Inequality along the European green transition *

Guido Ascari[†] Andrea Colciago [‡] Timo Haber[§] Stefan Wöhrmüller [¶]

March 2025

Abstract

The EU aims for 42.5% green energy consumption by 2030. What are the effects of the European green transition on inequality? We answer this question using a heterogeneous-agent model with non-homothetic preferences for energy and non-energy goods, calibrated to European data. We study the impact of an increase in carbon taxes designed to meet the EU target under different revenue-recycling strategies. Redistributing tax revenues via uniform transfers reduces consumption inequality, shifts the welfare burden to high-income households, but leads to significant output losses. Subsidizing green energy producers boosts energy production, reduces output losses, and requires a smaller carbon tax to meet the EU target. However, it increases consumption and income inequality, with the highest welfare costs borne by low-income and asset-poor households. Our findings highlight key trade-offs between equity and efficiency in green transition policies.

Keywords: Green Transition, Inequality, Carbon Pricing
JEL codes: Q43, Q52, E6

*The views expressed in this paper are those of the authors and should not be attributed to De Nederlandsche Bank. We thank Sam Fankhauser, Leonardo Melosi, Marco Del Negro, Francois Lafond, Maria Sole Pagliari, Emilien Ravigne and seminar participants at DNB, Tilburg University, University of Amsterdam, and Rome La Sapienza, for their insights and discussions.

[†] De Nederlandsche Bank and Unversity of Pavia g.ascari@dnb.nl or guido.ascari@unipv.it.
[‡] De Nederlandsche Bank and University of Milan Bicocca: andreacolciago@gmail.com.
[§] De Nederlandsche Bank: t.f.haber@dnb.nl.
[¶] De Nederlandsche Bank and University of Amsterdam: s.h.p.wohrmuller@dnb.nl.

1 Introduction

The transition to a greener economy is one of the European Union's most urgent and complex challenges. The EU has set ambitious goals to significantly reduce carbon dioxide emissions and substantially increase the share of renewable energy. Figure 1 illustrates the trajectory of renewable energy consumption in Europe over the past two decades, along with the EU's target of achieving 42.5% renewable energy consumption by 2030.[1] Given current trends, reaching this target appears increasingly challenging.

While renewable energy targets are crucial for mitigating climate change, they also pose significant socio-economic challenges, because the costs of the green transition are likely not to be equally shared across households. For example, if the green transition leads to higher energy prices, it would disproportionately impact lower-income households, who typically spend a larger share of their income on energy.

The novelty of this paper is to explore the distributional effects of the green transition in the European Union. Specifically, assuming the EU increases its carbon tax to reach the new target, we investigate the distributional consequences of different uses of the revenues of the carbon tax. Our results reveal significant trade-offs between equity and efficiency in green transition policies.

To study the aggregate and distributional effects of the green transition, we develop an incomplete markets general equilibrium model where households face idiosyncratic income risk. Following Aiyagari (1994), we assume that income risk is only partially mitigated through savings in physical capital. We extend this classical framework by incorporating two essential features for understanding the broader implications of the green transition. First, we introduce both green and non-green energy producers, enabling us to capture the dynamic effects of the green transition on energy production and consumption. Second, we introduce non-homothetic preferences over energy and non-energy goods, following Boppart (2014). This approach generates non-linear Engel curves that are consistent with empirical evidence showing that lower-income households allocate a larger share of their consumption to energy than higher-income households (Levinson and O'Brien, 2019). We then empirically estimate both the degree of non-homotheticity in preferences and the parameters of the income process using data from the Dutch Household Survey LISS Panel, thereby calibrating our model with robust, empirically grounded parameters. Our results reveal significant non-homotheticity in preferences, underscoring its importance for analyzing the distributional impacts of the green transition. In doing so, our use and estimation of the Boppart (2014) utility function constitutes a significant contribution to the literature, as it not only aligns with microdata but also has crucial implications for the distribution of the costs associated with the green transition.

We then turn to assess the effects of the green transition in the EU from 2015 to 2030. Without any change in policy, we assume that the green technology grows linearly from 2015 to 2030 at

[1] The revised Renewable Energy Directive EU/2023/2413 raised the EU's binding renewable energy target for 2030 to a minimum of 42.5%, up from the previous 32%, with an aspiration to reach 45%. The directive took effect across all EU countries on 20 November 2023 (see here).

the same average rate observed between 2005 and 2015. This technological progress drives an expansionary economic path, with output, wages, and capital increasing over time. Although energy prices decline along this trajectory, the share of renewable energy reaches only 30% by 2030, falling short of the EU's 42.5% target.

To address this shortfall, we introduce a gradually increasing carbon tax designed to meet the EU's renewable energy goal by 2030 and investigate how different revenue allocation schemes affect the economy at both the aggregate and individual level. Specifically, we examine three fiscal policy options for redistributing carbon revenue: (i) financing government consumption, (ii) providing uniform lump-sum transfers to households, and (iii) subsidizing green energy production. We then compare the aggregate, distributional, and welfare outcomes of these revenue recycling mechanisms with the no-policy baseline, where the transition relies solely on green technological progress, as described above.

The introduction of a carbon tax affects energy usage in both consumption and production. When revenues are used to finance government spending, the carbon tax significantly raises brown energy prices, leading to a sharp decrease in brown energy production. Green energy prices rise moderately, and total energy production declines compared to the baseline. Lump-sum transfers help cushion the impact of higher energy prices, resulting in a less substantial drop in energy consumption. Finally, green energy subsidies lead to the largest increase in green energy production and require a smaller carbon tax increase to meet the renewable energy target, resulting in a more moderate decline in total energy production

Next, we analyze the aggregate effects. Using the carbon tax to fund government spending leads to a significant economic contraction by increasing energy prices, which in turn reduces output, capital, and consumption. Transfers to households partially offset this contraction by increasing disposable income, which stimulates the consumption of non-energy goods. However, as uniform transfers reduce income risk they diminish the incentive for precautionary savings. As a result, savings decrease, and physical capital accumulation lags behind that of other scenarios. Green energy subsidies result in the mildest output contraction, as the subsidies reduce energy costs and stimulate green energy production, thereby mitigating the negative effect on aggregate variables.

When revenues fund government spending, consumption inequality rises, as higher energy costs disproportionately impact poorer households, who have less flexibility to adjust their energy consumption compared to wealthier households. Uniform transfers reduce both consumption and income inequality by providing additional income to poorer households. However, wealth inequality rises, as the decline in precautionary savings leaves more households financially constrained. Green subsidies have a limited impact on redistribution, as both rich and poor households experience similar reductions in energy consumption.

All individuals experience a welfare loss during the green transition, regardless of the policy or their position in the wealth-income distribution.[2] However, the distribution of welfare costs

[2] In our analysis, we focus on the non-environmental welfare costs.

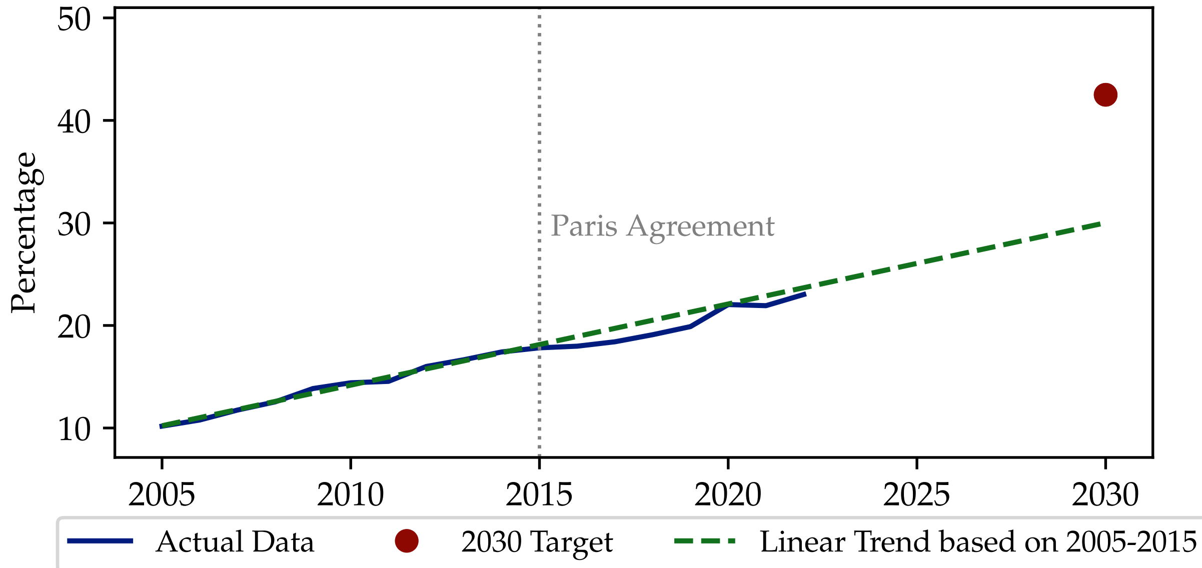


Figure 1: Share of energy consumption from renewable sources in Europe.
Source: European Environment Agency

differs significantly across scenarios. Uniform transfers primarily affect high-income individuals, independently of their wealth. This is because uniform transfers redistribute income from rich to poor households, mitigating the impact of higher energy prices. In contrast, green subsidies do not entail such redistribution, so households with both low income and low wealth suffer the most. Under this scenario, wealthy individuals experience the smallest welfare losses, regardless of their income. Moreover, we also show that non-homotheticity plays a crucial role in shaping both overall welfare effects and their distribution across households under different fiscal policies.

These findings highlight relevant trade-offs between equity and efficiency. Hence, it is important to consider both the aggregate and distributional welfare impacts when evaluating policy trade-offs during the green transition.

Policy recommendations thus depend on the goals of the policymaker. If the goal is to reduce consumption inequality and protect vulnerable households, lump-sum transfers would be the most effective policy. If the policymaker prioritizes aggregate economic stability, subsidizing green energy production is the preferred approach, as this policy results in lower output overall costs, higher overall energy consumption, and a lower carbon tax.

The remainder of the paper is structured as follows. Section 1.1 provides a brief overview of the related literature. Section 2 presents the model and defines the equilibrium. Section 3 describes the estimation of utility parameters, the calibration strategy, and the stationary distributions of income, wealth, and consumption. Section 4 examines transition dynamics under alternative fiscal policy scenarios. Section 4.5 analyzes the distribution of welfare costs across income and wealth levels. Finally, Section 5 concludes.

1.1 Related Literature

The literature on the effects of the green transition within macroeconomic models is rapidly expanding. Studies such as Del Negro, di Giovanni and Dogra (2023) and Olovsson and Vestin (2023) examine the inflationary impact of climate policies in economies with nominal rigidities, while Ferrari and Nispi Landi (2022) explore the role of expectations in shaping inflationary dynamics. Airaudo, Pappa and Seoane (2023) focus on the green transition in a small open economy, and Fried (2018) analyzes the effect of carbon taxation on green innovation.

However, all of these papers feature a representative agent framework, which overlooks distributional aspects. Some recent contributions that incorporate household heterogeneity include Fried, Novan and Peterman (2018, 2024), Benmir and Roman (2022), Douenne, Hummel and Pedroni (2023), Känzig (2023), Boehl and Budianto (2024), Labrousse and Perdereau (2024), and Kuhn and Schlattmann (2024). Compared to these studies, our model integrates in a unifying framework key features that are critical for understanding the green transition: non-homothetic preferences, uninsurable income risks, and a disaggregated energy production sector. This allows us to provide a more comprehensive analysis of the aggregate and distributional effects of the green transition. In particular, we build our preferences on the specification by Boppart (2014) who provides a non-Gorman specification of utility that matches the fact that the poor spend relatively more on energy goods than the rich. These preferences imply non-linear Engel curves over the different goods and hence also heterogeneous MPCs. In this case, indirect redistribution of income has aggregate consequences. Coenen, Lozej and Priftis (2024), Fried et al. (2018), and Fried et al. (2024) study alternative methods of recycling carbon tax revenues in heterogeneous agent economies and their implications for inequality. Coenen et al. (2024), similar to Känzig (2023), employ a two-agent New Keynesian (TANK) framework. Like them, we compare the aggregate and distributional effects of uniform transfers and subsidies to green energy producers. However, their TANK model leads to a degenerate income and wealth distribution, where only Ricardian agents hold wealth, and it does not incorporate a precautionary savings motive. We argue that this motive is crucial for understanding how savings and consumption decisions differ among agents under alternative policy scenarios. Fried et al. (2018) uses an overlapping generations (OLG) model to investigate the intergenerational redistribution effects associated with different uses of carbon tax revenues. Boehl and Budianto (2024) studies transfer vs subsidies recycling schemes with endogenous innovation in a climate HANK model, but does not model non-homothetic preferences. Labrousse and Perdereau (2024) examine a different aspect of heterogeneity than those discussed so far, focusing on regional disparities in energy consumption patterns. In contrast, Douenne et al. (2023) take a normative approach, analyzing the design of optimal pollution taxation in a setting with ex-ante heterogeneous households and no idiosyncratic risk. Finally, our results point to a policy trade-off between reducing emissions and inequality. Kuhn and Schlattmann (2024) stress a similar trade-off in a partial equilibrium life-cycle model with subsidies to households to incentivize the adoption of clean commitment goods.

Our final contribution is quantitative, as we calibrate our model to European data. For households, we rely on Dutch microdata, while for firms, we use the simplified Energy Balances from Eurostat. The latter dataset has also been recently employed by Coenen et al. (2024).

2 Model

The economy consists of a household sector, the government and three production sectors. Two of these sectors produce energy, while the remaining sector produces a non-energy good. The two energy-producing sectors differ in their input requirements. Both use capital and labor, but one also utilizes a fossil natural resource. For this reason, we refer to the energy produced in the latter sector as brown energy, and that produced in the former as green energy.

Brown and green energy are then combined into an energy good, which both serve as an input for producing the non-consumption good and is consumed by households. Households are heterogeneous in terms of income and discount factors. The government levies a tax on the brown energy producer and can recycle the revenues in different ways. There is no aggregate uncertainty in the economy.

2.1 Households

The household sector is modeled as a continuum of households facing uninsurable income risk. At each point in time t, a household i is characterized by the idiosyncratic part of its labor income y_{it},[3] asset holdings a_{it}, and a household-specific discount factor β_{it}. Household income is subject to both persistent and transitory shocks, denoted by ε and ψ, respectively. The pair (ε, ψ) follows an exogenous Markov process with transition matrix Γ. In addition to income risk, households face idiosyncratic uncertainty in their discount factor. The discount factor β_{it} evolves according to a two-state exogenous Markov process with transition matrix Γ_β, where β^{low} represents currently impatient agents, and $\beta^{\text{high}} > \beta^{\text{low}}$ represents currently patient agents.

In each period, households derive utility from consuming a non-energy good, c_{it}, and an energy good, e^c_{it}. The former serves as the numeraire. As is standard, the household's problem can be solved in two stages. In the intertemporal dynamic stage, households allocate their resources between savings for future periods, a_{it+1}, and real total expenditure, x_{it}. In the intratemporal static stage, they decide how to split their total expenditure, given by $x_{it} = c_{it} + p^e_t e^c_{it}$ in real terms, between the non-energy and energy good, taking the relative price of energy, p^e_t, as given. Hence, households receive a utility flow $U(x_{it}, p^e_t)$, where $U(\cdot)$ represents the intratemporal indirect utility function.

Households can reallocate resources intertemporally by investing in physical capital a_t, which yields a net real return r_t, while being subject to a no-borrowing constraint. Household $i's$ budget

[3] This is standard from Aiyagari (1994). The aggregate effective labor endowment is fixed and normalized to 1. Given inelastic unit labor supply by households, the stochastic idiosyncratic component of labor income $w_t y_{it}$ can be interpreted as idiosyncratic productivity.

constraint, in real terms, reads as

$$x_{it} + a_{it+1} \leq (1 + r_t)a_{it} + w_t y_{it} + T_t, \tag{1}$$

where y_{it} denotes household $i's$ labor endowment, w_t denotes the real wage, and T_t are uniform lump-sum transfers. Taking prices and transfers as given, each household solves the following dynamic programming problem

$$V_t(a_{it}, y_{it}, \beta_{it}) = \max_{x_{it}, a_{it+1}} U\left(x_{it}, p_t^e\right) + \beta_{it}\, \mathbb{E}_t \left[V_{t+1}\left(a_{it+1}, y_{it+1}, \beta_{it+1}\right)\right] \tag{2}$$

$$\text{s.t.} \quad x_{it} + a_{it+1} \leq (1 + r_t)a_{it} + w_t y_{it} + T_t \tag{3}$$

$$a_{it+1} \geq \underline{a}. \tag{4}$$

In the latter, the expectation $\mathbb{E}_t$ is taken over the realizations of idiosyncratic income and discount factor shocks.

