Geography versus Income: The Heterogeneous Effects of Carbon Taxation

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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. First, the distributive effects of carbon taxation are driven by geography more than income, with rural households suffering larger welfare losses. Second, taxing households' direct emissions is regressive, while taxing firms' direct emissions is progressive. Third, we simulate various revenue-recycling policies using targeted transfers. We find that it is possible to reduce emissions and mitigate welfare losses 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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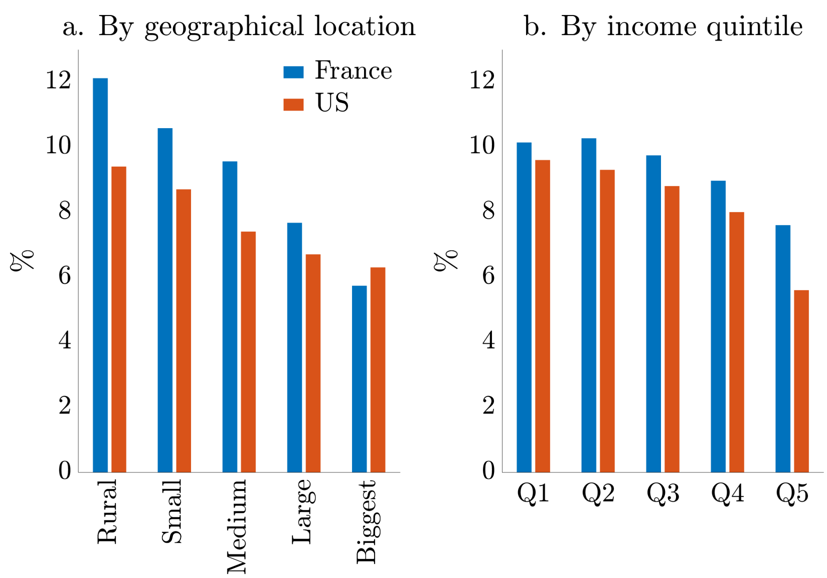
1 Introduction

Carbon taxes reduce emissions but create unequal costs for households, as energy represents a larger share of consumption for low-income and rural populations. 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 survey data[1], energy expenditure shares greatly vary across living areas. Rural areas are characterised by higher energy needs related to transportation and heating, while urban households benefit from public transportation and live in smaller housing units, reducing their energy costs.

Figure 1: Energy share in total expenditure



In this paper, we emphasize the importance of geographical constraints in analysing both aggregate and distributive effects of carbon taxes. We introduce geographical 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, we capture the rich heterogeneity in energy use observed in the data, and investigate the different impacts of carbon taxes across households. Finally, we consider various revenue-recycling scenarios and

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

propose a carbon taxation framework to mitigate welfare losses associated with the green transition. In this context, our analysis yields three key findings.

First, **geography outweighs income or wealth in determining the distributive effects of carbon taxation**. We consider a gradual increase in the carbon tax reaching 250€ per ton of CO_2 in 2030[2], 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. The lowest income quintile experiences a welfare drop of -6.3% CE after the tax increase, against -5.0% for the highest income quintile. However, the gap in welfare losses is stronger between living areas. Rural households, featuring high incompressible energy needs, experience a welfare decrease of -7.3%, against -4.0% for households living in the largest cities.

Second, **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 fuel 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 fuel-intensive energy-mix. Therefore, taxing direct households' emissions is regressive, with a welfare change equal to -2.5% CE for the bottom income quintile against -1.6% for the top. 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 amount to -1.8% for low-income households (Q1) against -2.1% for high-income ones (Q5).

Third, we find it possible **to reduce emissions while mitigating welfare losses associated with the green transition**. In our benchmark scenario, the government uses the carbon tax revenue to increase public spending. Then, we allow for different lump-sum transfers policies: either uniform rebates, or targeted ones towards rural or poor households. While increasing public spending yields the greatest emissions reduction because it is less energy intensive than households' consumption, transfer policies dominate in terms of welfare. Indeed, the most welfare-enhancing transfer scenario, targeting low-income and rural households, increases aggregate welfare by 5.4% CE, compared to a decrease of 5.7% in our benchmark scenario. This scenario

[2]The carbon tax in France was implemented at 7€ per tCO_2 in 2014 and was supposed to reach 250€ per tCO_2 in 2030. This target was voted in the 2018 French Budget Bill, before the Yellow Vests protest.

mitigates political risks associated with carbon taxation frameworks as it makes the policy progressive and vastly favours rural and peripheral areas. Yet, this comes at a cost in terms of emissions, as they decline by 16.7% annually compared to 17.5% in the benchmark scenario. The difference is small but accumulates overtime. It also increases the share of losers within large cities and high income groups while uniform transfers concentrate fewer large losers among rural households.

Our paper contributes to the literature assessing the distributive effects of climate policies in general equilibrium models, with a special emphasis on the importance of geographical heterogeneity, and a clear distinction between firm carbon tax and household carbon tax. 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 carbon taxes across households, using micro-simulation, Computable General Equilibrium (CGE) or heterogeneous-agent general equilibrium models. Based on micro-simulations, Cronin, Fullerton and Sexton (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 household carbon tax, but we add a firm carbon tax within a general equilibrium set-up, and find that it is progressive. Within the CGE literature, Rausch, Metcalf and Reilly (2011) and Goulder et al. (2019) conclude that the progressivity of "source-side" effects offsets the regressive "use-side"[3] effects in the U.S., while Ravigné, Ghersi and Nadaud (2022) estimate that the overall effect is still regressive in France. Compared to these papers, our income and wealth distributions are endogenous, based on idiosyncratic income risks, and we introduce horizontal heterogeneity related to living areas. In this regard, we are closer to the macro literature that integrates energy and environmental issues within heterogeneous-agent general equilibrium models, like in Fried, Novan and Peterman (2018), Fried (2018), Benmir and Roman (2022), Auclert et al. (forth.), Fried, Novan and Peterman (2023), Pieroni (2023), Douenne, Hummel and Pedroni (2023) or Langot et al. (2023). We depart from these contributions by introducing geographical heterogeneity in energy needs, producing a rich and realistic households heterogeneity in energy consumption[4]. Compared to 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

[3]Following Rausch, Metcalf and Reilly (2011), we define "source-side" effects as those related to changes in relative factor prices and "use-side" effects related to the composition of total expenditures.

[4]Only Fried (2018) introduced geographical heterogeneity to study climate adaptation, focusing on the case of severe storms in the U.S.

towards a new steady state. Finally, an essential dimension of heterogeneity relates to geography – see Redding and Rossi-Hansberg (2017) or Couture et al. (2024). Related to climate change, Cruz and Rossi-Hansberg (2024) use a dynamic assessment model to quantify the heterogeneity of welfare losses associated to global warming across the world, and Fajgelbaum et al. (2019) investigate location choices in response to state taxes in the U.S. We focus on within-country spatial heterogeneity, achieved by incorporating varying geographical minimum energy consumption needs and energy mixes based on survey data.

