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Road to Net Zero: Carbon policy and redistributive dynamics in the green transition

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Road to Net Zero: Carbon Policy and Redistributive Dynamics in the Green Transition

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Road to Net Zero: Carbon Policy and Redistributive Dynamics in the Green Transition*

Abstract

This paper examines the macroeconomic and distributional effects of the European Union's transition to Net Zero emissions through a gradually increasing carbon tax. I develop a New Keynesian Environmental DSGE model with two household types and distinct energy and non-energy sectors. Five alternative uses of carbon tax revenues are considered: equal transfers to households, targeted transfers to Hand-to-Mouth households, subsidies to green energy firms, and reductions in labor and capital income taxes. In the absence of technological progress, the carbon tax policy induces a persistent increase in energy prices and a reduction in GDP, investment, and consumption. Headline inflation falls below zero in the medium run, reflecting weaker aggregate demand. Distributional outcomes vary significantly depending on the implemented revenue recycling scheme: targeted transfers are the most progressive but entail larger macroeconomic costs, while subsidies and tax cuts mitigate output and investment losses but are less effective in narrowing the consumption gap. A limited foresight scenario, in which agents learn about policy targets sequentially, generates more volatile adjustment paths and temporary inflationary spikes around announcements, but long-run outcomes remain close to the baseline.

Keywords: DSGE, fiscal redistribution, green transition, inequality, macroeconomic effects, net zero, TANK

JEL classification: E32, H23, P28, Q43, Q52

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1 Introduction

The European Commission (EC) has launched a comprehensive set of measures, known as the European Green Deal, to reduce national greenhouse gas (GHG) emissions in the Union to “Net Zero”¹ by 2050 in the European Union (EU), in accordance with the Paris Agreement goal to keep the increase in the global average temperature to well below 2°C above pre-industrial levels. This ambitious transformation raises important questions about the long-run macroeconomic and distributional effects of climate policy in the EU, which this paper addresses through a structural theoretical framework.

According to economists, the most effective strategy for reducing greenhouse gas emissions is to impose economic disincentives that discourage their production. Such disincentives can be implemented through price-based instruments, such as carbon taxes or emission allowances, like the cap-and-trade system currently used in the EU. Results from the empirical literature on the macroeconomic impact of these measures in the EU remain mixed. Bettarelli et al. (2025) show that a carbon tax shock can exert significant inflationary pressure, with a certain degree of heterogeneity across countries, depending on their initial inflation level and emission intensity. Metcalf and Stock (2023) analyze the impact of national carbon taxes across European countries, finding negligible, if not positive in some cases, effects on GDP and employment. On the contrary, Känzig and Konradt (2023) find that the EU-wide emission trading scheme (ETS) can have adverse effects for the economy. Additionally, some studies show that costs are not equally distributed, and that the danger of negative distributional effects is real either across countries (Berthold et al., 2023) and within society (Känzig, 2025).

The mixed empirical evidence highlights the need for a structural model able to disentangle the channels through which carbon pricing affects macroeconomic aggregates and distribution. This paper develops a two-agent, New Keynesian (TANK) Environmental DSGE (E-DSGE) model tailored to the EU Net Zero transition. Households are represented by two groups: Hand-to-Mouth (HM) agents, who consume their entire income each period, and Savers (S), who smooth consumption intertemporally. HM households allocate a larger share of their consumption to energy goods, making them more vulnerable to price shocks. On

¹The term Net Zero refers to a state in which the anthropogenic GHG emissions going into the atmosphere are balanced by anthropogenic removals (e.g. air or biomass capture and geological storage). This corresponds to an average reduction of emissions between 95% and 97% from the 1990 level.

the production side, I distinguish between energy and non-energy sectors, with energy disaggregated into green and dirty producers. Both dirty and non-energy production are subject to carbon taxation, with the latter accounting for additional environmental regulatory costs included in the EU's Net Zero Strategy. Revenues from carbon taxation are recycled through five alternative schemes: uniform transfers, targeted transfers to HM households, subsidies to green firms, labor income tax cuts, and capital income tax cuts. Emission-reduction targets are imposed for 2030, 2040, and 2050, with the carbon price rising to ensure consistency with these objectives. In the baseline simulation, I deliberately exclude green technological progress, thus providing a conservative benchmark for the macroeconomic and distributional consequences of carbon pricing.²

The analysis yields three main findings. First, a gradually increasing carbon tax that delivers Net Zero induces a persistent GDP loss of about 2% in the baseline scenario, while energy prices rise persistently. Headline inflation rises temporarily after the policy announcement but turns negative for most of the transition, returning to zero only by 2050. Energy inflation, by contrast, remains positive for an extended period, with a sharp initial spike and gradual decline until around 2040. Both measures are consistently higher under income tax cut scenarios. Second, alternative recycling schemes generate a trade-off between macroeconomic stabilization and distributional fairness: HM-targeted transfers are the most progressive but also the most costly in terms of GDP, while subsidies and tax cuts are relatively less contractionary but also less effective in narrowing the consumption gap. Third, credibility and the timing of information about policy targets play a crucial role in determining the stability of the transition and the short-run adjustment dynamics. Under limited foresight, sequential announcements of intermediate targets generate strong volatility in GDP, inflation, and inequality around announcement dates, even though long-run levels remain similar to the baseline. By contrast, in a flexible-price economy, transition costs are smaller but inequality increases, as wages and capital returns adjust more sharply.

The contribution of this paper is to provide a tractable yet comprehensive DSGE framework for studying the macroeconomic and distributional consequences of the EU's Net Zero transition. The framework combines microfoundations, heterogeneity, and nominal frictions to jointly account for inflation dynamics, labor supply, sectoral reallocation, inequality, and

²Appendix C.1 reports results under exogenous growth in green technology, where transition costs are substantially lower and long-run growth is positive.

monetary–fiscal interactions. At the same time, I extend the short-run E-DSGE literature by comparing long-run transition dynamics under perfect foresight to a limited foresight case, where agents receive information about the policy path only sequentially at intermediate targets.

Literature Review

The macroeconomic analysis of climate policy has evolved along two broad approaches. The first, rooted in integrated assessment models (IAMs), links the economy and the climate system in a single global framework. The pioneering DICE model by Nordhaus (1977, 2010) and Nordhaus and Sztorc (2013) integrates carbon emissions, temperature dynamics, and aggregate output, providing the foundation for long-run climate–economy interactions. Extensions have incorporated inequality (Dennig et al., 2015; Emmerling et al., 2024; Zhao et al., 2022), and more recently, within-country heterogeneity (Young-Brun et al., 2025), showing that redistributing carbon tax revenues can simultaneously enhance welfare and equity. A related but distinct stream is represented by computable general equilibrium (CGE) models, which emphasize the sectoral and fiscal incidence of carbon taxation and the efficiency–equity trade-offs of revenue recycling (e.g. Goulder et al. (2019)). While IAMs are dynamic and suitable for long-run climate assessments, their macroeconomic core remains highly aggregated and abstracts from short-run adjustment mechanisms. CGE models, by contrast, are typically static or rely on steady-state comparisons, lack nominal frictions, and oversimplify household heterogeneity.

The second approach – closer to this paper – builds on Environmental DSGE (E-DSGE) models, which combine microfoundations with explicit policy shocks and dynamic adjustment. Early contributions by Fischer and Springborn (2011) and Heutel (2012) examined optimal carbon taxation in RBC settings. Subsequent studies introduced nominal rigidities (Annicchiarico & Di Dio, 2015, 2017; Holtemöller & Sardone, 2024), financial frictions (Carattini et al., 2023), and labor market imperfections (Gibson & Heutel, 2023). More recent work investigates inequality: Känzig (2025) studies EU ETS shocks, while Benmir and Roman (2022) analyzes US carbon pricing with sticky prices and abatement learning. Most of these papers, however, focus on short-run fluctuations.

My paper contributes to this second strand by extending the analysis to long-run transition dynamics and explicitly modeling heterogeneous households. Building on the two-agent

(TANK) framework of Bilbiie (2008), I incorporate both credit constraints and differences in energy consumption shares. Closely related papers include Coenen et al. (2024), who study redistribution in the euro area; Ascari et al. (2025), who use a HANK model with non-homothetic preferences to analyze inequality without nominal frictions; and Sahuc et al. (2025), who estimate a global NK model where carbon pricing acts as a supply shock and monetary policy drives inflation outcomes.

Relative to these studies, my model combines features usually analyzed separately. Compared with Ascari et al. (2025), it adds nominal rigidities and monetary policy, while extending the analysis to a broader set of tax revenue recycling schemes. Compared with Sahuc et al. (2025), it incorporates micro heterogeneity and differentiated carbon taxation across sectors, bringing distributional and sectoral reallocation dynamics into the picture. In contrast to Känzig (2025), who studies short-run EU ETS shocks in an E-DSGE, my model distinguishes green and dirty energy production, allows both energy and non-energy sectors to emit, and examines multiple fiscal recycling schemes along a long-run Net-Zero transition path. By jointly incorporating redistribution, household heterogeneity, nominal rigidities, and the timing of information about policy targets, the model captures the interaction between fiscal design, price adjustment, and inequality throughout the Net-Zero transition. This unified framework makes it possible to trace how carbon taxation propagates through production and income channels, shaping the trade-offs between macroeconomic adjustment and distributional outcomes.

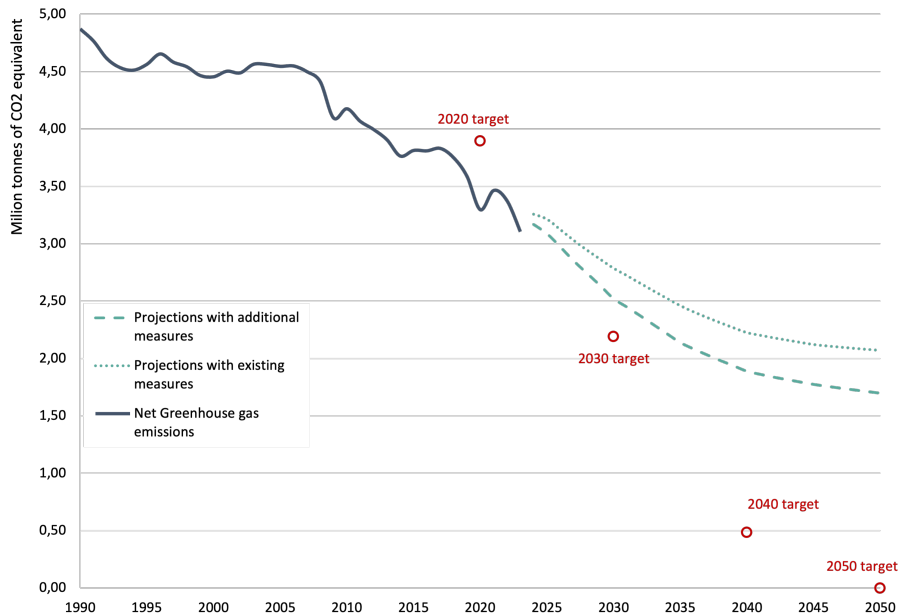
The remainder of the paper is structured as follows. Section 2 briefly reviews the EU’s current policy framework, emission targets, and redistribution strategies. Section 3 presents the model structure and the revenue recycling schemes. Section 4 describes the baseline transition to Net Zero and its macroeconomic and distributional effects. Section 5 discusses alternative scenarios. Section 6 concludes.

2 Emissions and Environmental Policy Framework in the EU

To understand the current context of the EU’s Net Zero transition, it is useful to examine both the trajectory of emissions and the institutional framework of climate policy. Figure 1 shows total GHG emissions projections for the EU-27. While emissions have followed a general downward trend over past decades, the most recent projections by the European

Environment Agency still fall short of the reductions required to meet the 2030 intermediate targets and remain misaligned with the long-term objective of Net Zero by 2050. This persistent gap underscores the need for stronger policies to ensure that emission reductions are not only sustained but accelerated.

Figure 1: Total emissions projections, EU-27



Source: Eurostat, Member States' greenhouse gas (GHG) emission projections, 2024, European Environment Agency (EEA); National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism, April 2024; Approximated estimates for GHG emissions, 2023.

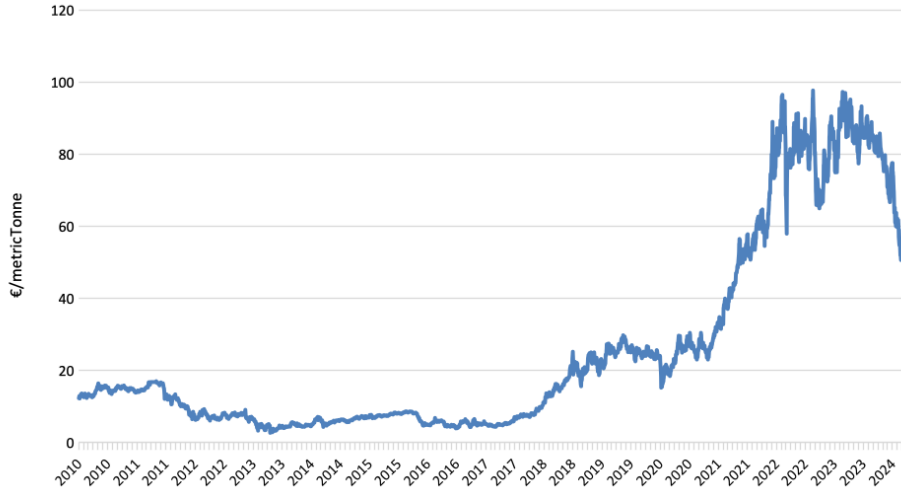
The main instrument for reducing emissions cost-effectively is the EU Emissions Trading System (EU-ETS), launched in 2005 and currently covering about 45% of EU GHG emissions.³ For over a decade after its introduction, the carbon price traded within the EU-ETS remained close to zero, failing to provide meaningful incentives for abatement.⁴ Since 2017, however, the price has increased steadily (Figure 2), reflecting not only policy reforms (such as the Market Stability Reserve and the Fit-for-55 package) but also a structural shift in market expectations. As Sitarz et al. (2024) argue, the surge in carbon prices can be explained by firms and investors becoming more farsighted and internalizing the EU's long-term commitment to Net Zero, thereby reinforcing the credibility of a permanently rising carbon price

³By 2027, the EU will introduce the EU-ETS2, covering emissions from buildings, road transport, and additional sectors, expected to replace most national carbon taxes.

⁴The near-zero price of ETS allowances until 2017 was mainly due to the overallocation of permits, the collapse in emissions during the 2008 financial crisis, and the absence of a Market Stability Reserve. The 2018 reform introduced the MSR and reinforced EU climate targets, which reduced the surplus of allowances and restored the credibility of the system, driving the subsequent increase in carbon prices.

path.

Figure 2: ETS Spot Price, €/metric tonne, 2010–2025

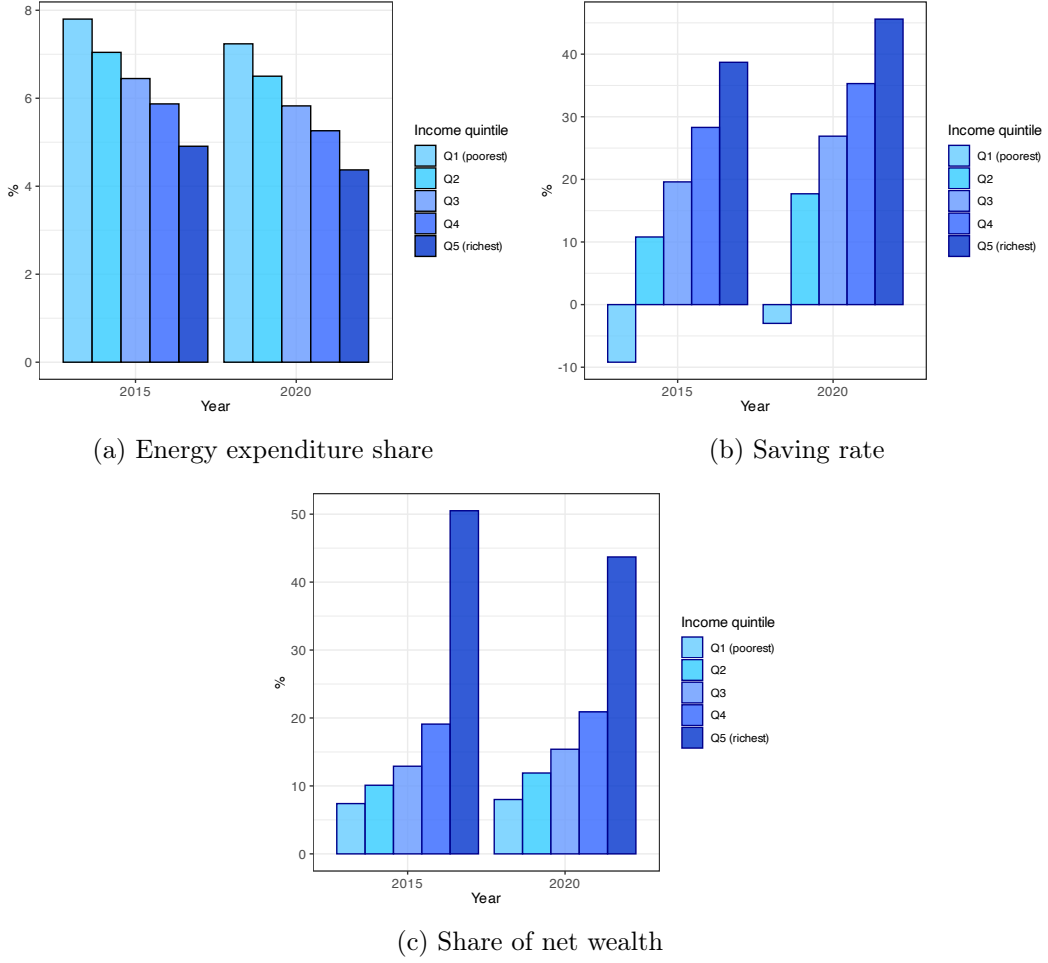


Source: Datastream, LSEG Workspace.

Distributional concerns are central to the political feasibility of carbon pricing. Regressive effects can emerge through two channels: (i) a *source-side* effect, as factor returns (wages and capital income) adjust, and (ii) a *use-side* effect, as households differ in the share of their budget allocated to carbon-intensive goods. Figure 3, panel A, shows that households in the bottom quintile of the EU income distribution spend about twice as much on electricity, gas, and fuels as a share of their income compared to the richest quintile. Panel B highlights that these households also have (on average) negligible saving rates, which limits their ability to smooth consumption intertemporally. Panel C shows that the top two quintiles hold around 65-70% of total wealth in the EU, underscoring the large concentration of assets. Taken together, these patterns imply that low-income households are particularly exposed to carbon pricing: they face higher energy-related expenses, have fewer savings to buffer shocks, and derive little protection from asset income.

To mitigate these risks, the EU has introduced explicit redistribution and compensation mechanisms, including the *Social Climate Fund* (SCF) and the *Just Transition Fund* (JTF). The SCF provides resources to Member States to support vulnerable groups (for instance those in energy or transport poverty) through structural investments and temporary income support. The JTF facilitates structural change by financing employment opportunities in low-carbon sectors and promoting diversification in regions highly dependent on fossil-fuel industries. These instruments reflect the EU's recognition that fairness is essential to sustain

Figure 3: Households' consumption, saving, and wealth by income quintile, EU



Source: Eurostat (EU-27). For Panel A, values are averages across EU country-level data (2015-2020) and EU-SILC for earlier years. For Panels B and C, data are from Eurostat's "Income, Consumption and Wealth" experimental statistics (since 2015).

political support for Net Zero policies.

In summary, the combination of (i) persistent inequality in energy expenditure, saving capacity, and wealth distribution, and (ii) the credibility of a permanently rising carbon price since 2017, provides strong motivation for the model developed in this paper. The evidence supports the use of a heterogeneous-agent framework with Hand-to-Mouth and Saver households, and the assumption of perfect foresight over a growing carbon price path consistent with EU targets.

