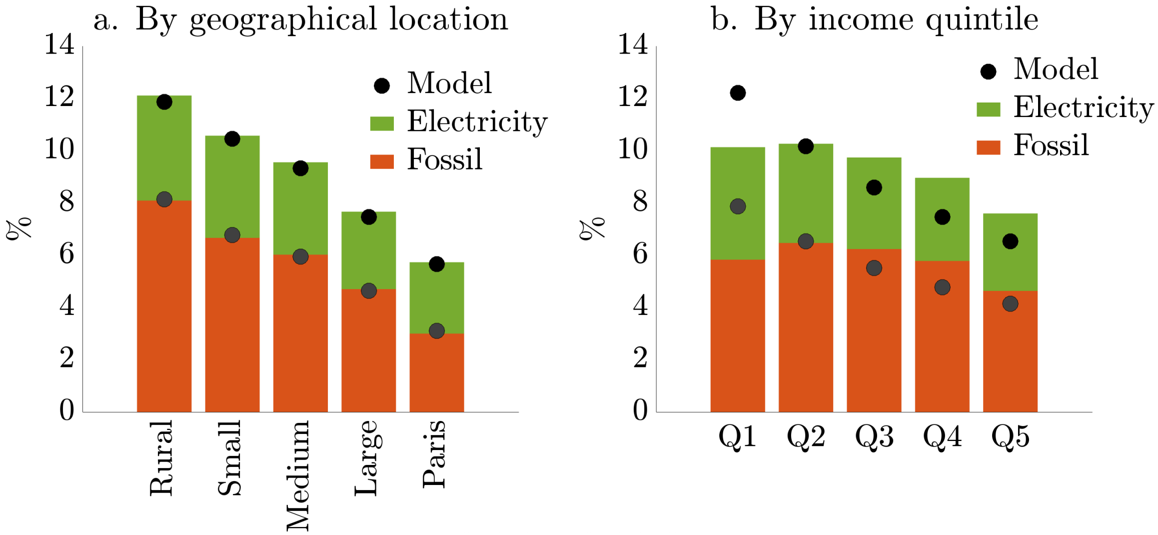
3 Calibration on French macro and micro data

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. Appendix A.2 presents a complete Table with all our parameters.

3.1 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 estimated to fit the nonhomotheticity in energy consumption.

Figure 2: Energy share in total consumption



a. By geographical location

b. By income quintile

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.5. 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. We assume the same elasticity of substitution across energy types for firms (ϵ_y). Appendix C.1 presents our benchmark results with other choices since literature estimates range from 0.02 in the short-run in Hassler et al. (2021) to 2 in the long-run for Papageorgiou et al. (2017).

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 distribution[3] (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 out of liquid wealth transfers of 18%. That is in the range of empirical estimates, and close to Kaplan et al. (2018).

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[3] from the 2021 Insee survey "Revenus et patrimoine des ménages" (RPM 2021)

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 income quintile.
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: $\frac{a}{\text{GDP}} = 2$. The borrowing constraint is set at $\bar{a} = 0$. Like in Kaplan et al. (2018), we set the intertemporal elasticity of substitution (IES) $1/\theta$ to 1. Finally we set our Frisch elasticity $1/\psi$ to 3, a little higher than in Ferriere et al. (2023). This aims at recovering plausible labor supply adjustments at the bottom of the disposable income distribution.

3.2 Firms

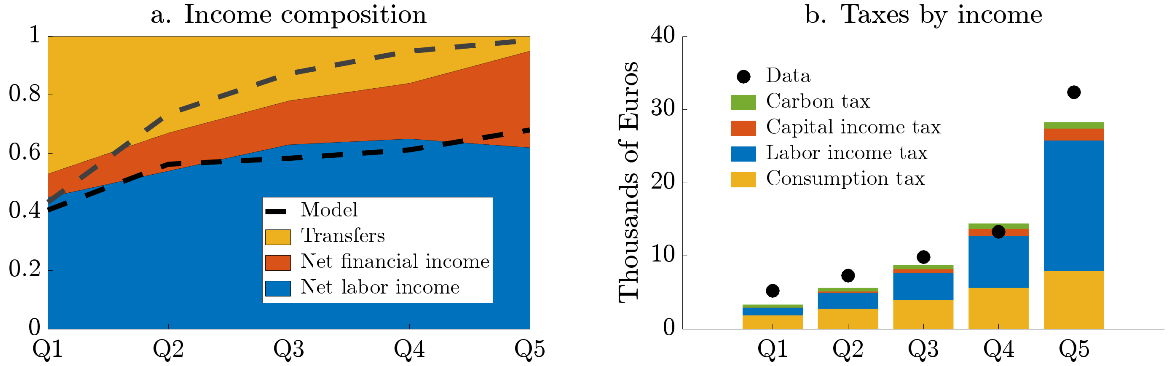
Goods and services firm: the energy share is set to $\omega_y = 0.43$ to account for the fact that the G&S sector represents 60% of total energy. The elasticity of substitution between energy and the capital-labor bundle is set to $\sigma_y = 0.4$ following Artus and Peyroux (1981) and Hassler et al. (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 $\delta = 5.1\%$ to match the aggregate share of investment in GDP (10%).