In this paper, we further emphasize the importance of *general equilibrium effects* to assess the aggregate and distributive effects of carbon taxation. 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". Due to the heterogeneous composition of disposable income across households, source-side effects are likely to modify the distributive effects of carbon taxes, as in Rausch, Metcalf and Reilly (2011) or Mathur and Morris (2014). 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 scenarios. Barrage (2020) shows that considering existing distortionary taxes is necessary to compute the optimal carbon tax. We introduce incomplete financial markets into her framework, which makes lump-sum transfers welfare-improving, as they allow agents to self-insure against idiosyncratic productivity shocks. Close to us, Fried, Novan and Peterman (2018) study the distributional effects of different revenue-recycling policies within a life-cycle model. We depart from them by focusing on targeted transfers contingent on location or income, as this option is often favored by governments and the benefits are better understood by citizens[5]. This creates a variety of "equity-efficiency" trade-offs for the government that we can quantify. 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 taxes may be progressive as they distort activity incomes while transfer incomes are indexed: we obtain the same result in our experiment for the increase in the fossil fuel tax on firms only.

The remainder of the paper is organized as follows. Section 2 presents our quanti-

[5]See Douenne and Fabre (2020) and Douenne and Fabre (2022).

tative 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

Given our goal to highlight the distributive effects of carbon taxation, 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 subject to 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:[6]

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

[6]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.

subject to:

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

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

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

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

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

Equation 1 implicitly defines utility following Comin, Lashkari and Mestieri (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 σ. Here, Λ_c and Λ_e control the share of expenditures devoted to c and e^h, and ϵ_c and ϵ_e control the income elasticity of demand for each good. 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_t^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 subject to 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, Krusell and Olovsson (2021) points toward a very low short-run substitutability between energy and other inputs once the technology factors have been chosen. Moreover, Casey (2024) shows that Cobb-Douglas production functions with energy inputs vastly overestimate transitional emissions adjustments. Both papers motivate our choice for a CES production function, with σ_y being the elasticity of substitution between energy and non-energy inputs. Moreover, we assume constant return to scale, which is coherent with the full pass-through of positive energy price shocks thatLafrogne-Joussier, Martin and Méjean (2023) uncovers using French firm micro-data. 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, with neutral dynamics for the rest of the world.

2.3 Fiscal authority

The fiscal authority gets revenue from taxes on labor income, capital income, consumption and carbon taxation (i.e. fossil fuel consumption). 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 $x \in \{a, c, N^h, F^h\}$, the government has the following budget constraint:

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

Following Heathcote, Storesletten and Violante (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. 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:

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

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 goods and services (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.

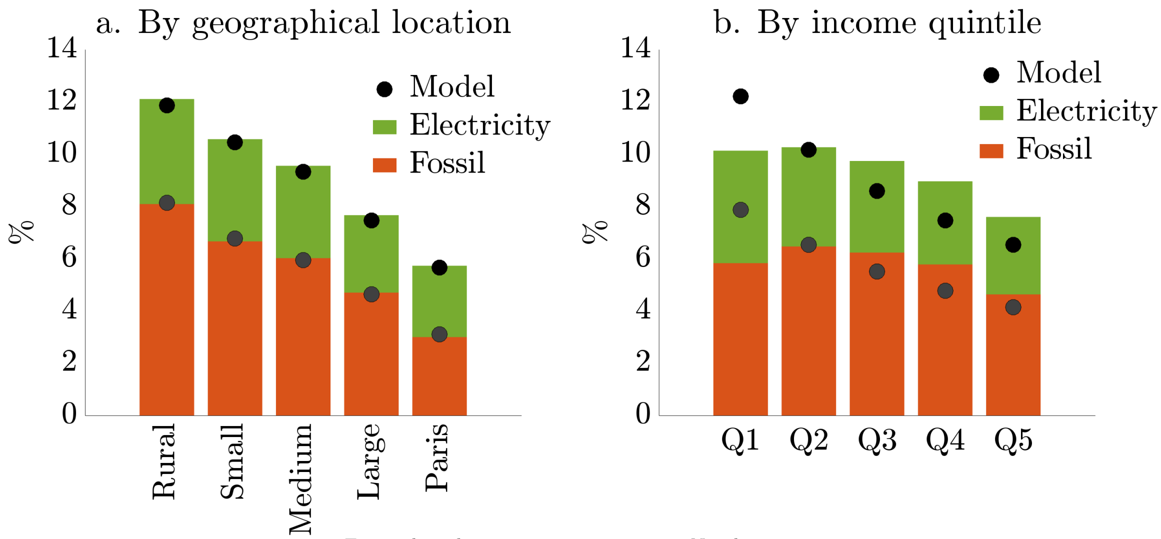
3 Calibration on French macro and micro data

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.4 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 type, and $\gamma(k)$ to match 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



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.

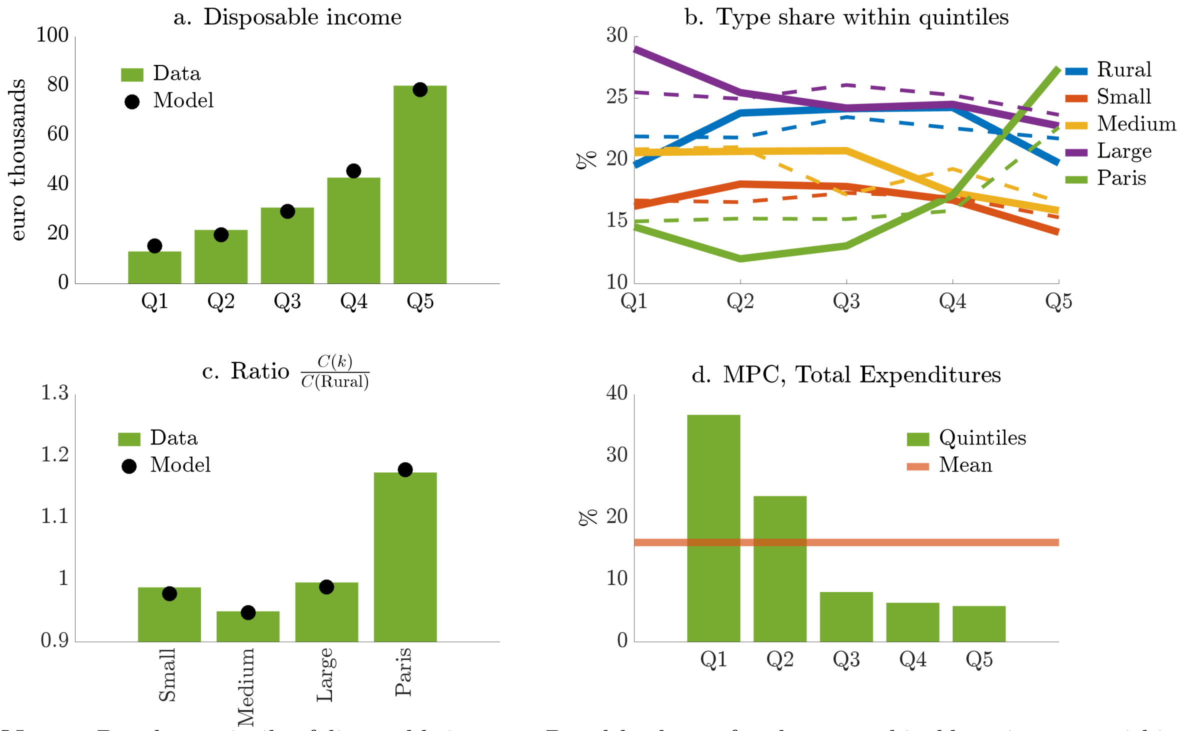
We estimate σ, the elasticity of substitution between energy and G&S consumption, using National Accounts longitudinal data from Insee (Insee 2022 – NA), ranging from 1959 to 2021. Our regressions are described in Appendix A.6. We get $\hat{\sigma} = 0.2$, significant at the 1% threshold, and set the elasticity of substitution between fossil fuel and electricity to $\epsilon_h = 0.2$. Energy consumption appears thus a substitute rather than a complement to other consumption goods. We assume the same elasticity of substitution across energy types for firms (ϵ_y). Compared to the literature estimates ranging from 0.02 in the short-run in Hassler, Krusell and Olovsson (2021) to 2 in the long-run for Papageorgiou, Saam and Schulte (2017), using an elasticity of 0.2 should provide an upper bound effect of carbon taxation in the long run. Appendix C.1 presents our benchmark results with other choices.