Since we aim to capture non-homotheticity and the low substitutability between energy and non-energy consumption, we adopt the flexible specification of Boppart (2014) and parameterize the indirect utility function as follows

$$U\big(x_{it}, p_t^e\big) = \frac{1}{\epsilon}\left(x_{it}\right)^{\epsilon} - \frac{\nu}{\gamma}\left(p_t^e\right)^{\gamma} - \frac{1}{\epsilon} + \frac{\nu}{\gamma}, \tag{5}$$

where $0 \leq \epsilon \leq \gamma < 1$ and $\nu > 0$. As we will clarify later, ϵ governs both the degree of non-homotheticity in the consumption bundle and the intertemporal elasticity of substitution. The parameter γ plays a key role in determining the intratemporal elasticity of substitution between energy and non-energy consumption, while ν controls the relative weight of the two sectors in the utility representation. By applying Roy's identity to the indirect utility function in Equation (5), we derive the Marshallian demand functions for expenditure on the non-energy and energy goods. Furthermore, the expenditure system implies the following expenditure shares

$$\eta_{it}^{e^c} = \nu \left(\frac{1}{x_{it}}\right)^{\epsilon} \left(p_t^e\right)^{\gamma} \quad \text{and} \quad \eta_{it}^{c} = 1 - \nu \left(\frac{1}{x_{it}}\right)^{\epsilon} \left(p_t^e\right)^{\gamma}. \tag{6}$$

Note that the expenditure shares are a function of both relative prices and total expenditure. If $\epsilon > 0$, expenditure shares are a non-linear function of total expenditure and preferences are non-homothetic. If $\epsilon = 0$, on the other hand, the expenditure shares only vary with relative prices, but are invariant to changes in total expenditure. Hence, expenditure expansion paths are linear and preferences are homothetic. Intertemporal optimization yields the following Euler Equation

$$\left(x_{it}\right)^{\epsilon-1} \geq \beta_{it}\mathbb{E}_t \left[\left(x_{it+1}\right)^{\epsilon-1} \left(1 + r_{t+1}\right)\right], \tag{7}$$

which clarifies that the elasticity of intertemporal substitution of expenditure is equal to $\frac{1}{1-\epsilon}$.

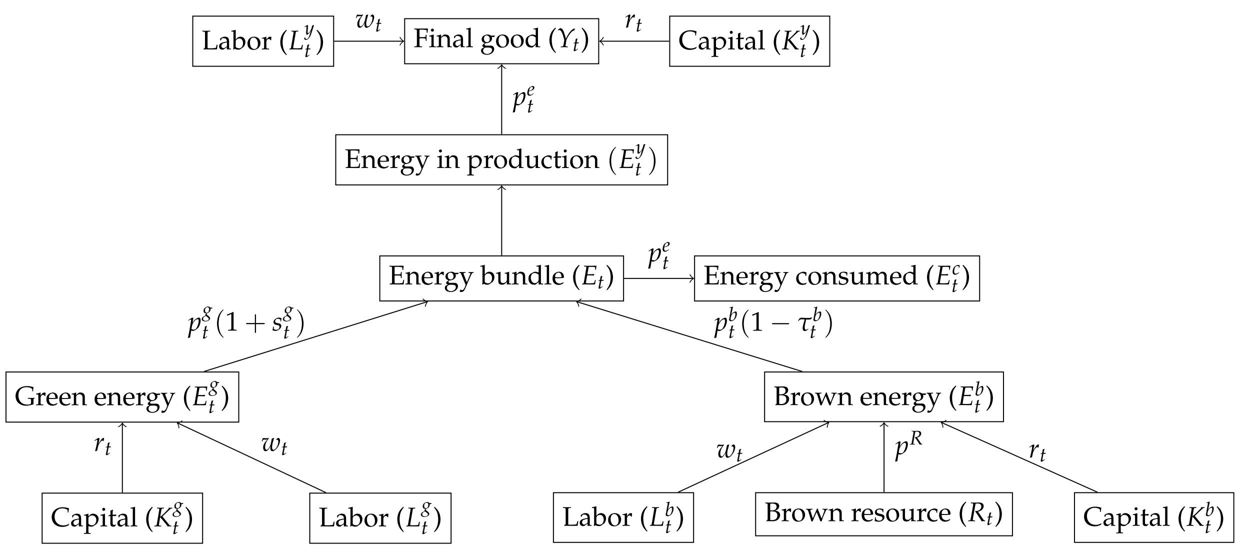


Figure 2: Overview of the production structure in the model

2.2 Production

Figure 2 provides an overview of the production side of the economy. At the base of the structure are the green and brown energy sectors. Moving upward, we find the energy bundler, which supplies energy to both production firms and households. At the top, final good producers complete the structure. The figure also highlights the production inputs used at each stage. We describe the structure starting from the final goods sector.

Final good sector The production of the final non-energy good requires two inputs. The first one is a Cobb-Douglas (CD) bundle between labor and capital, defined as $\mathcal{K}_t^y \equiv (K_t^y)^\alpha (L_t^y)^{1-\alpha}$, where α is a constant included between zero and one. The second input is energy, E_t^y. The two inputs are bundled with the Constant Elasticity of Substitution (CES) production function

$$Y_t = \left(\xi_y (\mathcal{K}_t^y)^{\frac{\rho_y - 1}{\rho_y}} + (1-\xi_y)(E_t^y)^{\frac{\rho_y - 1}{\rho_y}} \right)^{\frac{\rho_y}{\rho_y - 1}}, \tag{8}$$

taking input prices r_t, w_t, and p_t^e as given.[4] The parameter ρ_y defines the elasticity of substitution between the two inputs of production.

The final good producers demand capital and labor to minimize the cost of producing $\mathcal{K}_t^y$. As a result of the CD structure characterizing $\mathcal{K}_t^y$, and perfect competition, the relative price of one unit of $\mathcal{K}_t^y$ is

$$p_t^{\mathcal{K}} = \left(\frac{w_t}{1-\alpha} \right)^{1-\alpha} \left(\frac{r_t + \delta}{\alpha} \right)^{\alpha}. \tag{9}$$

[4] A CES production function provides greater flexibility in the substitutability between the composite input and energy, compared to the constraints imposed by a Cobb-Douglas production function. We will exploit this flexibility in our calibration strategy.

The demand for L_t^y is determined by

$$w_t = p_t^{\mathcal{K}} \, (1-\alpha) \, (L_t^y)^{-\alpha} (K_t^y)^{\alpha}, \tag{10}$$

while that for K_t^y reads as:

$$r_t + \delta = p_t^{\mathcal{K}} \alpha (L_t^y)^{1-\alpha} (K_t^y)^{\alpha-1}. \tag{11}$$

Recall that the price of the final good is the numeraire. Then, the demand for $\mathcal{K}_t^y$ is

$$\frac{\mathcal{K}_t^y}{Y_t} = \xi_y \left(p_t^{\mathcal{K}} \right)^{-\rho_y}, \tag{12}$$

while that for E_t^y reads as

$$\frac{E_t^y}{Y_t} = \left(1 - \xi_y\right) \left(p_t^e\right)^{-\rho_y}. \tag{13}$$

Energy production Energy is produced in two sectors: the green energy sector and the brown energy sector. The green energy sector uses labor and capital to generate energy, while the brown energy sector additionally relies on fossil resources. We do not account for resource scarcity in our analysis, as our focus is on the transition to 2030—a period during which the EU has set specific climate targets. Given this relatively short time frame, constraints on fossil resources are unlikely to be a significant limiting factor.[5]

Since fossil resource prices, such as oil, are determined in global markets, we model the European Union as a price taker, and assume a perfectly elastic supply at an exogenous price. In contrast, (relative) energy prices remain endogenous. The representative firm in the green energy sector is described by the following production function

$$E_t^g = Z_t^g \left(K_t^g\right)^{\alpha_g} \left(L_t^g\right)^{1-\alpha_g}, \tag{14}$$

where Z_t^g denotes total factor productivity (TFP) in the green sector. The associated profit function is

$$\Pi_t^g = p_t^g (1 + s_t^g) E_t^g - w_t L_t^g - r_t K_t^g, \tag{15}$$

where s_t^g denotes a green production subsidy (described in Section 2.3).

Brown energy firms produce energy using two inputs: the first one is a bundle between brown labor L_t^b and capital K_t^b as the one defined for the final good producers, denoted by $\mathcal{K}_t^b$, while the second one is a natural resource of fossil origin, denoted by R_t.[6] The two are bundled via the

[5] Another reason for neglecting resource scarcity is that, as noted by Fried (2018), the prices of brown resources have not followed the typical pattern predicted by Hotelling's rule, which assumes resource scarcity.

[6] R should be interpreted as a composite of coal, oil, and natural gas. While we do not explicitly model substitutability across these sources, we focus on the substitutability between renewables and non-renewables in energy production.

following CES production function

$$E_t^b = Z_t^b \left(\xi_b \left(\mathcal{K}_t^b \right)^{\frac{\rho_b - 1}{\rho_b}} + (1 - \xi_b) R_t^{\frac{\rho_b - 1}{\rho_b}} \right)^{\frac{\rho_b}{\rho_b - 1}}, \tag{16}$$

where Z_t^b denotes TFP in the brown energy sector. We normalize TFP in the brown sector to 1, allowing TFP in the green sector to be interpreted relative to that of the brown sector. Assuming that the government imposes a carbon tax τ_t^b on the revenues generated in the brown energy sector, the profit function of the representative firm reads as

$$\Pi_t^b = p_t^b (1 - \tau_t^b) E_t^b - p_t^{\mathcal{K}} \mathcal{K}_t^b - p^R R_t \tag{17}$$

where Π_t^b is the relative price of brown energy and p^R denotes the relative price of the fossil resource. Finally, green and brown energy are combined by a perfectly competitive energy provider using the following CES production function

$$E_t = \left(\xi (E_t^b)^{\frac{\rho_e - 1}{\rho_e}} + (1 - \xi)(E_t^g)^{\frac{\rho_e - 1}{\rho_e}} \right)^{\frac{\rho_e}{\rho_e - 1}}, \tag{18}$$

where E_t denotes the energy good demanded by both the final goods producer and the household sector.

2.3 Government

The government runs a balanced budget. As mentioned above, it levies a carbon tax τ_t^b on the revenues of the brown energy producers. There are three possible ways the government can utilize the revenue from this carbon tax. First, the government can allocate the tax revenues for unproductive government spending, G_t. This recycling scheme will be employed for all tax revenues in the initial steady state. Second, the government can rebate the proceeds back to the green energy producer in the form of a production subsidy, s_t^g. Finally, the government can distribute the tax revenues to households through a transfer schedule T_t. Taking these options into account, the government budget constraint reads as follows:

$$G_t + T_t + p_t^g s_t^g E_t^g = p_t^b \tau_t^b E_t^b. \tag{19}$$

2.4 Equilibrium

Definition 1. Given exogenous sequences for fiscal policy $\{\tau_t^b, G_t, s_t^g, T_t\}$ satisfying the government budget constraint (19), and a price sequence for the price of the fossil resource $\{p_t^R\}$, a competitive equilibrium is a set of prices

$$\{r_t, w_t, p_t^b, p_t^g, p_t^e\}$$

and quantities

$$\{Z_t^g, K_t^g, K_t^b, K_t^y, L_t^g, L_t^b, L_t^y, R_t, E_t^g, E_t^b, E_t^y, E_t, Y_t\},$$

firm policies, household policies, and distribution over their state variables $(a_{it}, y_{it}, \beta_{it})$ such that firms optimize, households optimize, the distribution evolves consistently with optimal policies and the following market clearing conditions hold:

1. Energy markets clear: $E_t = E_t^y + \int e_{it}^c d\Lambda_t(a_{it}, y_{it}, \beta_{it})$
2. Labor markets clear: $\int y_{it} d\Lambda_t(a_{it}, y_{it}, \beta_{it}) = 1 = L_t^y + L_t^b + L_t^g$
3. Asset markets clear: $\int a_{it+1} d\Lambda_t(a_{it}, y_{it}, \beta_{it}) = K_{t+1}^y + K_{t+1}^g + K_{t+1}^b$
4. The goods market clears by Walras' Law.

3 Parametrization

Since a closed-form solution to this model is not possible, we employ numerical methods to solve for the equilibrium. To ensure our approach is grounded in empirically plausible parameter values, we utilize both calibration and estimation techniques. We describe our parametrization approach for each sector of the economy. Parametrization is on a quarterly basis.

Household parameters We use the Dutch Household Survey LISS Panel to estimate the income risk profile and preference parameters. Specifically, we use the LISS Panel data from 2009 to 2019 to estimate the parameters of the exogenous income process.[7]

Following Floden and Lindé (2001) and Straub (2019), we model income as having both a persistent and a transitory component, employing a two-step estimation approach. In the first step, we regress the annualized log average monthly gross household income on a set of household characteristics as follows

$$\begin{aligned}\log(y_{it}) =& \alpha + \alpha_t + \gamma_1 \text{ age}_{it} + \gamma_2 \text{ age}_{it}^2 + \gamma_3 \text{ age}_{it}^3 + \\ & \iota \text{ educ}_{it} + \rho \text{ occupation}_{it} + \theta \text{ gender}_{it} + \sigma \text{ size}_{it} + u_{it}.\end{aligned} \tag{20}$$

In the second step, we use the residuals u_{it} to estimate the parameters $(\rho, \sigma_\psi^2, \sigma_\varepsilon^2)$ of the following persistent-transitory process, using a Minimum Distance Estimator

$$u_{it} = \kappa_{it} + \psi_{it} \qquad \text{where: } \psi \sim \mathcal{N}(0, \sigma_\psi^2), \tag{21}$$

$$\kappa_{it} = \rho \kappa_{it-1} + \varepsilon_{it} \qquad \text{where: } \varepsilon \sim \mathcal{N}(0, \sigma_\varepsilon^2). \tag{22}$$

The persistent component exhibits an AR(1) coefficient of 0.9422, while the variance of its innovations is 0.0186. The variance of transitory shocks is estimated at 0.0113. These parameter estimates align with findings from similar studies, such as Krueger, Mitman and Perri (2016) for the US.

[7] Further details on data usage and preparation are provided in Appendix A.

Further details on the estimation procedure are provided in Appendix B. Next, we use the *Time Use and Consumption* waves of LISS data archive to estimate ϵ, the parameter capturing the degree of non-homotheticity in the preference formulation proposed in Equation (5).[8] Specifically, we compute the expenditure share on energy, denoted as η^d, and total expenditure, denoted as x. Following Boppart (2014), we estimate ϵ using the following regression

$$\log \eta_{it}^d = \alpha - \epsilon \log x_{it} + \alpha_t + v_{it}, \tag{23}$$

where total expenditure is instrumented by total income, and α_t captures time-fixed effects. We estimate a value $\epsilon = 0.58$. Since this estimate is statistically significantly different from zero across multiple specifications, we conclude that the data exhibit considerable non-homotheticity. Further details on the estimation procedure are provided in Appendix C.

Having a reliable estimate for ϵ, we set $\gamma = \epsilon$. In this case, the elasticity of substitution between the energy and non-energy good is $1 - \gamma = 0.42$ for all the households. Notice that this value aligns with the estimates of Balke and Brown (2018) for the US economy. We calibrate the preference parameter ν to match the average energy expenditure shares.