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 $\frac{F_N}{F} = 1\%$. We assume that electricity is produced using few fossil fuel inputs because France relies mainly on nuclear power plants and hydroelectricity from dams. Finally, the exogenous price p^F of the imported fossil fuel is set such that fossil fuel imports account for 2% of the GDP. Since France is a little country, we can assume that French demand shocks do not affect fossil fuels world prices.

3.3 Fiscal authority

We set lump-sum transfers according to the rule $T(z) = \frac{\bar{T}}{z}\left(\int_i \frac{1}{z_i}\mathrm{d}i\right)^{-1}$ to match the share of transfer in each disposable income quintile, as shown in Figure 4.a. We set the labor tax progressivity to $\tau = 0.08$ following Ferriere et al. (2023). The level of the tax λ is set such that public spending $\bar{G}$ makes approximately 29% of GDP. We set the effective VAT rate τ^{VAT} to 22.24% and the effective capital income tax rate to 9.02% following Auray et al. (2022) estimates. Finally, we calibrate τ^h and τ^f initial levels so that energy taxes account for 7% of total government revenues[4]. The resulting amount of tax paid by each households is shown in Figure 4.b. The fit with data is good, as we mostly miss corporate taxes in the model.

Figure 4: Income composition and taxes by income quintile


a. Income composition

b. Taxes by income

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

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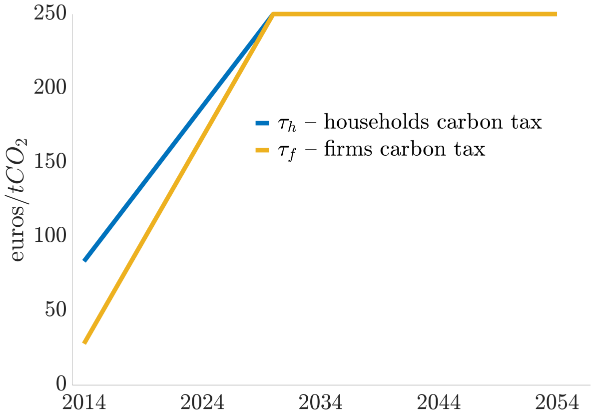
[4] Additionally, we use the effective carbon tax estimates from the French Sustainable Development Agency (CGDD) to account for different energy mix and exemptions across households and firms. See Appendix A.4 for more details.

4 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 the initial shock, households know for certainty the path for carbon taxes. After 2030, we keep the excise tax level unchanged at 250€/tCO$_2$. Initial taxes for households and firms are different, consistent with effective carbon taxes computations made by the French government (see Appendix A.4).

Figure 5: Experiment: Increase in carbon taxes



In this section, our welfare results are presented in "consumption equivalent" (CE) terms: we compute the 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[5]. In subsection 4.1 and 4.2, we assume the governement clears the budget constraint only by adjusting public spending, to isolate the distributive effects associated to carbon taxation. In 4.3, we consider alternative recycling scenarios for carbon tax revenue, such as lump-sum transfer towards households, that may be contingent to income and location. Transitional dynamics of aggregate variables are shown in Appendix B.2.

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[5] Formally, we compute for each initial wealth a_0 and productivity z_0 the following equality:

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

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. Numerical implementation is described in Appendix B.1.

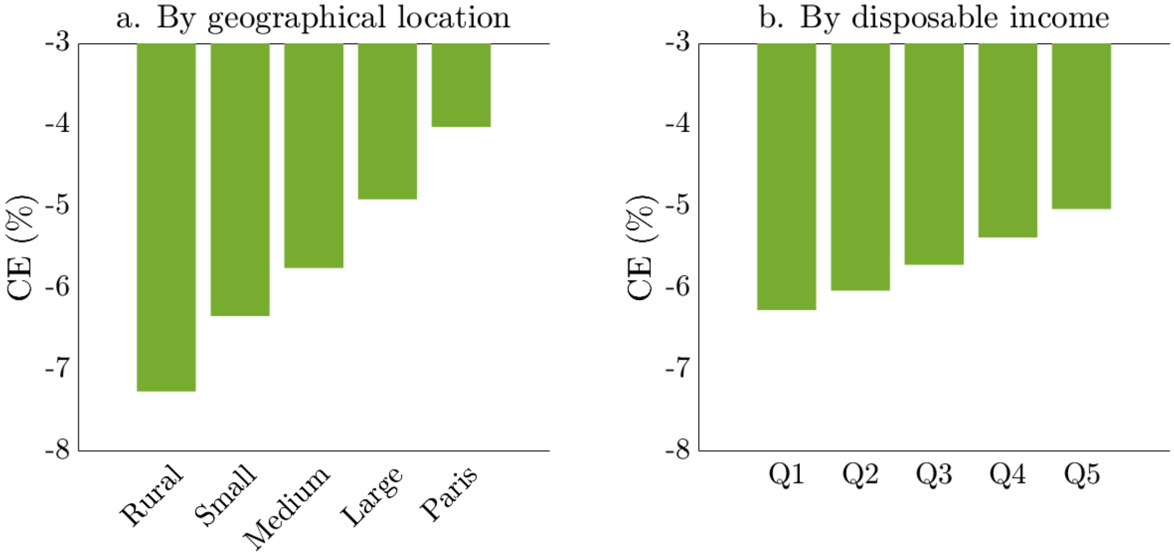
4.1 Geography trumps income

First, **rural households lose more than low-income households** on average. In Figure 6, we find that the carbon tax increase 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.