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[7] (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

[7]From the 2021 Insee survey "Revenus et patrimoine des ménages" (RPM 2021)

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, Moll and Violante (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 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, Moll and Violante (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 firms in the G&S sector make 60% of total energy consumption. The elasticity of substitution between energy and the capital-labor bundle is set to $\sigma_y = 0.2$. The capital share is set to $\alpha = 0.2$ to match the share of labor revenue $\frac{wl}{\text{GDP}} = 65\%$ following Cette, Koehl and Philippon (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%).

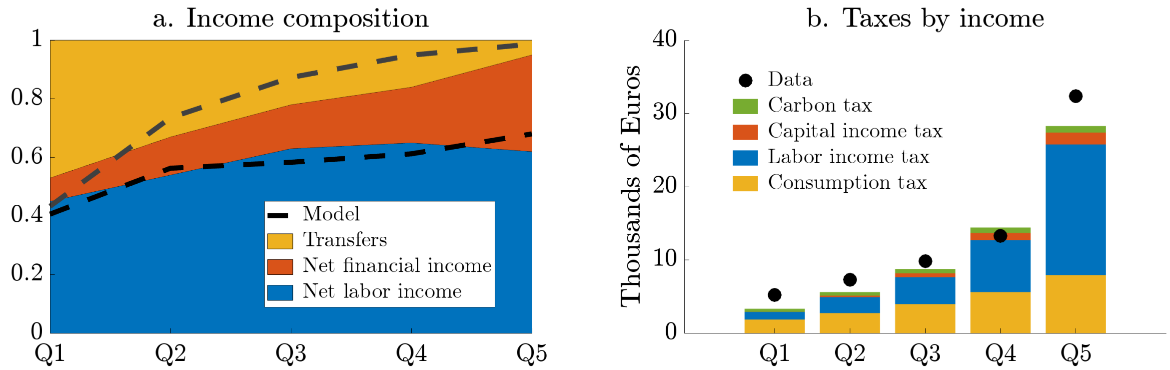
Electricity firm: the electricity sector is capital intensive, so we set $\eta = 0.12$ to have $\frac{l_N}{l} = 2\%$ and $\zeta = 0.874$ to have $\frac{F_N}{F} = 1\%$. We assume that electricity is produced using few fossil fuel inputs because France relies mainly on nuclear power plants and hydroelectricity 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 $T(z) = \frac{\bar{T}}{z}\left(\int_0^1 \frac{1}{z_i}\mathrm{d}i\right)^{-1}$ 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_{2014} and τ^f_{2014} initial levels so that energy taxes account for 7% of total government revenues[8]. 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.

[8]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.5 for more details.

Figure 4: Income composition and taxes by income quintile

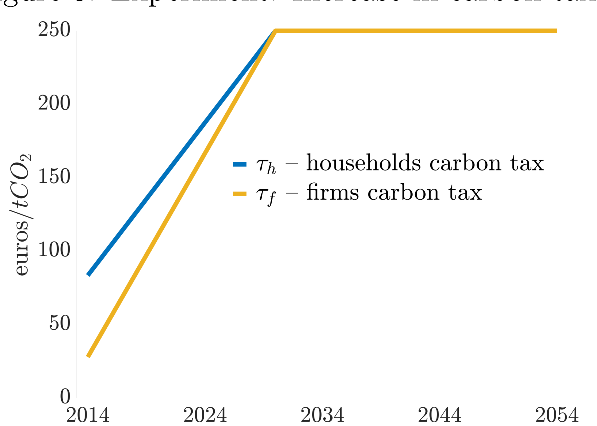


Notes: Panel *a*: composition of income data and model fit. Panel *b*: taxes paid by households in the model and data (excluding social contribution). **Source** : Revenus et patrimoine des ménages, Édition 2021.

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[9]. 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 in 2018 (see Appendix A.5).

Figure 5: Experiment: Increase in carbon taxes



In this section, our welfare results are presented in "consumption equivalent" (CE)

[9]This scenario is taken from Quinet (2019), and administrative report that inspired the French Budget Bill for 2018.

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[10]. 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.

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 significantly widens the rural-urban gap. In other words, geography predominates over income in understanding the distributive effects of carbon taxation, as the tax burden depends more on living area than on income.

Along the income dimension, poorer households incur a slightly higher average loss (-6.2% CE) compared to higher-income households (-5.1%). As shown in next section, the progressive distortion on labor and capital income, resulting from the firms' carbon tax, mitigates the regressive effect of households' carbon tax, coming from the downward nonhomotheticity of energy consumption.