3 Model

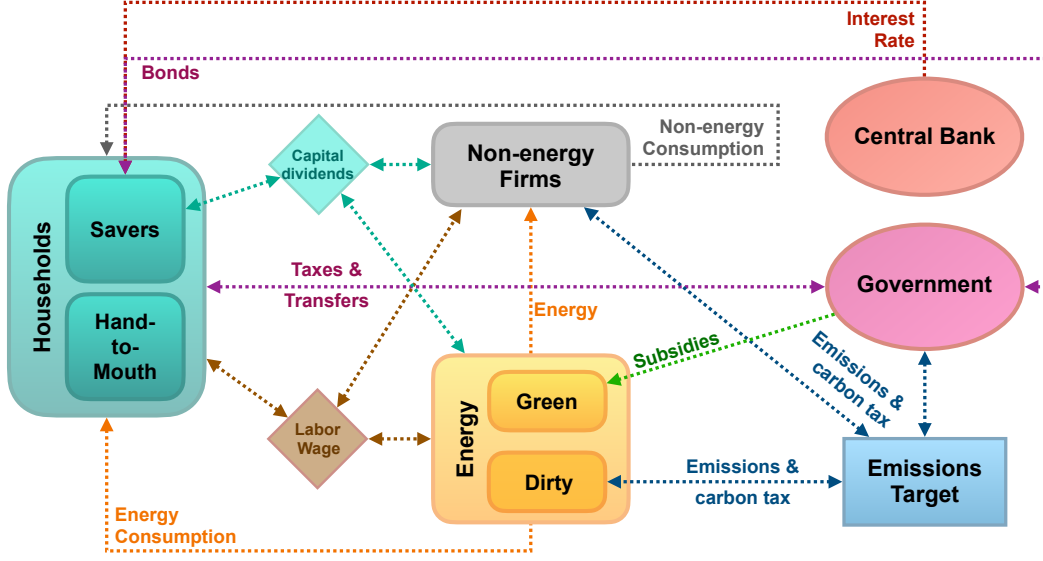
The model is calibrated to the European Union and treats it as a single, closed economy within a two-agent New Keynesian (TANK) E-DSGE framework designed to study the transition

to Net Zero. Households are represented by two groups: Hand-to-Mouth (HM) agents, who cannot access financial markets and consume their current income, and Savers (S), who smooth consumption intertemporally. The two groups differ in their consumption baskets, with HM allocating a larger share to energy goods. For simplicity, the share of HM does not vary over time. On the production side, firms operate in monopolistically competitive markets with nominal rigidities in prices and wages. The non-energy sector produces final goods using labor, capital, and energy as inputs, and emits at a relatively low intensity. The energy sector is disaggregated into green and dirty producers: both employ labor and capital, but only dirty energy is polluting, while green energy is emission-free. Consequently, both dirty energy and non-energy output are taxed for their emissions. The central bank follows a Taylor-type rule, and the government levies labor and capital income taxes, as well as a carbon tax. Carbon tax revenues are recycled through alternative schemes targeting households or firms. Emission-reduction targets are imposed for 2030, 2040, and 2050. The carbon price rises to ensure consistency with these targets. The baseline deliberately excludes green technological progress, providing a conservative benchmark for the macroeconomic and distributional consequences of carbon pricing.

The framework builds on two-agent DSGE models (Bilbiie, 2008; Galí et al., 2007) and environmental-macro models (Annicchiarico & Di Dio, 2015, 2017; Ferrari & Nispi Landi, 2024a; Hassler et al., 2021, 2022; Heutel, 2012). Relative to these approaches, the model embeds several features central to the EU’s Net Zero transition: heterogeneous household energy expenditure, a disaggregated energy block, differentiated carbon taxation across sectors, different carbon tax revenue recycling schemes, and long-run transition dynamics under perfect foresight.

A sketch of the model is shown in Figure 4.

Figure 4: Scheme of the Two-Agents E-DSGE model.



3.1 Households

There is a continuum of infinitely lived households $[0, 1]$ with the same utility function. Households gain utility from consumption x and disutility from labor ℓ . As in Bilbiie (2008), a fixed share of families $(1 - \Delta)$ has access to capital and bond markets, owns final-goods firms and supplies labor, maximizing the standard intertemporal problem $\max \mathbb{E}_t \sum_{i=0}^{\infty} \beta^i U(x_{S,t+i}, \ell_{S,t+i})$, where β is the intertemporal discount factor. I call this group Savers (S). The remaining share of households, Δ , hold no assets and consume their entire income each period. I call these households Hand-to-Mouth (HM). The utility function takes the additively separable CRRA form as follows:

$$U(x_{j,t}, \ell_{j,t}) = \frac{x_{j,t}^{1-\varphi_c} - 1}{1-\varphi_c} - \psi_j \frac{\ell_{j,t}^{1+\varphi_\ell}}{1+\varphi_\ell}, \text{ where } j=\{\text{HM}, \text{S}\} \quad (1)$$

φ_c is the inverse elasticity of intertemporal substitution; ψ_j weights the disutility of working and φ_ℓ is the inverse of the Frisch elasticity.

3.1.1 Hand-to-Mouth

Hand-to-Mouth households consume their entire disposable income each period. Their budget constraint is:

$$p_{HM,t}x_{HM,t} = (1 - \tau_{\ell,t})w_{HM,t}\ell_{HM,t} + \mathcal{T}_{HM,t}, \quad (2)$$

where $p_{HM,t}$ is the price index of the HM consumption basket (relatively more energy-intensive than that of Savers), $w_{HM,t}$ is the wage, $\tau_{\ell,t}$ is the labor income tax, and $\mathcal{T}_{HM,t}$ are government transfers.

The first-order condition with respect to labor is

$$\frac{x_{HM,t}^{-\varphi_c}}{p_{HM,t}} w_t = \psi_{HM} \frac{\ell_{HM,t}^{\varphi_\ell}}{(1 - \tau_{\ell,t})}. \quad (3)$$

This condition highlights that a lower labor tax ($\tau_{\ell,t}$) directly increases the after-tax wage on the left-hand side, inducing HM households to supply more labor.

3.1.2 Savers

Savers smooth consumption intertemporally and accumulate capital and bonds. Their budget constraint is:

$$b_t + p_{S,t}x_{S,t} + i_{S,t} = b_{t-1} \frac{r_{t-1}}{\pi_{y,t}} + (1 - \tau_{K,t})r_{k,t}k_{S,t-1} + (1 - \tau_{\ell,t})w_{S,t}\ell_{S,t} + \mathcal{T}_{S,t}, \quad (4)$$

where $p_{S,t}$ is the price index of the S consumption basket (less energy-intensive), b_t are bond holdings, $i_{S,t}$ is investment, $(r_{t-1}/\pi_t)b_{t-1}$ are real bond returns, $(1 - \tau_{K,t})r_{k,t}k_{S,t-1}$ is after-tax capital income, $(1 - \tau_{\ell,t})w_{S,t}\ell_{S,t}$ is after-tax labor income, and $\mathcal{T}_{S,t}$ are transfers. Here, $\pi_{y,t} = P_{y,t}/P_{y,t-1}$ denotes inflation in the final non-energy good y_t , which is the numéraire of the model.

Capital accumulates subject to quadratic adjustment costs:

$$k_{S,t} = (1 - \delta)k_{S,t-1} + i_{S,t} \left[1 - \frac{\phi_i}{2} \left(\frac{i_{S,t}}{i_{S,t-1}} - 1 \right)^2 \right], \quad (5)$$

where $\phi_i > 0$ measures the size of adjustment costs. This formulation penalizes sharp changes in investment, preventing unrealistically large jumps in response to the introduction of carbon

policies. This slows the flow of capital from polluting to non-polluting sectors during the transition.

The first-order conditions are:

$$p_{S,t} \lambda_{S,t} = x_{S,t}^{-\varphi_c}, \quad (6)$$

$$w_{S,t} \lambda_{S,t} = \psi_S \frac{\ell_{S,t}^{\varphi_\ell}}{(1 - \tau_{\ell,t})}, \quad (7)$$

$$q_t = \beta \mathbb{E}_t \frac{\lambda_{S,t+1}}{\lambda_{S,t}} \left[(1 - \tau_{K,t+1}) r_{k,t+1} + q_{t+1} (1 - \delta) \right], \quad (8)$$

$$1 = q_t \left[1 - \frac{\phi_i}{2} \left(\frac{i_{S,t}}{i_{S,t-1}} - 1 \right)^2 - \phi_i \left(\frac{i_{S,t}}{i_{S,t-1}} - 1 \right) \frac{i_{S,t}}{i_{S,t-1}} \right] \\ + \beta \mathbb{E}_t q_{t+1} \left[\frac{\lambda_{S,t+1}}{\lambda_{S,t}} \phi_i \left(\frac{i_{S,t+1}}{i_{S,t}} - 1 \right) \left(\frac{i_{S,t+1}}{i_{S,t}} \right)^2 \right], \quad (9)$$

where $\lambda_{S,t}$ is the marginal utility of consumption and q_t is Tobin's q .

The Euler equation for bonds is

$$\lambda_{S,t} = \beta \mathbb{E}_t \left(\lambda_{S,t+1} \frac{r_t}{\pi_{y,t+1}} \right). \quad (10)$$

linking current and future marginal utility of consumption. It captures how Savers respond to real interest rates, i.e. the nominal return r_t adjusted for next period's non-energy inflation $\pi_{y,t+1}$. A higher expected real return induces Savers to postpone consumption and increase saving, while higher expected inflation lowers the effective return and shifts incentives towards current consumption.

Relative to Hand-to-Mouth households, Savers respond not only to current income but also to intertemporal prices. The presence of capital taxation ($\tau_{K,t}$) and investment adjustment costs (ϕ_i) directly shapes their saving and investment behavior.

Finally, households differ in labor productivity: Savers are more productive than HM households, hence earn a higher wage:

$$w_{HM,t} = \psi_{l_{HM}} w_t, \quad (11)$$

$$w_{S,t} = \psi_{l_S} w_t, \quad (12)$$

where $\psi_{l_{HM}}$ and ψ_{l_S} determine relative productivity and w_t is the baseline wage paid by firms.

3.1.3 Consumption basket

Households consume both energy and non-energy goods. The composite consumption index $x_{j,t}$ is modeled as a constant elasticity of substitution (CES) aggregator:

$$x_{j,t} = \left[(1 - \gamma_j)^{\frac{1}{\epsilon_j}} c_{j,t}^{\frac{\epsilon_j - 1}{\epsilon_j}} + \gamma_j^{\frac{1}{\epsilon_j}} E_{j,t}^c \frac{\epsilon_j - 1}{\epsilon_j} \right]^{\frac{\epsilon_j}{\epsilon_j - 1}}, \quad (13)$$

where γ_j denotes the share of energy in the consumption basket and ϵ_j is the elasticity of substitution between non-energy goods $c_{j,t}$ and energy goods $E_{j,t}^c$. Both parameters differ across household types.

The associated price index is

$$p_{j,t} = \left((1 - \gamma_j) + \gamma_j p_{E,t}^{1 - \epsilon_j} \right)^{\frac{1}{1 - \epsilon_j}}. \quad (14)$$

All real variables are expressed in units of the non-energy good y_t : $p_{E,t} \equiv P_{E,t}/P_{y,t}$, $p_{j,t} \equiv P_{j,t}/P_{y,t}$, and all wages, returns, and taxes are deflated by $P_{y,t}$, chosen as numéraire.

Demands for non-energy and energy goods follow:

$$c_{j,t} = (1 - \gamma_j) \left(\frac{1}{p_{j,t}} \right)^{-\epsilon_j} x_{j,t}, \quad (15)$$

$$E_{j,t}^c = \gamma_j \left(\frac{p_{E,t}}{p_{j,t}} \right)^{-\epsilon_j} x_{j,t}. \quad (16)$$

An increase in the relative price of energy $p_{E,t}$ reduces demand for $E_{j,t}^c$, with the size of the adjustment governed by the substitution elasticity ϵ_j .

3.2 Firms

This section formalizes the production side of the economy. I distinguish between non-energy producers of final consumption goods and energy producers, with the latter split into green and dirty technologies. Technologies are fixed at their steady-state levels, so that the baseline scenario isolates the effect of carbon taxation from endogenous technological change.⁵

⁵Results with technological growth in the green sector are shown in Appendix C.1.

3.2.1 Non-energy goods producers

Each firm (i) produces a differentiated non-energy consumption good $y_t(i)$ according to a CES technology that combines value added and energy inputs:

$$y_t(i) = TFP_{y,t} \left[v^{\frac{1}{\xi_y}} (VA_t(i))^{\frac{\xi_y-1}{\xi_y}} + (1-v)^{\frac{1}{\xi_y}} (A_{E,t} E_{y,t}(i))^{\frac{\xi_y-1}{\xi_y}} \right]^{\frac{\xi_y}{\xi_y-1}}, \quad (17)$$

$$VA_t(i) = A_{y,t}(i) (k_{y,t-1}(i))^\alpha (\ell_{y,t}(i))^{1-\alpha}, \quad \alpha \leq 1, \quad (18)$$

$$TFP_{y,t}(i) = 1 - D_t(e_{s,t}), \quad (19)$$

where $VA_t(i)$ is value added, defined as a Cobb-Douglas aggregate of sector-specific capital $k_{y,t-1}(i)$ and labor $\ell_{y,t}(i)$, with α the capital share. $E_{y,t}(i)$ is the energy input, multiplied by the technology shifter $A_{E,t}$. v measures the relative weight of value added in the CES function, while ξ_y is the elasticity of substitution between value added and energy. $A_{y,t}(i)$ denotes the value-added technology. Finally, $TFP_{y,t}$ is total factor productivity net of environmental damages $D_t(e_{s,t})$, which reduce effective output as emissions increase.

Emissions in the non-energy sector are modeled as a flow proportional to production:

$$e_{y,t}(i) = y_t(i) \gamma_y (1 - \mu_{y,t}(i)), \quad (20)$$

where γ_y is the emission intensity per unit of output and $\mu_{y,t}(i) \in [0, 1]$ is the fraction of emissions abated. The interpretation is that firms can reduce emissions by diverting resources toward cleaner processes, installing CO₂ capture devices, or improving efficiency. Abatement is a flow decision: in every period, firms choose how much of their emissions to abate, which implies a contemporaneous cost.

The cost of abatement is captured by a convex function

$$g(\mu_{y,t}(i)) = \theta_{1,y} (\mu_{y,t}(i))^{\theta_2}, \quad (21)$$

with $\theta_{1,y} > 0$ a scale parameter and $\theta_2 > 1$ determining curvature.⁶ This specification implies rising marginal costs: higher abatement rates become progressively more expensive.

⁶I scale $\theta_{1,y}$ by relative emissions intensity so that steady-state carbon prices are equalized across sectors.

The profit function of a representative non-energy firm is

$$\begin{aligned}\Pi_{y,t}(i) &= y_t(i) - w_t \ell_{y,t}(i) - r_{k,t} k_{y,t-1}(i) - \tau_{y,t}(i) e_{y,t}(i) \\ &\quad - g(\mu_{y,t}(i)) y_t(i) - p_{E,t} E_{y,t}(i),\end{aligned}\tag{22}$$

where w_t is the wage, $r_{k,t}$ the rental rate of capital, $\tau_{y,t}$ the emissions tax per unit of $e_{y,t}$, and $p_{E,t}$ the energy price. The last two terms capture, respectively, the cost of abatement and the cost of energy.

Profit maximization delivers standard input demand conditions. From the FOC with respect to capital:

$$r_{k,t} = V A_t^{\frac{\xi_y - 1}{\xi_y}} v^{\frac{1}{\xi_y}} \alpha \frac{mc_{y,t}}{k_{y,t}} y_t^{\frac{1}{\xi_y}},\tag{23}$$

where $mc_{y,t}$ is the real marginal cost.

From the FOC with respect to labor:

$$w_t = V A_t^{\frac{\xi_y - 1}{\xi_y}} v^{\frac{1}{\xi_y}} y_t^{\frac{1}{\xi_y}} (1 - \alpha) \frac{mc_{y,t}}{\ell_{y,t}}.\tag{24}$$

From the FOC with respect to energy:

$$p_{E,t} = (1 - v)^{\frac{1}{\xi_y}} mc_{y,t} y_t^{\frac{1}{\xi_y}} E_{y,t}^{-1/\xi_y}.\tag{25}$$

Finally, from the FOC with respect to abatement effort:

$$\tau_{y,t} \gamma_y = \theta_{1,y} \theta_2 (\mu_{y,t})^{\theta_2 - 1}.\tag{26}$$

This condition states that firms increase abatement until its marginal cost equals the avoided cost of the emissions tax.

3.2.2 Energy sector

Aggregate energy is a CES aggregate of dirty $E_{D,t}$ and green $E_{G,t}$ inputs:

$$E_t = \left[\nu^{\frac{1}{\chi}} (E_{G,t})^{\frac{\chi-1}{\chi}} + (1 - \nu)^{\frac{1}{\chi}} (E_{D,t})^{\frac{\chi-1}{\chi}} \right]^{\frac{\chi}{\chi-1}},\tag{27}$$

where χ is the elasticity of substitution and ν the share parameter. The CES structure captures the degree of substitutability between green and dirty energy: the higher χ , the stronger the reallocation of demand toward green energy when $p_{D,t}$ rises relative to $p_{G,t}$.

The corresponding energy price index is

$$p_{E,t} = \left[\nu p_{G,t}^{1-\chi} + (1-\nu) p_{D,t}^{1-\chi} \right]^{\frac{1}{1-\chi}}. \quad (28)$$

Demands for the two energy types are:

$$E_{G,t} = \nu \left(\frac{p_{G,t}}{p_{E,t}} \right)^{-\chi} E_t, \quad (29)$$

$$E_{D,t} = (1-\nu) \left(\frac{p_{D,t}}{p_{E,t}} \right)^{-\chi} E_t. \quad (30)$$

The relative price of green versus dirty energy determines the composition of aggregate energy use.

Dirty energy producers. Dirty firms employ a Cobb-Douglas technology with labor and capital:

$$\max_{\ell_{D,t}, k_{D,t-1}, \mu_{D,t}} \quad p_{D,t} E_{D,t} - \tau_{D,t} e_{D,t} - \theta_1 (\mu_{D,t})^{\theta_2} E_{D,t} - w_t \ell_{D,t} - r_{k,t} k_{D,t-1}, \quad (31)$$

$$s.t. \quad E_{D,t} = A_{D,t} (k_{D,t-1})^{\alpha_E} (\ell_{D,t})^{1-\alpha_E}. \quad (32)$$

where $A_{D,t}$ is dirty energy technology, α_E the capital share, $k_{D,t-1}$ and $\ell_{D,t}$ are sector-specific inputs, and $\mu_{D,t}$ is the fraction of emissions abated.

Emissions from dirty production are

$$e_{D,t} = E_{D,t} \gamma_D (1 - \mu_{D,t}), \quad (33)$$

with abatement cost

$$g(\mu_{D,t}) = \theta_1 (\mu_{D,t})^{\theta_2}. \quad (34)$$

This is analogous to the non-energy sector: abatement is a flow that trades off output against reduced emissions.

FOCs yield factor demands and the abatement condition:

$$r_{k,t} = \alpha_E \frac{E_{D,t}}{k_{D,t}} mc_{D,t}, \quad (35)$$

$$w_t = (1 - \alpha_E) \frac{E_{D,t}}{\ell_{D,t}} mc_{D,t}, \quad (36)$$

$$\tau_{D,t} \gamma_D = \theta_1 \theta_2 \mu_{D,t}^{\theta_2 - 1}. \quad (37)$$

As before, optimal abatement equates marginal abatement costs with the carbon tax.

Green energy producers. Green firms also employ a Cobb-Douglas technology, but are emission-free:

$$\max_{\ell_{G,t}, k_{G,t-1}} (1 + \mathcal{T}_{pG,t}) p_{G,t} E_{G,t} - w_t \ell_{G,t} - r_{k,t} k_{G,t-1}, \quad (38)$$

$$s.t. \quad E_{G,t} = A_{G,t} (k_{G,t-1})^{\alpha_E} (\ell_{G,t})^{1-\alpha_E}. \quad (39)$$

where $A_{G,t}$ is green energy technology and $\mathcal{T}_{pG,t}$ is a production subsidy.

FOCs are

$$r_{k,t} = \alpha_E \frac{E_{G,t}}{k_{G,t}} mc_{G,t}, \quad (40)$$

$$w_t = (1 - \alpha_E) \frac{E_{G,t}}{\ell_{G,t}} mc_{G,t}. \quad (41)$$

The subsidy $\mathcal{T}_{pG,t}$ lowers effective marginal costs $mc_{G,t}$. In the presence of price rigidities, it enters the Phillips curve as a negative cost-push term, stimulating green energy production by reducing relative price distortions.

3.3 Environment

The environmental block follows the standard approach of the E-DSGE literature, where emissions are modeled as a flow, accumulated into a stock of atmospheric pollution that generates economic damages, and where abatement is a costly but effective activity to reduce emissions.⁷

⁷This setup abstracts from more complex formulations common in the IAM literature, such as non-linear climate feedbacks or stochastic tipping points, which could be meaningfully integrated in future research (e.g. Nordhaus and Sztorc (2013)).

The accumulation of the pollution stock is defined as

$$M_t = \eta M_{t-1} + e_t + e^{ROW}, \quad \text{with} \quad e_t = e_{y,t} + e_{D,t}, \quad (42)$$

where M_t denotes the mass of greenhouse gases in the atmosphere, e_t is the flow of domestic emissions (the sum of non-energy and dirty energy firms' emissions), e^{ROW} represents exogenous emissions from the rest of the world, and $\eta \in (0, 1)$ is the persistence parameter describing the slow natural decay of atmospheric pollution.

Economic damages are modeled as a quadratic function of the pollution stock:

$$D_t = d_0 + d_1 M_t + d_2 M_t^2, \quad (43)$$

with parameters (d_0, d_1, d_2) calibrated to match empirical damage estimates. This functional form is standard in E-DSGE models and ensures that damages increase non-linearly as the pollution stock rises. In the production block, these damages directly reduce effective total factor productivity, thereby lowering output.

Finally, aggregate abatement spending is defined as

$$z_t = g(\mu_{y,t})y_t + g(\mu_{D,t})E_{D,t}, \quad (44)$$

where $g(\cdot)$ is the convex abatement cost function specified at the sectoral level, $\mu_{y,t}$ and $\mu_{D,t}$ are the fractions of emissions abated in the non-energy and dirty energy sectors, respectively, and y_t and $E_{D,t}$ are their outputs in real terms (relative to the numéraire).

