Distributional Consequences of Climate Policies*

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Abstract

Policies to support the transition to a carbon-neutral economy are high on the policy agenda, and their effectiveness and distributional consequences are actively debated. One reason for this is that quantitative answers regarding the reduction-redistribution trade-offs of such policies remain limited. This paper makes two contributions to the discussion. First, we empirically show that infrequently adjusted consumption goods, i.e. consumption commitment goods such as cars or heating systems, together with their complementary consumption (gas, oil), account for more than 35 percent of household carbon emissions. Second, we develop a quantitative life-cycle model with heterogeneous adoption rates of carbon-neutral commitment goods by income to quantify the reduction-redistribution trade-off of different policy mixes. Since rich households emit more, policies targeting their adjustment of commitment consumption are most effective in reducing total carbon emissions. Heterogeneous adoption rates imply that, on the financing side, most policies will redistribute from a majority of poorer households to high-income households. Votes on the implementation of these climate policies will then not find a majority. Our results show that a percentage subsidy financed by a progressive income tax yields a combination of rapid emission reductions with positive net transfers for a majority of households.

Keywords: Climate change, Inequality, Tax and Transfer policies, Commitment Consumption

JEL: E21, H23

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1 Introduction

Policies to slow climate change are high on the political agenda of governments around the world. With two-thirds of total carbon emissions coming from household consumption, household consumption is at the center of the discussion on how to reduce carbon emissions. A wide range of climate taxes and subsidies have been proposed to increase the uptake of modern, carbon-neutral consumer goods. However, a key question in times of high inequality is whether such policies will have adverse distributional consequences and can find majorities among the electorate. So far, quantitative answers are scarce. The aim of this paper is to fill this gap by providing a quantitative analysis of different tax and transfer policies in terms of their reduction-redistribution trade-off.

As a first step, we use rich consumption data from the German Income and Consumption Survey (*Einkommens- und Verbrauchsstichprobe*, EVS) together with the EXIOBASE dataset, which provides information on the amount of carbon emissions produced by different consumption goods. Combining these two sources, we show that long-term consumption commitments, such as cars and heating systems, and their complements, such as gasoline and oil, are key to reducing carbon emissions. They generate more than 35 percent of total household carbon emissions while accounting for only about 10 percent of household expenditures. We also confirm the empirical finding that high-income households have significantly higher carbon footprints than low-income households. This fact creates a policy trade-off between speeding up the reduction of carbon emissions through subsidies and the distributional consequences of such subsidies. A policy aimed at rapid reduction must be attractive to high-income households, which in turn implies that its financing will lead to transfers from low-income to high-income households. The redistribution can be further exacerbated during the transition period as high-income households are faster in adopting new carbon-neutral technologies, so that they receive subsidies earlier and would pay less carbon taxes if used for financing. To assess and quantify this reduction-redistribution trade-off, we build in the second step a quantitative life-cycle model with consumption commitments that can be either old, e.g. traditional gasoline- or diesel-powered cars or oil heaters, or modern and carbon neutral, e.g. electric cars or heat pumps. Using the calibrated model, we evaluate different subsidy policies, percentage and lump sum subsidies for modern commitment goods, in combination with different financing schemes, taxes on labor income, consumption taxes, or carbon taxes. We compare these different policies in terms of how quickly the adjustment process to modern commitment goods takes place and what their distributional consequences are in terms of net transfers between low to high income households. We take these distributional consequences to determine if a policy mix will find political support or if the climate policy would fail in the political process.

We calibrate our model to Germany in 2018 and study the adoption process of modern consumption commitment goods over time. We demonstrate that the model matches average consumption pattern for commitment consumption, saving behavior by income groups over the life-cycle, and importantly the available evidence on heterogeneity in adoption rates between high- and low-income households. Starting in 2024, we implement different policy mixes and compare the consequences for the adoption process compared to a situation with no climate policy. We always compare transition paths 25 years into the future and impose that each policy mix must have a balanced budget for the current population over the transition path, so that subsidies for modern commitment goods must be financed by taxes. Comparing the transition paths for different policy mixes, we find that a policy with a percentage subsidy on the modern commitment good increases the speed of adoption and generates a majority of winners if it is financed by a progressive income tax. Non-progressive taxes redistribute from a majority of low-income households to high-income households, with the worst distributional consequences of a carbon tax that is falling disproportionately on low-income households as they are slowest in adopting the modern commitment good. The quantitative effects in terms of redistribution across policy mixes are substantial. The policy that combines a percentage subsidy on modern commitment goods with a carbon tax reduces emissions the most, but leads to negative net transfers for low-income households of up to 600 euros per year and net transfers for high-income households of up to 900 euros per year. A less redistributive policy combining a lump-sum subsidy for modern commitment goods with a linear income tax leads to positive net transfers for the majority of households in today's economy, but at the cost of almost 20 percent less reduction in carbon emissions at the end of the transition period. The percentage subsidy financed by a progressive tax will lead to one out of five households adopting the modern carbon-neutral technology at the end of the transition period compared to less than one out ouf ten households without any climate policy. Importantly, the progressive financing will avoid net transfers from low-income to high-income households and will therefore lead to a majority of households supporting this policy. A policy that is popular in the public debate combines a carbon tax with transfer payments to counteract redistributive effects. When we compare this policy to the other policy mixes with explicit subsidies, we find that it yields similar distributional outcomes as the progressive tax financing but leads to an order of magnitude smaller reduction of carbon emissions.