Along the income dimension, poorer households incur a slightly higher average loss (-6.2% CE) than top incomes (-5.1%). As shown in next section, 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.

Therefore, the geographical dimension appears more relevant. Rural households suffered from a 7.2% welfare loss while Parisian households' welfare only drops by 4%. This is because the intermediate input tax is slightly homogeneous across living areas while the final consumption tax affect disproportionately households with higher incompressible energy needs.

Figure 6: Welfare change in transition (in % CE)



We confirm these findings by performing a weighted linear regression of the welfare change on disposable income and geographical location[6]. While the geographical location explains $R^2 = 77\%$ of welfare losses variability, disposable income only reaches $R^2 = 12\%$ and wealth $R^2 = 16\%$. This confirms that geographical heterogeneity is

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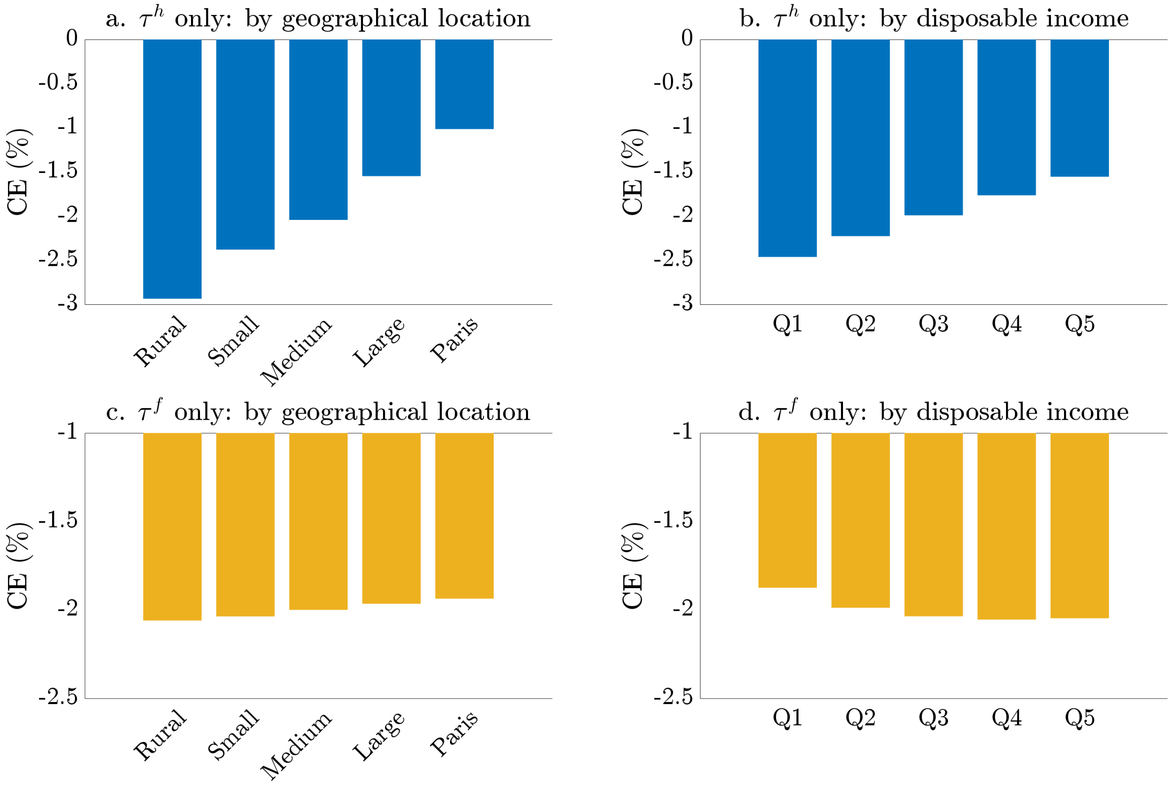
[6] $\text{CE}_i = a_0 + a_1 \text{Disposable income}_i + a_2 \bar{e}_i + u_i$.

more important than income inequalities to understand the distributive effects of carbon taxes.

4.2 Taxing firms' or households' direct emissions

In this section, we focus on the distributive effects of taxing only households' fossil fuel consumption (final consumption tax, τ^h) or only firms' fossil fuel 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% 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 incomes.

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 only households' fossil fuel 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. The household energy tax therefore induces a higher welfare loss for rural (-2.9% CE) and low-income households (-2.5%), compared to Parisian (-1%) and high-income households (-1.6%).

On the other hand, taxing firms' direct emissions is progressive. As in Diamond and Mirrlees (1971), it pulls away the economy from its technological productivity frontier and reduces real wage and energy price. This affects disproportionately more medium and high-income households who earn capital and labor incomes, than low-income households, for whom public transfers represent a higher income share. Yet, the reallocation towards a capital intensive sector (electricity sector N) mitigates the loss at the top of the wealth distribution. Therefore, the welfare loss for the first income quintile (-1.8%) is lower than the welfare loss for the four others (-2%), making the tax on firm energy consumption slightly progressive. In Appendix C.2, we run the same exercise assuming homothetic preferences and identical fossil fuel consumption shares across incomes and geography. This allows to focus on our income channel by erasing all expenditure channels. We find that our progressivity result is robust to that assumption.