3.4 Nominal Frictions and Monetary Policy

In the baseline model, firms in all sectors operate in monopolistically competitive markets, with sticky prices and sticky wages. Nominal price rigidities are modeled by introducing quadratic adjustment costs $AC_t^P(i)$ à la Rotemberg (1983), which intermediate firms pay when adjusting their price with respect to the inflation target. Similarly, households pay a quadratic wage-adjustment cost $AC_{j,t}^W(i)$ which penalizes deviations of wage inflation from

the inflation target. Group-specific consumption inflation is defined as

$$\pi_{j,t} = \frac{P_t^j}{P_{t-1}^j} \quad (45)$$

$$= \frac{P_t^j}{P_{y,t}} \cdot \frac{P_{y,t}}{P_{y,t-1}} \cdot \frac{P_{y,t-1}}{P_{t-1}^j} \quad (46)$$

$$= \frac{p_{j,t}}{p_{j,t-1}} \pi_{y,t}, \quad j \in \{HM, S\}, \quad (47)$$

where P_t^j is the nominal consumption price index of household group j , $p_{j,t} \equiv P_t^j/P_{y,t}$ is the relative price index in terms of the final non-energy good y_t , and $\pi_{y,t} = P_{y,t}/P_{y,t-1}$ is inflation in the numéraire. Headline inflation is constructed as a population-weighted geometric mean,

$$\pi_t = \pi_{HM,t}^{\Delta} \pi_{S,t}^{1-\Delta}. \quad (48)$$

This choice is consistent with aggregating CES baskets across groups using population weights.

Nominal rigidities imply that firms and households face Phillips-curve-type relations linking inflation to marginal costs and adjustment costs. Full derivations of the price and wage Phillips curves, together with the adjustment cost functions, are reported in Appendix A.

The central bank follows a simple feedback rule of the Taylor (1993) class:

$$\frac{r_t}{\bar{r}} = \left(\frac{r_{t-1}}{\bar{r}} \right)^{\rho_m} \left[\left(\frac{\pi_t}{\bar{\pi}} \right)^{\phi_\pi} \left(\frac{y_t}{y_{t-1}} \right)^{\phi_y} \right]^{1-\rho_m}, \quad (49)$$

where \bar{r} and $\bar{\pi}$ denote the Ramsey steady-state nominal rate and inflation, ρ_m is the degree of policy inertia, ϕ_π the response to the inflation gap, and ϕ_y the response to output growth, as in Schmitt-Grohé and Uribe (2007).⁸

3.5 Market Clearing

The model is closed by standard market clearing conditions, which ensure that factor and goods markets balance in every period.

⁸As the authors explain, this formulation requires the central bank to hold only minimum information regarding the efficient level of output. Alternatively, the output gap can be defined as the deviation of actual output from its flexible level. This approach yields similar results.

Labor demand from firms equals the aggregate labor supplied by households:

$$\ell_t = \ell_{y,t} + \ell_{D,t} + \ell_{G,t} = \Delta \ell_{HM,t} + (1 - \Delta) \ell_{S,t}, \quad (50)$$

where $\ell_{y,t}$, $\ell_{D,t}$ and $\ell_{G,t}$ are labor demands from non-energy, dirty energy, and green energy firms, respectively, while $\ell_{HM,t}$ and $\ell_{S,t}$ denote the labor supplied by Hand-to-Mouth and Saver households. The parameter Δ is the share of HM households in the population. Capital also clears across sectors:

$$k_t = k_{y,t} + k_{D,t} + k_{G,t}. \quad (51)$$

Since only Savers have access to capital markets, aggregate capital and investment are scaled by their population share $(1 - \Delta)$:

$$k_t = (1 - \Delta) k_{S,t}, \quad (52)$$

$$i_t = (1 - \Delta) i_{S,t}. \quad (53)$$

The energy market clears when total energy supply matches aggregate demand for both consumption and production:

$$E_t = E_{c,t} + E_{y,t}, \quad (54)$$

where $E_{c,t}$ is household energy consumption and $E_{y,t}$ the energy input used by non-energy producers. Household-level energy consumption aggregates as

$$E_{c,t} = \Delta E_{c,HM,t} + (1 - \Delta) E_{c,S,t}. \quad (55)$$

Similarly, non-energy goods consumption aggregates as

$$c_t = \Delta c_{HM,t} + (1 - \Delta) c_{S,t}, \quad (56)$$

and total household consumption of final goods is

$$x_t = \Delta x_{HM,t} + (1 - \Delta) x_{S,t}. \quad (57)$$

Finally, goods market clearing requires that final output equals the sum of all expenditure components:

$$y_t = c_t + i_t + g_t + z_t + \frac{AC_t^P}{P_t} + \frac{AC_t^W}{P_t}, \quad (58)$$

where g_t denotes government spending and z_t total abatement expenditure. This condition highlights that abatement shows up as an explicit resource cost in the economy, crowding out consumption and investment when carbon policies tighten. The terms $\frac{AC_t^P}{P_t}$ and $\frac{AC_t^W}{P_t}$ represent, respectively, the (real) resource costs associated with price and wage adjustment frictions à la Rotemberg (1983).

3.6 Abatement and Carbon Tax path

To close the environmental block of the model, I define the trajectory of abatement and the associated carbon tax path. Following Ferrari and Nispi Landi (2023), I take the abatement targets as exogenous, consistent with the policy announcements of the European Commission. In particular, I set the initial abatement levels μ_D and μ_y at zero in 2020, and increase them linearly to reach Net Zero abatement in 2050. This corresponds to a 95% reduction in total domestic emissions.

Intermediate targets are fixed at 55% abatement in 2030 and 90% in 2040, in line with the official EU targets. Formally, the abatement schedule is defined ex ante, and the implied carbon tax rates τ_y and τ_D are then determined ex post by the condition that firms equate the marginal cost of abatement to the emissions tax. Between each target year, carbon taxes grow linearly in quarterly steps, so that over the 2020-2050 horizon (120 quarters) the policy path smoothly converges to Net Zero. After 2050, both the abatement level and the carbon tax are held constant at their terminal values.

This setup is deliberately conservative: by treating abatement targets as exogenous and fixing green technologies at their steady-state level, the model isolates the direct effect of carbon pricing in driving the emissions trajectory, abstracting from additional contributions of technological progress.

3.7 Redistribution Policy and Inequality Measures

The government acts as the central fiscal authority, collecting labor and capital income taxes from households, and carbon taxes from polluting firms. To study how fiscal policy shapes the distributional effects of carbon taxation, I adopt a flexible structure that allows revenues from emissions taxation to be reallocated across households and firms through different channels. This setup follows the standard practice in the E-DSGE literature but is enriched here to accommodate five distinct revenue recycling schemes.

Total carbon tax revenues are given by $\tau_{Y,t}e_{Y,t} + \tau_{D,t}e_{D,t}$, i.e. the product of the sectoral emissions taxes and the corresponding emissions from non-energy and dirty energy firms. These revenues can either be redistributed directly, or used to reduce distortionary income taxes. The policy space is described by a set of parameters summarized in Table 1.

Table 1: Revenue recycling policy parameters

Parameter	Description
σ	= 0: revenues are used to reduce distortionary taxes. = 1: revenues are redistributed to households or firms.
σ_{HH}	= 0: redistribution targets firms. = 1: redistribution targets households.
σ_{HM}	= Δ : revenues are distributed proportionally across all households. = 1: revenues are directed only to Hand-to-Mouth households.
ξ_ℓ	Share of revenues used to reduce the labor income tax (when $\sigma = 0$).
ξ_K	Share of revenues used to reduce the capital income tax (when $\sigma = 0$).

This parametrization spans five policy experiments, which can be summarized as:

1. $\mathcal{T}_{HM,t}$: lump-sum (targeted) transfers to HM households ($\sigma = 1, \sigma_{HH} = 1, \sigma_{HM} = 1$);
2. $\mathcal{T}_{HH,t}$: lump-sum (weighted by population share) transfers to all households ($\sigma = 1, \sigma_{HH} = 1, \sigma_{HM} = \Delta$);
3. $\mathcal{T}_{pG,t}$: production subsidies to green firms ($\sigma = 1, \sigma_{HH} = 0$);
4. $\mathcal{T}_{\tau_\ell,t}$: reduction in labor income tax ($\sigma = 0, \xi_\ell = 1$);
5. $\mathcal{T}_{\tau_K,t}$: reduction in capital income tax ($\sigma = 0, \xi_K = 1$).

When revenues are used to reduce distortionary taxes, the labor and capital income tax

rates become endogenous and time-varying. For labor:

$$\begin{aligned}\tau_{\ell,t} &= \bar{\tau}_{\ell} - \mathcal{T}_{\tau_{\ell,t}}, \quad \text{with} \\ \mathcal{T}_{\tau_{\ell,t}} &= \xi_{\ell}(1 - \sigma) \frac{\tau_{Y,t}e_{Y,t} + \tau_{D,t}e_{D,t}}{w_{HM,t}\ell_{HM,t}\Delta + w_{S,t}\ell_{S,t}(1 - \Delta)},\end{aligned}\tag{59}$$

and analogously for capital:

$$\begin{aligned}\tau_{K,t} &= \bar{\tau}_K - \mathcal{T}_{\tau_{K,t}}, \quad \text{with} \\ \mathcal{T}_{\tau_{K,t}} &= \xi_K(1 - \sigma) \frac{\tau_{Y,t}e_{Y,t} + \tau_{D,t}e_{D,t}}{r_{k,t}k_{S,t}}.\end{aligned}\tag{60}$$

The denominators normalize the recycling by the relevant tax base, ensuring that revenues are redistributed proportionally to total labor or capital income. In all other scenarios, tax rates remain at their baseline values $\bar{\tau}_{\ell}$ and $\bar{\tau}_K$.

To quantify the distributional effects of these policies, I use two measures of inequality. First, the income Gini coefficient, which ranges from 0 in the case of perfect equality to 1 in the case of maximum inequality. With only two household groups, the Gini reduces to

$$G_t = \frac{1}{n} \left(n + 1 - 2 \left(\frac{n y_{HM,t} + (n - 1) y_{S,t}}{y_{HM,t} + y_{S,t}} \right) \right),\tag{61}$$

where $n = 2$, and $y_{HM,t}$ and $y_{S,t}$ denote the disposable incomes of HM and S households, respectively.

Second, I track the relative consumption gap between the two groups, measured as the ratio $x_{S,t}/x_{HM,t}$. This indicator captures how revenue recycling schemes affect household welfare through consumption, complementing the income-based Gini measure.

3.8 Calibration

The model is calibrated to EU data at a quarterly frequency. The calibration strategy follows two principles: (i) household and firm parameters are tied as closely as possible to observed EU statistics; (ii) environmental and policy parameters are taken from standard values in the literature, and are not questioned in this paper, although robustness checks are provided for some key cases.

Households. The share of HM households Δ is set to 40%, corresponding to the bottom two income quintiles in the European Union Statistics on Income and Living Conditions (EU-SILC),⁹ who hold a small share of net wealth and display almost no savings on average (see Figure 3). This choice ensures that the model reflects the wealth concentration and limited asset market participation documented in EU-SILC data. Consumption basket parameters are obtained from Eurostat’s Household Final Consumption Expenditure (HFCE), disaggregated by COICOP classification.¹⁰ In particular, the category “Electricity, gas, and other fuels” absorbs 7.8% of HM income and 4.9% of S income, which translates into distribution parameters γ_{HM} and γ_S via the re-parametrization of Cantore and Levine (2012). Consistent with Känzig (2025), the elasticity of substitution between energy and non-energy goods is set lower for HM ($\epsilon_{HM} = 0.05$) than for S ($\epsilon_S = 0.275$), capturing the more rigid consumption structure of poorer households. Other household-side parameters, such as the discount factor, intertemporal elasticity, and Frisch elasticity, follow Drygalla et al. (2018) and standard macro values.

Firms. Production parameters are calibrated from Eurostat data. The non-energy sector is relatively labor intensive, with capital share $\alpha = 0.37$, while the energy sector is more capital intensive, $\alpha_E = 0.73$.¹¹ The share of energy in non-energy production is 13% ($1 - v$). The elasticity of substitution between the value-added bundle and energy inputs (ξ_y) is taken from van der Werf (2008), who provide long-run estimates for EU economies. The elasticity of substitution between intermediate goods (ξ), the Calvo price parameter (θ_c), and the implied Rotemberg adjustment costs (ϕ_p) follow standard values in the New Keynesian literature (Ascari & Rossi, 2012).

Energy. The renewable share in the EU energy mix is around 25% (Eurostat), which determines the weighting parameter ν in the CES aggregator of green and dirty energy.¹² The elasticity of substitution between green and dirty energy χ is set to 1.8, consistent with

⁹EU-SILC is a harmonized microdata survey providing information on income distribution, wealth, and living conditions across EU member states.

¹⁰COICOP (Classification of Individual Consumption by Purpose) categorizes household expenditures by detailed purpose, including energy-related items such as electricity, gas, and other fuels.

¹¹Capital intensity is calculated from labor intensity in each sector, measured as the ratio of compensation per employee to gross value added (GVA), corrected for the employed-to-employee ratio to account for the self-employed.

¹²The CES weighting parameter ν is calibrated to match the observed renewable energy share of final consumption.

the range of 1-2 typically used in the literature.

Environment. The environmental block follows standard E-DSGE calibrations. The total global emissions stock is set at 877.56 GtG in 2020, with EU emissions benchmarked at 10% of global emissions, in line with the 8-10% range observed between 2010 and 2019.¹³ Emissions from the rest of the world (ROW) are assumed to be fixed and set at nine times the level of EU emissions before the carbon policy is implemented. Because ROW emissions remain unchanged, reducing emissions in the EU has a smaller impact on total carbon stock and environmental damage. The share of emissions attributable to energy is 80% (Q_E), reflecting the fact that, while direct energy production accounts for roughly 30% of emissions, energy combustion constitutes the bulk of EU GHG emissions. Household energy consumption accounts for 28% of total energy demand (Q_{Ec}). From these values, emission intensities are derived: $\gamma_y = 0.050$ for the non-energy sector and $\gamma_D = 1.158$ for dirty energy, both expressed in tons of CO₂ per unit of output in model numéraire.¹⁴

The abatement cost function follows the convex specification standard in the E-DSGE literature (Gibson & Heutel, 2023). To ensure that both sectors face the same carbon tax τ at the margin, I scale the coefficient of the non-energy abatement cost function by its relative emission intensity.¹⁵ This scaling ensures that abatement costs are proportional to sectoral emissions, harmonizing the implied carbon price.

The environmental damage function parameters (d_0, d_1, d_2) and the pollution decay rate η are taken from Gibson and Heutel (2023) and Allen et al. (2018). These parameters are standard in the IAM and E-DSGE literature and are not the focus of this paper. However, robustness checks are conducted on the abatement cost specification, including a scenario with equal abatement costs across sectors (see Section 5.3).

Other parameters. Policy-related parameters, such as the monetary policy rule coefficients (ϕ_π, ρ_m) and the fiscal policy parameters, are set to conventional values in the New

¹³This benchmark is consistent with Eurostat and IPCC statistics on EU and global GHG emissions.

¹⁴In euro terms, the calibration implies intensities of about 58 g/€ for the non-energy sector and 1.3 kg/€ for the dirty energy sector. For a comparison, Eurostat data for 2019 report values of ca. 50 g/€ for manufacturing and 3.5 kg/€ for energy supply. The discrepancy on the dirty side arises because the model treats the EU as a closed economy, so that all energy demand is produced domestically. This inflates the size of the energy sector in steady state and lowers the implied intensity per euro.

¹⁵Formally, the abatement cost coefficient for the non-energy sector is rescaled by γ_y/γ_D so that the marginal abatement condition $\tau_{s,t}\gamma_s = \theta_1\theta_2\mu_{s,t}^{\theta_2-1}$ implies the same τ across sectors.

Keynesian literature.

Table 2: Model parameters

Parameter	Description	Value	Source
Households			
β	Discount factor	0.995	Drygalla et al. (2018)
φ_c	Inverse elasticity of intertemporal sub.	1.5	Drygalla et al. (2018)
φ_l	Inverse Frisch elasticity	2.0	Standard value
ξ_w	CES parameter of labor supply	6	Standard value
ϕ_w	Wage adjustment cost	59.113	Implied from θ_c (Ascari & Rossi, 2012)
ϵ_{HM}	Elasticity of subs energy/non-energy goods, HM	0.05	Känzig (2025)
ϵ_S	Elasticity of subs energy/non-energy goods, S	0.275	Känzig (2025)
γ_{HM}	Distribution parameter HM	0.118	Energy share $\omega_{HM} = 7.8\%$, EU-SILC
γ_S	Distribution parameter S	0.069	Energy share $\omega_S = 4.9\%$, EU-SILC
ϕ_i	Investment adjustment cost	10	Standard value
$\bar{\tau}_\ell$	Labor income tax rate	20%	Eurostat
$\bar{\tau}_K$	Capital income tax rate	25%	Eurostat
Δ	Share of HM households	40%	Eurostat
Firms			
ξ_y	Elasticity of sub. between VA and energy	0.38	van der Werf (2008)
ξ	Elasticity of sub. between intermediate goods	6	Standard value
α	Share of capital in value added	0.37	Eurostat
$1 - v$	Share of energy in non-energy production	0.13	Eurostat
θ_c	Calvo price parameter	0.75	Standard value
ϕ_p	Price adjustment cost	59.113	Implied from θ_c (Ascari & Rossi, 2012)
χ	Elasticity of sub. between energy sources	1.8	Standard value
ι	Share of renewable energy	0.25	Eurostat
ν	Weighting parameter of renewable energy	0.3156	Implied from ι
α_E	Share of capital in energy production	0.73	Eurostat
Q_{Ec}	Share of energy used for consumption by HH	28%	Eurostat
Q_E	Energy sector share of total emissions	80%	Eurostat
Environment			
γ_D	Energy sector emissions intensity	1.158	Implied from Q_E
γ_y	Non-energy sector emissions intensity	0.050	Implied from Q_E
d_0	Damage function constant	-0.0076	Gibson and Heutel (2023)
d_1	Damage function linear parameter	8.1e-6	Gibson and Heutel (2023)
d_2	Damage function quadratic parameter	1.05e-8	Gibson and Heutel (2023)
θ_1	Abatement cost function coefficient	0.074	Gibson and Heutel (2023)
$\theta_{y,1}$	Abatement cost function coefficient Non-energy firm	0.003	Gibson and Heutel (2023)
θ_2	Abatement cost function exponent	2.6	Gibson and Heutel (2023)
η	Pollution decay rate	0.9965	Allen et al. (2018)
Other			
ϕ_π	Mon. pol. response to inflation	1.5	Standard value
ρ_m	Monetary policy inertia	0.8	Standard value

4 The Net Zero Policy

In this section, I simulate the long-run transition to an emission-free economy, where the government sets ambitious abatement targets and the price of emissions rises gradually over time. All figures report percentage deviations from the initial steady state (no policy). By the end of the transition, both non-energy and dirty energy firms fully abate their emissions. The policy is announced at the beginning of the simulation. Given the post-2017 rise in the EU ETS price and the ensuing credibility of a persistently increasing carbon price, the baseline simulation is solved under perfect foresight, so that agents internalize the full tax path at announcement. Under perfect foresight, agents anticipate the full trajectory of the carbon tax, which is designed to achieve a 95% reduction in emissions by 2050. The gradual increase

in the carbon tax raises the user cost of emissions and induces firms to spend on abatement; because abatement is costly, marginal costs increase and, in the new steady state, wages and the rental rate of capital are lower. In the baseline simulation, technology is held constant at its steady-state level.¹⁶ A key contribution of the paper is to compare five alternative uses of carbon tax revenues – from household transfers to firm subsidies and income tax reductions – along the path toward the EU’s 2050 Net Zero target. Each scheme delivers distinct macroeconomic and distributional effects, revealing a trade-off between aggregate outcomes (smaller declines in GDP, consumption, and investment) and equity.

4.1 Macroeconomics and Distributional Effects

Production and investment. Real activity declines in the long run in all scenarios once the Net Zero policy is implemented. However, GDP losses are mitigated when carbon tax revenues finance cuts in labor or capital income taxes, producing a temporary medium-run expansion above the pre-tax level (see Figure 5). By the end of the transition, GDP is approximately 1.7-2.2% below its pre-policy level, in line with euro-area evidence and policy simulations.¹⁷ These figures incorporate the (modest) benefit from lower climate damages: as emissions fall, the pollution stock declines slowly (given the high persistence governed by η), reducing TFP losses. The implied gain is about 0.5% of GDP, which is small because the EU accounts for roughly 10% of global emissions.¹⁸ Investment displays a sharp initial contraction, fluctuates around intermediate targets, and then stabilizes. In the capital tax reduction scenario only, investment reacts temporarily positively to the carbon tax (see Figure 6).