Following Auclert, Rognlie and Straub (2024), we assume that each household's discount factor, β_{it}, evolves according to a two-state Markov chain. Households with β^{low} are currently impatient, while those with $\beta^{\text{high}} > \beta^{\text{low}}$ are currently patient. Each period, an agent retains their existing discount factor with probability $1 - q$. With probability q, they receive a new independent draw, where β takes the value β^{low} with probability $\omega_{\beta^{\text{low}}}$ and β^{high} with probability $1 - \omega_{\beta^{\text{low}}}$. We calibrate $q = 0.04$, implying that households receive a new draw of β approximately once every 25 years. As suggested by Krusell and Smith, Jr (1998), we interpret this as capturing generational turnover. The value of β^{high} is chosen to ensure that the real interest rate in the initial steady state is 3%. Meanwhile, $\Delta\beta \equiv \beta^{\text{high}} - \beta^{\text{low}}$ and the transition probability $\omega_{\beta^{\text{low}}}$ are set to jointly match both the wealth Gini coefficient and the average marginal propensity to consume (MPC) in the Euro Area. Specifically, we target a wealth Gini of 0.73 — the average of quarterly Gini coefficients for the Euro Area in 2015, as reported in the ECB's Distributional Wealth Accounts. To calibrate the MPC, we draw on empirical estimates from European data. Based on the average of the findings in Jappelli and Pistaferri (2014), Crawley and Kuchler (2023), and Christelis, Georgarakos, Jappelli, Pistaferri and van Rooij (2019), we set the average MPC to 0.44.

Production of Final Goods The gross capital share α in the capital-labor bundle is set to a standard value of 0.36. The elasticity of substitution between the capital-labor bundle and energy is set to 0.04, following Hassler, Krusell and Olovsson (2022). This near-zero elasticity implies that the energy income share in final goods production closely tracks movements in the energy price. The share parameter ξ_y is set to machine epsilon to approximate the observed energy income share of 7.2%. Finally, the depreciation rate δ is calibrated to match a capital-to-output ratio of 3.197, as reported by Eurostat.

[8] The survey focuses on time use and consumption expenditures.

Energy production Turning to energy production, we aim to match two key relative magnitudes between brown and green energy. First, we target the relative price of green to brown energy, which was 1.8 in 2015, as documented by Jo (2024). The latter must be consistent with the initial quantity of fossil resources used in the production of brown energy, denoted as R_0. Second, we target the relative supply of brown and green energy. Using Eurostat's simplified energy balances, we calculate that the ratio of green to brown energy, both measured in tonnes of oil equivalent, was approximately $\frac{E^{g,\text{data}}}{E^{b,\text{data}}} = 0.1686$ in 2015.

In model units, this implies that $\frac{p^g E^g}{p^b E^b} = 0.1686$, which leads to $\frac{E^g}{E^b} = 0.0937$. We set the elasticity of substitution between brown and green energy, ρ_e, to 1.8, based on microeconometric evidence from Papageorgiou, Saam and Schulte (2017).

Finally, we calibrate the share parameter ξ of the energy bundle. The first-order condition for the energy bundler yields the following equation

$$\left(\frac{\xi}{1-\xi}\right)^{\frac{\rho_e-1}{\rho_e}} \left(\frac{E^g}{E^b}\right)^{\frac{1}{\rho_e}} = \frac{p^b}{p^g}. \tag{24}$$

Using the target values for $\frac{E^g}{E^b}$ and $\frac{p^b}{p^g}$, we can solve for ξ analytically. This approach results in a value $\xi = 0.674$.

Brown energy is produced using a capital-labor bundle and a brown fossil resource. The capital-labor bundle follows a Cobb-Douglas specification with a capital share of 0.597, as in (Barrage, 2020). We set the elasticity of substitution between these inputs to 0.25, as in Coenen, Lozej and Priftis (2023). Additionally, we calibrate the share parameter ξ_b numerically to match a labor share of 30%. Following Barrage (2020) and others, we assume that green energy production also follows a Cobb-Douglas function in capital and labor. Thus, we set $\alpha_g = 0.597$.

Government The only instrument available to the government for raising revenue is the carbon tax τ_t^b. Given the European context of our application, we calibrate the revenue share to match the European revenues from environmental taxes as a percentage of GDP in 2015. According to Eurostat, this amounted to 2.436% in 2015.

We summarize the model's parameterization in two tables. Table 1 reports the estimated and assigned parameters. Table 2 presents the parameters used to target empirical moments, along with the target values, and corresponding model-implied moments. The model fits the data targets very well. Finally, Table 3 evaluates the model's performance in matching untargeted moments. Given the parameterization described above, the model underestimates the Gini coefficient for income, likely due to the absence of return heterogeneity in financial income. In contrast, the labor share in energy and the energy-to-output ratio are overestimated relative to the data, while the empirical energy shares are exactly matched. Overall, we consider the model successful in matching empirical moments, both targeted and untargeted.

Table 1: Estimated and assigned parameters

	Description	Value	Target/source
	Households		
	Preferences		
ϵ	Degree of non-homotheticity	0.58	Estimated, LISS panel
γ	EoS factor	0.58	Literature
β^{high}	High discount factor	0.979	Asset market clearing with $r = 0.03$
	Income process		
ϱ	Income shock persistence	0.9422	Estimated, LISS panel
$\sigma^2_{\varepsilon^\kappa}$	Variance of innovations to persistent shock	0.0186	Estimated, LISS panel
σ^2_ψ	Variance of transitory shocks	0.0113	Estimated, LISS panel
	Production		
	Final goods production		
ρ_y	EoS between capital-labor and energy	0.04	Hassler et al. (2021)
α	Capital share	0.36	Literature
	Energy bundler		
ρ_e	EoS between brown and green energy	1.8	Papageorgiou et al. (2017)
	Brown energy production		
ρ_b	EoS between capital-labor and fossil resource	0.25	Bodenstein et al. (2011)
α_b	Capital share in the C-D bundle	0.597	Barrage (2020)
	Green energy production		
α_g	Capital share	0.597	Barrage (2020)
Z^g_0	TFP green energy	1.0	Normalization

Note. This table provides parameters that we estimated using the LISS data archive, and parameters that we sourced from the relevant literature. The first column shows the parameter symbols, the second the description, the third the value, and the fourth the sources or the target.

Table 2: Numerically calibrated parameter values and moments

Parameter	Value	Moment		Model	Data
δ	0.0994	Capital-Output Ratio	$\frac{K}{Y}$	3.197	3.197
ξ_b	0.0601	Labor share in brown energy prod	$\frac{wL^b}{p^b E^b}$	0.300	0.300
ν	0.1583	Avg. exp. share in energy	$\int \frac{p^e e^c_i}{x_i} d\Lambda_i$	0.130	0.130
τ_d	0.1244	Carbon tax rev. to GDP	$\frac{\tau_b p^b E^b}{Y}$	0.0244	0.0244
$\Delta\beta$	0.0471	Gini wealth	$\text{Gini}(\Lambda_i)$	0.761	0.730
$1 - \omega_{\beta^{\text{low}}}$	0.4661	Average MPC	$\int \frac{\partial c_i}{\partial x_i} d\Lambda_i$	0.453	0.440
p^R	0.022	Rel. price between green and brown energy	$\frac{p^g}{p^b}$	1.8	1.8

Note. This table provides the numerically calibrated parameters together with the corresponding moments of our benchmark calibration. We use the TikTak algorithm of Arnoud, Guvenen and Kleineberg (2019) to calibrate all parameters, except the last two, which are set manually. The first column shows the parameter symbols, the second the value, the third the moment description, and the last two columns show the corresponding values in the model and the data.

3.1 Steady state

Before examining the transitional dynamics, we first discuss the characteristics of steady-state household expenditure and the properties of the stationary distribution across different variables.

Table 3: Untargeted Moments

Moment	Model Value	Data Value
Income Inequality (Gini)	0.256	0.308
Brown Energy Share	0.856	0.856
Labor Share in Energy	0.117	0.024
Total Energy over Output	0.147	0.072

Note. This table provides untargeted moments comparing model-generated values with real-world data.

Household expenditure characteristics Panel (a) of Figure 3 illustrates households' energy expenditure as a function of total expenditure. The solid (blue) line represents the lowest permanent income type, while the dashed (red) line corresponds to the highest.

Two key observations emerge. First, for a given level of total expenditure, energy expenditure is identical across income types. This result arises because both income types face the same intratemporal decision problem, where total expenditure is predetermined. Second, energy expenditure is *concave* in total expenditure. This follows directly from the non-homothetic preferences and the Marshallian demand system derived from Equation (5).

Panel (b) of Figure 3 illustrates the key implication of this concavity by displaying a heatmap of energy expenditure shares, plotted against the percentiles of income and wealth. The share of expenditure on energy decreases with both income and asset holdings, with a slightly stronger effect for asset holdings. The lowest expenditure share is observed among those with high asset wealth, regardless of their income level. Hence, what primarily matters for a household's expenditure share is cash-on-hand. Even if a household is at the borrowing constraint (i.e., holding the lowest asset position), a high income level significantly reduces its expenditure share. Similarly, low-income households with high asset holdings also have a lower expenditure share.

The use of the Boppart (2014) utility function is a distinctive feature of our model. First, the above patterns align with empirical evidence from microdata, as shown in Figure C.1 in Appendix C. Second, the fact that expenditure shares are not evenly distributed across households, and are a decreasing function of both income and wealth, have important implications for the distribution of the welfare costs of the green transition.

Steady State Inequality Steady-state inequality metrics, summarized in Table 4, reveal notable patterns across household quantities. The Gini coefficient for energy consumption is 0.11, indicating a relatively homogeneous distribution of energy expenditure, in line with the specification of our preferences. This suggests a lower concentration of energy consumption compared to both income and wealth.

Additional measures of concentration commonly used in the literature further support this observation. The mean-to-median ratio and percentile ratios (99-50 and 90-50) for energy consumption are significantly lower than those for non-energy consumption and total expenditure, reinforcing the relatively equal distribution of energy consumption. In contrast, wealth concentration is substantially higher, with a 99-50 ratio of 99.91 and a 90-50 ratio of 37.73, highlighting

Figure 3: Expenditure expansion paths and energy expenditure shares across the distribution

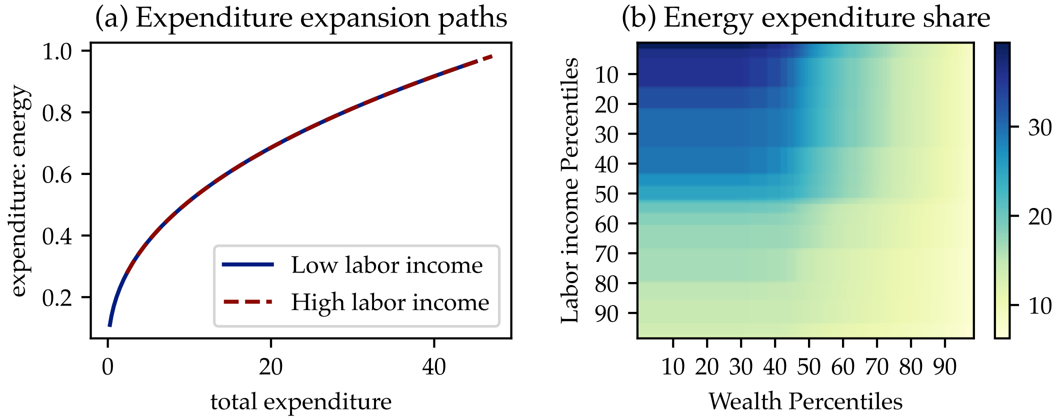


Table 4: Steady-State Inequality Metrics for various household quantities

Variable	Gini	Mean pctile	$\frac{\text{Mean}}{\text{Median}}$	$\frac{\text{99th}}{\text{50th}}$	$\frac{\text{90th}}{\text{50th}}$
Total Expenditure	0.27	63	1.15	3.70	1.84
Non-Energy Consumption	0.29	63	1.17	3.99	1.93
Energy Consumption	0.11	57	1.03	1.73	1.29
Wealth	0.76	72	11.72	99.91	37.73
Income	0.26	60	1.09	2.75	1.78

Note. This table provides the Gini coefficient, the location of the mean, the ratio of the mean to the median and the respective 99th-50th and 90th-50th percentile ratios across the distributions of total expenditure, non-energy consumption, energy consumption, wealth and total income (net of transfers).

the high concentration of assets among the top percentiles of the distribution.

4 Macroeconomic and Distributional Consequences of the Green Transition

In this section, we explore the macroeconomic and distributional effects of the green transition under different policy scenarios. First, we present our baseline case of reference, and we precisely define our policy scenarios. Then, we will describe the consequences of each scenario in turn in comparison with the baseline. Under each transition, the price of the fossil resource is exogenous and assumed to remain constant.

4.1 The green transition

We define the initial steady state of our economy as 2015, the year of the Paris Agreement. In this steady state, the government imposes a carbon tax equal to $\tau^b_{2015} = 0.12$ and uses the revenues to fund wasteful government consumption. Importantly, our model features technological progress in the production of green energy. In our baseline transition experiment green technology, Z_g, grows linearly from 2015 to 2030 at the same average rate observed between 2005 and 2015. Appendix F presents the transition paths of key variables under this baseline scenario, which assumes no fiscal intervention beyond the automatic adjustment of government spending to maintain a balanced budget. Because of the technological growth in the green sector, the economy in this baseline transition is on an expansionary path where output, wages, and capital grow to the new long-run equilibrium. Energy prices decline along the transition path. However, by 2030, the share of renewable energy reaches only 30%.

To address this shortfall, we introduce a gradually and steadily increasing carbon tax, aiming to achieve the new EU target of renewable energy share of 42.5% by 2030. Starting from the initial steady state, the carbon tax, τ^b, rises steadily and linearly from $\tau^b_{2015} = 0.12$ to a level consistent with the 42.5% target. The carbon tax increase is modeled as a fully unanticipated policy. After 2030, both the carbon tax and green technology are assumed to remain constant.

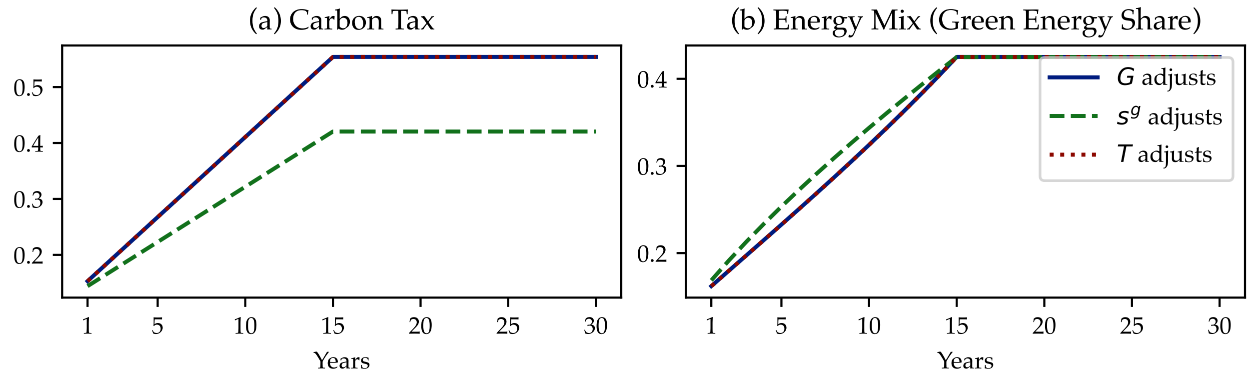
A key contribution of our paper is the analysis of three alternative uses for the carbon tax revenue, each leading to a distinct transition path to 2030.

In the first scenario, all revenues are allocated to wasteful government consumption, G_t, aligning with the fiscal policy in our baseline transition scenario described above. We refer to this as scenario "G." In the second scenario, denoted as scenario "T", the revenues are distributed equally to households as lump-sum transfers, directly increasing disposable income and potentially mitigating the financial burden of higher carbon taxes, especially for poor households. This scenario mimics the government intervention in some euro area countries during the recent energy inflation surge. Finally, in the third scenario, labeled "s^g", the fiscal authority redirects the revenues to subsidize green energy production, encouraging the adoption of clean energy.

The left panel in Figure 4 shows the assumed path of the carbon tax over 30 periods, while the right panel illustrates the dynamics of the green energy share over the three different scenarios. Solid (blue) lines refer to scenario G, dotted (red) lines to scenario T, and dashed (green) lines to scenario s^g. Green energy subsidies necessitate a smaller increase in the carbon tax to meet the 2030 green energy share target and imply a persistently higher share of green energy usage during the transition to 2030, in comparison with the other two policies.