Furthermore, while taxing households' direct emissions did not interact meaningfully with the borrowing constraint, taxing firms heavily modifies savings behavior throughout the income distribution. The drop in activity incomes reduces idiosyncratic income risks for high-types leading to a fall in savings rate. Conversely, low-type households are now closer to the borrowing constraint, implying higher precautionary savings, as shown by the decomposition of the budget constraint change in each scenario plotted in Appendix B.3.

4.3 The equity-efficiency trade-off of recycling policies

We have shown in subsection 4.1 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 increase public spending (*Benchmark G*), or to increase lump-sum transfers, either uniformly across households (*Uniform*), conditional on geographical location (*Rural*), income (*Poor*) or both (*Poor × rural*)[7]. In Figure

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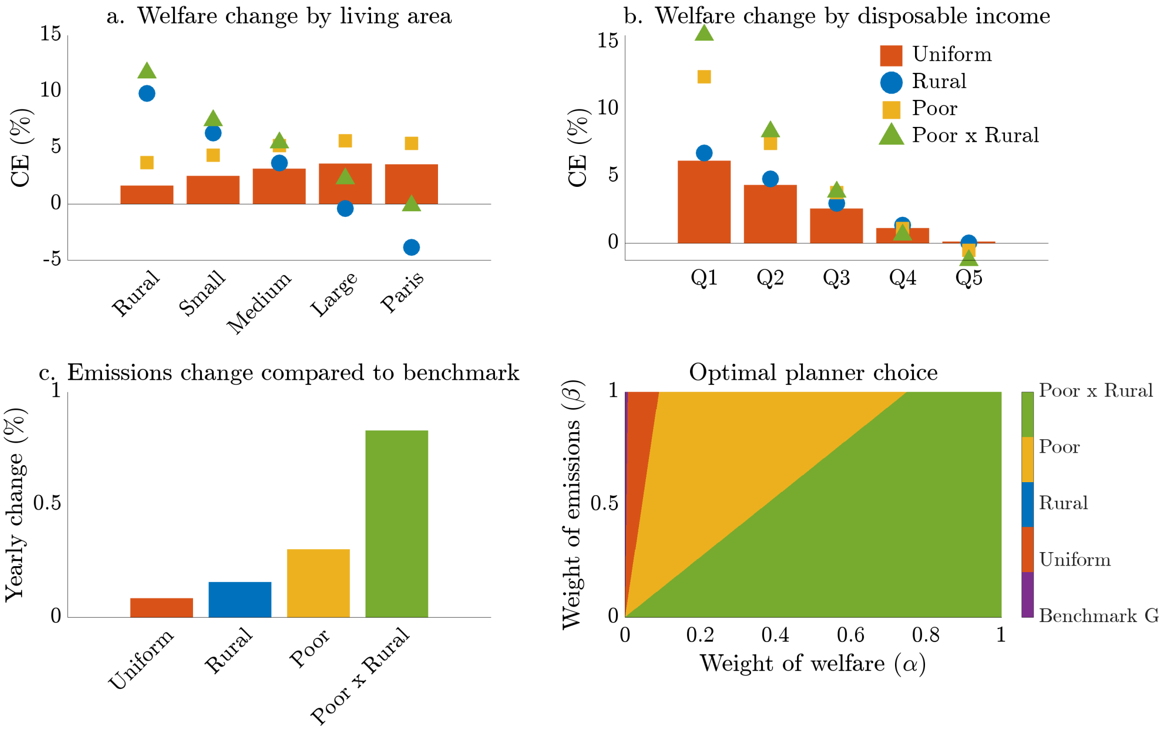
[7] Formally, we assume in each scenario that individual transfers are described by $T_i = \frac{v_i}{\int v}\text{CTR}$, with v the weight vector and "CTR" the Carbon Tax Revenue. We consider the following vectors: (1)

8, we compare these scenarios in the light of three objectives: optimizing households' welfare, reducing CO_2 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.

Panels *a* and *b* in Figure 8 show welfare changes with respect to the no policy case along both geographical and income dimensions. Recall that in Section 4.1 with *Benchmark G* scenario, we found that carbon taxes decrease emissions by 17.5%, but also welfare by 5.7% CE on average, with a bigger loss for rural and low-income households. We quantify the share of losers by disposable income quintile and by living areas for each scenarios in Table 2 in Appendix B.4.

Figure 8: Comparison between transfer recycling policies


a. Welfare change by living area

b. Welfare change by disposable income

c. Emissions change compared to benchmark

Optimal planner choice

The *Uniform* scenario, with the flat redistribution of the carbon tax, revenue allows a 2.9% increase in aggregate welfare following the carbon tax increase. This transfer represents a higher gain for low-income households (6.2%) but is almost negligible for high-income households (0.1%). As this transfer increases households consumption, including fossil energy consumption, it induces a 0.1% increase in annual emissions, which is small compared to the welfare gain in terms of welfare. Therefore, **we show**

Benchmark G: $v_i = 0$, (2) Uniform: $v_i = 1$, (3) Rural: $v_i = \bar{e}_i$, (4) Poor: $v_i = 1/z_i$, (5) Poor×Rural : $v_i = (\bar{e}_i + 0.4)^2/z_i^2$, where the "0.4" allows households with $\bar{e}_i = 0$ to receive transfers.

that it is possible to simultaneously reduce emissions, disposable income inequalities, and to increase aggregate welfare. This result also relates to the double dividend literature. Indeed, incomplete financial markets make the carbon tax combined with transfers welfare improving, without needing a climate damage function. This is because transfers allow agents to self-insure against idiosyncratic productivity shocks.