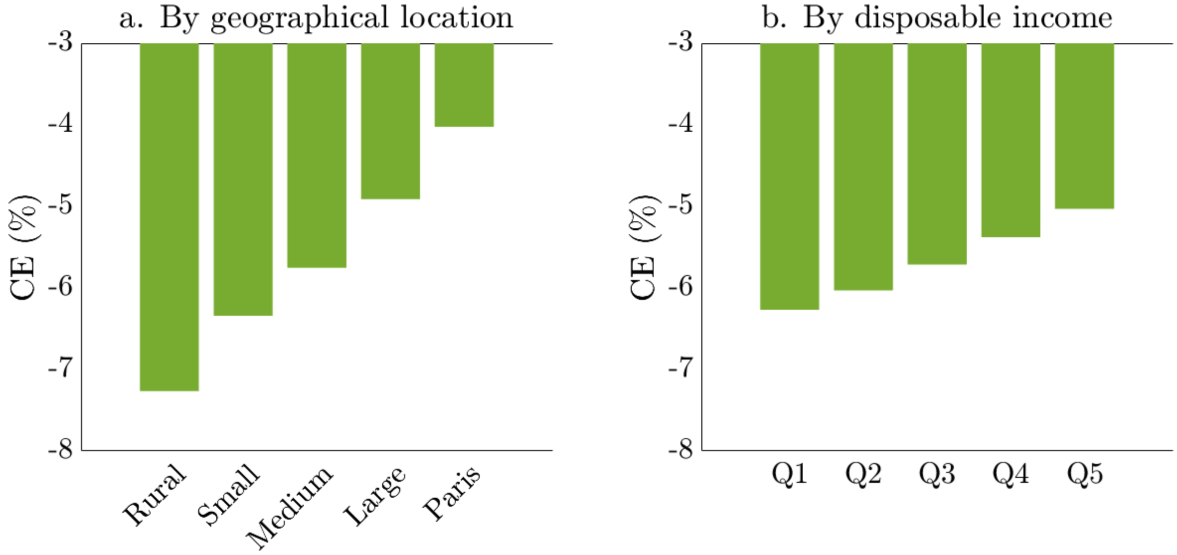
Therefore, the geographical dimension appears more relevant. Rural households experience a 7.2% welfare loss while Parisian households' welfare only declines by 4%. This is due to the intermediate input tax being somewhat uniform across living areas, while the final consumption tax disproportionately affects households with higher incompressible energy needs.

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

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

with x^{SS} the path of the variable x without carbon tax increase, and x^{carbon} the path with the carbon tax increase and the new steady state. Numerical implementation is described in Appendix B.1.

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



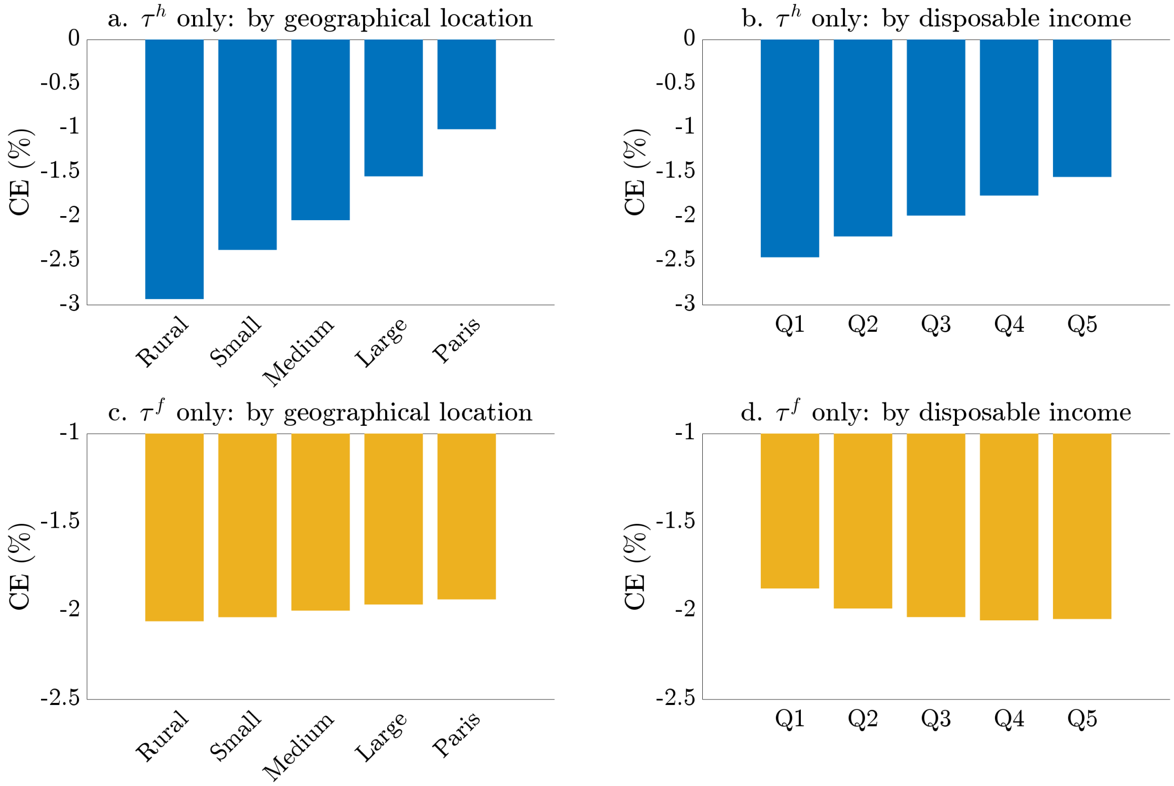
We confirm these findings by performing a weighted linear regression of the welfare change on disposable income and geographical location[11]. While geographical location accounts for 77% of welfare losses variability, disposable income only explains 12% and wealth 16%. This confirms that geographical heterogeneity is 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 analysis is closely related to the seminal 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. In Appendix C.3, we find that comparing our two scenarios while reaching the same emissions reduction target yields identical distributional results. Two main distortions of our model drive our results: the nonhomotheticity of energy consumption and the heterogeneous distribution of labor and capital incomes.

[11] $\text{CE}_i = a_0 + a_1 \text{Disposable income}_i + a_2 \bar{e}_i + u_i$, weighted by the density.

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 disproportionately affects 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 increases 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%). Again, the gap in average welfare losses is stronger between living areas than between income groups.

On the other hand, taxing firms' direct emissions is progressive. As in Diamond and Mirrlees (1971), it pushes the economy away from its technological productivity frontier and reduces real wage and energy price. This disproportionately affects medium and high-income households, who earn capital and labor incomes, compared to low-income households, for whom public transfers represent a higher income share. However, 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 conduct the same exercise assuming homothetic preferences and identical fossil fuel consumption shares across incomes and geography. This allows us to focus on our income channel by eliminating all expenditure channels. We find that our progressivity result is robust to this 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 decrease in the saving 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