In the following subsections, we assess the macroeconomic, distributional, and welfare effects of the green transition under these three fiscal policy scenarios in turn. To disentangle the impact of fiscal policy from that of technological progress, we present the dynamics of key macroeconomic variables relative to their counterparts in the baseline transition experiment, where only technological progress is at play. Therefore, unless otherwise stated, in all the following figures the variables will be expressed in percentage deviation from the baseline scenario. As for Figure 4, also in the following figures solid blue lines represent the G scenario, red dotted lines correspond to the T scenario, while dashed green lines refer to the s^g scenario. For each scenario, we examine aggregate effects and their distributional impacts.

Figure 4: Carbon tax path along the green transition.



4.2 Carbon tax revenue used to finance government spending

Aggregate effects Figure 5 presents energy market outcomes across all fiscal policy scenarios. It illustrates the relative price of energy (panel (a)) and its equilibrium quantity (panel (b)), along with the relative prices and the quantities of brown energy (panels (c) and (d)) and green energy (panels (e) and (f)). Additionally, it shows the amount of energy used in final goods production (panel (g)) and the amount of fossil resources consumed in brown energy production (panel (h)).

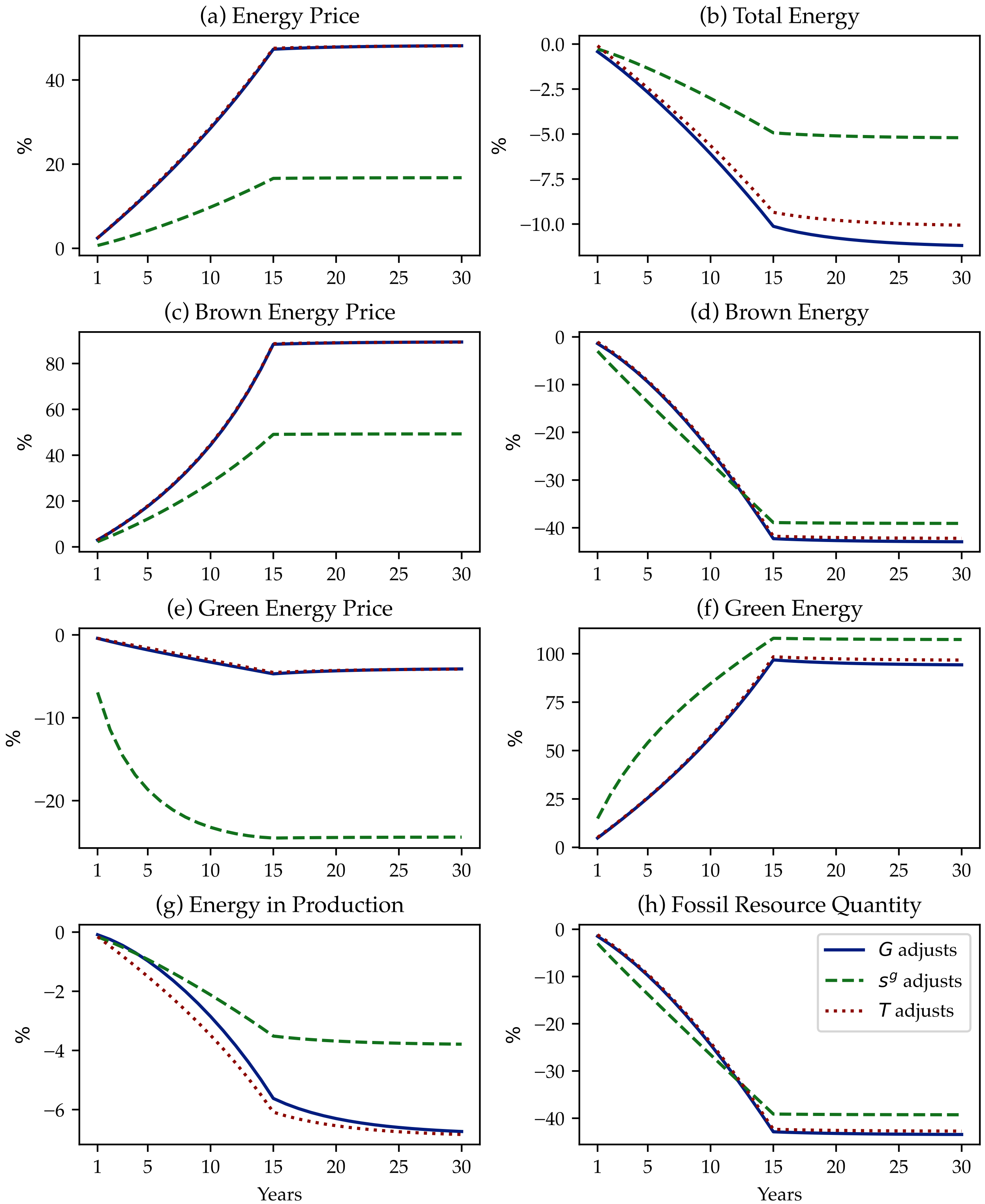
Let us focus on the blue lines in this subsection. As expected, compared to the baseline scenario, the carbon tax increases the relative price of brown energy and reduces fossil resource consumption. This is the main and intended effect of the carbon tax. It follows that the price of energy, which is produced using both brown and green energy, also rises with respect to the baseline.[9] The impact on energy usage in 5 mirrors the price dynamics. Total brown energy production falls substantially by more than 40% by the time the transition is accomplished. Energy production also declines as both households and firms cut their energy demand. The strong increase in green energy usage only partially offset the sharp reduction in brown energy production. Note that the price of green energy slightly falls, despite the strong increase in green energy usage in consumption and production. This general equilibrium effect is driven by the supply side of the model, which involves a reallocation of labor and capital towards the green energy sector, as explained below. As the price of brown energy increases, energy providers substitute brown with green energy.

In the literature (e.g., Fried, 2018), carbon emissions are typically modeled as a function of fossil resource consumption, assuming a constant conversion rate. For this reason, a reduction in the usage of R (panel (h)) and the production of brown energy can be interpreted as a reduction in emissions.

The carbon tax induces a strong increase in the production of green energy and a large realloca-

[9] As said above, unless otherwise stated, in all the following figures the variables will be expressed in percentage deviation from the baseline scenario. So we will not anymore state 'relative to the baseline' in what follows.

Figure 5: Dynamics of relative energy prices and energy quantities along the transition.



tion of both labor and capital from the brown to the green sector (see Figure E.1 in Appendix E).[10]

[10] Our model does not feature any factor reallocation costs across brown and green energy sectors. Hence, effectively, our assumptions make the supply of green energy flat, i.e., an almost constant marginal cost. While it would be easy to introduce reallocation costs, it is also clear what the effect would be, i.e., they would make the transition even more inflationary in terms of energy prices.

Moreover, the cost of producing green energy tends to decrease because of the general equilibrium effects induced by the contraction of factor prices.

Indeed, Figure 6 illustrates the strong contractionary effect on output, capital, and consumption all of which grow more slowly than in the baseline following the increase in the carbon tax.[11] Consumption (both of energy and non-energy) drops substantially because of the negative wealth effects on households due to the increase in taxes, as in a standard real business cycle model. The consumption of energy (Panel (d)) clearly drops by more than the one of non-energy (Panel (c)) because of the substitution effect. While output of the final good decreases because of lower consumption, government spending increases by design, so ex-ante the final output contraction (Panel (a)) might be not obvious. Note that this can be seen as an example of a negative fiscal multiplier, given that this scenario could also be interpreted as an increase in government spending financed by an increase in the carbon tax. Two main factors reduce the effects of an increase in government spending on final output with respect to a standard real business cycle model. First, because labor is in fixed supply in our model, there is no wealth effect on labor supply, which is the key mechanism in standard real business cycle model to generate an expansionary effect of an increase in government spending (financed with lump-sum taxes). Second, and most importantly, our model is multi-sectorial and the carbon tax is a distortionary tax on a production input. The tax on brown energy makes an input of production more costly, so effectively it acts as a negative productivity shock. Output production depends on energy, capital, and labor, and as firms reduce energy use, they also reduce their demand for capital and labor. Aggregate capital – and investment – drop substantially (Panel (b)). The contractionary effects are therefore affecting the dynamics of factor prices along the transition, as displayed in Figure 7. Both the return on capital and wages decrease persistently, with the latter experiencing a particularly strong decline.

Distributional effects Figure 8 shows that the behavior of consumption is similar across the wealth distribution (Panels (a)-(d)). Both asset-rich and asset-poor agents significantly reduce their consumption of both the non-energy good and of energy, not surprising the latter relatively more than the former. Note that asset-rich households can more easily shift their consumption from energy to non-energy goods during the transition. Disposable income also decreases sharply for all households across the wealth distribution (see Panel (e) and (f)). In the initial periods, however, asset-poor agents experience a sharper contraction in consumption than wealthier agents, which leads to the increase in the Gini coefficients on consumption of both the non-energy good and of energy, as shown in Panels (a) and (b) of Figure 9, which displays the dynamics of the Gini coefficient of concentration in non-energy consumption, energy consumption and wealth. Note that the richer households' greater ability to substitute away from energy leads to a much larger increase in the Gini coefficient for non-energy consumption compared to that for energy consumption. Panel (c) shows that wealth is becoming slightly more concentrated, while Panel (d) shows

[11] Again, we remind to the reader that the statement is relative to the baseline, where the economy is growing. Figure E.2 in Appendix E shows the dynamics of the same variables in deviations from the initial steady state, to highlight the dynamics of the levels of the variables.

Figure 6: Dynamics of output, capital, non-energy and energy consumption along the transition.

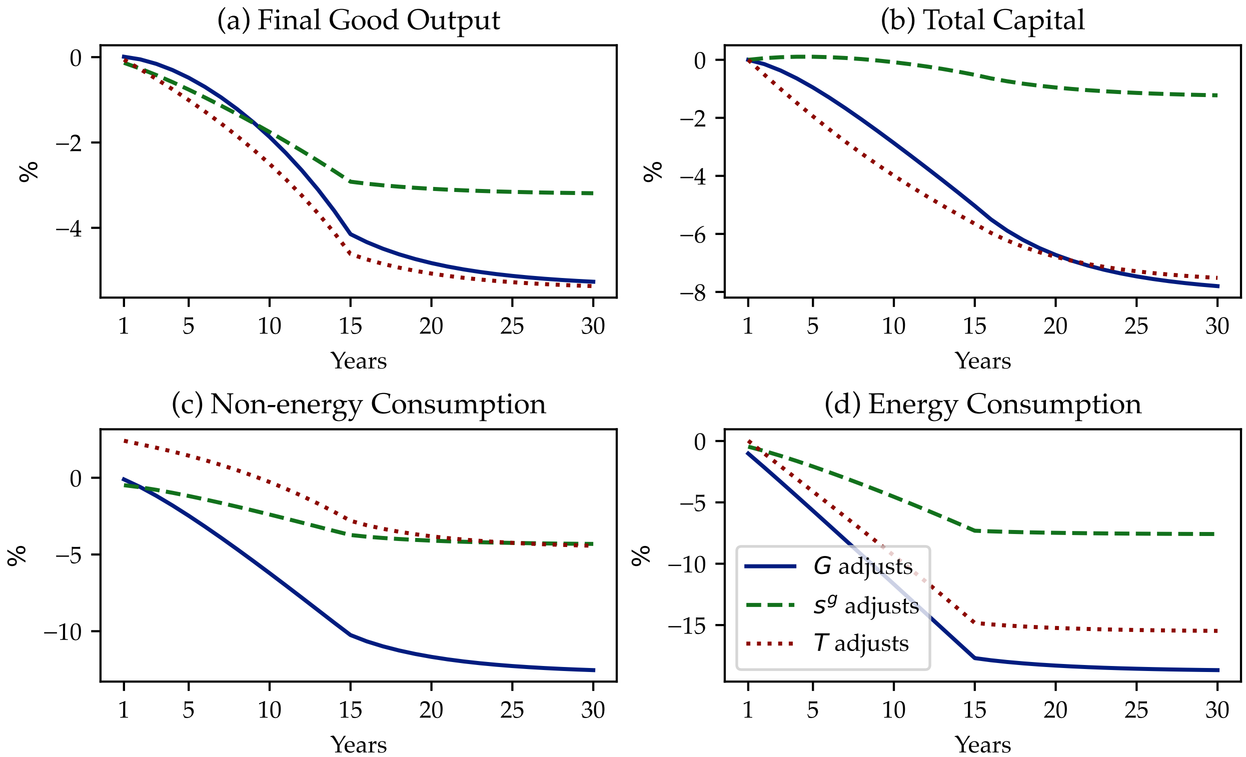
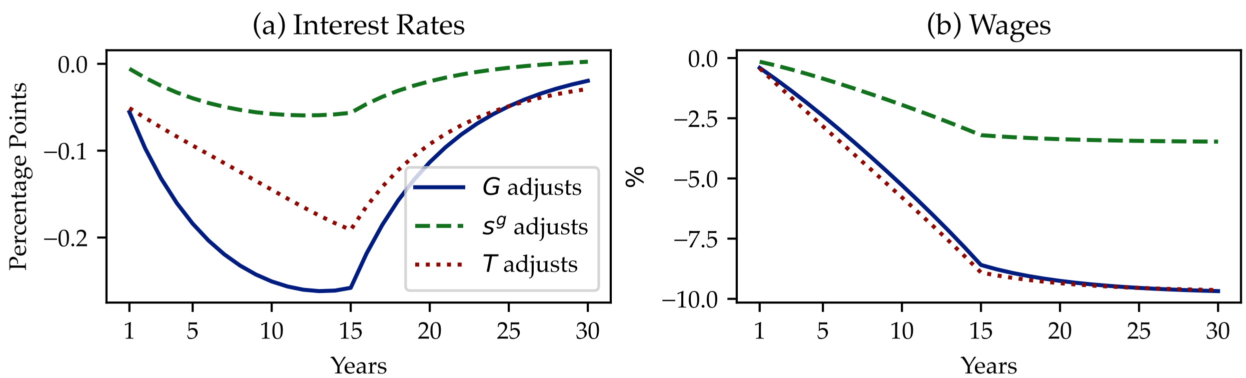


Figure 7: Dynamics of wages and returns to capital along the transition.