The uniform transfer policy benefits to low-income households, but cannot compensate the high cost incurred by rural households. Therefore, it is biased towards the Parisian households (+3.5%), while rural households makes the smallest winning group (+1.6%). Additionally, 27% of rural households and 13% of small cities inhabitants are worse off after the policy while only 2.4% of Parisians lose from it. The *Uniform* scenario creates few losers on aggregate (only 9.5%), but those are over-represented within little cities and incur high losses. If we want to take into account the geographical dimension, we need to implement targeted transfers, conditional on location or revenue. The *Rural* scenario is comparable to the uniform scenario along the income dimension, but it benefits mostly to rural households (+9.8%), while all Parisian households experience a loss (−3.9%). Moreover, 15% of households within the Q1 are losers. Conversely, the *Poor* scenario targets low-income households, reinforcing the progressive effect along the income dimension, while favouring again Parisian households (14% of losers) compared to rural ones (31.4% of losers). Therefore, our *Poor*×*Rural* considers a combination of the two targeted scenarios. As the uniform scenario, it is highly progressive on average, but it also benefits mostly to rural households (+11.6%), while being neutral on average for Parisian households. Moreover, compared to the *Uniform* (+2.9%), *Rural* (+3.2%) and *Poor* (+4.8%), the *Poor* ×*Rural* is the best welfare policy, with an increase in aggregate welfare equal around +5.4%. Yet, the *Poor*×*Rural* scenario creates more losers than *Uniform* transfers: 31% of losers against 9.5%. They are now over-represented in large cities. Therefore, it is possible to design a carbon tax that increases aggregate welfare, reduces income inequalities and still benefits rural households, but the share of losers increases.

Morever, each gain in welfare comes with a loss in terms of emissions, creating a tradeoff between welfare and climate efficiency. Compared to the benchmark scenario, each transfer policy increases emissions. The *Poor*×*Rural* scenario, which yields the highest welfare gains, comes with a 0.8% increase in annual total emissions. While this may seem small compared to the benchmark, this increase accumulates over the year, leading to a 49% increase in CO_2 stock over 50 years. In order to quantify the tradeoff between welfare and climate efficiency, we consider a social planner with the following welfare function:

$$\mathbb{W}_0 = \alpha \cdot \sum_{t=0}^{\infty} \text{Welfare change}_t + \beta \cdot \sum_{t=0}^{\infty} \text{Emissions reduction}_t$$

where α is the weight given to welfare and β the weight given to climate. Panel *d* of Figure 8 shows the planner's favorite policy depending on the joint value of (α, β). In the polar case where the planner does not care about welfare but only about emissions (α close to 0), the scenario *Benchmark G* in purple is preferred. For a higher, but still small, preference for welfare, the *Uniform* transfer scenario dominates. As the taste for welfare increases, the Poor scenario, and finally the *Poor*×*Rural* scenario, dominate. Therefore, depending on the relative weight given to the climate transition over the aggregate welfare and the inequality, the planner's optimal scenario may differ. As the distributional effects of carbon taxation are key for its social acceptability, we consider that a transfer policy is preferable to the increase in public spending. The choice of the transfer scenario depends on the willingness to compensate the cost of the transition for rural and poor households, and to maximize the climate efficiency of the tax.

5 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' direct emissions or firms' direct ones. 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 quantify aggregate and disitrbutive effects of several revenue-recycling policies. A uniform transfer allows to reduce emissions and to increase welfare, but it widens the rural-urban gap, while targeted transfers towards low-income and rural households are 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 Data and calibration

A.1 Data

In Figure 1 we use consumer expenditure surveys from France and the US.

- France: we use Enquête Budget des Familles 2017 (BdF 2017). We define energy as the sum of: electricity, fuels for heating and fuels used in vehicles. The city size classification from Insee in BdF (2017) is: Rural (less than 2,000 inhabitants), Small cities (¡ 20,000), Middle-sized cities (between 20,000 and 100,000), Large cities (over 100,000) and finally Parisian agglomeration.

- U.S.: we use the 2022 CE Table from the U.S. Bureau of Labor Statistics Consumer Expenditure Survey. We define energy as the sum of the following categories: Natural gas, Electricity, Fuel oil and other fuels and Gasoline, other fuels, and motor oil. We classify cities in the U.S. as followed: Outside urban area (Rural), Small cities (less than 100,000 inhabitants), Middle-sized cities (between 100,000 and 250,000), Large cities (between 250,000 and 1,000,000) and Biggest cities (over 1,000,000).