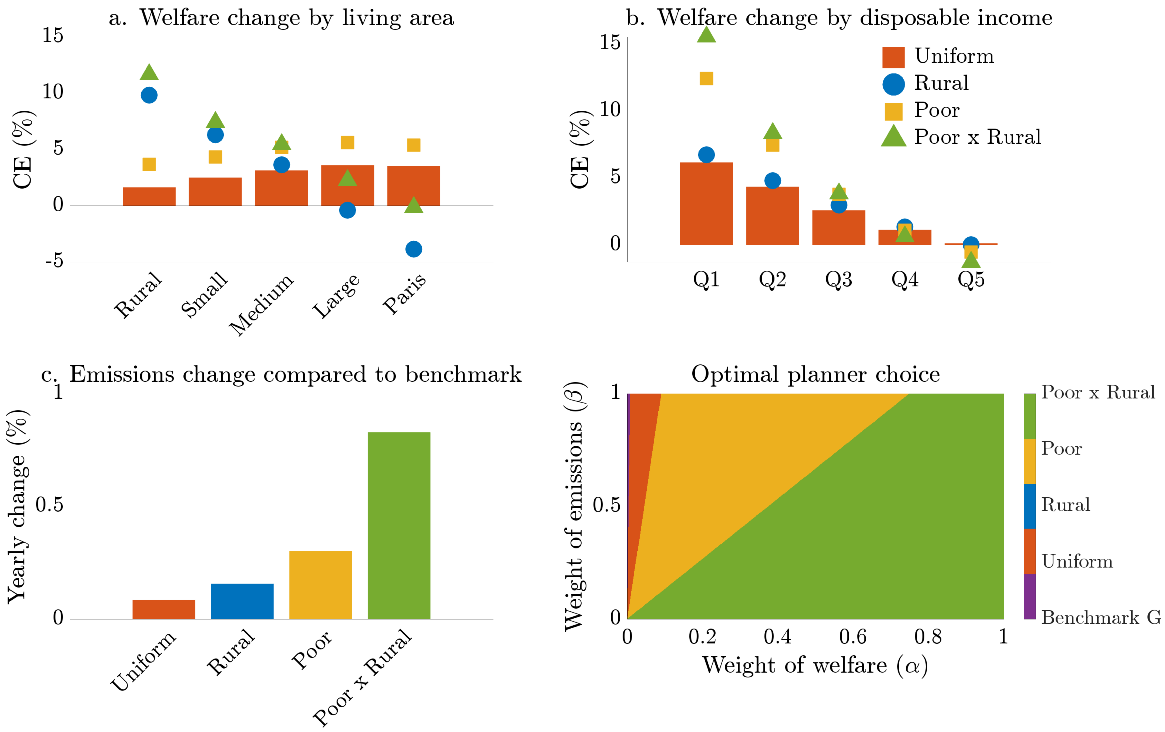
We have demonstrated in subsection 4.1 that geography is more important than income in identifying the losers of carbon taxation. Therefore, is it possible to compensate these losses, while still reducing emissions? In this section, we allow the government to use the carbon tax revenue to increase lump-sum transfers[12], either uniformly across households (*Uniform*) or conditionally based on geographical location (*Rural*), income (*Poor*) or both (*Poor* $\times$ *Rural*)[13]. In Figure 8, we compare these scenarios in terms of three objectives: optimizing households' welfare, reducing CO_2 emissions, and minimizing the number of losers. Indeed, aggregate welfare alone is insufficient to address the political acceptability of the tax: if redistribution increases total welfare by compensating the most affected households, but creates numerous small losers, 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 larger 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 5 in Appendix B.4.

[12]The scenario *Benchmark G* is the one from subsection 4.1, where the government uses additional fiscal revenues to increase public spending.

[13]Formally, we assume in each scenario that individual transfers are described by $T_i = \frac{v_i}{\int_0^1 v_i}\text{CTR}$, with v the weight vector and "CTR" the Carbon Tax Revenue. We consider the following vectors: (1) 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 $\times$ 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.

Figure 8: Comparison between transfer recycling policies



The *Uniform* scenario, with a flat redistribution of the carbon tax revenue, allows for a 2.9% increase in aggregate welfare following the carbon tax increase. This transfer represents a larger 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. Therefore, **we show that it is possible to reduce emissions and mitigate political risks associated with the green transition**, as aggregate welfare increases and disposable income inequalities decrease. This result also align with the literature on the double dividend. Indeed, incomplete financial markets make the carbon tax combined with transfers welfare-improving, without the need for a climate damage function, as transfers allow agents to self-insure against idiosyncratic productivity shocks.

The uniform transfer policy benefits low-income households, but cannot compensate for the high cost incurred by rural households. Therefore, it is biased towards the Parisian households (+3.5%), while rural households represent 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 experience losses. The *Uniform* scenario creates few losers on aggregate (only 9.5%), but these are over-represented within little cities and incur high losses. To account for the geographical dimension, targeted transfers conditional on location and income are necessary. The *Rural* scenario is comparable to the uniform scenario along the income dimension, but it primarily benefits rural households (+9.8%), while all Parisian households experience losses (−3.9%). Yet, 15% of households within the lowest income quintile 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. Like the uniform scenario, it is highly progressive on average, but it primarily benefits rural households (+11.6%), while being neutral on average for Parisian households. Compared to the *Uniform* (+2.9%), *Rural* (+3.2%) and *Poor* (+4.8%), the *Poor* × *Rural* represents the best welfare policy, with an increase in aggregate welfare of +5.4%. Yet, the *Poor* × *Rural* scenario creates more losers than *Uniform* transfers: 31% of losers compared to 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.

Moreover, each gain in welfare is accompanied by a loss in terms of emissions, creating a tradeoff between welfare and climate efficiency. Transfer policies results in higher emissions compared to the benchmark scenario. The *Poor* × *Rural* scenario, which yields the highest welfare gains, is associated with a 0.8% increase in annual total emissions. While this may seem small compared to the benchmark, this increase accumulates over the year, resulting in a 49% increase in tCO_2 stock over 50 years. To quantify the tradeoff between welfare and climate efficiency, we consider a social planner with the following welfare function:

$$\mathbb{W} = \alpha \cdot \text{Welfare change} + \beta \cdot \frac{1}{T} \cdot \sum_{t=1}^{T} \text{Emissions reduction}_t$$

where α is the weight given to welfare (in % consumption equivalent) and β the weight given to climate (in % of annual emissions reduction). Panel d of Figure 8 illustrates the planner's preferred 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 preference for welfare increases, the *Poor* scenario, and finally the *Poor* × *Rural* scenario, becomes dominant. Therefore, depending on the relative weight given to climate transition over aggregate welfare and 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 an increase in public spending. The choice of the transfer scenario depends on the willingness to compensate the transition costs for rural and poor households, while maximizing the climate efficiency of the tax. In Appendix C.3, we compare all revenue-recycling scenarios, adjusting the level of carbon taxes to reach the same decrease in emissions at the final steady state as in *Benchmark G*. We find that the *Poor* $\times$ *Rural* strictly dominates all scenarios in terms of aggregate welfare.

5 Conclusion

In this paper, we evaluate the distributive effects of carbon taxation using a quantitative heterogeneous-agent framework. While 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 16-year increase in carbon taxes, and show that geography is more important than income to assess the distributive effects of carbon taxation. Second, since energy serves both as a final consumption good for households and an intermediate input for firms, we examine the distributive effects of taxing only consumers' direct emissions versus firms' direct emissions. We find that the carbon tax on households is regressive, as it disproportionately affects individuals with a high energy share, while the carbon tax on firms is progressive, as it reduces labor and capital incomes. Third, we quantify aggregate and distributive effects of several revenue-recycling policies. While a uniform transfer policy facilitates emissions reduction and welfare increase, it widens the rural-urban gap. In contrast, targeted transfers directed towards low-income and rural households yield greater welfare improvements, but result in a smaller reduction in emissions and to more losers among residents of large cities.