The contraction in aggregate energy production is even stronger than the decline in GDP (see Figure 6). Productive inputs reallocate from dirty to green energy. By the end of the transition, dirty energy output is about 12% lower while green energy output is roughly 17% higher. As shown in Figure 7, in the non-energy sector labor fluctuates at short and

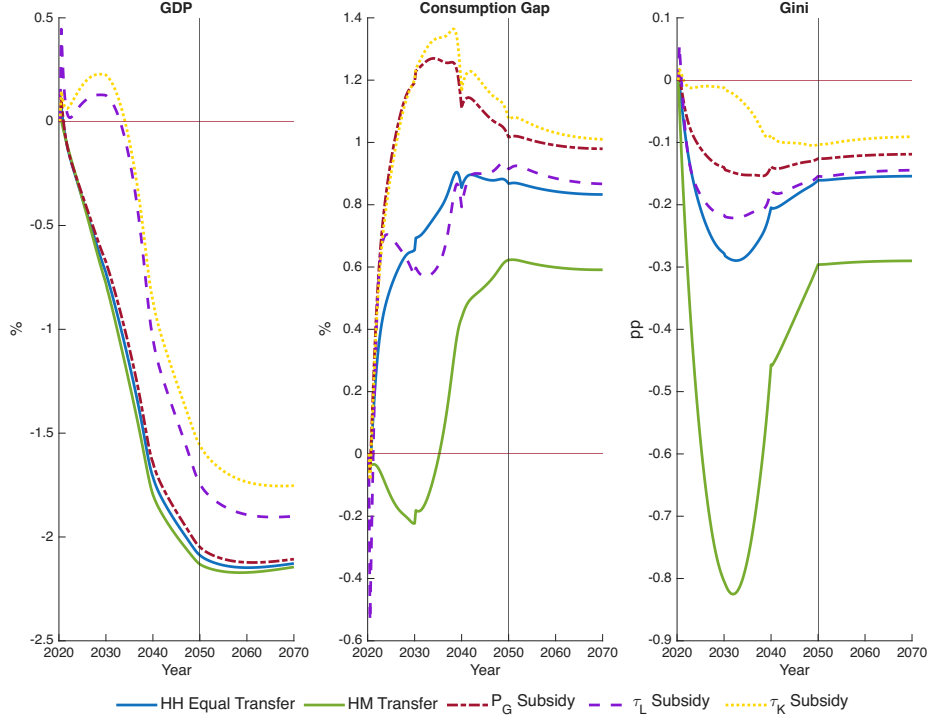
¹⁶Green technological change is important for the transition; a large literature studies the interaction between climate policy and innovation (e.g., Fried (2018) and Kruse-Andersen (2025)). Here the baseline deliberately abstracts from green TFP growth to isolate the direct macro and distributional effects of fiscal policy. Appendix C.1 reports a scenario with green energy technology growing at 2% per year until 2050, consistent with the empirical findings.

¹⁷Comparable long-run output costs are reported in Ferrari and Nispi Landi (2024b) and Coenen et al. (2024) for the euro area, as well as in the *Clean Planet for All* report by the European Commission (2018) and in the Network for Greening the Financial System (2025) scenarios, which project GDP reductions around 2% for low-innovation transitions.

¹⁸If, for instance, all high-income countries (about 40% of global emissions) coordinated to reach Net Zero, the gain would be around 1.5%.

medium horizons before stabilizing above its initial level in all scenarios. Capital in non-energy declines, reflecting lower aggregate investment and a reallocation toward the expanding green energy sector, which is more capital intensive.

Figure 5: GDP and Inequality, Transition to Net Zero



Note: variables are percentage deviations from the initial steady state; inequality measure (Gini) in percentage points deviation.

Prices and inflation. Price dynamics depend on the recycling scheme. Energy inflation peaks immediately after the announcement of Net Zero. It is particularly strong when tax revenues reduce labor or capital income taxes. Year-on-year energy inflation rises by up to 2 pp in the labor tax cut scenario, due to a short run demand boost, and remains positive throughout the transition. Headline inflation behaves differently: the spike is short-lived and, in the case of household transfers, headline inflation quickly turns negative and remains below baseline for most of the horizon (see Figure 6). Overall, the deflationary impulse in headline reflects relative price movements – non-energy prices fall with weaker demand – even as energy-specific inflation remains positive.

Relative energy prices move in opposite directions along the transition (see Figure 7). The dirty energy price increases persistently, while the green energy price declines until around the 2040 intermediate target and then partially recovers. The fall in the green price is strongest

under production subsidies, which, by construction, lower green producers' marginal costs.

Household dynamics. In the very short run, aggregate consumption rises under every recycling scheme. Savers benefit most from firm subsidies or a cut in income taxes and temporarily raise consumption above its pre-policy level. The largest decline in activity occurs when revenues are directed exclusively to HM households, as transfers reduce their incentive to work and lower aggregate labor supply. By the end of the transition, Savers consumption $x_{S,t}$ settles between -1.5% and -2% compared to the pre-tax period. HM consumption x_{HM} rises temporarily with targeted transfers or labor tax cuts but, in the long run, falls by 2.3-3%. The smallest long-run drop occurs under targeted transfers; the largest occurs under green production subsidies (see Figure 6).

Households adjust labor supply differently across schemes (Figure 6). HM households are liquidity constrained and consume current income each period. In the short run, when they receive transfers that offset income losses, they reduce hours (the income effect dominates). In the long run, because they rely entirely on labor income and real wages are lower, HM hours rise persistently. Savers reduce labor supply mainly when (i) green production is subsidized and (ii) the capital income tax is cut. In case (i), higher profits in the green sector (owned by Savers) generate a wealth effect that supports consumption despite fewer hours, widening the consumption gap. In case (ii), the tax cut raises the after-tax return on savings $(1 - \tau_{K,t})r_{k,t}$. Given this, a lower gross rental rate $r_{k,t}$ can finance investment without discouraging saving; the initial rise in the capital stock increases the marginal product of labor and lifts real wages relative to other schemes, allowing Savers to work less while sustaining consumption. In response to the rising carbon tax, both real wages and the gross rental rate of capital fall on impact. Wages remain permanently below the pre-tax level (-2 to -2.5%), while $r_{k,t}$ gradually recovers. Under tax-cut recycling, both wages and $r_{k,t}$ can display a short-lived positive response. Notably, the capital tax cut $\tau_{K,t}$ mitigates the wage decline but amplifies the fall in the gross rental rate $r_{k,t}$, even as the net return to Savers increases.

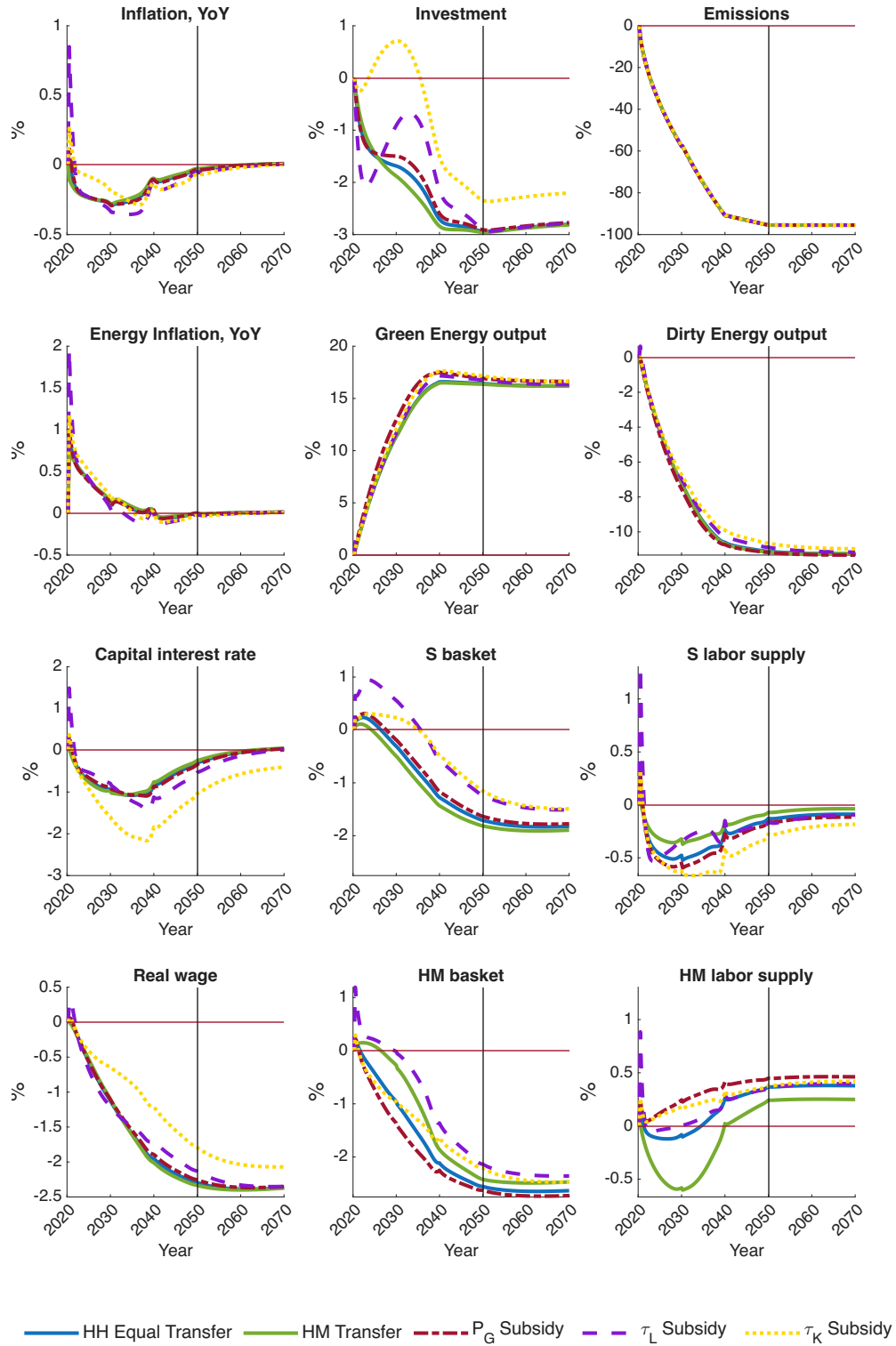
Inequality measures. All revenue recycling policies display some degree of progressivity in income terms. As shown in the right panel of Figure 5, every scheme lowers the Gini coefficient, with the largest decline (about 1 pp) under transfers targeted to HM households. The reduction occurs shortly after the policy is introduced and bottoms out between 2030 and 2040, when carbon tax revenues peak. Turning to consumption inequality (central panel

of Figure 5), only targeted transfers and labor tax cuts deliver a temporary reduction in the consumption gap. In the long run, the gap rises above its initial level in all schemes, by up to 1.4%. Once again, HM-targeted transfers yield the smallest long-run increase in the consumption gap, while green production subsidies and capital income tax cuts are the most regressive on this metric.

The two measures of inequality move in opposite directions for two main reasons. First, the income Gini coefficient captures differences in disposable income but does not account for variations in profits, which affect only Savers and represent an additional form of wealth. Second, Savers can use their savings to adjust consumption over time. By doing so, they are able to consume relatively more than HM households while income inequality narrows.

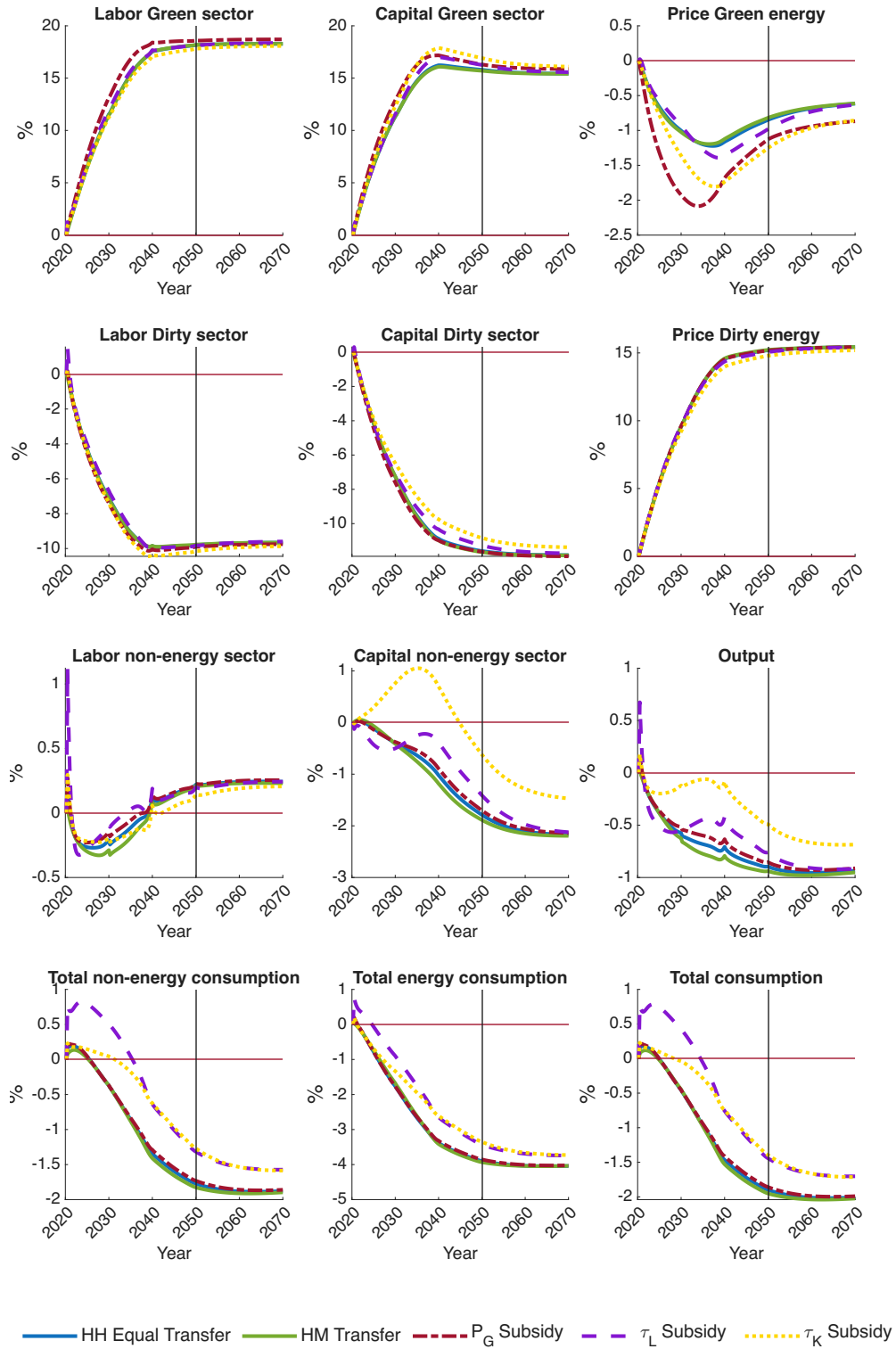
These results reveal a clear output-equity trade-off. Firm subsidies and cuts to labor or capital income taxes deliver smaller declines in GDP, consumption, and investment – implying better aggregate outcomes (as measured by smaller level losses) – but they widen the consumption gap. Direct transfers to households, especially when targeted to HM, are the most progressive but entail larger aggregate level losses.

Figure 6: Macro Dynamics, Transition to Net Zero



Note: variables are percentage deviations from the initial steady state; inflation in annualized net deviations.

Figure 7: Labor and Capital Markets, Transition to Net Zero



Note: variables are percentage deviations from the initial steady state.

4.2 Discussion

After accounting for the differences across revenue recycling schemes, a common pattern emerges. A gradually increasing carbon tax that credibly delivers Net Zero induces a persistent reduction in the level of real GDP: it depresses energy production, consumption, and investment. It is inflationary for the energy component although headline inflation falls below zero in the medium run. It reallocates labor and capital from dirty to green energy. It lowers real wages and has mixed effects on inequality. These outcomes follow directly from model structure and policy design: the baseline excludes green technological progress to isolate direct fiscal incidence; under perfect foresight, agents internalize the entire carbon price path at announcement; higher production costs push down equilibrium wages and the gross rental rate, with heterogeneous labor-supply adjustments by HM and S households.

These findings can be positioned within the broader literature on the macroeconomic and distributional effects of carbon pricing. A first comparison is with Ascari et al. (2025), who adopt a HANK framework with non-homothetic preferences estimated on microdata. Their simulations of a carbon tax achieving a 42.5% renewable share by 2030 point to larger output and wage losses than in my framework, reflecting the absence in their framework of nominal rigidities and the inclusion of green productivity growth. On the inequality side, both approaches highlight the same output-equity trade-off: transfers reduce inequality at the cost of deeper output losses, while subsidies and tax cuts are more efficient but regressive. The qualitative patterns are strikingly consistent.

The results also connect with the empirical evidence of Känzig (2025), who estimates the effects of carbon price shocks on the European economy. He finds a short-run contraction of GDP and a modest increase in consumer prices, with redistributive transfers cushioning the impact on low-income households. My model is consistent with this evidence: it generates a small initial increase in inflation at the policy announcement, followed by persistent deflationary pressures as aggregate demand contracts. Revenue recycling schemes again emerge as crucial in shaping distributional outcomes without altering the path of emissions.

Finally, the contrast with Sahuc et al. (2025) highlights the role of monetary policy. Their global NK framework interprets carbon pricing as a cost-push shock with climate damages lowering both productivity and the natural rate. In this setting, the choice of the monetary policy rule is decisive: a standard Taylor rule yields persistent “greenflation,” while a climate-adjusted rule largely stabilizes inflation. My model, in contrast, delivers long-run deflationary

pressures because the demand contraction dominates, reflecting the taxation of dirty energy and non-energy output, the absence of green TFP growth, and the conservative calibration of damages (with the EU representing only 10 percent of global emissions).¹⁹ Redistribution plays a much more central role here than in Sahuc et al. (2025), highlighting the fiscal rather than monetary dimension of the transition.

These differences also point to some of the limitations of my framework. I treat the EU as a closed economy, so all energy consumed is assumed to be produced domestically. While this overstates the size of the domestic energy sector, it ensures that energy consumption and emission intensity across sectors are coherent with the data. In addition, the new EU Carbon Border Adjustment Mechanism (CBAM) covers electricity imports from non-EU countries, which subjects them to a carbon price equivalent to that of EU domestic production.

In the baseline setting, I also exclude endogenous green technological progress (discussed in Appendix C.1), which likely underestimates the growth potential of the transition. While this is a clear simplification, the effects on inequality remain consistent, with a robust trade-off between aggregate outcome and distributional outcomes across recycling schemes. Beyond consumption habits, I model household heterogeneity along two dimensions only – asset market participation and relative productivity – which prevents a full analysis of wealth inequality. Although household heterogeneity is limited, the model is still able to reproduce the main trade-offs documented in richer HANK settings and in the data, providing clear intuition on the channels at play. Finally, in the baseline framework I assume perfect foresight, abstracting from uncertainty, an assumption that I relax in robustness exercises.

These simplifying assumptions make the model conservative in terms of output costs and distributional impacts. Hence, the results should be interpreted as a conservative benchmark. At the same time, the tractability of the framework is a strength. This makes it particularly suitable for policy analysis where transparency of mechanisms is essential. In the next section, I extend the analysis by exploring robustness to alternative scenarios (see Section 5), including flexible-price versions of the model (as in Ascari et al. (2025)), limited foresight, and alternative abatement cost specifications.

The main findings described here are robust to alternative parameterizations and modeling assumptions. Appendix C reports additional exercises, including endogenous growth of

¹⁹Results are similar in terms of inequality if only the energy sector is taxed, while long-run GDP losses are about 1 percentage point smaller (see Appendix C.2).

green energy productivity, alternative abatement cost elasticities, different shares of Hand-to-Mouth households, and variations in the initial relative productivity of green versus dirty energy (A_G/A_D). While the quantitative magnitude of GDP and inequality effects changes, the qualitative equity–output trade-off remains intact.

5 Alternative Scenarios

5.1 Net Zero Simulation with Limited Foresight

In the baseline, households have perfect foresight: once the carbon policy is announced in $t = 1$ (2020-Q1), they internalize the full path of the carbon tax until 2050 and anticipate the associated income and price dynamics. As a robustness exercise, I also consider a limited foresight scenario. In this case, households learn about the policy step by step. At the initial announcement, they perceive the 2030 target – a 55% emission reduction – as final, meaning the tax will not increase further. Once the 2030 emission-reduction target is reached in $t = 40$, households receive information about the subsequent 2040 target (a 90% reduction by $t = 80$). Finally, once the 2040 target is achieved, they learn about the ultimate 2050 target, corresponding to a 95% reduction in $t = 120$. The rationale behind this assumption is that agents may find short- and medium-term targets credible, reflecting a realistic belief in the authorities’ ability to enforce them. However, they may not internalize the longer-term targets, as these appear too distant. The evolution of carbon tax in euros $\tau_t^\text{€}$ for different time horizons is depicted in Figure 8.²⁰ At the end of the simulation, the carbon price stabilizes around 180 € per ton of CO_2 , in line with EU reports.