A.2 Table of parameters

Parameter	Description	Value	Notes
Households			
β	Discount factor	0.92	$\frac{a}{\text{GDP}} = 2$
θ	Intertemporal ES	1	Kaplan et al. (2018)
$1/\psi$	Frisch elasticity	3	Ferriere et al. (2023)
ϕ	Labor disutility	1	Normalization
σ	ES between c and e^h	0.26	Estimation in Appendix A.5
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, 0.14, 0.28, 0.38, 0.51]	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	$\frac{p^F F}{GDP}$=2%
ω_y	Energy share	0.43	$\frac{p^y E^y}{p^h E^h + p^y Ey + p^F F^N} = 60\%$
σ_y	ES between e^y and (k, l)	0.2	Hassler et al. (2021)
α	Capital share	0.28	$\frac{wl}{GDP}$ from Cette et al. (2019)
γ_y	Share of fossil in Y mix	0.33	$\frac{F^y}{F} = 59\%$
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	5.1%	to match $\frac{I}{GDP} = 10\%$
Government			
$\bar{T}$	Transfers	0.3	$\frac{\bar{G}}{Y} = 0.29$
$\bar{d}$	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	22%	effective VAT rate: Auray et al. (2022)

A.3 Aggregate targets

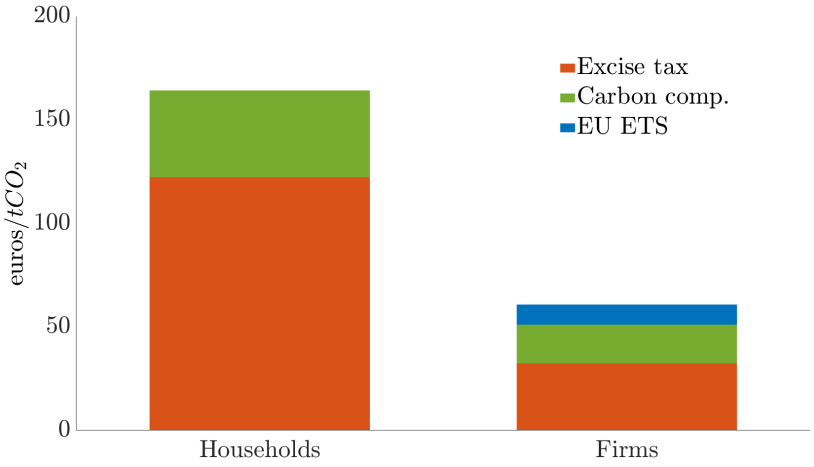
Table 1: Empirical targets vs Model results

	Model	Target	Parameter	Value	Sources & notes
a/GDP	260%	200%	β	0.92	Piketty and Zucman (2014)
l_N/l	2%	2.3%	η	0.12	Insee 2023 – EAE
wl/GDP	63.1%	65%	α	0.2	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
$p^F F$/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%	$\bar{T}$	0.2	Auray et al. (2022)
R^c/SB	6.7%	7%	τ^f	0.012	PLF 2023

A.4 Effective carbon taxes

In France, CO_2 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€/tCO_2 against 83.2€/tCO_2 in 2022. Finally, 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.

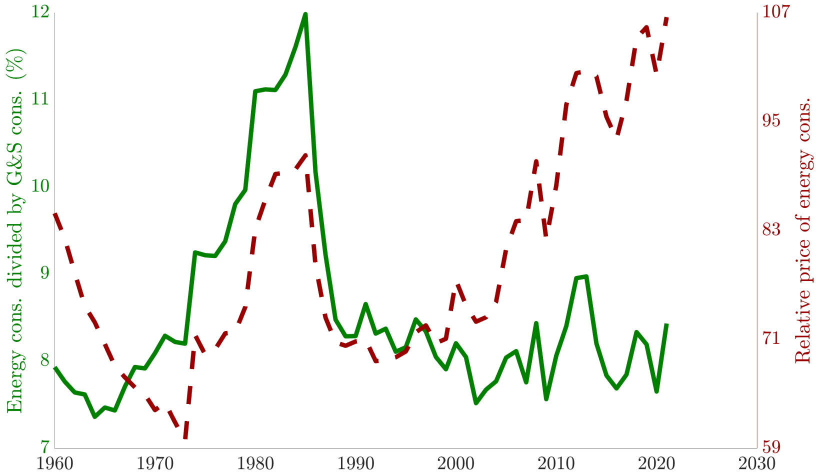
Figure 9: Effective carbon tax for France, 2020



A.5 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: Consumption ratio and relative price of energy



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

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

Thus, we can estimate σ through the following OLS estimation:

$$\Delta \ln(e_t^h) - \Delta \ln(c_t) = -\sigma \Delta \ln(p_t^e + \tau^h) + u_t$$

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.

B Quantitative results – complements

B.1 Consumption equivalents

With a utility function à la Comin et al. (2021) we compute the welfare change along the transition in consumption equivalent terms like in Ferriere et al. (2023). We use the following formula:

$$\text{CE}_i = \frac{\tilde{c_i} - c_i}{c_i} \times 100 \tag{7}$$

with $\tilde{c_i}$ defined inverting Equation (1):

$$\tilde{c_i} = \left[\frac{(u_i \exp(\Delta_i))^{\frac{(\sigma-1)}{\sigma}\epsilon_c}}{\Lambda_c^{\frac{1}{\sigma}}} - \left(\frac{\Lambda_e}{\Lambda_c}\right)^{\frac{1}{\sigma}} (e_i^h - \bar{e}_i)^{\frac{(\sigma-1)}{\sigma}} (u_i \exp(\Delta_i))^{\frac{(\sigma-1)}{\sigma}(\epsilon_c - \epsilon_e)} \right]^{\frac{\sigma}{\sigma-1}} \tag{8}$$

and with $\Delta_i = (1-\beta)\,(V_1(\tau) - V_{SS}))$ i.e. the discounted change in value function along the transition path.