We leave for future research the exploration of the optimal carbon tax revenue recycling policy. In this study, we focused on polar scenarios for transfers, setting aside the possibility of using the revenue to reduce existing taxes or invest in mitigating incompressible energy consumption. Nonetheless, we believe that transfers are of primary importance for communication and political acceptability. By explicitly separating the carbon tax revenue from the state budget, transfers clarify that the purpose of this tax is to influence behavior rather than to finance public deficits. Finally, a promising avenue for future research would be to improve our geographical model, allowing households to migrate across regions and engage in distinct segmented local labor markets.

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A Data and calibration

A.1 Data on energy

In Figure 1 and 2, we use consumer expenditure surveys from France and the U.S., and we classify "Energy" and living area categories as explained below:

Table 1: Explanation for energy and geography data

	France	**United States of America**
Sources	Enquête Budget des Familles 2017 (BdF 2017)	U.S. Bureau of Labor Statistics Consumer Expenditure Survey 2022
Energy	Sum of: electricity, fuels for heating and fuels used in vehicles.	Sum of: natural gas, electricity, fuel oil and other fuels and gasoline, other fuels, and motor oil.
Living area categories		
Rural	Less than 2,000 inhabitants	Outside urban area
Small cities	Between 2,000 and 20,000	Less than 100,000 inhabitants
Medium cities	Between 20,000 and 100,000	Between 100,000 and 250,000
Large cities	Over 100,000	Between 250,000 and 1,000,000
Biggest cities	Parisian agglomeration	Over 1,000,000

In Table *Consommation finale effective par fonction (niveaux diffusables les plus fins)* from 2022 Insee National Accounts[14], we download aggregate data on annual households consumption. We use relative inflation indexes to estimate the relative price of energy (p^h) for households and annual consumption series to estimate the consumption ratio ($\frac{e^h}{c}$). Both are plot in Figure 10. We use consumption data in volume terms for the estimation of σ in Section A.6.

A.2 Data on income

For Figure 3.a, we use the average disposable income by decile from Revenus et patrimoine des ménages, Édition 2021. For Figure 3.c, we use Enquête Budget des Familles 2017. For Figure 3.b, we follow Douenne (2020) as reproduced below:

[14] Available at: https://www.insee.fr/fr/statistiques/6793592?sommaire=6793644#consulter

Table 2: Geographical composition of each revenue decile (%) from Douenne (2020)

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	Mean
Rural	16.8	22.3	24.0	23.6	25.2	23.1	25.6	22.9	22.1	17.4	22.3
Small cities	14.0	18.5	19.6	16.5	18.3	17.4	16.5	17.0	17.1	11.2	16.6
Medium cities	19.6	21.6	19.6	21.8	19.4	22.1	17.0	17.7	16.8	15.0	19.1
Large cities	33.3	24.7	26.3	24.6	24.3	24.1	24.2	24.8	22.1	23.4	25.2
Paris	16.3	12.9	10.6	13.4	12.8	13.3	16.7	17.6	21.9	33.0	16.9
Sum	100	100	100	100	100	100	100	100	100	100	

For Figure 4, we use the *Revenus et patrimoine des ménages, Édition 2021*, that we reproduce below:

Table 3: Revenues and taxes by income decile (thousand euros)

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Primary income	10.5	15.9	21.0	25.9	31.3	36.4	42.2	49.5	60.4	133.1
Net labor income	4.8	9.5	13.5	17.5	21.7	25.7	30.0	35.4	42.0	69.2
Net financial income	1.8	2.1	2.8	3.2	3.7	4.4	5.4	6.6	9.6	52.3
Sum of taxes	-4.8	-5.6	-6.7	-7.9	-9.2	-10.5	-12.1	-14.5	-18.5	-46.3
Taxes on products and production	-4.2	-4.7	-5.1	-5.6	-6.3	-6.7	-7.3	-8.0	-9.4	-12.7
Taxes on income and wealth	-0.6	-1.0	-1.6	-2.3	-3.0	-3.7	-4.9	-6.5	-9.0	-33.6

A.3 Aggregate targets

Table 4: 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, Koehl and Philippon (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

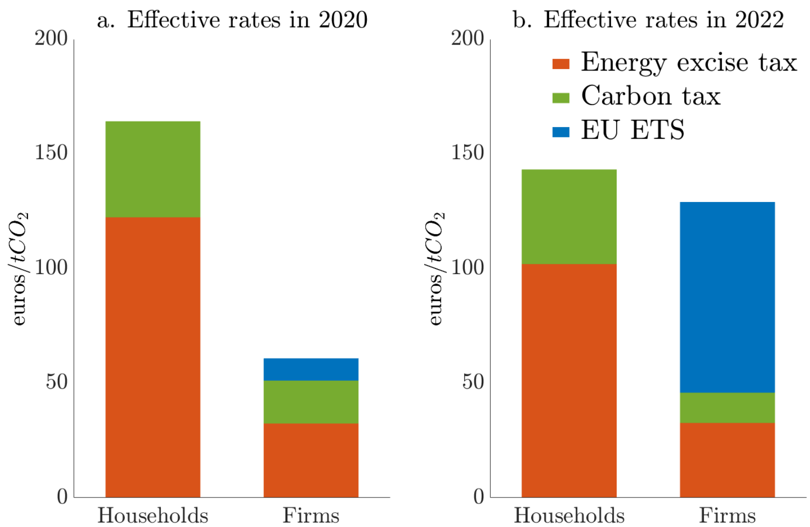
A.4 Table of parameters

Parameter	Description	Value	Notes and targets
Households			
β	Discount factor	0.92	$\frac{a}{\text{GDP}} = 2$
θ	Intertemporal ES	1	Kaplan, Moll and Violante (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.6
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	Comin, Lashkari and Mestieri (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, Krusell and Olovsson (2021)
α	Capital share	0.28	$\frac{wl}{GDP}$ from Cette, Koehl and Philippon (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%	$\frac{I}{GDP} = 10\%$
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: Auray et al. (2022)

A.5 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 at that time. We assume that those exemptions will be lift off in the future such that effective carbon tax rates will reach identical levels in 2030.