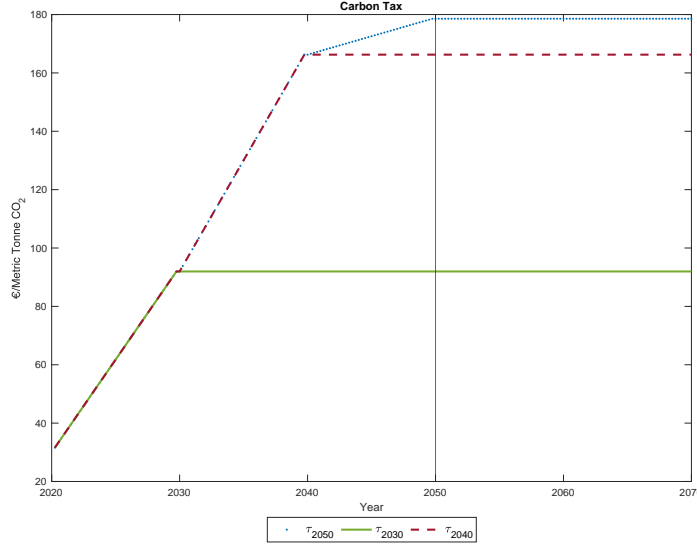
In this scenario, agents base their decisions solely on the next announced emission-reduction target and update them sequentially as new targets are communicated.²¹ This sequential updating generates staggered and more volatile adjustment paths compared to the baseline perfect foresight case.

Figure 9 compares GDP and inequality under the two information structures. Relative to the baseline, limited foresight produces sharper negative spikes in GDP around the an-

²⁰The carbon tax τ_t is expressed in model units. By multiplying it by the ratio of nominal GDP (in euro) to GDP in model units, and converting from carbon to CO_2 units, the implied euro price of CO_2 per metric tonne can be recovered.

²¹The exact timing of when agents correct their expectations (before or during the shock) influences how sharply the economy reacts to the tax changes (τ_Y and τ_D) and how quickly it transitions to the new equilibrium.

Figure 8: Carbon Tax at Different Time Horizons Targets



Note: Energy and Non-Energy Carbon tax expressed in Euros per ton of CO₂.

nouncement dates, while long-run levels remain broadly aligned. Inequality also becomes more volatile: both the Gini coefficient and the consumption gap react more strongly at the 2030 and 2040 announcements, reflecting that redistribution interacts with unexpected income and price shocks. In particular, HM households are more vulnerable to these fluctuations because their energy-intensive consumption baskets make them sensitive to temporary surges in inflation. Additionally, their reliance on labor income means that consumption is closely tied to the volatile labor supply.

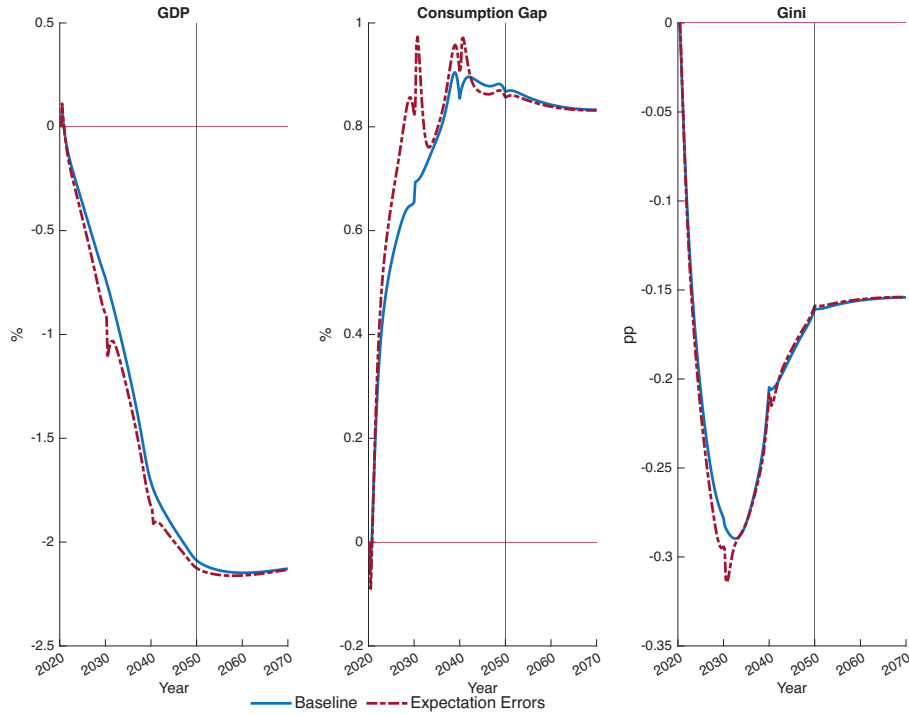
The mechanisms behind these fluctuations differ across household types. During the first phase, Savers sustain consumption above the baseline by cutting investment, since they expect the tax to stabilize and transfers to remain permanent once the 2030 target is reached. When the 2040 target is announced, this belief is corrected abruptly: consumption falls sharply, labor supply contracts, and investment becomes highly volatile. HM households, by contrast, keep consumption closer to the baseline on average, but their labor supply exhibits strong swings at the time of announcements.

Inflation dynamics mirror these patterns. Headline inflation is initially higher than in the baseline because households underestimate the future growth of the carbon tax and therefore expect higher real incomes. When new targets are revealed, beliefs are revised and decisions are adjusted accordingly, producing temporary deflationary shocks. Energy inflation follows a similar path to the baseline but with stronger volatility around announcements. The insta-

bility of labor income, lower investments, and relatively high inflation amplify consumption inequality.

Overall, the limited foresight scenario highlights that credibility and communication of long-run climate policy targets are crucial. Sequential announcements amplify short-run fluctuations in output, inequality, and labor supply, even though long-run outcomes remain close to the baseline.

Figure 9: GDP and Inequality, Baseline vs Limited Foresight



Note: variables expressed as percentage deviation from the initial steady state; inequality measure (Gini) in percentage points deviation.

5.2 Net Zero Simulation with Flexible Prices and Wages

In the absence of nominal frictions (flexible prices and wages), prices adjust more rapidly and the transition path is smoother. Figure 10 compares GDP and inequality between the baseline and the flexible-price model. Relative to the baseline, GDP losses are smaller: by the end of the transition, output is about 0.5% higher. Income inequality, however, is substantially larger in the flexible scenario. Higher wages and faster labor adjustment shift income more unevenly across households, so that the reduction in the Gini coefficient is smaller than under sticky prices. The opposite holds for consumption inequality: with price

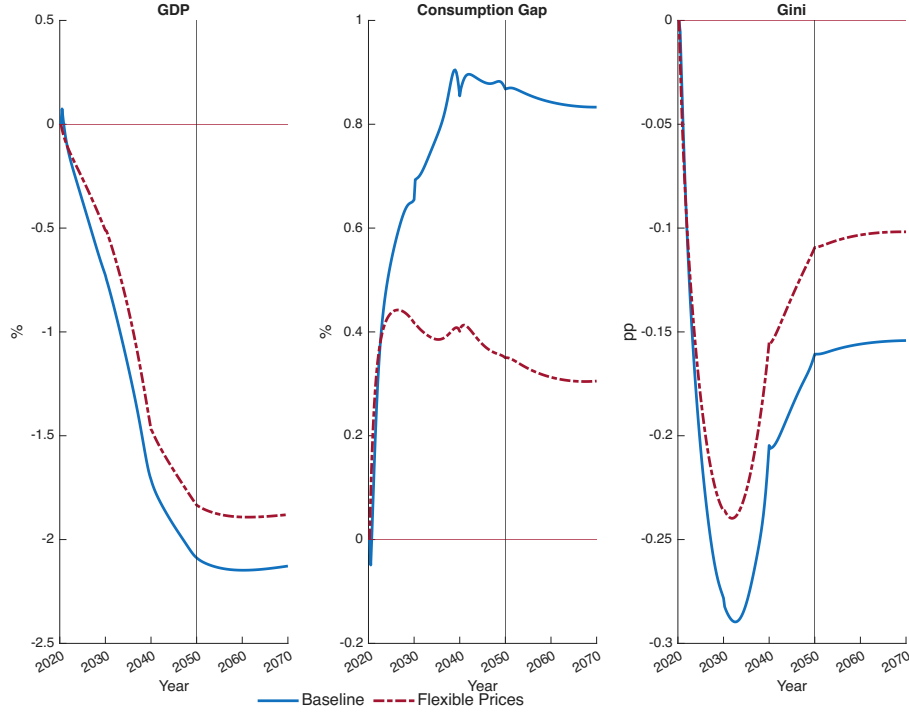
flexibility, lower mark-ups compress firms' profits, reducing the income advantage of Savers and narrowing the consumption gap.

Other macroeconomic dynamics are reported in Appendix Figures B.6-B.7. Energy production is about 1% higher than in the baseline. Inflation also behaves differently: the policy is strongly inflationary in the short run (up to 0.6%), with year-on-year energy inflation peaking at 1.5% and remaining above the baseline until the end of the first phase. Household behavior reflects these changes. HM households sustain relatively higher consumption, while Savers allocate more resources to investment. As a result, investment falls by only 2% – one percentage point less than in the baseline, so the consumption gap remains narrower than with sticky prices. Savers also supply more labor, about 0.2% above the initial steady state by the end of the transition, which contributes to the higher aggregate wage bill and to the lower reduction in income inequality.

Sectoral dynamics also differ. In a flexible-price environment, dirty energy production contracts less than in the baseline. With faster price adjustment, firms can allocate more resources to abatement and adjust more efficiently to the carbon tax. This allows dirty energy to decline less steeply, while green energy continues to expand along the path to Net Zero.

Overall, nominal frictions dampen inflation volatility but impose adjustment costs on both producers (through sticky prices) and workers (through sticky wages). In a fully flexible economy, wages are higher, labor supply expands, and both consumption and investment rise. As a result, output losses are mitigated, but the reduction in inequality is more limited, with a lower reduction in the income Gini, even though the consumption gap is smaller.

Figure 10: GDP and Inequality, Baseline vs Flexible Prices



Note: variables expressed as percentage deviation from the initial steady state; inequality measure (Gini) in percentage points deviation.

5.3 Net Zero Simulation with Equal Abatement Cost for Dirty Energy and Non-energy sectors

Assuming that reducing emissions entails the same cost in both sectors, as in Ferrari and Nispi Landi (2024b) – that is, $\theta_1 = \theta_{y,1}$ – the transition becomes substantially more costly than in the baseline scenario. Figure 11 compares GDP and inequality across the two cases, while Figures B.8 and B.9 in the Appendix report additional macroeconomic dynamics.

The decline in GDP increases dramatically from about 2% in the baseline to nearly 12% in this high-cost scenario. At the same time, inequality reacts more strongly: income inequality falls more sharply because labor income is compressed across households, but the consumption gap widens substantially. Relatively higher firm profits, driven by lower input costs, benefit Savers more, which reduce investments in favor of consumption; while HM households suffer the most from wage cuts. As a result, overall inequality in consumption rises despite the stronger reduction in income inequality.

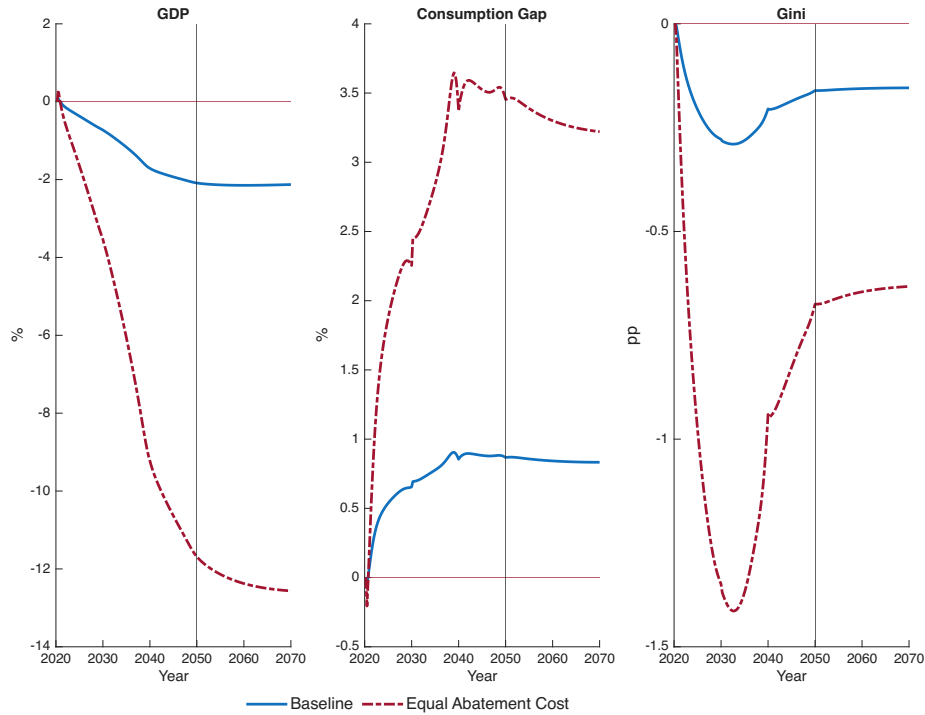
These aggregate patterns are explained by deeper macroeconomic adjustments. Consumption contracts strongly for both household groups (–14% for HM and –11% for Savers),

and investment experiences the steepest drop. Agents anticipate persistently lower wages and returns on capital, which depress demand for both energy and non-energy goods. On the production side, green energy expands by only about 10%, while dirty energy contracts by 20% (Figure B.9). This weaker reallocation reflects the higher abatement burden imposed on the non-energy sector, which absorbs a larger share of resources relative to the baseline.

These demand-side effects also translate into deflationary pressures. The energy component of inflation falls sharply, and headline inflation drops as low as -1.5% around the first intermediate target before gradually returning toward zero by the end of the horizon (Figure B.8). Wages decline permanently, stabilizing roughly 15% below the initial steady state, while the return on capital falls by 7% before recovering only at the end of the transition. Given these persistent income losses, Savers reallocate expenditure from investment to consumption, further weakening capital accumulation.

Overall, these results are consistent with the findings of Ferrari and Nispi Landi (2024b), but the assumption of equal abatement costs across sectors implies an unrealistically steep decline in GDP. While informative as a robustness check, such a calibration likely overstates the macroeconomic costs of the transition.

Figure 11: GDP and Inequality, Baseline vs Equal Abatement Cost



Note: variables expressed as percentage deviation from the initial steady state; inequality measure (Gini) in percentage points deviation.

6 Conclusion

In this paper I develop a Two-agent New Keynesian Environmental DSGE model with disaggregated energy and non-energy sectors to analyze the EU’s transition to Net Zero under a gradually rising carbon tax. Five revenue recycling schemes are compared: household transfers (equal or targeted), subsidies to green firms, and cuts to labor and capital income taxes. Three main conclusions emerge.

First, in the absence of technological progress, the transition entails a persistent output loss of about 2% of GDP. Consumption, investment, and real wages decline, while resources reallocate toward green energy. Energy prices rise persistently and stabilize around 2040, implying sustained energy inflation until then. Headline inflation, however, falls below zero in the medium term, as anticipated income cuts reduce demand. Income tax reductions mitigate the contraction and briefly raise output, but at the cost of temporary inflationary pressures.

Second, distributional outcomes differ across recycling schemes. While all policies reduce income inequality to some degree, the consumption gap worsens in the long run. Targeted transfers to Hand-to-Mouth households deliver the strongest redistributive gains, but also the weakest macroeconomic outcome. Subsidies and capital tax cuts mitigate output losses but are comparatively regressive, as they increase profits and capital income accruing to Savers.

Third, the information structure – perfect versus limited foresight – is central to the short and medium-run dynamics of the transition. With limited foresight, sequential announcements of intermediate emission-reduction targets generate sharp fluctuations in GDP, consumption, and inflation around announcement dates, even though long-run outcomes remain close to the baseline. This highlights the importance of credibility and communication in climate policy.

Overall, the results show that recycling mechanisms create a trade-off between macroeconomic stabilization and distributional fairness. Policymakers face the choice between measures that are less contractionary but provide weaker distributional relief, and more progressive schemes that come with higher macroeconomic costs. Technology can ease this tension: scenarios with green productivity growth (Appendix C.1) show smaller output losses in the short/medium term and more favorable distributional outcomes, but the trade-off is not eliminated.

Relative to existing approaches, the framework combines household heterogeneity, sectoral disaggregation, and nominal rigidities in a tractable long-run DSGE setting. This allows for a unified analysis of the macroeconomic and distributional implications of carbon pricing, complementing richer HANK models (e.g. Ascari et al. (2025)) and global NK frameworks (e.g. Sahuc et al. (2025)). By linking policy design and the timing of information disclosure to transition dynamics, the paper contributes both methodologically and substantively to the literature on the macroeconomics of the Net Zero transition.

Future work could extend the framework by incorporating endogenous technological change, border adjustments, and richer monetary-fiscal interactions to provide a more comprehensive assessment of Europe's path to Net Zero. The results suggest that transparent communication of long-term climate targets and careful design of revenue recycling schemes are essential for sustaining public support for Net Zero.

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Appendix

A Nominal Frictions: Price and Wage Rigidities

The baseline model features monopolistic competition, sticky prices, and sticky wages. For brevity, I show only the equations for the non-energy sector, as the equations for the energy intermediate producers follow the same logic.

I define the non-energy goods y as an aggregation of intermediate inputs $y(i)$ produced by a continuum of monopolistically competitive firms indexed with i , with constant elasticity of substitution:

$$y_t = \left(\int_0^1 (y_t(i))^{\frac{\xi_t-1}{\xi_t}} di \right)^{\frac{\xi_t}{\xi_t-1}}. \quad (\text{A.1})$$

where ξ_t is the elasticity of substitution parameter and y_t is the Dixit-Stiglitz aggregator (Dixit & Stiglitz, 1977). Nominal price rigidities are modeled by introducing quadratic adjustment costs $AC_t^P(i)$ à la Rotemberg (1983), which intermediate non-energy firms pay when adjusting their price with respect to the inflation target:

$$AC_t^P(i) = \frac{\phi_p}{2} \left(\frac{P_{y,t}(i)}{P_{y,t-1}(i)} - \bar{\pi} \right)^2 y_t P_{y,t}. \quad (\text{A.2})$$

where ϕ_p is an adjustment cost parameter.

From the FOC with respect to price $P_{y,t}(i)$, I obtain the non-energy goods Phillips curve²²:

$$\begin{aligned} \pi_{y,t} (\pi_{y,t} - \bar{\pi}) = & \beta \mathbb{E}_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{y_{t+1}}{y_t} \pi_{y,t+1} (\pi_{y,t+1} - \bar{\pi}) \right] \\ & + \frac{\xi_t}{\phi_p} \left[mc_{y,t} - \frac{\xi_t - 1}{\xi_t} + \tau_{y,t} (1 - \mu_{y,t}) \gamma_y + \theta_{1,y} \mu_{y,t}^{\theta_2} \right], \end{aligned} \quad (\text{A.3})$$

The inflation level for HM and S price index and the headline inflation π_t are as follows

$$\pi_{HM,t} = \pi_{y,t} \frac{p_{HM,t}}{p_{HM,t-1}} \quad (\text{A.4})$$

$$\pi_{S,t} = \pi_{y,t} \frac{p_{S,t}}{p_{S,t-1}} \quad (\text{A.5})$$

$$\pi_t = \pi_{HM,t}^\Delta \pi_{S,t}^{1-\Delta}. \quad (\text{A.6})$$

²²In the green energy Phillips curve, the marginal cost variable is reduced by the variable $\mathcal{T}_{pG,t}$ to account for the subsidy to green energy production.

Individual labor supply varieties are aggregated using the Dixit-Stiglitz function.

$$\ell_{j,t} = \left(\int_0^1 (\ell_{j,t}(i))^{\frac{\xi_W-1}{\xi_W}} di \right)^{\frac{\xi_W}{\xi_W-1}}, \quad \text{and} \quad j \in \{HM, S\}. \quad (\text{A.7})$$

where ξ_W is the elasticity of substitution between individual labor supply. The latter is defined as a function of individual to aggregate wage share

$$\ell_{j,t}(i) = \left(\frac{W_{j,t}(i)}{W_{j,t}} \right)^{-\xi_W} \ell_{j,t}, \quad (\text{A.8})$$

such that the aggregate intermediate wage reads

$$W_{j,t} = \left(\int_0^1 W_{j,t}(i)^{1-\xi_W} di \right)^{\frac{1}{1-\xi_W}}. \quad (\text{A.9})$$

Again I introduce sectoral nominal wage rigidity in the form of quadratic adjustment costs à la Rotemberg:

$$AC_{j,t}^W(i) = \frac{\phi_W}{2} \left(\frac{W_{j,t}(i)}{W_{j,t-1}(i)} - \bar{\pi} \right)^2 \ell_{j,t} W_{j,t}, \quad (\text{A.10})$$

which is added to the left-hand side of the budget constraint of both households (2 and 4). Here ϕ_W represents the nominal wage adjustment cost parameter. Households' utility maximization problem yields the following new FOC with respect to $w_t^j(i)$:

$$mrs_{j,t} = \frac{\psi_j \ell_{j,t}^{\varphi_1}}{\lambda_{j,t}(1 - \tau_L)} \quad (\text{A.11})$$

$$\begin{aligned} \pi_{j,t}^W (\pi_{j,t}^W - \bar{\pi}) = & \beta \frac{\lambda_{j,t+1}}{\lambda_{j,t}} \frac{\ell_{j,t+1}}{\ell_{j,t}} \frac{w_{j,t+1}}{w_{j,t}} \pi_{j,t+1}^W (\pi_{j,t+1}^W - \bar{\pi}) \\ & + \frac{\xi_W}{\phi_W} (1 - \tau_L) \left(\frac{mrs_{j,t}}{w_{j,t}} - \frac{\xi_W - 1}{\xi_W} \right), \end{aligned} \quad (\text{A.12})$$

where:

$$\begin{aligned} \pi_{j,t}^W &= \frac{W_{j,t}}{W_{j,t-1}} \\ &= \frac{W_{j,t}}{p_t} \frac{p_t}{p_{t-1}} \frac{p_{t-1}}{W_{j,t-1}} \\ &= \frac{w_{j,t}}{w_{j,t-1}} \pi_{y,t}. \end{aligned} \quad (\text{A.13})$$

and $mrs_{j,t}$ is the inverse of the marginal rate of substitution between consumption and leisure; $\pi_{j,t}^W$ is the household j wage inflation.