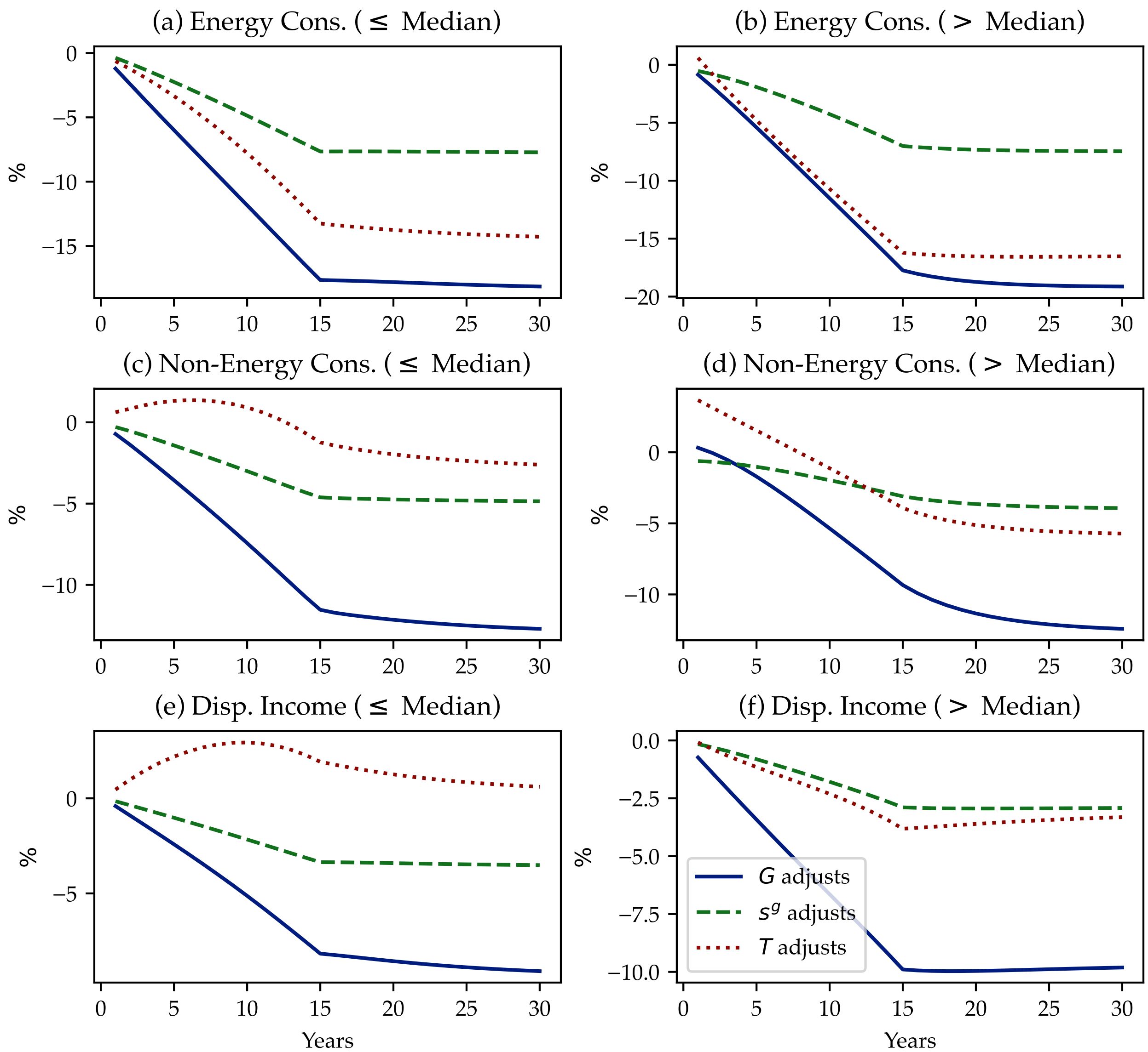
that the fraction of households at the borrowing constraint remains substantially unchanged.

4.3 Carbon Tax Revenue Used for Transfers to Households

In this scenario, all revenue from the carbon tax is redistributed to households through uniform lump-sum transfers. In the figures, this transition is represented by red dotted lines.

Aggregate effects Figure 5 shows that the dynamics of relative energy prices and quantities between the brown and the green energy sectors in this T scenario are the same as the ones in the

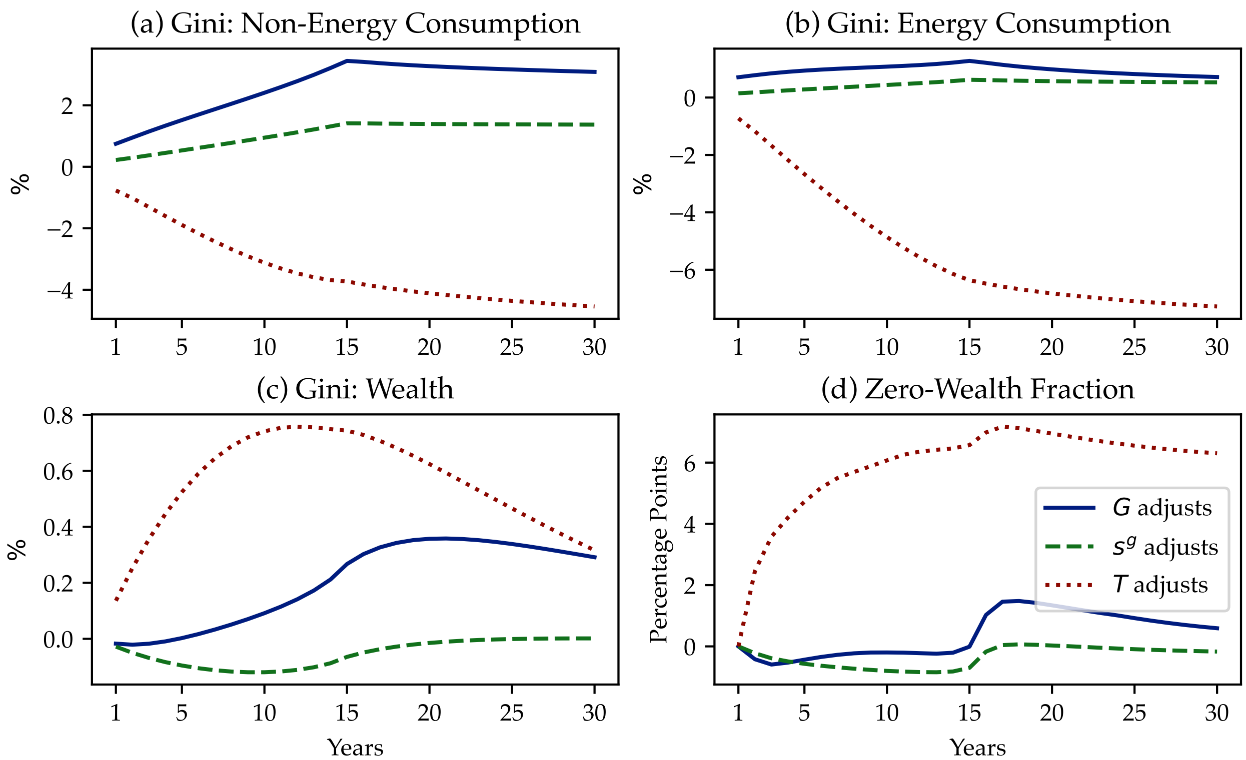
Figure 8: Dynamics of consumption, energy consumption and disposable income above and below the median of the wealth distribution along the transition.



previous G scenario. There are however some important differences in energy production and energy usage. Panel (b) shows that energy production falls less, but the energy used in the production of the final good (panel (g)) falls more. This occurs because the additional carbon tax revenue is rebated to households rather than spent on final output. Uniform transfers directly ease households' budget constraints, and proportionally more so for poor households with a high marginal propensity to consume (MPC). Households will have more resources available for consumption, and they will spend it partly on energy and partly on the non-energy good. Hence, with respect to the previous scenario, T diverts resources from final good producers to energy producers.

The dynamics of brown energy production are identical across the two scenarios. This is con-

Figure 9: Dynamics of the Gini coefficients for non-energy consumption, energy consumption, wealth, and the fraction of financially constrained households



firmed by the usage of R, which is identical across policies. This suggests that the environmental impact of the two policies is the same.

As shown in Figure 6, both non-energy and energy consumption are higher in the T scenario (Panel (c) and (d)). Of course, given the increase in the price of energy, households substitute away energy with non-energy consumption, such that the impact on non-energy consumption in the T scenario is initially positive. In contrast, final output contracts more than in the previous case, where all the receipts from the extra carbon tax were spent on the final good. Hence, this scenario diverts energy usage from final good production to consumption. The reallocation of resources away from final good production is also evident in the allocation of capital and labor across sectors (see Figure E.1 in Appendix E).

Additionally, due to transfer income, households' need for precautionary savings diminishes, leading to a reduction in their savings. As a result, capital decreases more in this T scenario (Panel (b)). With less energy and capital used in the production of the final good, wages experience a more significant decline in this scenario, while the return on capital rises (see Figure 7).

Distributional effects Figure 8 shows that, unlike in the previous G scenario, both asset-poor and asset-rich agents use the transfers to reduce energy consumption less (Panels (a) and (b)) and to increase their final good consumption relative to the baseline (Panels (c) and (d)). In particular, poor households use the transfer to reduce their energy consumption to a much lesser extent, despite the rise in its relative price. This outcome aligns with the transfer's primary goal: to support the income of poor households and shield them from the increase in energy prices. Finally, the significant redistributive effects of this transfer policy are evident in Panels (e) and (f), which show that disposable income increases for poor households, while it decreases for rich households. However, the decline is smaller than in the G scenario, as they also receive the transfer.

These dynamics result in lower consumption inequality in both goods (see Figure 9), in contrast to what we observed in the G scenario. The Gini coefficients for energy consumption and non-energy consumption decrease substantially, despite the fact that the price of energy has increased. Here, we observe a classic efficiency-equity tradeoff. The carbon tax has led to a reduction in both energy and non-energy production creating a significant distortion in the economy's resource allocation. However, the transfers have helped reduce consumption inequality. On the flip side, wealth inequality has risen considerably (Panel (c)), as wealth becomes more concentrated due to the decreased need for precautionary savings. Under Scenario T, since transfers are identical across households, poorer individuals receive a larger transfer, relative to their income, than wealthier individuals. This leads to lower savings compared to the baseline, which pushes a much larger fraction of agents towards their financial constraint (see Panel (d)), resulting in a substantial increase in the fraction of agents with no wealth. This, in turn, causes a significant rise in the Gini coefficient of wealth concentration. The distinguishing feature of the T scenario is its redistributive nature, which leads to a less dispersed disposable income, a decrease in the Gini coefficients for (both energy and non-energy) consumption, and a rise in the fraction of agents at zero wealth, in contrast with the other alternative scenarios.

4.4 Carbon Tax Revenue for Subsidy to Green Energy

Finally, we analyze the case where the revenue from the carbon tax is used to subsidize green energy firms via a VAT subsidy, as described above. The green dashed lines in the figures show the transition dynamics of the variables for this scenario.

Aggregate Effects We start again in the energy sector, where the effects differ significantly from those observed in the previous scenarios. As shown in Figure 5, the subsidy causes a sharp decline in the price of green energy (Panel (e)) – beyond what technological progress alone would achieve. The primary role of the subsidy is to further stimulate production in the green energy sector, facilitating the achievement of the green share target in the s^g scenario. As a result, a smaller increase in the carbon tax is needed compared to the other scenarios, as shown in Figure 4. The lower carbon tax results in a milder rise in brown energy price (Panel (c)), as well as in the aggregate energy price (Panel (a)). It follows that the quantity of energy produced (Panel (b)), as well as the one used in production (Panel (g)), falls by much less than in the previous two scenarios. The significant rise in the production of green energy (Panel (f)) is accompanied by a greater reduction in the quantity of brown energy at the beginning of the transition, but a lower one at the new steady state. The dynamics of fossil fuel usage R mirrors these latter dynamics, so the policy in the s^g scenario induces lower emissions at the beginning of the transition, but higher ones in the long-run.

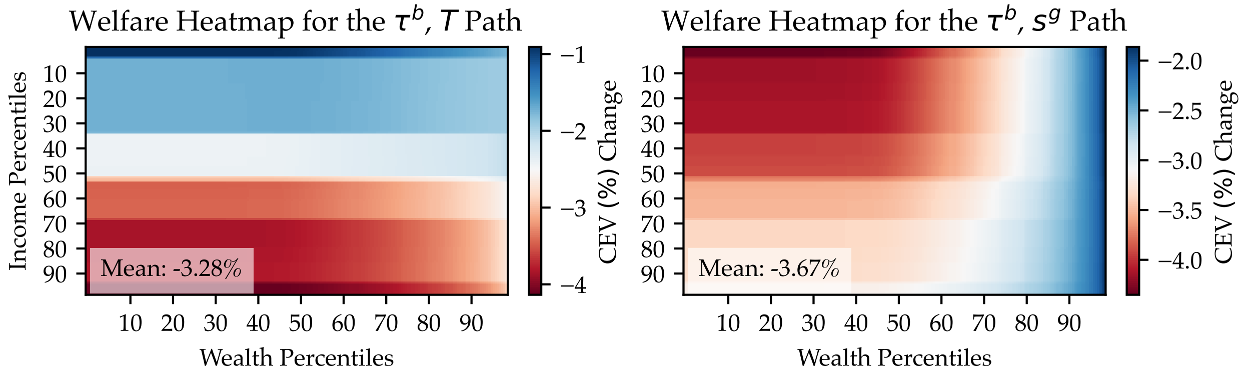
The boost in green energy production has a significant impact on the dynamics of aggregate variables, see Figure 6. Subsidies for green energy help mitigate the contractionary effects of the green transition, resulting in a smaller decline in output and capital compared to other scenarios. The lower energy price induces more energy usage in production, helping the productivity of labor and capital in the final good production. These dynamics shape factor prices throughout the transition, as the impact on factor prices is also more moderate. The reallocation of labor from final goods and brown energy production to green energy production, a trend observed across all scenarios, is quantitatively more pronounced in the s^g case (see Figure E.1 in Appendix E). The analysis suggests that subsidizing green energy production achieves the policy objective while imposing a lower overall cost on the economy. This is the scenario where energy consumption falls the least. Non-energy consumption falls slightly, but not as much as in the G scenario. If the fiscal policymaker aims to increase energy consumption, subsidies to firms, rather than households, are the more effective strategy. However, in our model economy – characterized by household heterogeneity, incomplete markets, and non-homothetic preferences – these costs may be distributed more unevenly across households compared to the previous T scenario.

Distributional Effects The lower aggregate costs associated with this policy translate into milder distributional effects. The decrease in both non-energy and energy consumption and in disposable income is similar across the wealth distribution, with a lower decrease in non-energy consumption and disposable income for rich households. The Gini coefficients for non-energy consumption and energy consumption mildly increase, while the Gini coefficient for wealth slightly decreases. Overall, concentration coefficients are not as significantly affected as under the other fiscal strategies. This suggests that uniform transfers to households are a more potent tool for reducing consumption inequality than subsidies. The opposite is true, however, for the wealth distribution. Considering the equity-efficiency trade-off, the choice depends on the policy goal. If the aim is to support poor households, given the consequence of the green transition, and reducing inequality, transfers are more effective. However, if the goal is to support aggregate output and limit the decrease in energy usage (both for production and for consumption purposes), while achieving a moderate increase in consumption inequality, subsidies are a better option.

4.5 Welfare Analysis

This Section presents the welfare implications of the green transition. Since the reductions in brown energy use and fossil resource consumption are comparable across scenarios, we expect that accounting for the welfare impact of environmental quality changes would not alter the policy ranking or, more importantly for our research question, the distribution of welfare costs among households. Hence, here we examine the non-environmental welfare effects of the alternative carbon revenue recycling schemes presented in the previous section.

Figure 10: Heat map of EEVs



Specifically, we provide an evaluation of the distributional impact of the different scenarios across the distributions of households' income and wealth. To do so, we compute individual expenditure-equivalent variations (EEV) – see Appendix D for details – and their distribution across the population, for all policy experiments. We also provide the average, population-weighted, welfare cost experienced by society during the transition to 2030.

Figure 10 presents a heat map illustrating the distribution of EEVs across wealth and income percentiles under scenarios T and s^g. The horizontal axis represents wealth percentiles, while the vertical axis shows income percentiles. Each point on the map corresponds to the EEV of a household with a given combination of wealth and income.

In both scenarios, all individuals experience a welfare loss, regardless of their position in the wealth-income distribution. However, the magnitude and distribution of these losses differ. Under the lump-sum transfer scenario T, losses are concentrated at the bottom of the figure, suggesting that high-income households bear the greatest burden under this fiscal policy. On the contrary, under scenario s^g, the largest welfare losses are concentrated in the top left corner of the map, indicating that households with both low income and low wealth suffer the most during the transition. This pattern arises because uniform transfers redistribute income toward poorer households, helping to offset the impact of higher energy prices, whereas green subsidies do not involve any redistribution.

Finally, note another important difference between the two scenarios. Under T, the welfare effects differ across income percentiles, for a given wealth, while they do not change much across the wealth distribution, for a given income – the color in the heatmap is distributed along horizontal bars. In this case, therefore, is the income distribution, not the wealth distribution, that matters for the distribution of welfare costs. Again, this is intuitive because uniform transfers redistribute *income* from high income to low income households. Under s^g, instead, the richest households suffer the least, no matter what their income is. Hence, both the income and wealth distributions play a crucial role in determining the distribution of welfare costs across households in the s^g scenario.

This analysis underscores the importance of considering both the aggregate and distributional welfare impacts when evaluating policy trade-offs during the green transition.

The role of non-homothetic preferences for welfare We conclude this section by discussing the role of the preference parameter ϵ for our welfare analysis. To do so, we set ϵ to zero, making preferences homothetic. We keep the other parameters fixed at the value of our benchmark calibration, and repeat the main scenarios. Figure G.1 in Appendix G displays the heat maps illustrating the distribution of EEVs across wealth and income percentiles under this preference specification.