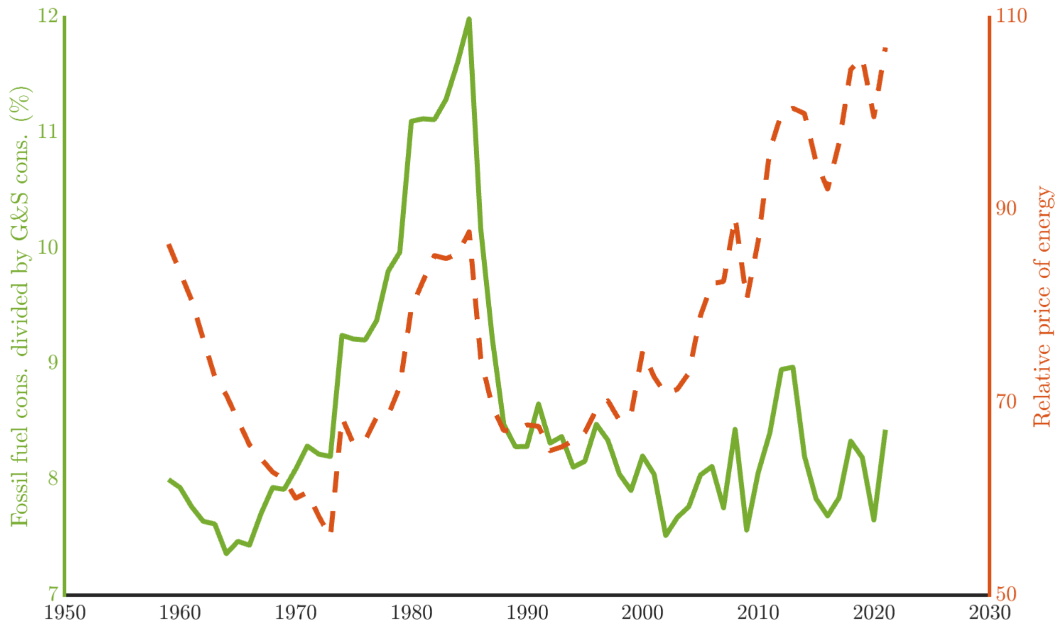
Figure 9: Effective carbon tax for France, 2020



A.6 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, Krusell and Olovsson (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^h than after.

Figure 10: Consumption ratio $(\frac{e^h}{c})$ and relative price of energy (p^h)



With Comin, Lashkari and Mestieri (2021) preferences, 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, assuming $\bar{e}$ is time-invariant, we estimate σ through a simple OLS estimation:

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

We get $\hat{\sigma} = 0.2$, significant at the 5% level. Restricting our estimation to the 1959-1990 period, we get $\hat{\sigma} = 0.28$ significant at the 5% level. Taking only the 1990-2021 period we get $\hat{\sigma} = 0.08$ not significantly different from zero. Adding an intercept to the regression always yields a zero for the constant term. As Hassler, Krusell and Olovsson (2021) that use U.S. data, we find very low short-run elasticity between energy and non-energy inputs in French data. In our benchmark calibration, we decide to set $\sigma = 0.26$. This nicely fits in between Casey (2024) pointing out that Cobb-Douglas functions vastly over-estimate transitional energy adjustments and Golosov et al. (2014) that use such a framework.

B Quantitative results – complements

B.1 Consumption equivalents

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

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

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

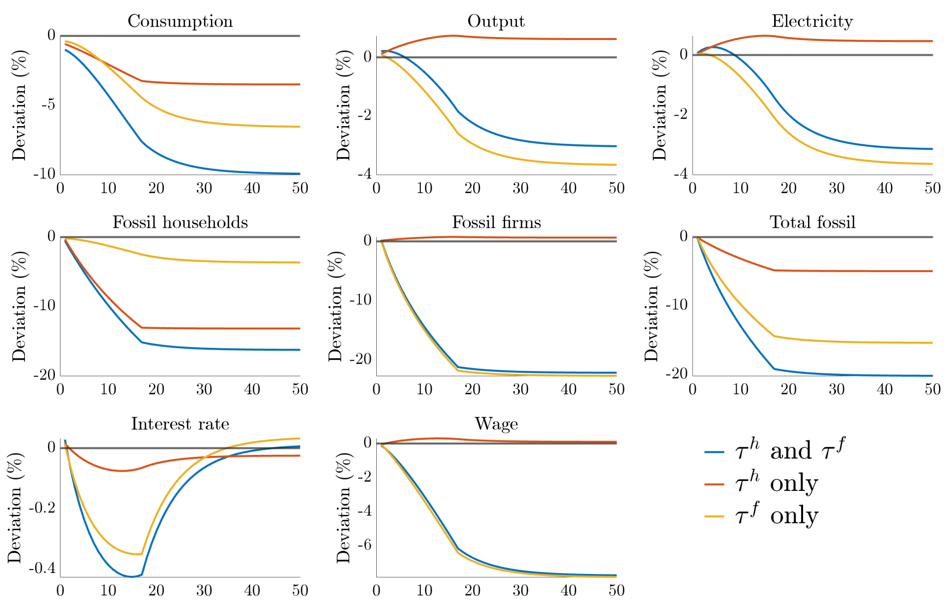
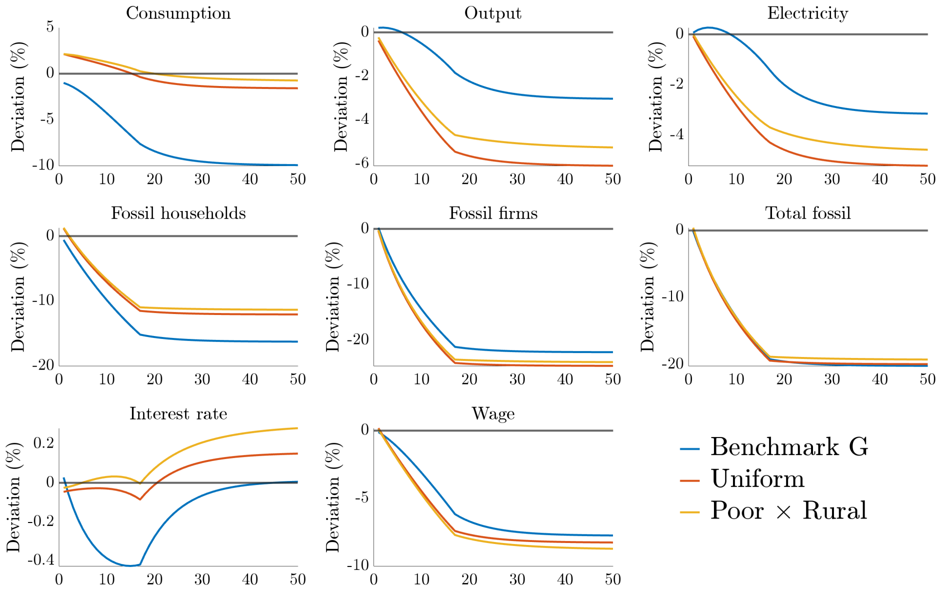