B.2 Transitional dynamics

Figure 11: IRF: comparison between $\tau^h + \tau^f$, τ^h only and τ^f only

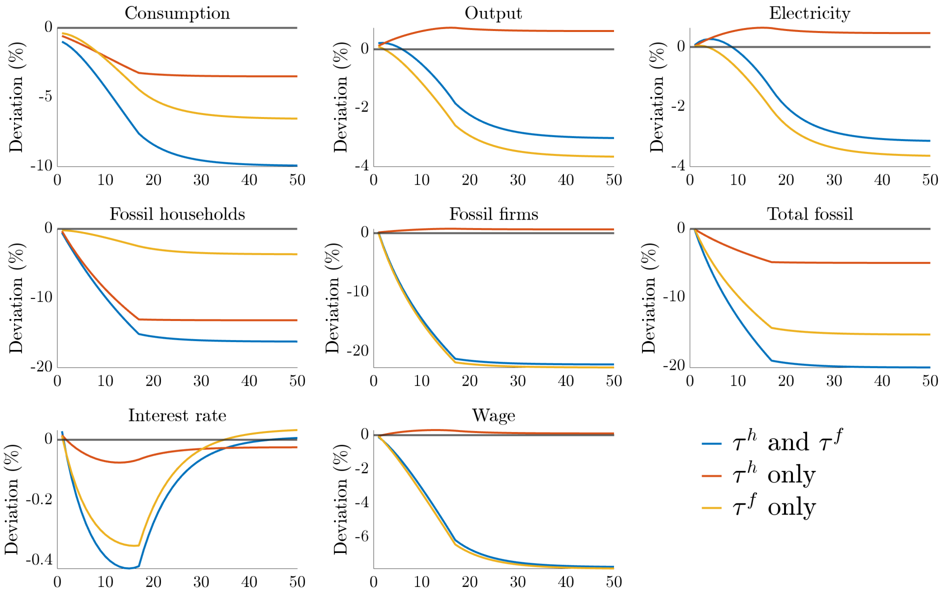
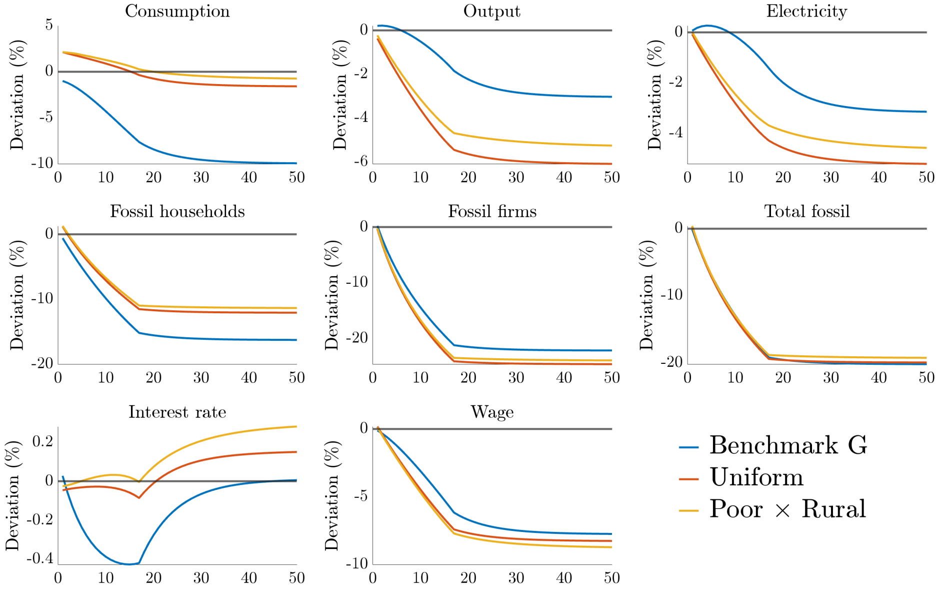


Figure 12: IRF: comparison between Benchmark G, T Uniform, T Rural × Poor



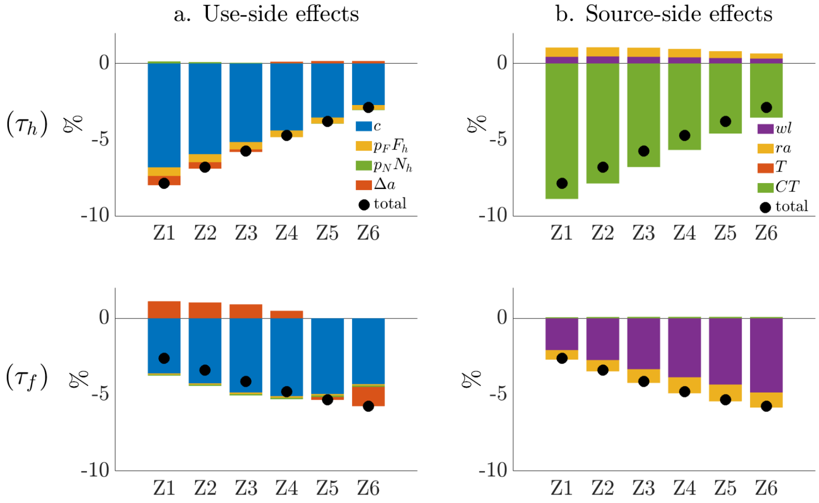
B.3 Distributive effects – Budget constraint decomposition