The distribution of welfare costs displays important differences in the homothetic case compared to the benchmark one. With homothetic preferences, energy expenditure depends only on relative prices, so expenditure shares are independent of total expenditure, that is, from income and wealth.[12] In this case, income-poor households allocate a smaller portion of their income to energy compared to the baseline. Hence, the carbon tax is less regressive, as the increase in energy prices during the green transition hurts all households proportionally.

Under the T scenario, thus, income-poor households gain from the policy having slightly positive EEVs. This is because they are hit less by the energy price increase relative to the non-homothetic case, but they still gain from the income redistribution due to the transfer. Moreover, for the same reason, wealthy households suffer (slightly) more under homothetic preferences, especially the high-income ones. Second, under the s^g scenario, as the negative welfare impacts of higher energy prices are distributed proportionally across households, welfare losses are much more compressed across the income and wealth distribution than in our baseline case. Thus, again, relative to our baseline scenario, low-income and asset-poor agents suffer less, while asset-rich households are impacted more. Furthermore, while both income and wealth matter for welfare costs in the baseline case, wealth becomes the more relevant factor when preferences are homothetic.

Overall, this sensitivity analysis underscores the relevance of non-homothetic preferences in our analysis. Non-homotheticity not only aligns households' expenditure shares with empirical data, but also influences both overall welfare effects and their distribution across households under different fiscal policies.

5 Conclusion

This paper explores the aggregate and distributional consequences of the European Union's green transition. Using a heterogeneous-agent general equilibrium model with non-homothetic preferences and a disaggregated energy sector, we assess the impact of increasing carbon taxation under different revenue-recycling scenarios.

A key feature of our model is the use of non-homothetic preferences leading to expenditure shares in energy consumption that decrease with both income and wealth. First, this feature con-

[12] In other words, Panel (b) in Figure 3 will have just one color.

curs with the empirical evidence from microdata. Second, the uneven distribution of expenditure shares across households has significant implications for how the costs of the green transition are distributed.

Our findings reveal important trade-offs between equity and efficiency. Using carbon tax revenues for lump-sum transfers reduces consumption and disposable income inequality while it shifts the highest welfare costs – measured by expenditure equivalent variation – onto high-income households by supporting low-income groups during the green transition. However, this policy also dampens precautionary saving incentives, resulting in a lower overall capital stock, a greater share of financially constrained households, and higher wealth inequality. In contrast, subsidizing green energy firms appears more efficient, as it boosts energy production – particularly green energy – results in lower aggregate output losses, and requires a lower carbon tax to meet the new EU target of a 42.5% renewable energy share by 2030. However, it only modestly increases consumption and disposable income inequality, with the Gini coefficient for wealth being barely affected. Notably, low-income and asset-poor households bear the highest welfare costs from the green transition, making subsidies to green energy firms less effective in mitigating inequality compared to direct household transfers.

These findings underscore the importance of considering distributional impacts when designing policies for the green transition. Policymakers must weigh the benefits of reducing consumption inequality against the broader goals of decarbonization and economic growth, as the optimal choice depends on societal priorities.

References

Airaudo, Florencia S., Evi Pappa, and Hernán D. Seoane. 2023. "The Green Metamorphosis of a Small Open Economy." *CEPR WP DP17863*.

Aiyagari, S. 1994. "Uninsured Idiosyncratic Risk and Aggregate Saving." *The Quarterly Journal of Economics*, 109(3): 659–684.

Arnoud, Antoine, Fatih Guvenen, and Tatjana Kleineberg. 2019. "Benchmarking Global Optimizers." National Bureau of Economic Research Working Paper 26340.

Ascari, Guido, and Tiziano Ropele. 2012. "Disinflation in a DSGE perspective: Sacrifice ratio or welfare gain ratio?" *Journal of Economic Dynamics and Control*, 36(2): 169–182.

Auclert, Adrien, Matthew Rognlie, and Ludwig Straub. 2024. "Fiscal and Monetary Policy with Heterogeneous Agents." National Bureau of Economic Research, Inc NBER Working Papers 32991.

Bakış, Ozan, Barış Kaymak, and Markus Poschke. 2015. "Transitional dynamics and the optimal progressivity of income redistribution." *Review of Economic Dynamics*, 18(3): 679–693.

Balke, Nathan S, and Stephen PA Brown. 2018. "Oil supply shocks and the US economy: An estimated DSGE model." *Energy policy*, 116: 357–372.

Barrage, Lint. 2020. "Optimal dynamic carbon taxes in a climate–economy model with distortionary fiscal policy." *The Review of Economic Studies*, 87(1): 1–39.

Benmir, Ghassane, and Josselin Roman. 2022. "The Distributional Costs of Net-Zero: A Heterogeneous Agent Perspective." *Manuscript*, 100.

Bodenstein, Martin, Christopher J. Erceg, and Luca Guerrieri. 2011. "Oil shocks and external adjustment." *Journal of International Economics*, 83(2): 168–184.

Boehl, Gregor, and Flora Budianto. 2024. "Carbon Taxes vs. Green Subsidies: Generational Conflicts and Distributional Consequences." *Manuscript*.

Boppart, Timo. 2014. "Structural Change and the Kaldor Facts in a Growth Model With Relative Price Effects and Non-Gorman Preferences." *Econometrica*, 82(6): 2167–2196.

Christelis, Dimitris, Dimitris Georgarakos, Tullio Jappelli, Luigi Pistaferri, and Maarten van Rooij. 2019. "Asymmetric Consumption Effects of Transitory Income Shocks*." *The Economic Journal*, 129(622): 2322–2341.

Coenen, Günter, Matija Lozej, and Romanos Priftis. 2024. "Macroeconomic effects of carbon transition policies: an assessment based on the ECB's New Area-Wide Model with a disaggregated energy sector." *European Economic Review*, 167: 104798.

Coenen, Günter, Matija Lozej, and Romanos Priftis. 2023. "Macroeconomic effects of carbon transition policies: an assessment based on the ECB's New Area-Wide Model with a disaggregated energy sector." European Central Bank Working Paper Series 2819.

Crawley, Edmund, and Andreas Kuchler. 2023. "Consumption Heterogeneity: Micro Drivers and Macro Implications." *American Economic Journal: Macroeconomics*, 15(1): 314–41.

Del Negro, Marco, Julian di Giovanni, and Keshav Dogra. 2023. "Is the Green Transition Inflationary?" *FRB of New York Staff Report*, No. 1053.

Douenne, Thomas, Albert Jan Hummel, and Marcelo Pedroni. 2023. "Optimal Fiscal Policy in a Climate-Economy Model with Heterogeneous Households." *Available at SSRN 4018468*.

Ferrari, Alessandro, and Valerio Nispi Landi. 2022. "Will the green transition be inflationary? Expectations matter." *ECB Working Paper 2726*.

Floden, Martin, and Jesper Lindé. 2001. "Idiosyncratic Risk in the United States and Sweden: Is There a Role for Government Insurance?" *Review of Economic Dynamics*, 4(2): 406–437.

French, Eric. 2004. "The Labor Supply Response to (Mismeasured but) Predictable Wage Changes." *The Review of Economics and Statistics*, 86(2): 602–613.

Fried, Stephie. 2018. "Climate Policy and Innovation: A Quantitative Macroeconomic Analysis." *American Economic Journal: Macroeconomics*, 10(1): 90–118.

Fried, Stephie, Kevin Novan, and William B Peterman. 2018. "The distributional effects of a carbon tax on current and future generations." *Review of Economic Dynamics*, 30: 30–46.

Fried, Stephie, Kevin Novan, and William B Peterman. 2024. "Understanding the inequality and welfare impacts of carbon tax policies." *Journal of the Association of Environmental and Resource Economists*, 11(S1): S231–S260.

Hassler, John, Per Krusell, and Conny Olovsson. 2021. "Directed Technical Change as a Response to Natural Resource Scarcity." *Journal of Political Economy*, 129(11): 3039–3072.

Hassler, John, Per Krusell, and Conny Olovsson. 2022. "Finite resources and the world economy." *Journal of International Economics*, 136: 103592.

Heathcote, Jonathan, Kjetil Storesletten, and Giovanni L. Violante. 2010. "The Macroeconomic Implications of Rising Wage Inequality in the United States." *Journal of Political Economy*, 118(4): 681–722.

Jappelli, Tullio, and Luigi Pistaferri. 2014. "Fiscal Policy and MPC Heterogeneity." *American Economic Journal: Macroeconomics*, 6(4): 107–36.

Jo, Ara. 2024. "Substitution Between Clean and Dirty Energy with Biased Technical Change." *International Economic Review*, n/a(n/a).

Känzig, Diego R. 2023. "The unequal economic consequences of carbon pricing." National Bureau of Economic Research.

Krueger, D., K. Mitman, and F. Perri. 2016. "Chapter 11 - Macroeconomics and Household Heterogeneity." In *Handbook of Macroeconomics*. Vol. 2, , ed. John B. Taylor and Harald Uhlig, 843–921. Elsevier.

Krusell, Per, and Anthony A Smith, Jr. 1998. "Income and wealth heterogeneity in the macroeconomy." *Journal of political Economy*, 106(5): 867–896.

Krusell, Per, Toshihiko Mukoyama, Ayşegül Şahin, and Anthony A Smith Jr. 2009. "Revisiting the welfare effects of eliminating business cycles." *Review of Economic Dynamics*, 12(3): 393–404.

Kuhn, Moritz, and Lennard Schlattmann. 2024. "Distributional consequences of climate policies." *CEPR, DP18893*.

Labrousse, Charles, and Yann Perdereau. 2024. "Geography versus income: the heterogeneous effects of carbon taxation." HAL Working Papers halshs-04464900.

Levinson, Arik, and James O'Brien. 2019. "Environmental Engel Curves: Indirect Emissions of Common Air Pollutants." *The Review of Economics and Statistics*, 101(1): 121–133.

Olovsson, Conny, and David Vestin. 2023. "Greenflation?" *Sveriges Riksbank Working Paper Series*, 420.

Papageorgiou, Chris, Marianne Saam, and Patrick Schulte. 2017. "Substitution between Clean and Dirty Energy Inputs: A Macroeconomic Perspective." *The Review of Economics and Statistics*, 99(2): 281–290.

Straub, Ludwig. 2019. "Consumption, Savings, and the Distribution of Permanent Income." Manuscript.

Appendix

A LISS panel and cleaning

The LISS (Longitudinal Internet Studies for the Social Sciences) panel, operated by CentERdata at Tilburg University, is a representative online survey of Dutch households. Established in 2007, the panel comprises approximately 5,000 households and reflects the demographics of the Dutch population. Members of the panel participate in surveys on diverse topics, including health, employment, education, and social values. For this study, we utilize two components of the dataset: the Background Variables (BV) module and the Time Use and Consumption (TUC) module. We can use the 2009, 2010, 2012, 2015, 2017, 2019, 2020 and 2021 waves for our analysis.

Background Variables The BV module provides longitudinal data on demographics and socioeconomic characteristics such as age, gender, education, and household income. We focus on household heads aged 20 to 64, representing individuals with active labor market participation. Observations are excluded if gross household income is below half the annual minimum wage or above €500,000, or if year-on-year income changes exceed a 500% increase or fall below an 80% decrease. Observations with fewer than nine months of data in a given year are excluded to ensure data completeness. Income values are deflated to 2015 euros using the Dutch Consumer Price Index (CPI) to account for inflation. This ensures the income data accurately reflects the socioeconomic conditions of the sample population.

Time Use and Consumption We use the Time Use and Consumption (TUC) module of the LISS panel to analyze household time use and expenditures, including energy-related spending. To construct total household expenditure, we sum several expenditure categories such as mortgage or rent payments, utility bills, transportation, insurance, childcare, and food. In years where variables differ by household composition (e.g., singles vs. families), we adjust the calculations to ensure consistency and comparability across households. For energy expenditures, we focus on gas and electricity costs, which we extract from the utility-related variables in the dataset.

We identify and exclude outliers using distributional thresholds for total household expenditure and energy expenditure. Specifically, we remove observations with expenditures that significantly exceed realistic bounds or exhibit implausible year-on-year changes. We also drop observations with missing or inconsistent household identifiers to maintain the longitudinal integrity of the data. Additionally, we construct household size and composition variables, such as the number of adults and children, to normalize expenditures and enable meaningful comparisons across households. After cleaning the TUC module, we merge it with the Background Variables (BV) module using unique household identifiers.

B Estimation of income process

Using the cleaned and processed BV dataset, we estimate the income process by regressing the logarithm of gross household income on the constructed variables. The model takes the form:

$$\begin{aligned}\log(y_{it}) =& \alpha + \alpha_t + \gamma_1 \text{ age}_{it} + \gamma_2 \text{ age}_{it}^2 + \gamma_3 \text{ age}_{it}^3 + \\ & \iota \text{ educ}_{it} + \rho \text{ occupation}_{it} + \theta \text{ gender}_{it} + \sigma \text{ size}_{it} + u_{it}.\end{aligned} \tag{B.1}$$

Using the residuals (u_{it}) obtained from the income regression described above, we estimate a persistent-transitory income process. This model decomposes observed income into two components: a persistent AR(1) process and a transitory shock. The specification is as follows:

$$u_{it} = \kappa_{it} + \psi_{it}, \qquad \text{where: } \psi_{it} \sim \mathcal{N}(0, \sigma_\psi^2), \tag{B.2}$$

$$\kappa_{it} = \rho\kappa_{it-1} + \varepsilon_{it}, \qquad \text{where: } \varepsilon_{it} \sim \mathcal{N}(0, \sigma_\varepsilon^2), \tag{B.3}$$

where κ_{it} is the persistent component, and ψ_{it} is the transitory shock. The persistent component evolves according to an AR(1) process with persistence ρ and innovation ε_{it}.

We estimate the parameters ρ, σ_ε^2 (variance of persistent shocks), and σ_ψ^2 (variance of transitory shocks) using Minimum Distance Estimator (MDE). Following the literature, the variance of measurement error (σ_ξ^2) is fixed at 0.02, based on estimates from French (2004) and Heathcote, Storesletten and Violante (2010), albeit using data from the Panel Study of Income Dynamics of US households. This approach reflects the inability to separately identify the variance of transitory shocks and measurement error in our data.

The estimation uses moments derived from the theoretical properties of the model. Variances and covariances of income across time periods form the basis of the moment conditions:

$$\mathbb{E}[u_{it}^2] = \frac{\sigma_\varepsilon^2}{1-\rho^2} + \sigma_\psi^2 + \sigma_\xi^2, \tag{B.4}$$

$$\mathbb{E}[u_{it}u_{i,t-s}] = \rho^s \frac{\sigma_\varepsilon^2}{1-\rho^2}, \quad \text{for } s > 0. \tag{B.5}$$

The MDE procedure minimizes the distance between the model-implied moments and their empirical counterparts using an identity weighting matrix. Variances capture the contributions of persistent and transitory components, while covariances identify the degree of persistence in income dynamics.

The results of the estimation are as follows:

$$\rho = 0.9422\ (\pm 0.0273), \tag{B.6}$$

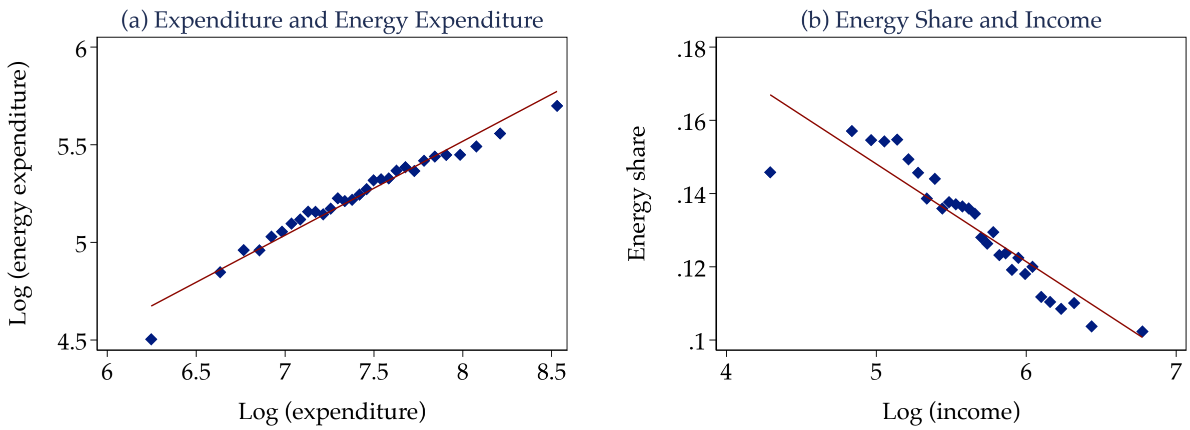
$$\sigma_\varepsilon^2 = 0.0186\ (\pm 0.0095), \tag{B.7}$$

$$\sigma_\psi^2 = 0.0113\ (\pm 0.0098), \tag{B.8}$$

where values in parentheses represent bootstrapped standard errors. These estimates are in line with findings from prior studies such as Floden and Lindé (2001) and Krueger et al. (2016) for US data. The estimated persistence parameter (ρ) indicates that income shocks are highly persistent, with the AR(1) process accounting for most of the observed income variation over time.