B Additional figures: Model comparisons

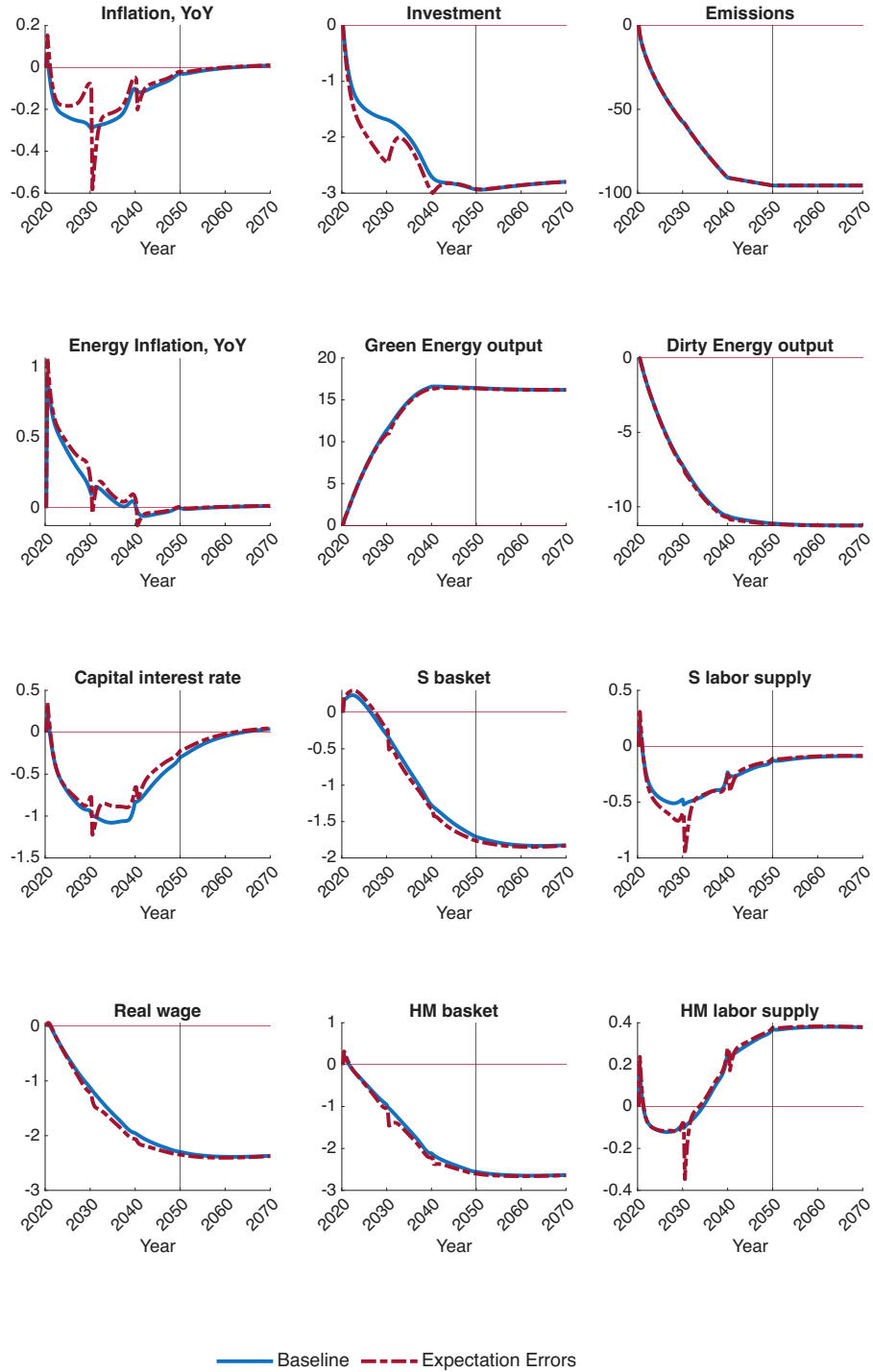
B.1 Limited Foresight

This section reports additional dynamics for the limited foresight scenario.

Figure B.1 reports the dynamics of consumption, investment, labor supply, and inflation under limited foresight relative to the baseline. During the first phase of the transition, Savers maintain higher consumption by cutting back on investment, while HM households keep their consumption path broadly aligned with the baseline. However, both groups show sharp swings in labor supply at the time of announcements, which amplifies volatility in income and inequality. Inflation dynamics follow a similar pattern: headline inflation is initially higher when households underestimate the long-run tax path, but it drops abruptly once new targets are revealed, producing short-lived deflationary shocks. Energy inflation remains broadly in line with the baseline but is more volatile around announcement dates.

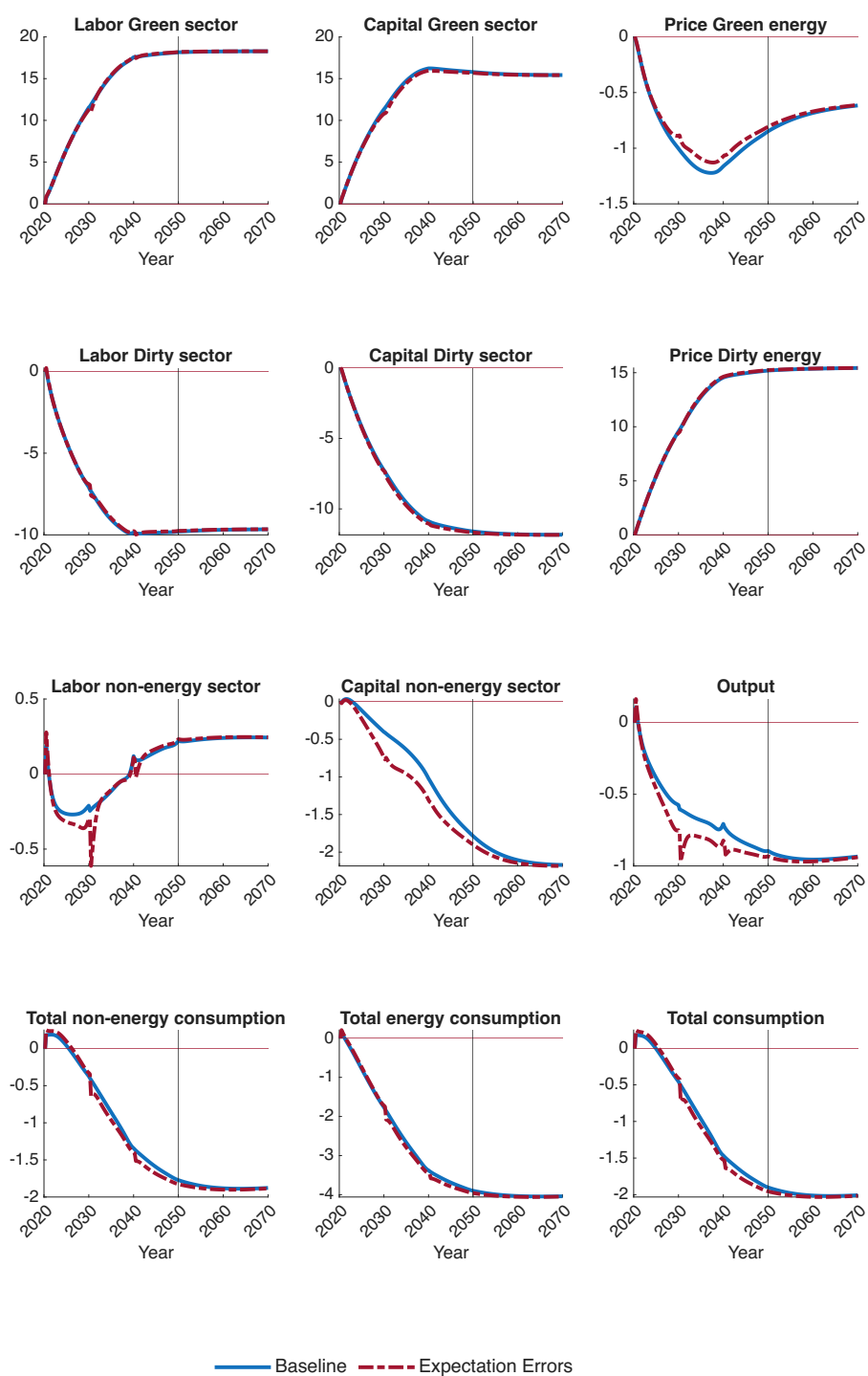
Figure B.2 shows that the reallocation of labor and capital across sectors is largely unaffected by the information structure: dirty energy declines and green energy expands in both scenarios, with no significant difference in long-run sectoral shares.

Figure B.1: Macro Dynamics, Baseline vs Limited Foresight



Note: variables expressed as percentage deviation from the initial steady state; inflation expressed in annualized net level deviation.

Figure B.2: Labor and Capital Markets, Baseline vs Limited Foresight



Note: labor variables expressed as percentage deviation from the initial steady state.

B.2 Stochastic Shock

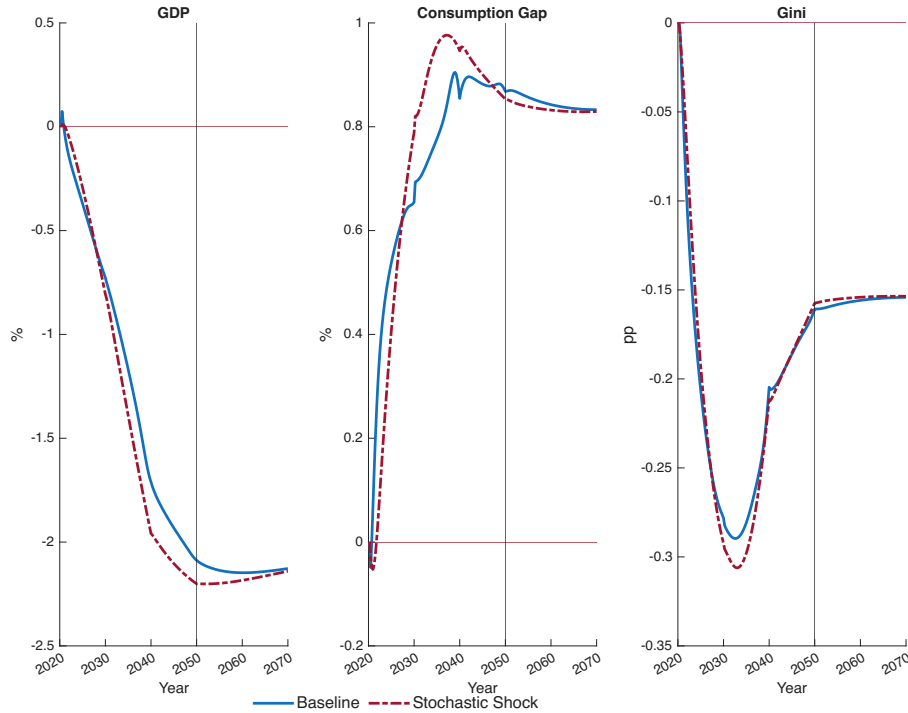
What if agents ignore the Net Zero policy and view the tax increase as a new, permanent shock each period? Unlike the scenario with few and limited foresight, there are no sudden, sharp changes in prices and other macroeconomic variables in this scenario. Instead, changes are smooth. For example, investments show a steady, almost linear decline, leading to a 3% total reduction in 2040 and a consequent reduction in GDP (see Figure B.3).

Energy inflation, on the other hand, remains more sustained because agents do not expect changes to the emissions tax over time. The policy remains only slightly deflationary in the medium term, as the demand effect still dominates, but to a lesser extent.

Consumption by households remains relatively high in the short and medium terms due to unexpected (increasing) government subsidies (see Figure B.4). Consumption gap is smaller in the first decade but worsens after 2030 as tax growth accelerates (Figure B.3).

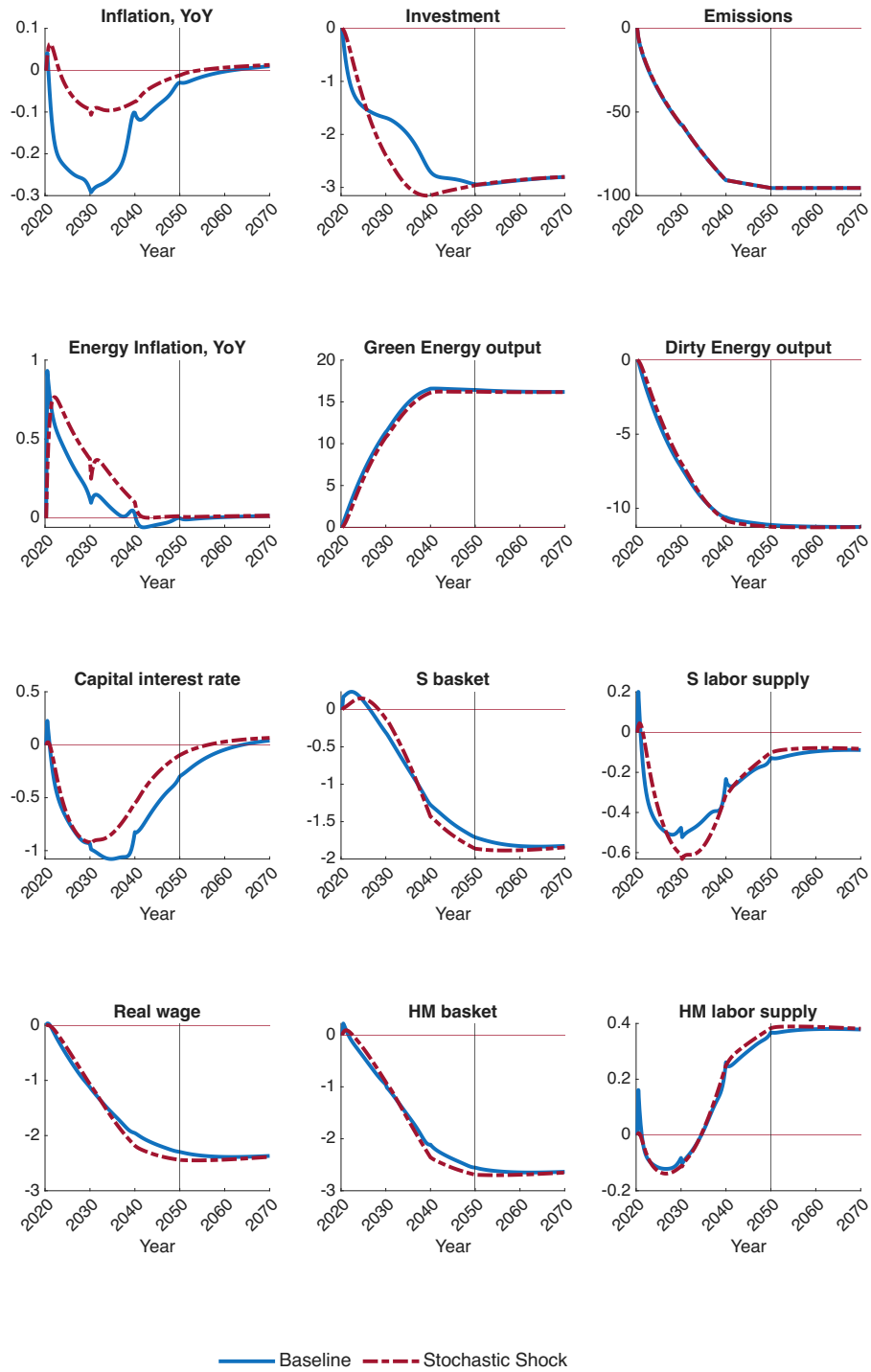
Inputs reallocation across sectors is again unaffected by the limits in agents' foresight ability (Figure B.5).

Figure B.3: GDP and Inequality, Baseline vs Stochastic Transition



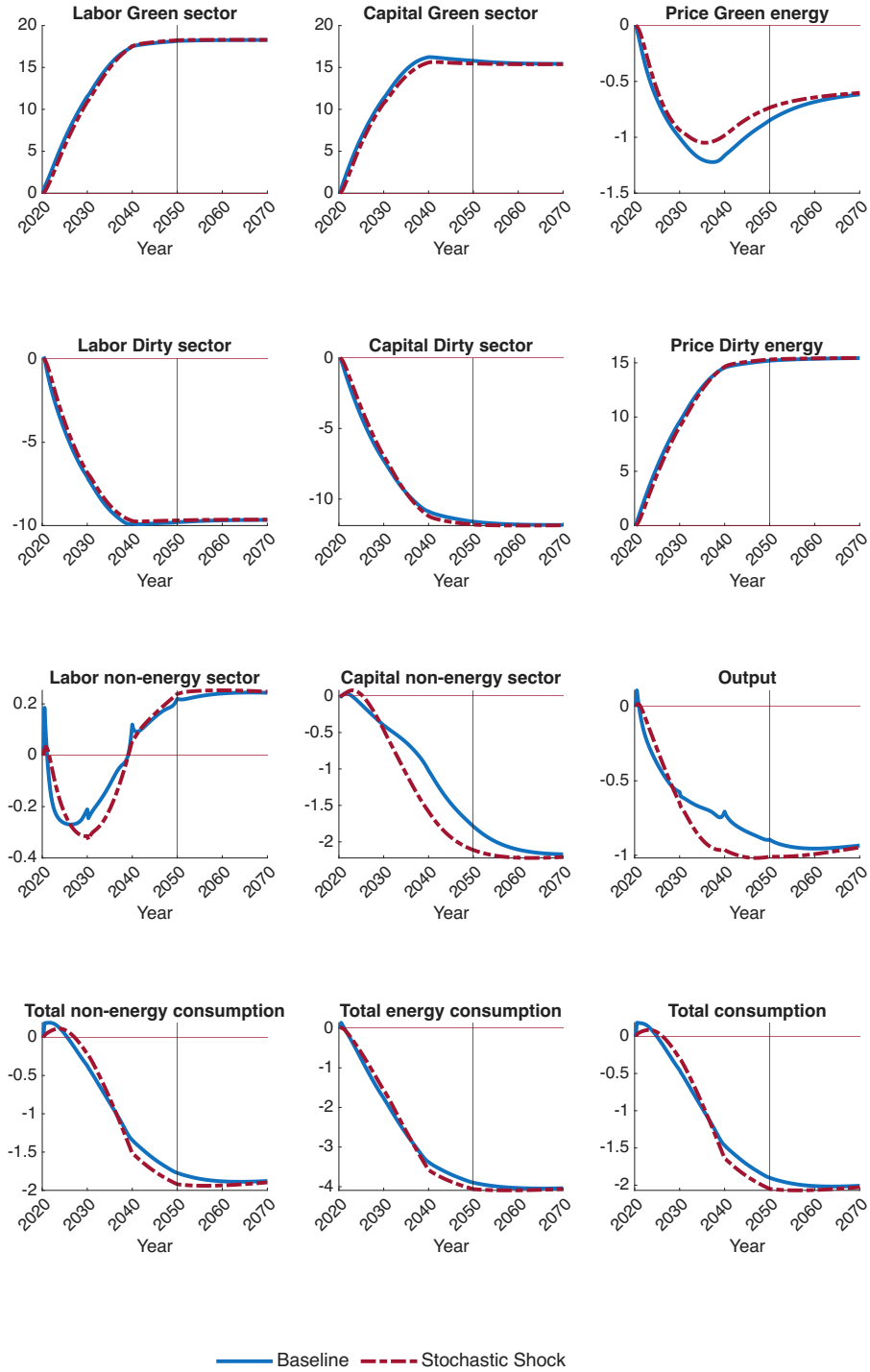
Note: variables expressed as percentage deviation from the initial steady state; inequality measure (Gini) in percentage points deviation.

Figure B.4: Macro Dynamics, Baseline vs Stochastic Transition



Note: variables expressed as percentage deviation from the initial steady state; inflation expressed in annualized net level deviation.