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

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

Figure 13 shows this decomposition by productivity types for rural households by comparing policy functions between steady states. 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 shows how the borrowing constraint interact with the two carbon taxes.

Figure 13: Rural households



a. Use-side effects

b. Source-side effects

B.4 Political economy – share of losers

Table 2: Share of losers (%)

	Benchmark	Uniform	Rural	Poor	Poor x rural
Q1	100	0	15	0	0
Q2	100	0	19.7	0	0.7
Q3	100	0	41	0	15.1
Q4	100	8	41.1	18.5	46.8
Q5	100	39.3	47.5	81.2	90.7
Rural	100	26.7	0	31.4	11.9
Small	100	12.8	0	24.2	19.9
Medium	100	3.6	1.3	16.3	27.3
Large	100	1.2	62.7	13.8	38.5
Paris	100	2.4	100	13.9	58.2
All	100	9.5	32.9	19.9	30.7
Welfare (% CE)	-5.7	2.9	3.2	4.8	5.4

C Quantitative results – robustness

C.1 Elasticities of substitution

In this section, we compare taxes on households emissions and taxes on firms emissions (as in Figure 6), but with alternative values for elasticities of substitution (ES). In our benchmark calibration, the ES between c and e^h is set to $\sigma = 0.26$, the ES between N^h and F^h is set to $\epsilon_h = 0.2$, the ES between $(k^y)^\alpha (l^y)^{1-\alpha}$ and e^y is set to $\sigma_y = 0.2$, and the ES between N^y and F^y is set to $\epsilon_y = 0.2$.

In Table 3 we show the results from our simulation by changing each elasticity of substitution, keeping others at their benchmark values. We find that our result from Section 4.1 is robust to those changes since the rural households lose more on average than low-income households (Q1) for all scenarios considered. As expected, the drop in total emissions increases with those elasticities, with a decrease in emissions reaching -56.7% when $\epsilon_y = 2$.

Table 3: Elasticities of substitution – *Benchmark G*

	Benchmark	σ		ϵ_h		ϵ_y		σ_y	
	Fig. 6	0.1	2	0.1	2	0.1	2	0.1	1
Welfare change (% CE) by disposable income quintile									
Q1	-6.3	-5.8	-28	-6.3	-6.3	-6.2	-7.5	-6	-8.3
Q2	-6	-5.6	-30.2	-6	-6	-6	-7.1	-5.8	-8.3
Q3	-5.7	-5.3	-32.1	-5.7	-5.6	-5.7	-6.4	-5.5	-8.1
Q4	-5.4	-5	-34.1	-5.4	-5.2	-5.4	-5.6	-5.1	-7.8
Q5	-5	-4.6	-35.9	-5	-4.7	-5.1	-4.7	-4.7	-7.7
Welfare change (% CE) by living area									
Rural	-7.3	-6.8	-36	-7.3	-7.1	-7.2	-7.9	-7	-12
Small	-6.3	-5.9	-33.3	-6.3	-6.2	-6.3	-7	-6.1	-9.6
Medium	-5.8	-5.3	-31.9	-5.8	-5.7	-5.7	-6.4	-5.5	-8
Large	-4.9	-4.5	-30.5	-4.9	-4.8	-4.9	-5.5	-4.6	-6
Paris	-4	-3.7	-27.9	-4	-3.9	-4	-4.4	-3.7	-4.3
Aggregate variables									
$\mathbb{W}$ (% CE)	-5.7	-5.3	-32	-5.7	-5.6	-5.7	-6.3	-5.4	-8
F^h	-14	-9.6	-50	-12.4	-39.2	-14	-13.4	-13.5	-11.3
$F^y + F^N$	-19.9	-19.9	-19.8	-19.9	-20.3	-14.4	-71	-17	-35.2
Emissions	-17.5	-16.1	-45.1	-16.9	-28.6	-14.2	-56.7	-15.4	-28.1

C.2 Homothetic preferences

In this section, we simulate the same experiment as in Section 4.2 using homothetic prefernces. We assume $\epsilon_e = 1$, $\forall k, \bar{e}(k) = 0$ and $\gamma_h(k) = 0.6$. Indeed, only capital and labor income distributions matter since the expenditure channel is erased. With this calibration, we can see in Figure 14 that taxing direct emissions of households (τ_h) becomes flat since preferences are now homothetic and since fossil fuel represents the same energy share across types. Conversely, the income channel stands up since we find that taxing firms' direct emissions is still progressive.

Figure 14: τ_h vs τ_f: homothetic preferences