C Estimation of ϵ

Figure C.1: Comparison of Energy Expenditure and Energy Share



We estimate ϵ, the key parameter of the non-homothetic preference formulation presented in Equation (5), using the Time Use and Consumption (TUC) waves from the LISS panel. To do this, we calculate the expenditure share on energy, η^d, and total expenditure, x. As outlined in Equation (23), our baseline regression is

$$\log \eta_{it}^d = \alpha - \epsilon \log x_{it} + \alpha_t + v_{it}, \tag{C.1}$$

where total expenditure (x_{it}) is instrumented by total household income. Here, α_t represents time fixed effects, and v_{it} is the error term. This approach accounts for the endogeneity between income and expenditure.

To prepare the data for estimation, we normalize expenditures and income for household composition using a modified OECD equivalence scale

$$\text{scale} = 1.0 + 0.5 \cdot (\text{adults} - 1) + 0.3 \cdot (\text{children}), \tag{C.2}$$

where adults is defined as the total household size minus the number of children. This scale adjusts household expenditures and income to account for differing household structures.

The key variables used in the estimation are as follows:

- *Total expenditure (x)*: Total household expenditure, adjusted for the equivalence scale.
- *Expenditure share on energy (η^d)*: The proportion of total household expenditure allocated to energy-related expenses, such as gas and electricity costs.
- *Income in service prices*: The logarithm of household income adjusted for equivalence scale and service price changes, $\log(\text{income after taxes and transfers}/(\text{scale} \cdot p_{\text{services}}))$.

Table C.1: Different estimations of ϵ

	(1)	(2)	(3)
Log Expenditure (IV)	-0.575***	-0.583***	-0.557***
	(0.034)	(0.037)	(0.124)
Observations	18608	18608	16242
R-squared	0.190	0.186	0.189
Fixed Effects	None	Time	ID + Time
Clustering	ID + Time	ID + Time	ID + Time

Note. Standard errors in parentheses. Significance levels: * p<0.1, ** p<0.05, *** p<0.01.

As mentioned before, total expenditure in service prices is instrumented by total household income in service prices. This instrumentation addresses potential measurement errors and the endogeneity of expenditure data. The results for estimations with different fixed effects are presented in Table C.1. All specifications suggest that there is a significant degree of non-homotheticity between non-energy and energy goods. This also confirmed by simple scatter plots that are shown in Figure C.1. Energy expenditure as is a positive and slightly concave function of total expenditure and the energy share is a downward sloping function of log income. Both are consistent with out theoretical predictions, as shown in Figure 3.

D Welfare computation

In order to calculate expenditure equivalent welfare we compare value functions in the initial steady state with the value when the policy was announced, following many papers such as Ascari and Ropele (2012) and Bakış, Kaymak and Poschke (2015). Below is a step by step description of our approach. To evaluate welfare, we calculate an expenditure equivalent measure (Δ) for each state of the household:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j) \right) U((1+\Delta_i)x_i^*, p^e) = \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j) \right) U\left(x_{it}, p_t^e\right), \tag{D.1}$$

where $\beta(j)$ is the discount factor between $j-1$ and j, with $\beta(0) = 1$. This measure represents the percentage change in expenditure required in the initial steady state to make a household indifferent between remaining in the initial steady state and transitioning to the new steady state or policy scenario.

Recall that expectations are taken over idiosyncratic shocks to income and discount factors. The indirect utility function is:

$$U\left(x_{it}, p_t^e\right) = \frac{1}{\epsilon} \left(x_{it}\right)^{\epsilon} - \frac{\nu}{\gamma} \left(p_t^e\right)^{\gamma} - \frac{1}{\epsilon} + \frac{\nu}{\gamma}, \tag{D.2}$$

Defining $\kappa \equiv \frac{\nu}{\gamma}\left(p^e\right)^\gamma + \frac{1}{\epsilon} - \frac{\nu}{\gamma}$ one can rewrite the left-hand side of Equation (D.1) as

$$
\begin{aligned}
\mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j)\right) U((1+\Delta_i)x_i^*, p^e) = \\
& (1+\Delta_i)^\epsilon \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j)\right) \frac{1}{\epsilon}(x_i^*)^\epsilon - \mathbb{E}_0^b \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j)\right) \kappa \\
& +(1+\Delta_i)^\epsilon \mathbb{E}_0^b \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j)\right) \kappa \\
& -(1+\Delta_i)^\epsilon \mathbb{E}_0^b \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j)\right) \kappa \\
& = (1+\Delta_i)^\epsilon \underbrace{\mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j)\right) \left(\frac{1}{\epsilon}(x_i^*)^\epsilon - \kappa\right)}_{V_{ss}^*} \\
& - \mathbb{E}_0^b \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j)\right) \kappa + (1+\Delta_i)^\epsilon \mathbb{E}_0^b \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j)\right) \kappa \\
& = (1+\Delta_i)^\epsilon \left(V_{ss}^* + \mathbb{E}_0^b \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j)\right) \kappa\right) - \mathbb{E}_0^b \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j)\right) \kappa
\end{aligned}
$$

The expectation operator $\mathbb{E}_0^b$ only takes into account uncertainty with respect to the discount factor.

To compute the steady-state value function V_{ss}^*, we use iterative policy function updates:

$$
V_{ss}^*(a_i, y_i, \beta_i) = U(x_i^*, p^c, p^e) + \beta_i \mathbb{E}_t \left[V_{ss}^*(a_i^*, y_i', \beta_i')\right],
$$

where x_i^* and a_i^* are the optimal expenditure and asset decisions from the policy functions.

To compute the right-hand side of Equation (D.1), we first then compute the sequence of value functions V_t using backward induction, starting from the terminal steady state. At each step:

$$
V_t^*(a_{it}, y_{it}, \beta_{it}) = U(x_{it}^*, p_t^c, p_t^e) + \beta_{it} \mathbb{E}_t \left[V_{t+1}(a_{it+1}^*, y_{it+1}, \beta_{it+1})\right].
$$

where variables with stars are again the optimal policies along the transition. Since $V_1^*(a_{it}, y_{it}, \beta_{it})$ summarizes the infinite sequence on the right-hand side of Equation (D.1), we can rewrite it as

$$
(1+\Delta_i)^\epsilon \left(V_{ss}^* + \mathbb{E}_0^b \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j)\right) \kappa\right) - \mathbb{E}_0^b \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j)\right) \kappa = V_1^*
$$

and solve for Δ_i to get

$$
\Delta_i = \left(\frac{V_1^* + \mathbb{E}_0^b \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j)\right) \kappa}{V_{ss}^* + \mathbb{E}_0^b \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j)\right) \kappa}\right)^{\frac{1}{\epsilon}} - 1. \tag{D.3}
$$

Finally, we follow Krusell, Mukoyama, Şahin and Smith Jr (2009) to rewrite the infinite sum over the discount factors. Define $d \equiv \mathbb{E}_0^b \sum_{t=0}^{\infty} \left(\prod_{j=0}^{t} \beta(j) \right)$ and let $\bar{d}_i$ be the value of d when $\beta(1) = \beta_i$ with $i = \{low, high\}$. The column vector $D = \begin{pmatrix} \bar{d}_{low} \\ \bar{d}_{high} \end{pmatrix}$ then solves

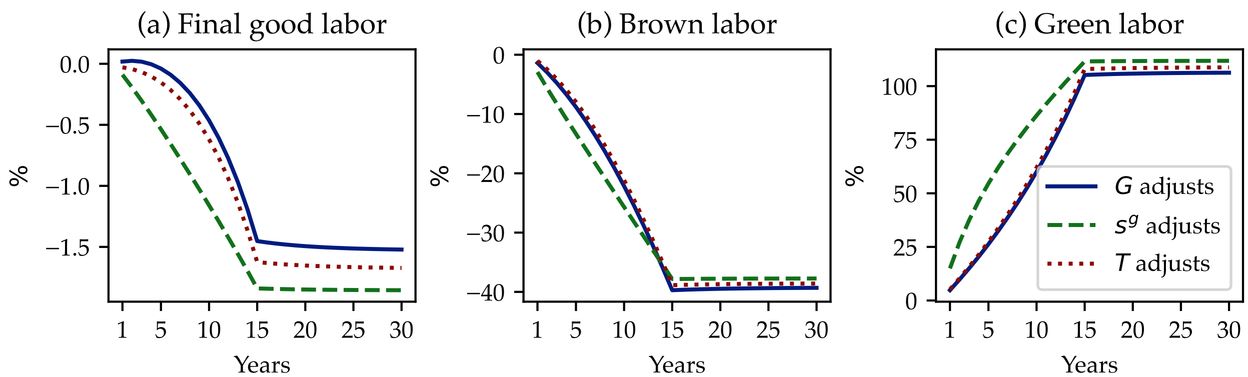
$$D = \mathcal{I} + B\Gamma_\beta D$$

where $\mathcal{I} = \begin{pmatrix} 1 \\ 1 \end{pmatrix}$ and $B = \begin{bmatrix} \beta_{\text{low}} & 0 \\ 0 & \beta_{high} \end{bmatrix}$. Solving yields $D = (I - B\Gamma_\beta)^{-1}\mathcal{I}$ such that Equation (D.3) becomes

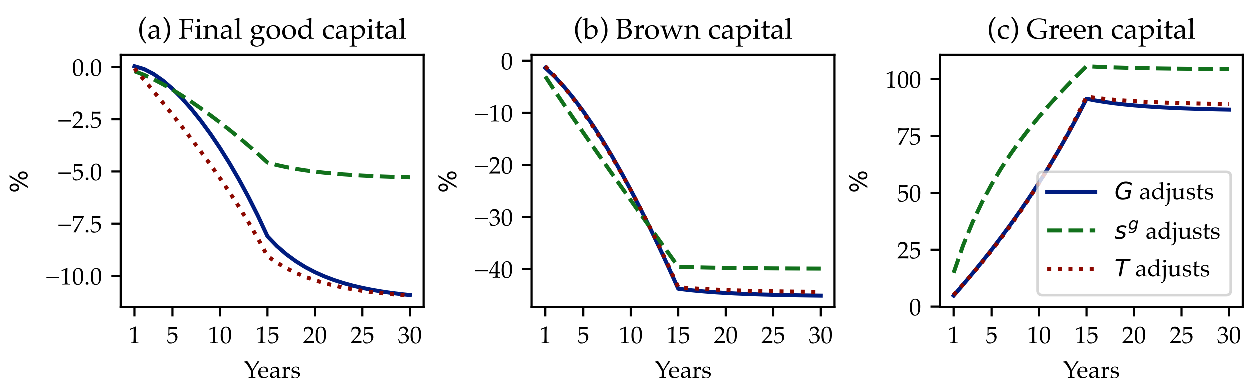
$$\Delta_i = \left(\frac{V_1^* + \bar{d}_i \kappa}{V_{ss}^* + \bar{d}_i \kappa} \right)^{\frac{1}{\epsilon}} - 1. \tag{D.4}$$

E Other figures

Figure E.1: Dynamics of labor and capital across sectors along the transition.

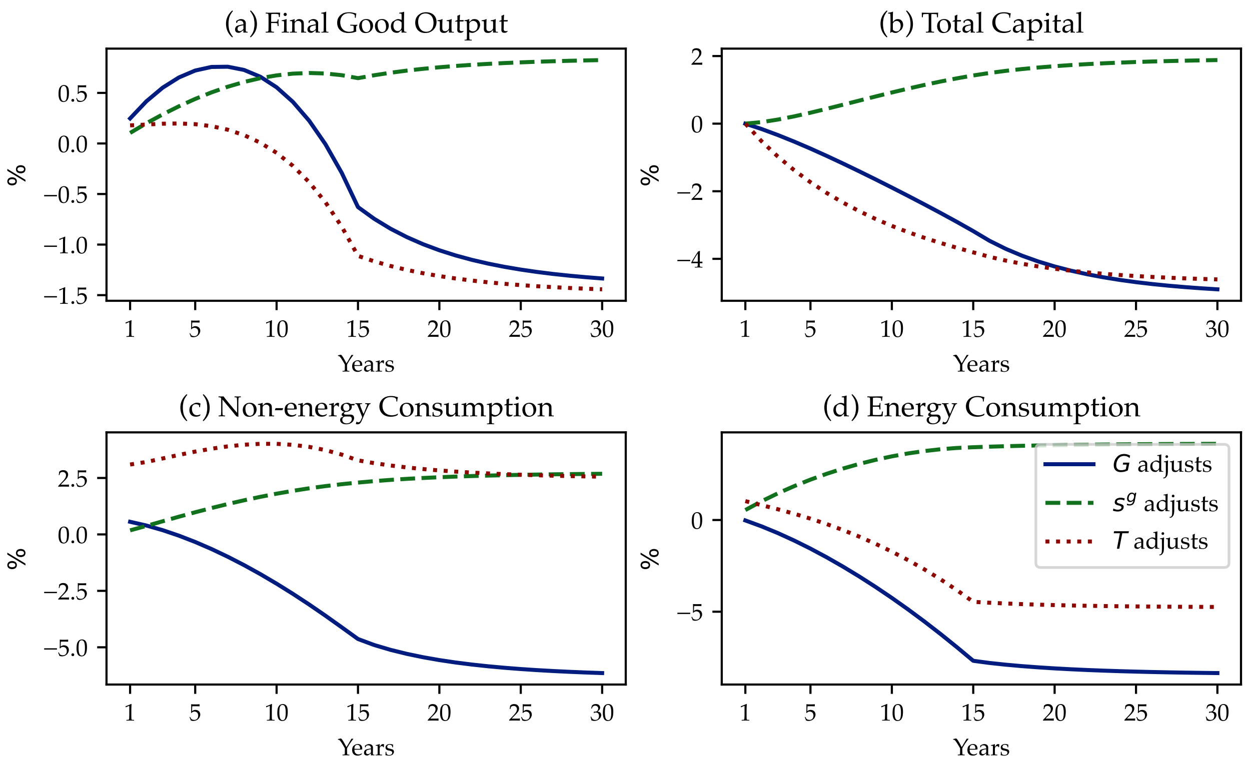


(a) Labor Responses



(b) Capital Responses

Figure E.2: Responses of output, capital, non-energy consumption and energy consumption for the three policies in terms of *deviations from the initial steady state*