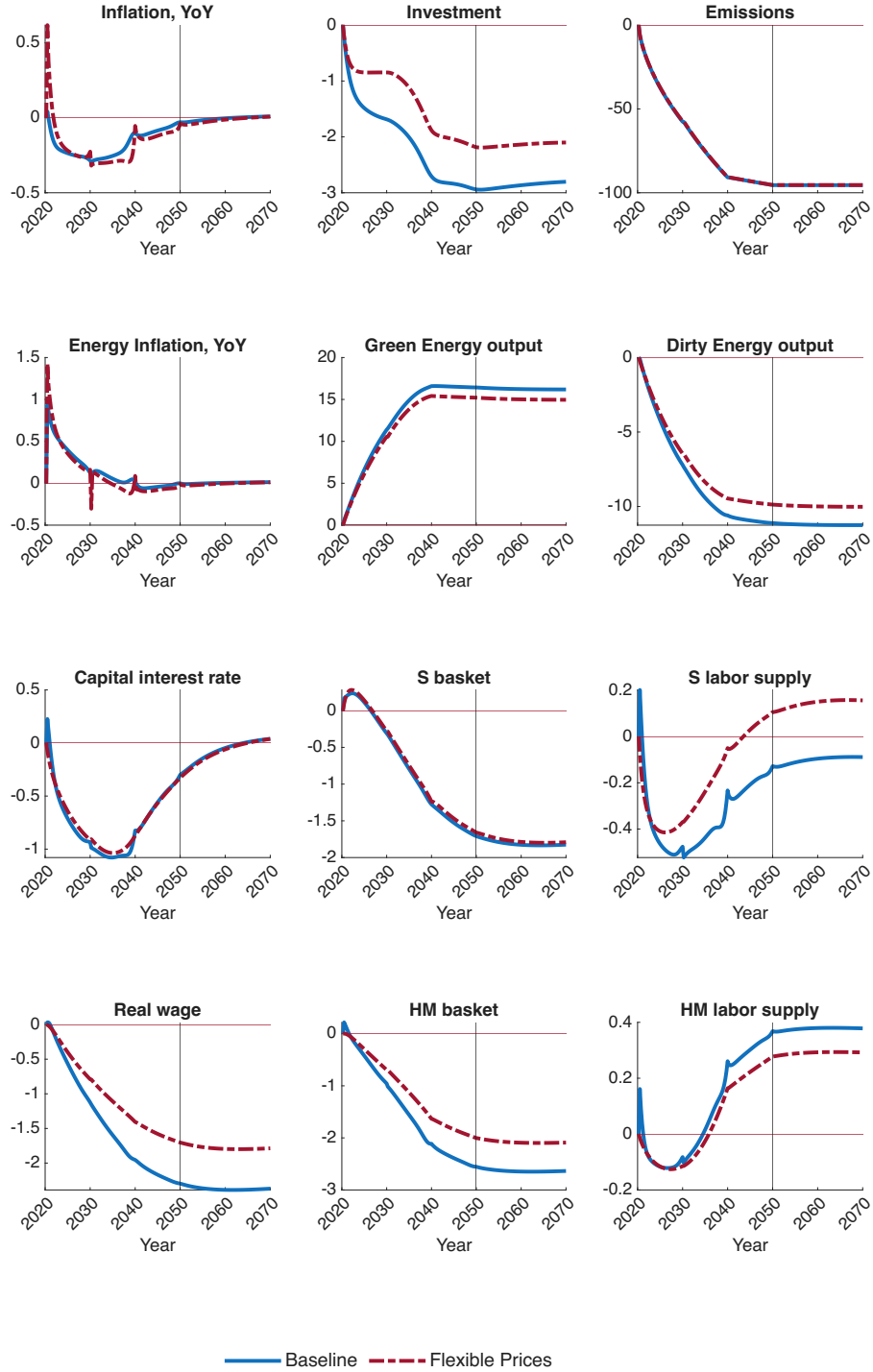
Figure B.5: Labor and Capital Markets, Baseline vs Stochastic Transition



Note: labor variables expressed as percentage deviation from the initial steady state.

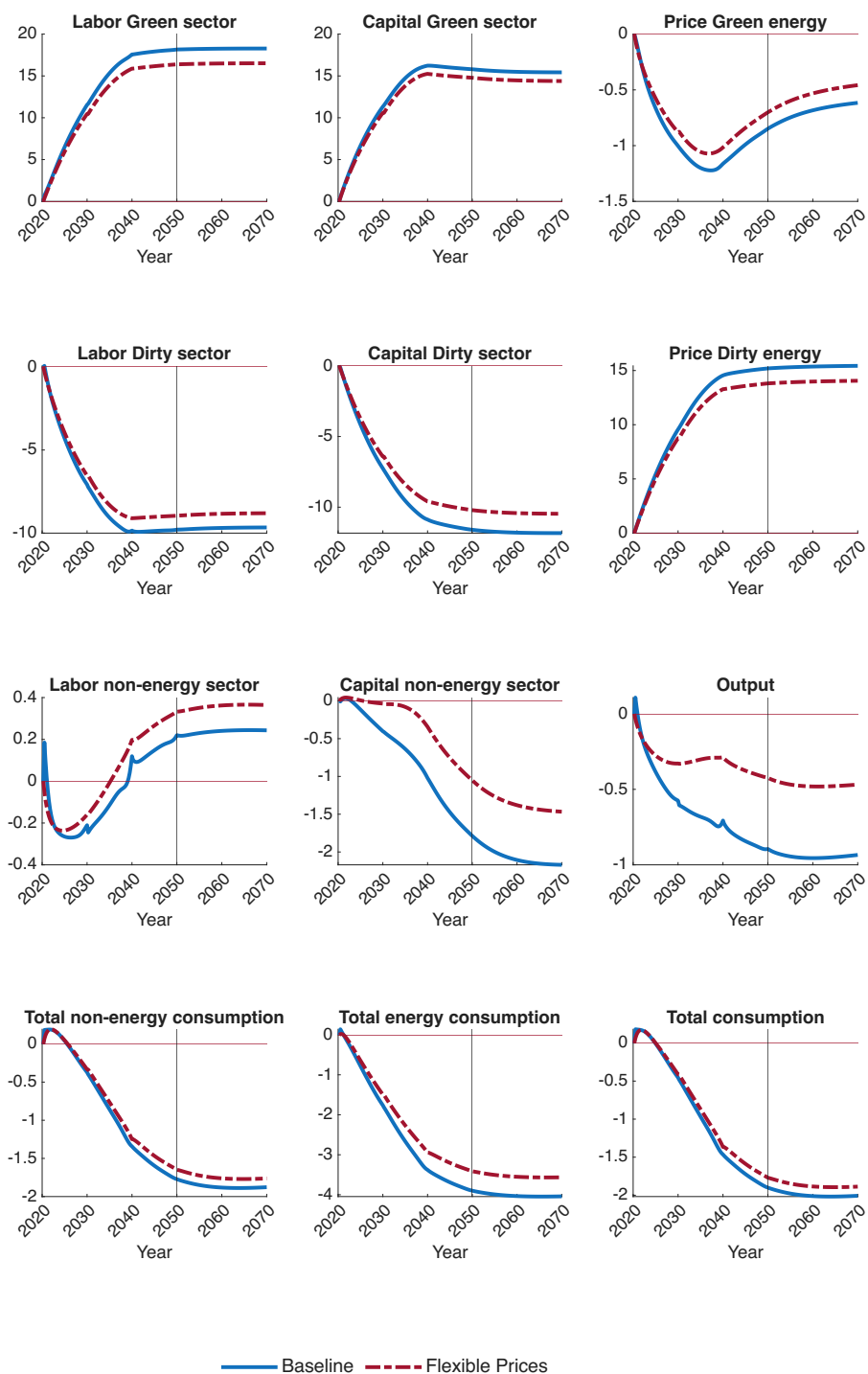
B.3 Flexible Prices

Figure B.6: Macro Dynamics, Baseline vs Flexible Prices



Note: variables expressed as percentage deviation from the initial steady state; inflation expressed in annualized net level deviation.

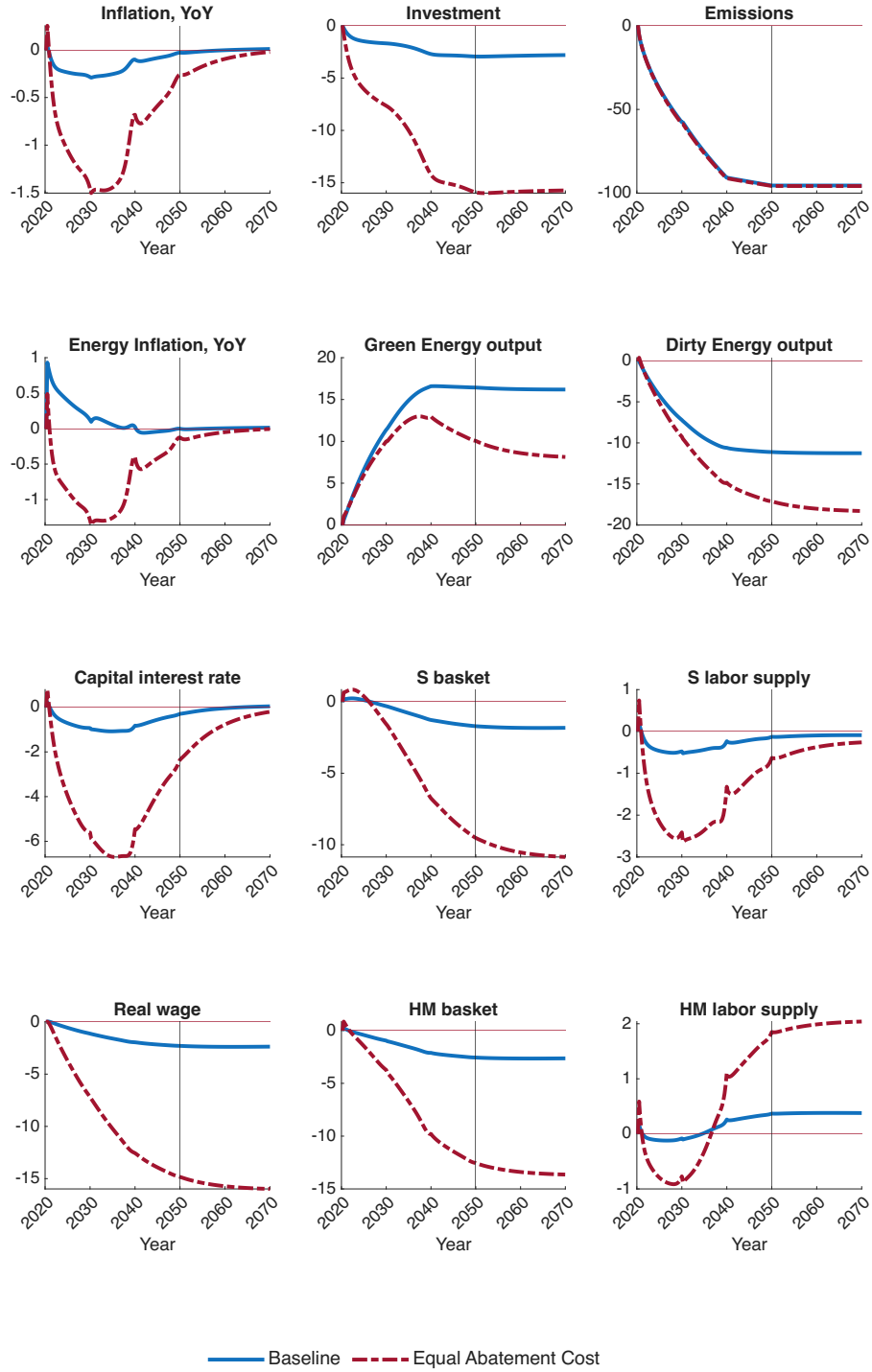
Figure B.7: Labor and Capital Markets, Baseline vs Flexible Prices



Note: labor variables expressed as percentage deviation from the initial steady state.

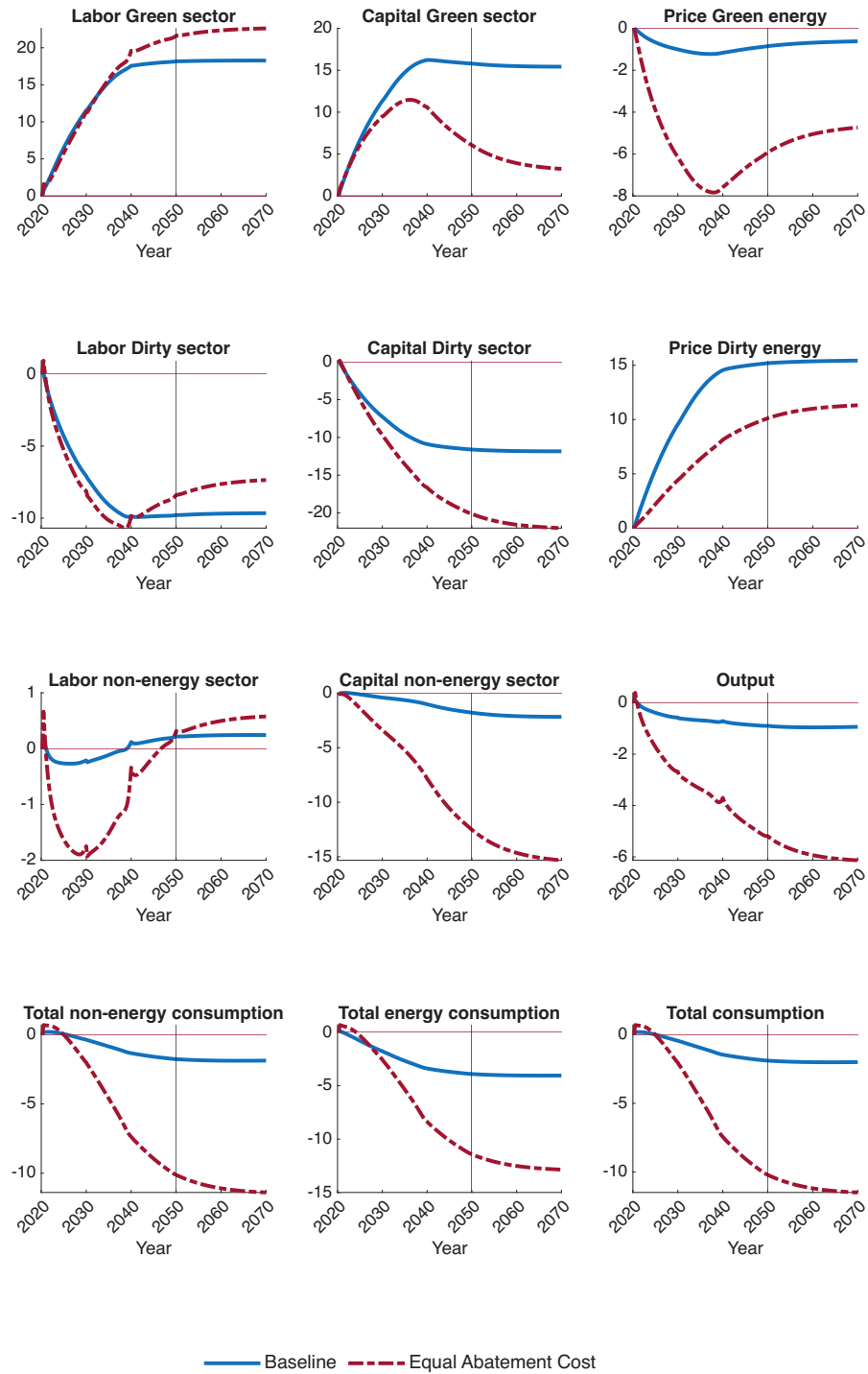
B.4 Equal Abatement Cost

Figure B.8: Macro Dynamics, Baseline vs Equal Abatement Cost



Note: variables expressed as percentage deviation from the initial steady state; inflation expressed in annualized net level deviation.

Figure B.9: Labor and Capital Markets, Baseline vs Equal Abatement Cost



Note: variables expressed as percentage deviation from the initial steady state.

C Robustness Checks

This appendix reports robustness exercises for selected parameters and assumptions. The objective is to verify that the main results – the trade-off between equity and macroeconomic outcome – are not sensitive to specific calibration choices. All simulations are performed under the same Net Zero policy described in the main text.

C.1 Exogenous Green Technology Growth

As discussed in Section 4, the baseline abstracts from endogenous growth in green energy productivity. Here I assume that green technology A_G grows linearly at 2% per year until 2050, consistent with empirical estimates. Figures C.10-C.12 report the dynamics under this assumption. As anticipated in the main text, the macroeconomic costs of the transition are substantially reduced. Output losses are roughly halved relative to the baseline (from about 2% to 0.6% below steady state), and positive spillovers from the expanding green sector eventually push GDP above its initial steady state after the 2050 target is reached. This improvement is partly due to the dynamics of TFP, which continues to rise as the pollution stock declines and environmental damages are mitigated. As in the baseline, GDP is highest under income tax cut scenarios, and in these cases it never falls below its pre-policy level.

Turning to inequality, Figure C.10 shows that the stronger expansion of the green sector alleviates consumption disparities. Income inequality remains broadly unaffected, with targeted transfers still generating the largest reduction in the Gini coefficient. The consumption gap, however, narrows across all revenue recycling schemes. Although it increases temporarily in the medium term (except under targeted transfers), it eventually falls up to 0.5% below the steady state.

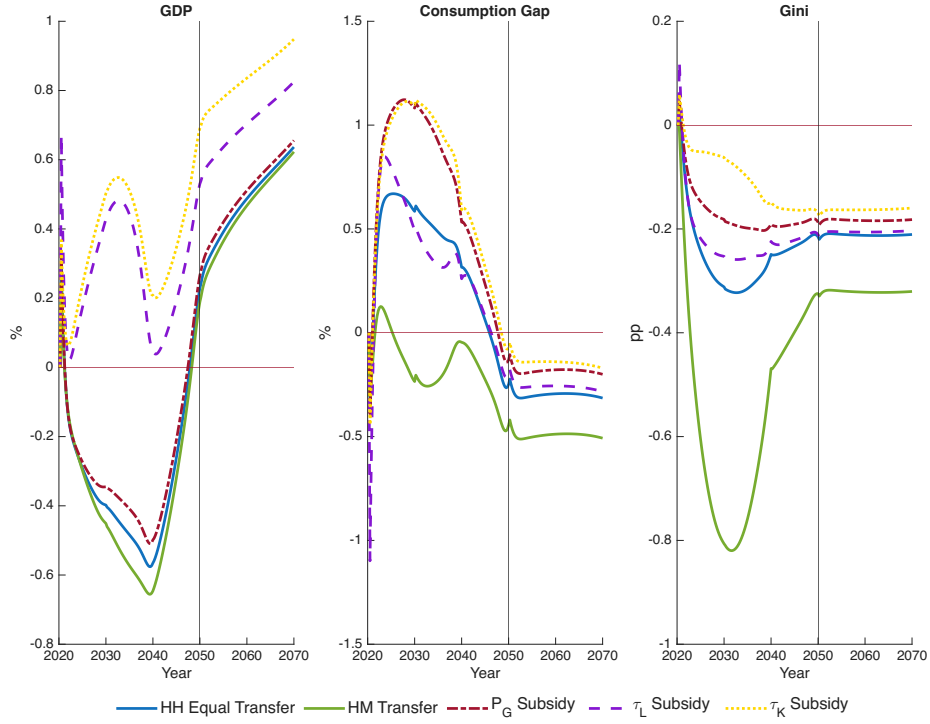
The tension between growth and distribution therefore remains, though in a milder form. Targeted transfers are still the most progressive, yet they deliver relatively slower growth compared with subsidies or tax cuts. Conversely, subsidies and tax cuts are less contractionary; while they can be temporarily regressive in the short to medium run, their long-run distributional profile becomes non-regressive under green growth, as both the Gini and the consumption gap decline below initial levels once productivity gains fully materialize.

Total green energy production nearly doubles over the transition (+160% in 30 years). Both household types increase consumption under all revenue recycling schemes and, in the long run, reduce labor supply slightly. The policy becomes inflationary: headline inflation

risers in the short run (peaking at about +1.5%) and stays around or above zero over most of the transition (see Figure C.11).