Figure 12: IRF: comparison between Benchmark G, T Uniform, T Rural × Poor



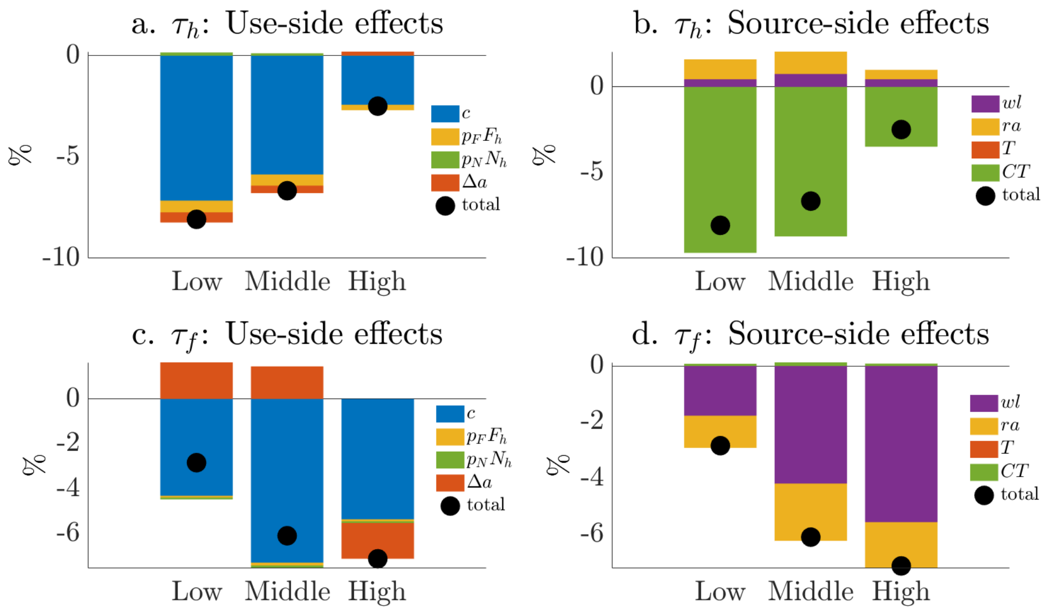
B.3 Distributive effects – Budget constraint decomposition

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 (low, middle, high) for rural households by comparing policy functions between steady states for the scenario from subsection 4.2. Top panels a and b show what happens when you increase only τ^h while bottom panels c and d illustrate the effects of an increase of τ^f. The change in savings shows how the borrowing constraint interacts with the two carbon taxes.

Figure 13: Budget constraint decomposition by productivity type, rural households



B.4 Political economy – share of losers

Table 5: 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 6 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 $\epsilon_y = 2$.

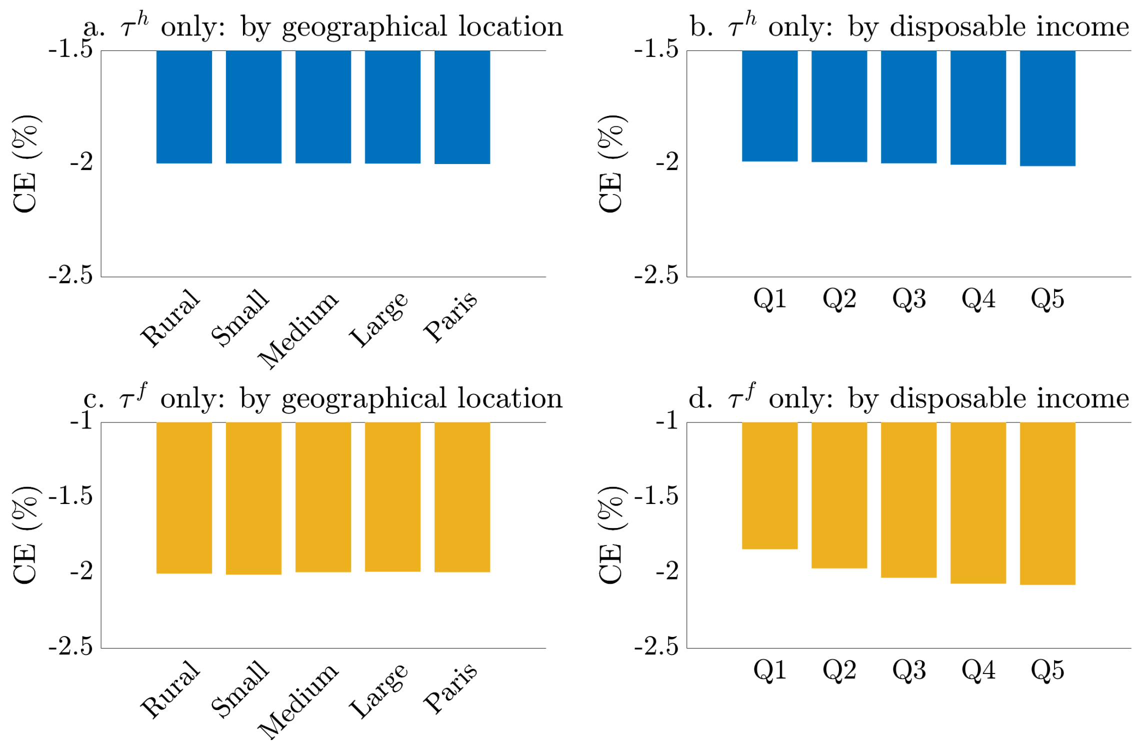
Table 6: Elasticities of substitution – *Benchmark G*

	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



C.3 Emissions reduction target

Figure 15: τ_h vs τ_f: 10% reduction emissions target

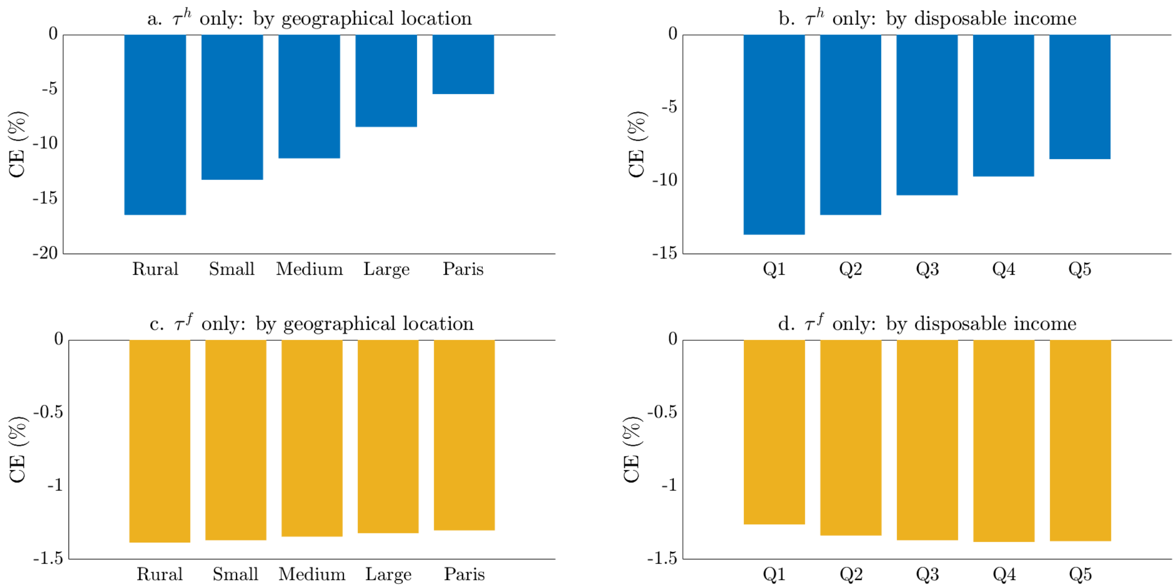


Figure 16: Comparison between recycling policies: 17.5% reduction emissions target