F Green transition with no policy intervention

Figure F.1: Energy Quantities

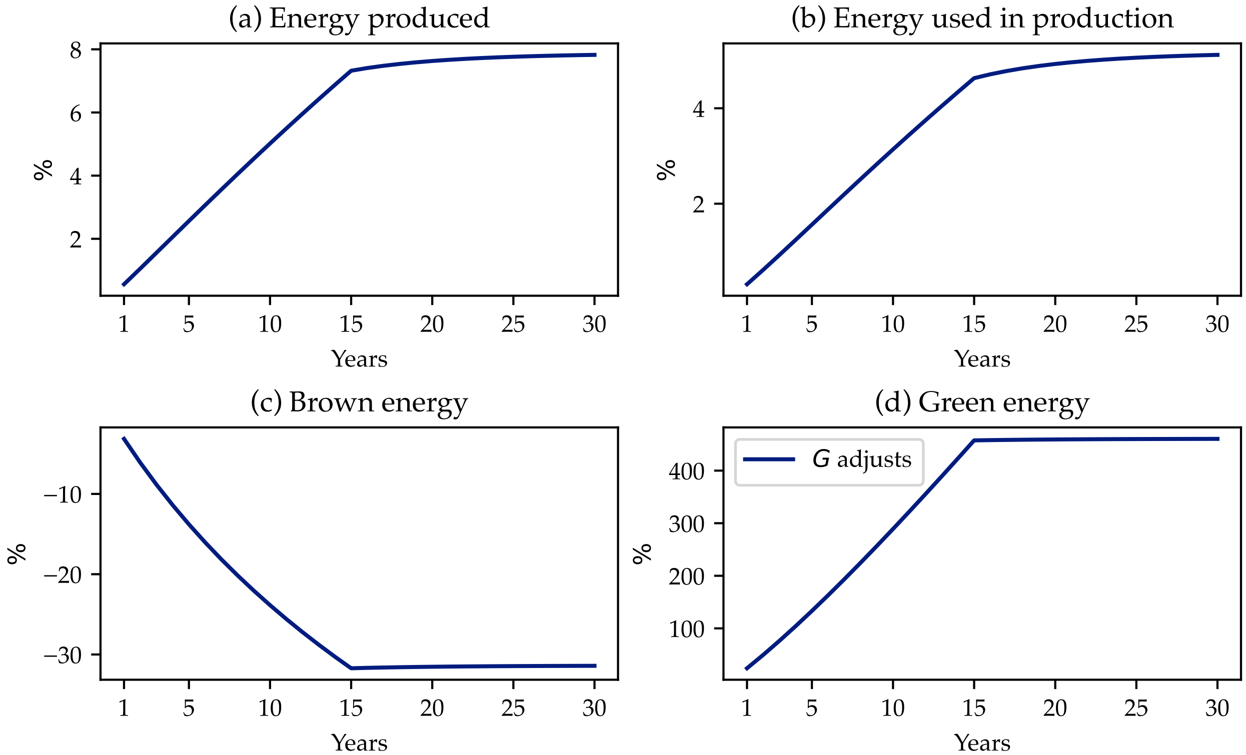


Figure F.2: Energy Prices

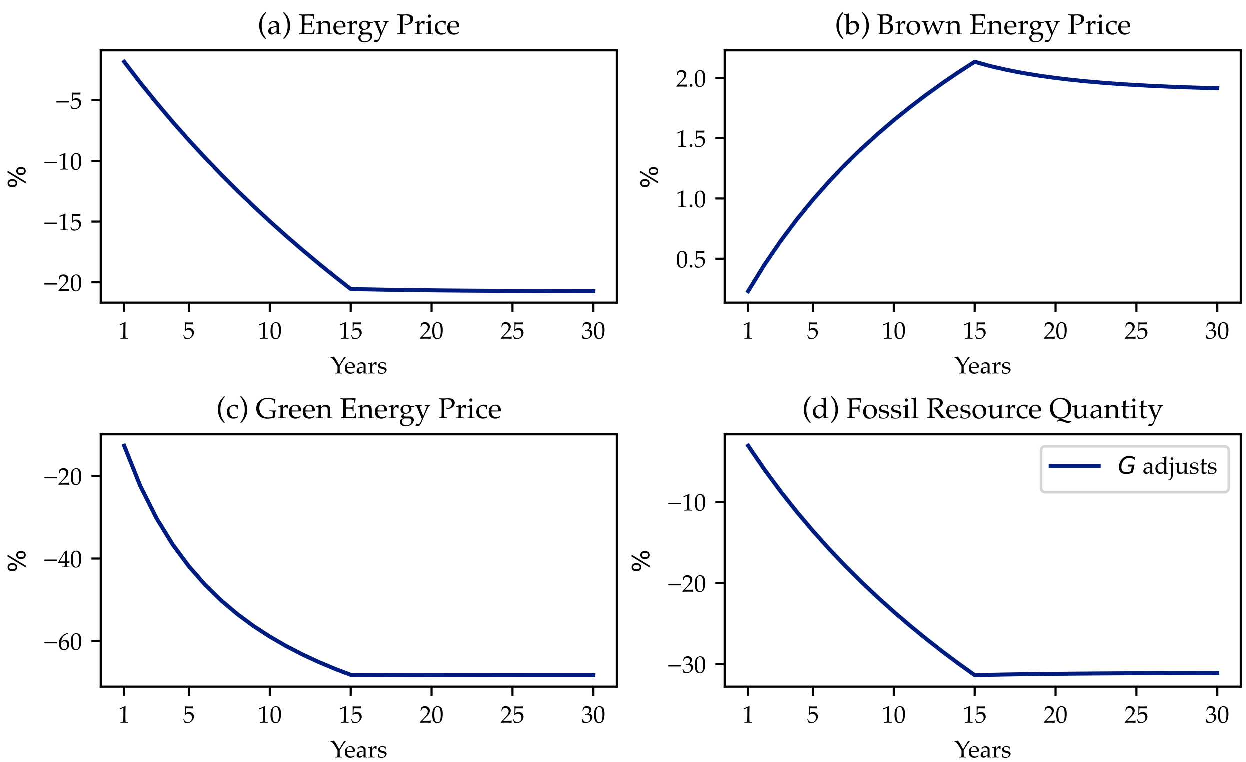


Figure F.3: Output, Capital, and Consumption

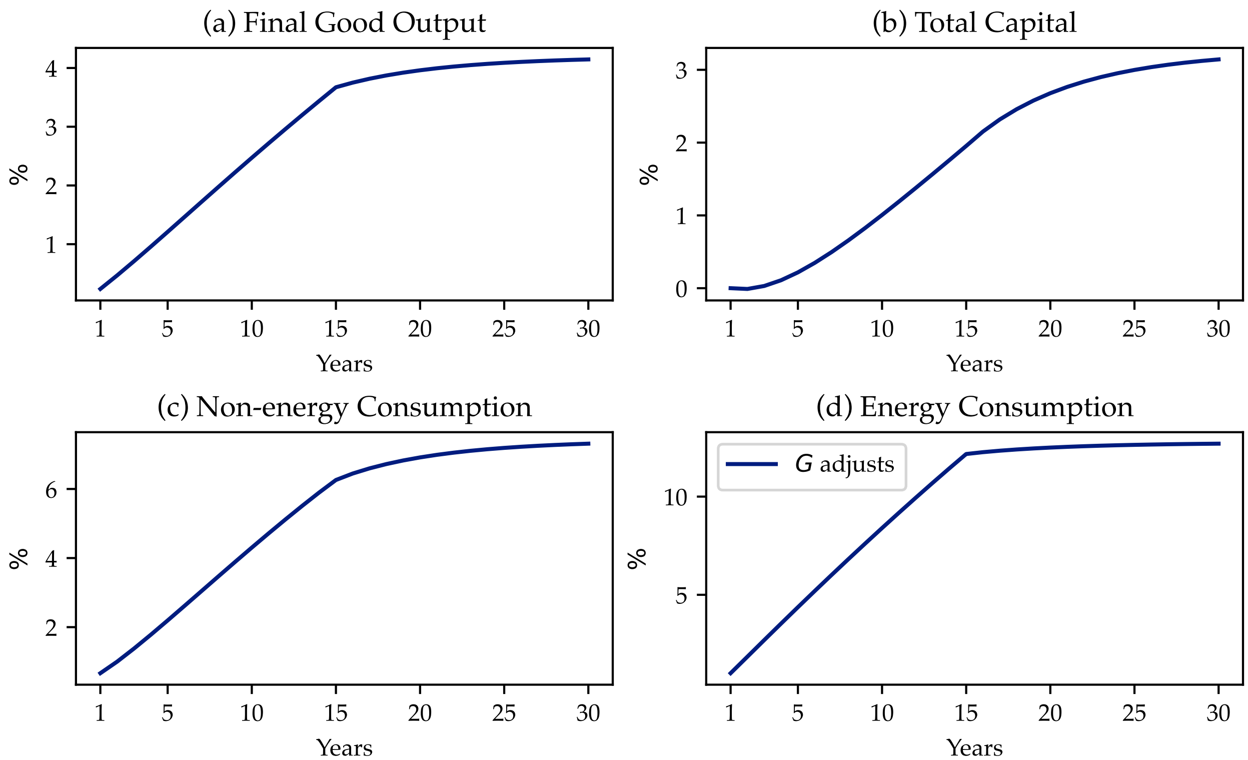


Figure F.4: Factors' Prices

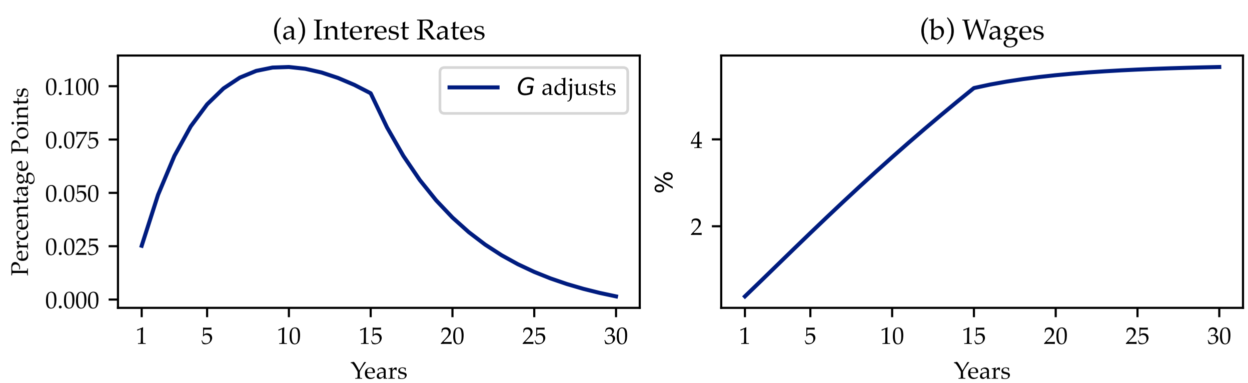
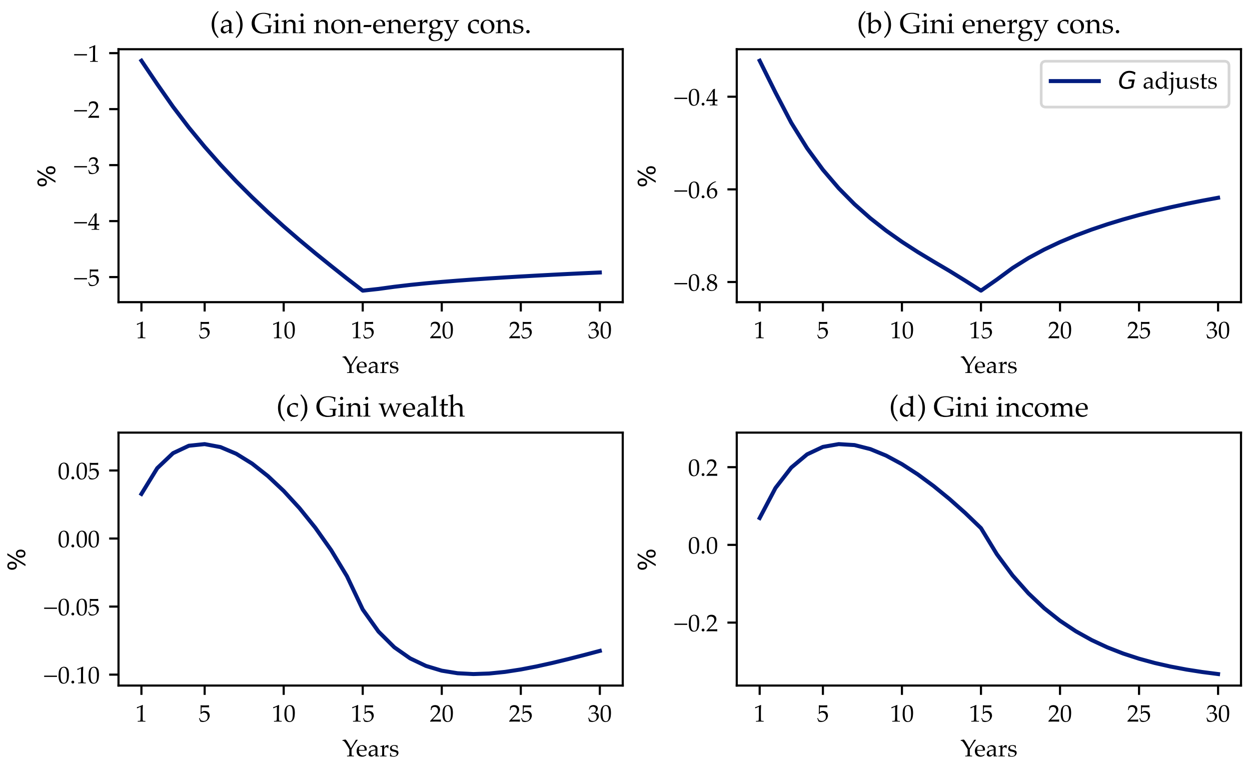


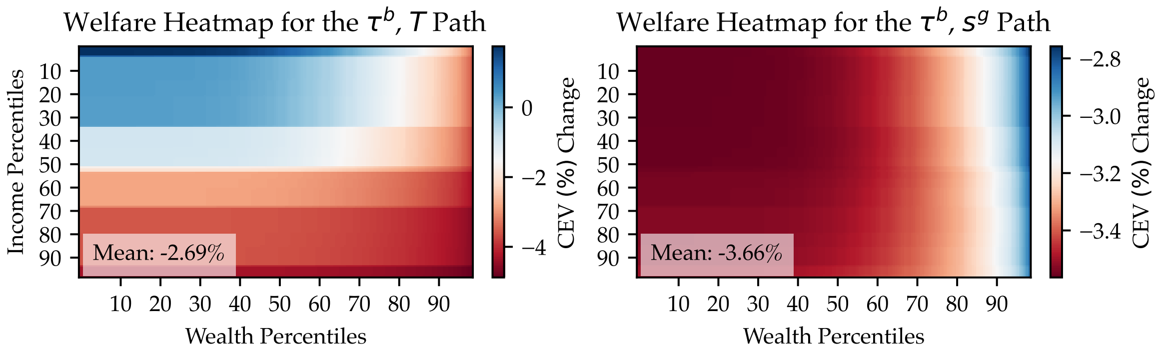
Figure F.5: Gini with no policy intervention



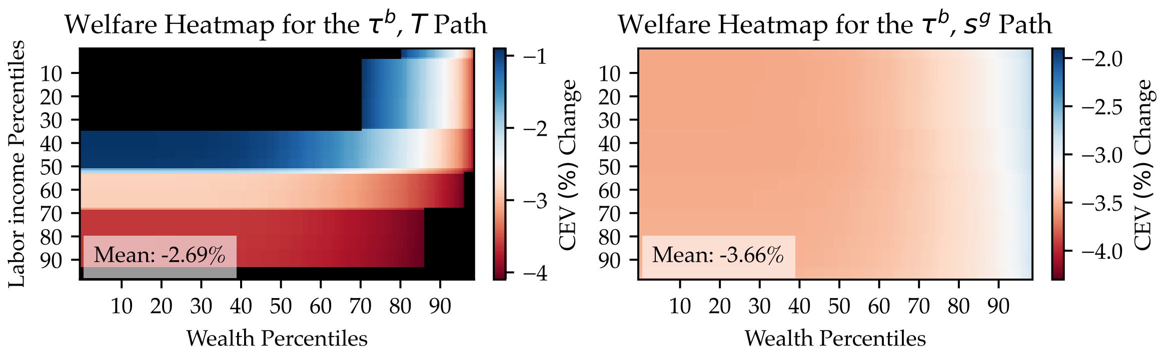
G Welfare heatmaps for homothetic preferences

Figure G.1: Welfare heatmaps for homothetic preferences

(a) Heat map of EEVs for ϵ=0



(b) Heat map of EEVs for ϵ=0 with the same limits as Figure 10



Note. The black areas in the bottom left panel represent values outside of the specified range. The black area in the top left represents values larger than -1, whereas the black are in the bottom right represents values smaller than -4.