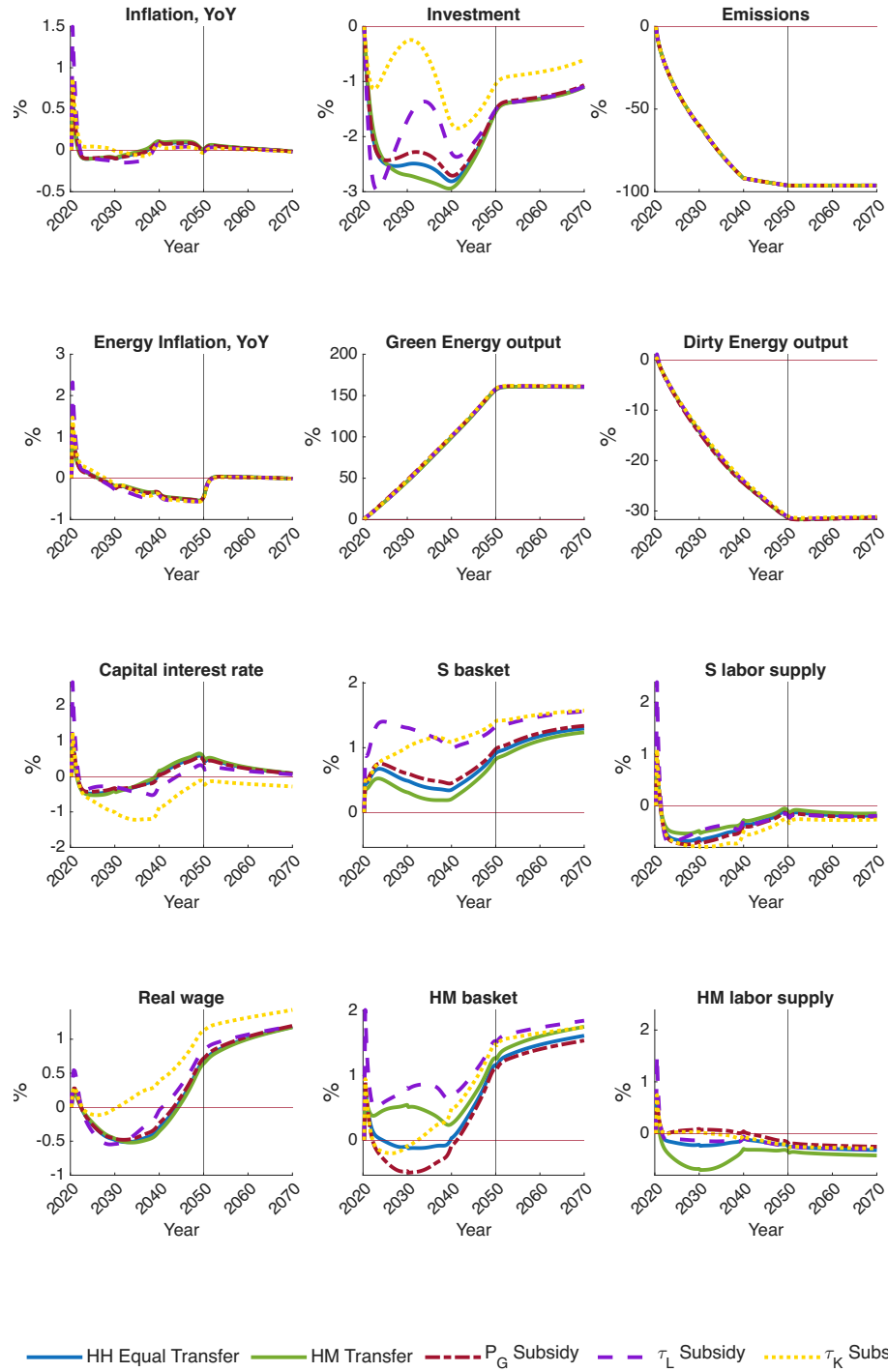
By contrast, energy inflation turns temporarily negative in the medium term, as technological progress reduces the relative price of green energy (see Figure C.11).

Figure C.10: GDP and Inequality with Green TFP Growth



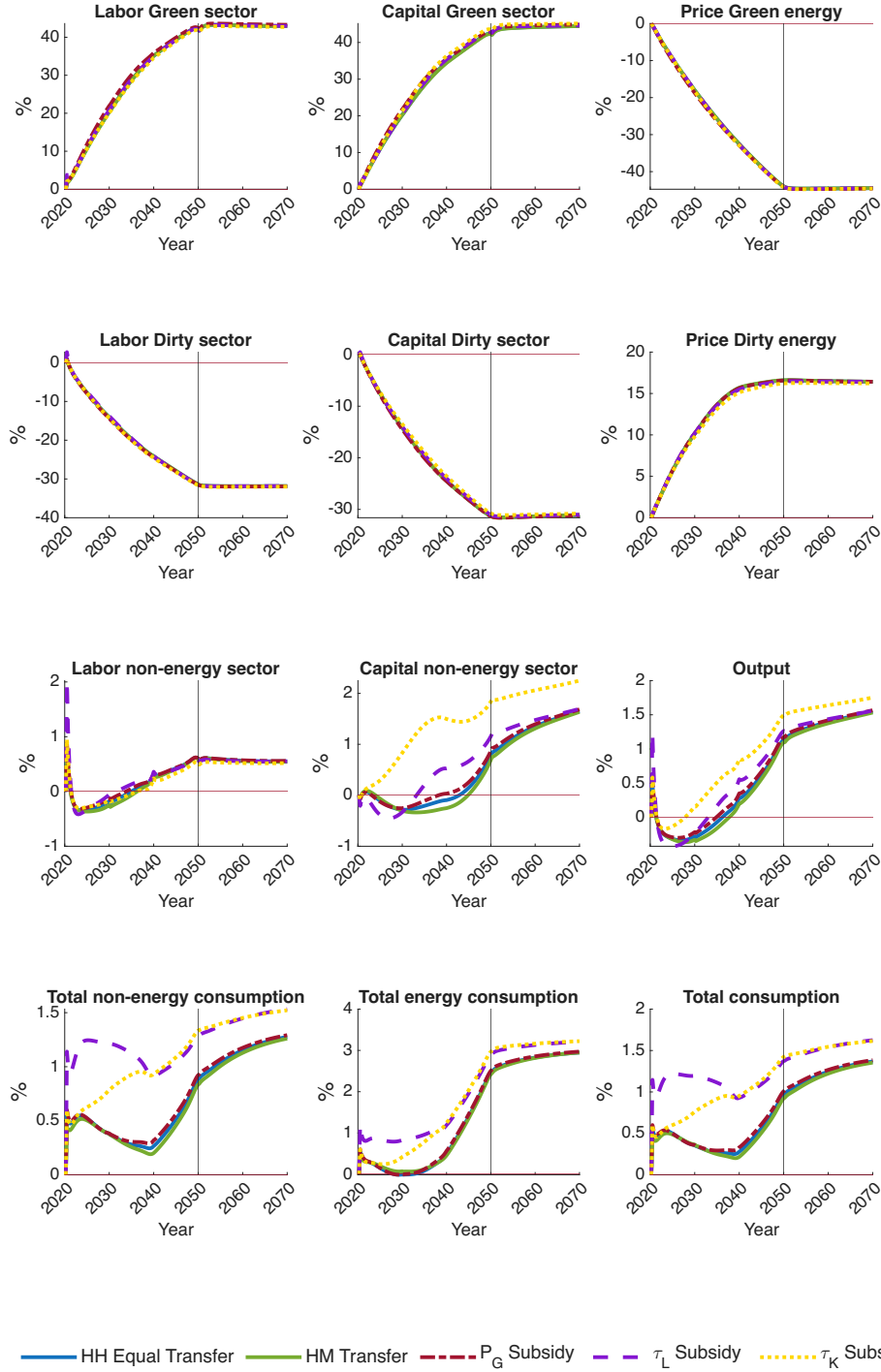
Note: variables expressed as percentage deviation from the initial steady state.

Figure C.11: Macro Dynamics with Green TFP Growth



Note: variables expressed as percentage deviation from the initial steady state.

Figure C.12: Labor, Capital and Emissions with Green TFP Growth

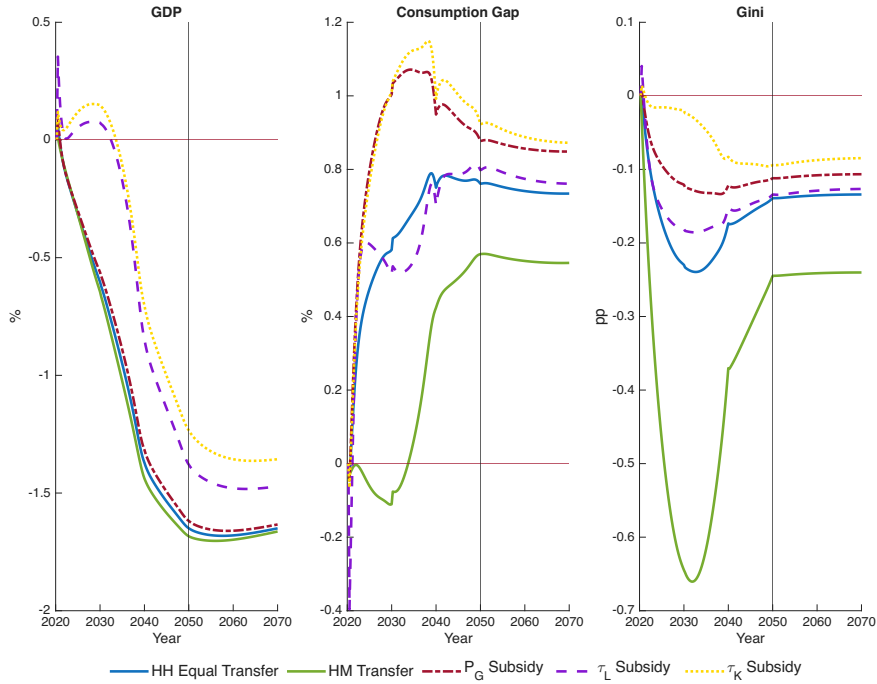


Note: variables expressed as percentage deviation from the initial steady state.

C.2 Dirty Energy Emissions Only

In the main simulation, both non-energy and dirty energy producers generate emissions, though with different intensities. Accordingly, both sectors are subject to carbon taxation. For non-energy firms, this can be interpreted as the cost associated with regulatory standards and production requirements embedded in the EU Net Zero framework. As a robustness exercise, I restrict carbon taxation to the energy sector only and report the results in Figure C.13. In this case, the reduction in GDP is about 1 percentage point smaller, while inequality measures remain virtually unchanged. Importantly, the relative ranking of revenue recycling schemes in terms of both inequality and macroeconomic outcome is unaffected. This suggests that taxing non-energy emissions mainly affects the overall magnitude of GDP losses, while leaving the distributional patterns across households essentially unchanged.

Figure C.13: Robustness to $em_y = 0$

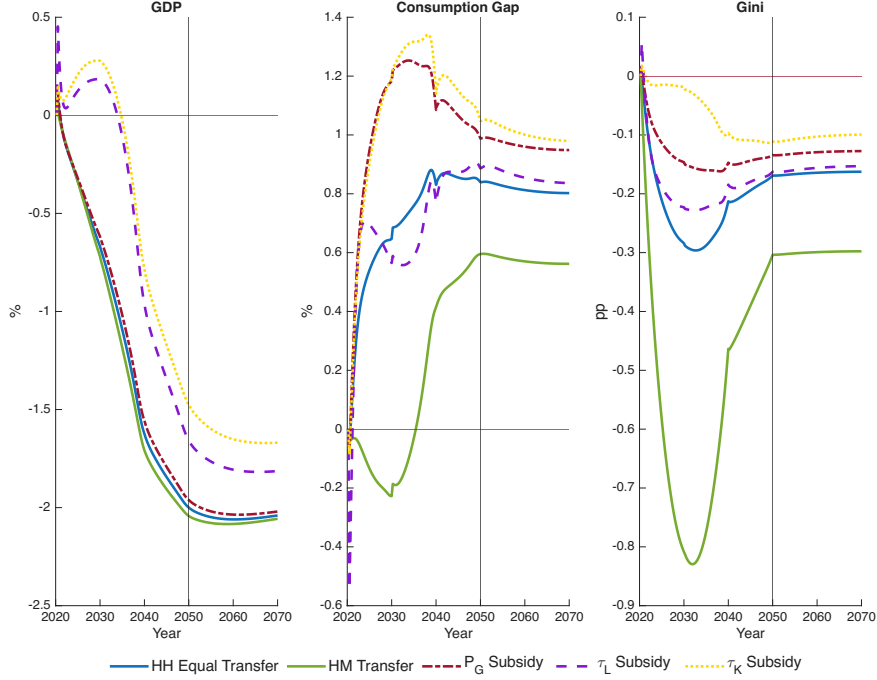


C.3 Equal Energy Consumption Elasticity

In the baseline, the elasticity of substitution between non-energy and energy goods differs across households: Savers have a higher elasticity than HM agents, consistent with the literature (Känzig, 2025). As a robustness check, I consider an alternative scenario in which both groups share the same elasticity, set to $\epsilon_{HM} = \epsilon_S = 0.5$. Results (Figure C.14) confirm that the scale of output losses and inequality, as well as the qualitative ranking of revenue recy-

clinging schemes, remain unchanged. This suggests that income heterogeneity and differences in energy expenditure shares – particularly the larger role of energy in HM consumption – dominate over elasticity differences in shaping the inequality dynamics.

Figure C.14: Robustness to $\epsilon_S = \epsilon_S$



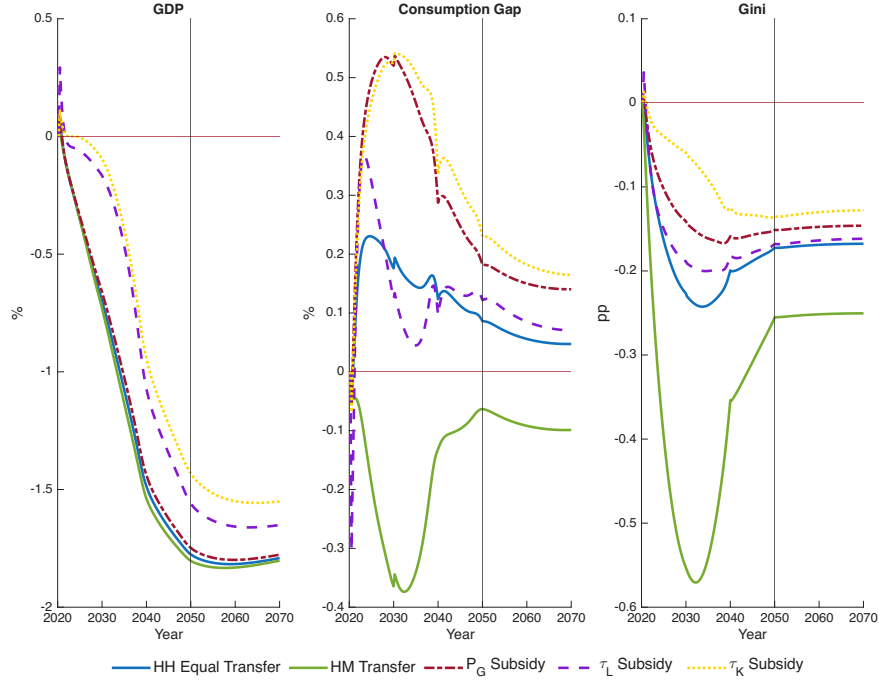
C.4 High Value-Added and Energy Substitutability

In the baseline, the elasticity of substitution between value added and energy in the non-energy production function is set below unity, following the empirical estimates of van der Werf (2008). As a robustness check, I consider a higher elasticity $\xi_y > 1$, implying good substitutability between inputs. Results (Figure C.15) show that output losses are sensitive to this parameter: GDP is about 0.5 percentage points higher compared to the baseline. Distributional outcomes also improve relative to the baseline: the consumption gap narrows under all revenue recycling schemes, with targeted transfers remaining the most progressive. Other schemes remain more regressive in the short and medium run, but the degree of regressivity is reduced compared to the baseline.

This reflects the fact that when non-energy production can more easily substitute away from energy, the economy experiences less pressure on labor and consumer prices. Wages are relatively higher, and inflationary dynamics are milder. By contrast, the return on capital improves less, as dirty energy contracts more strongly and this sector is more capital inten-

sive. Overall, higher substitutability mitigates both aggregate and distributional costs of the transition, although the relative ranking of revenue recycling schemes remains unchanged.

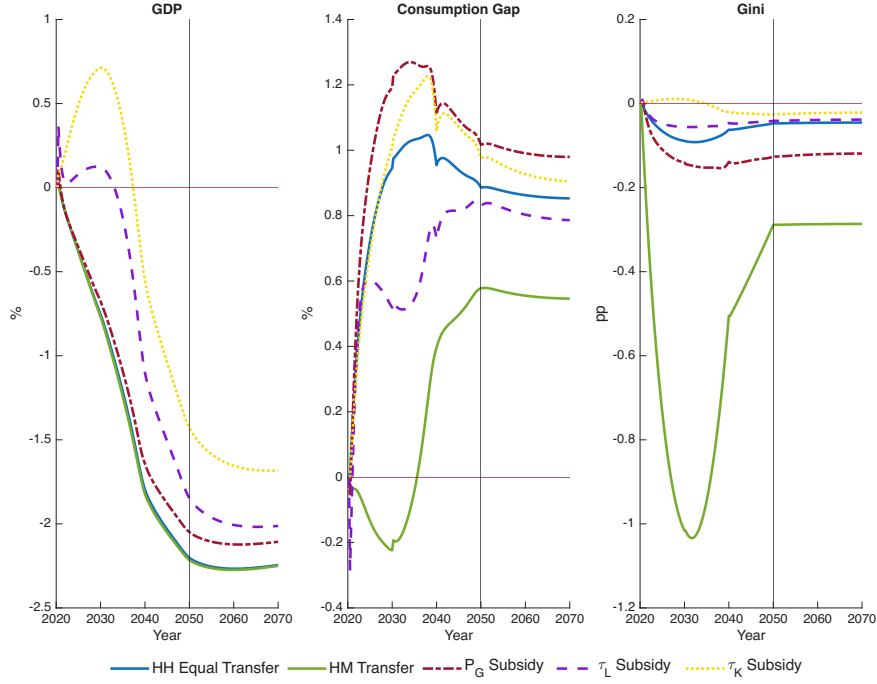
Figure C.15: Robustness to high ξ_y



C.5 Household Share Δ

The baseline assumes that 40% of households are Hand-to-Mouth, corresponding to the bottom two income quintiles in EU-SILC data. As a robustness check, I consider a lower share of $\Delta = 10\%$ (Figure C.16). With fewer liquidity-constrained households, distributional effects are attenuated: both the reduction in inequality and the expansion of the consumption gap are smaller than in the baseline. Aggregate macroeconomic outcome also improves slightly, especially under firm subsidies and capital income tax cuts, where higher saving capacity among households helps sustain investment and output. This confirms that the magnitude of distributional trade-offs is strongly linked to the prevalence of liquidity constraints in the population. In other words, reducing the share of HM households not only weakens distributional tensions but also improves the capacity of the economy to absorb the shock and smooth consumption, resulting in smaller output losses.

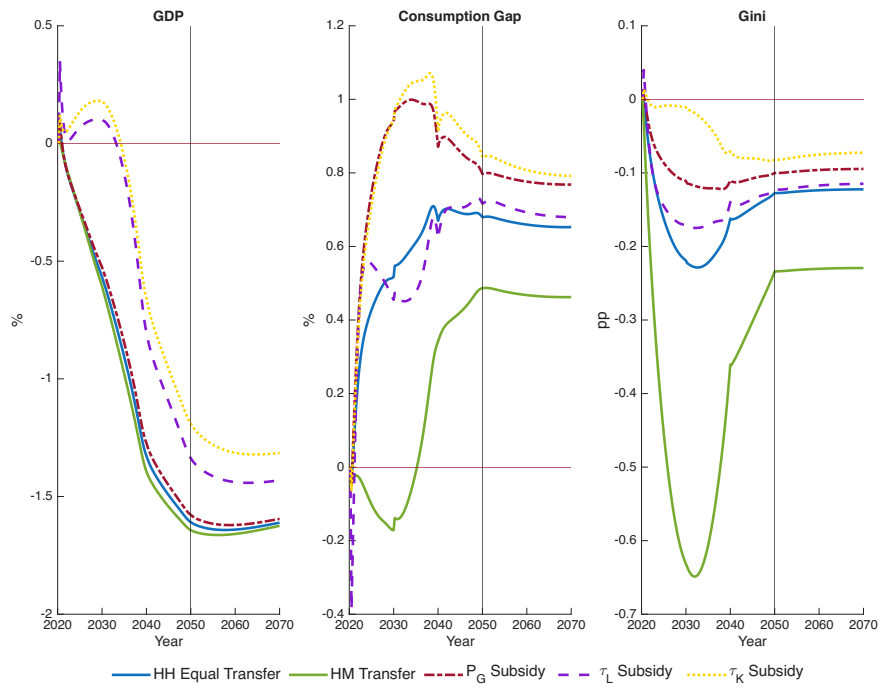
Figure C.16: Robustness to low HM Household Share Δ



C.6 Initial Technology Ratio A_G/A_D

Finally, I vary the initial ratio of green to dirty energy productivity, which determines the relative price p_G/p_D . In one case, green energy starts twice as productive as dirty energy ($A_G = 2A_D$). A higher initial competitiveness of green energy reduces GDP losses and inflation volatility, since the transition requires less reallocation across sectors. Conversely, if green energy starts less productive, GDP falls more and inequality widens, as households are more exposed to higher dirty energy prices. Figure C.17 illustrates the main dynamics. In terms of inequality, results remain robust: the relative ranking of revenue recycling schemes is unchanged. What changes is mainly the degree of sectoral reallocation, with a lower weight of dirty energy reducing the overall cost of the transition. This exercise is complementary to the green growth scenario discussed in Appendix C.1: while that case considers technological progress over time, here the focus is on the relative starting point of sectoral productivity. The baseline assumption of a relatively low A_G/A_D , although in line with the empirical literature, is therefore conservative, as it amplifies the macroeconomic costs of the transition.

Figure C.17: Robustness to High Initial Technology Ratio A_G/A_D



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