This paper contributes to three strands of literature. First, we contribute to the literature on consumption commitments, building on Chetty and Szeidl (2007) and Chetty and Szeidl (2016). Chetty and Szeidl (2007) show that, on the one hand, consumption commitments increase the welfare costs of moderate-sized shocks, as households only adjust non-committed consumption, such as food, while, on the other hand, they create a motive to take large gambles, as households are willing to adjust their committed consumption after large shocks. Chetty and Szeidl (2016) compare models of commitment consumption with those of habit formation. They show that the empirical finding of excessive sensitivity and excessive smoothness of consumption disappearing after large shocks is only consistent with models of consumption commitment. Other papers have examined the impact of commitment goods on wage rigidities (Postlewaite et al., 2008), housing consumption (Shore and Sinai, 2010), marriage behavior (Santos and Weiss, 2016), and unemployment insurance (Segovia, 2021). We contribute by first documenting as a novel fact that consumption commitments are highly carbon-intensive and thus key to the study of policies to reduce carbon emissions. Second, we contribute by developing a quantitative life-cycle model to study the effectiveness and redistributive consequences of different climate policies with consumption commitments.

Second, there is a large literature measuring environmental footprints for different countries and subgroups (Duarte et al., 2012; Hardadi et al., 2021; Isaksen and Narbel, 2017; Kerkhof et al., 2008; Miehe et al., 2016; Perobelli et al., 2015; Wiedenhofer et al., 2017). A key finding of this literature is that carbon emissions increase along the income distribution. Most important for our work is Hardadi et al. (2021). We rely on their approach of linking consumption categories and emissions data to compute carbon footprints. Relative to the literature, we add the distinction between commitment and non-commitment consumption and document that consumption commitments and their complements contribute a substantial share to household emissions. We evaluate the consequences and trade-offs of this heterogeneity for policy.

Finally, there are several studies that assess the distributional consequences of carbon pricing. An overview of the empirical literature is provided by Ohlendorf et al. (2021). Känzig (2021) examines this question using institutional features of the EU ETS and high-frequency data. In particular, he shows that poor households are more affected by increases in carbon taxes than richer ones. Glaeser et al. (2022) shows that gasoline taxes are regressive and are likely to become even more so in the future as richer households buy more electric cars. Fried et al. (2018) evaluates the distributional effects of a carbon tax on households living in a current and a future steady state in a general equilibrium life-cycle model calibrated to the US. They find that the optimal policy differs substantially between the two groups as the former prefers uniform, lump-sum rebates, while for the latter reducing existing distortionary taxes is optimal. Relatedly, Fried et al. (2022) study the question of the optimal return of carbon tax revenues to households from an efficiency perspective. They find that using two-thirds of the carbon tax revenues to reduce the distortionary tax on capital income is welfare-maximizing. Related to our work in terms of economic mechanism is Lanteri and Rampini (2023) who study the adoption of clean technologies by heterogeneous firms and find that clean technologies require larger down payments, leading financially constrained, smaller firms to optimally invest in dirtier and older capital than unconstrained, larger firms. We contribute to this literature in two ways. First, we highlight the role of consumption commitments for household carbon emissions. Second, we explicitly account for consumption commitments and differences in adjustment patterns across households when studying a rich set of policy mixes combining different subsidies and financing instruments.

The remainder of the paper is structured as follows. In Section 2, we describe the data for the empirical analysis and present our empirical results. In Section 3, we introduce the structural model, describe the calibration, and discuss the model fit. In Section 4, we conduct the policy experiments and quantify the reduction-redistribution tradeoff. Section 5 concludes.

2 Data and empirical results

For our analysis, we combine data from two different sources to study the distribution of carbon emissions at the household level. First, we use the German Income and Consumption Survey (*Einkommens- und Verbrauchsstichprobe*, EVS). The EVS data provide repeated cross sections on consumption expenditures of households similar to the U.S. *Consumer and Expenditure Survey* (CEX). The EVS provides detailed information on around 43,000 households (0.1% of the German households) and sample weights allow to construct representative statistics for the entire German population. It is collected every five years and is used as the source for the consumption basket of the German CPI. We employ the most recent wave with data from 2018. The information in the EVS goes beyond other consumption surveys as it provides jointly information on household consumption, income, wealth, and socioeconomic variables.

As a second data source, we use the EXIOBASE v3.6 in order to quantify the carbon emissions generated by different consumption goods. This dataset is compiled from multi-regional input-output tables and differentiates between 44 countries and five rest of the world regions, 163 industries, and 200 products.[1] We consider total emissions of consumption as the sum of direct emissions, e.g. emissions from driving a car, and indirect emissions, e.g. emissions from transporting a banana from South America to Germany (Hardadi et al., 2021). For direct emissions, we take aggregate emissions data from the German Statistical Office and distribute them to households based on their consumption expenditures. For indirect emissions, we follow Hardadi et al. (2021) and impute carbon emissions to consumption expenditures by linking the consumption categories of the EVS to those of the EXIOBASE. Our imputation differs from Hardadi et al. (2021) in two minor dimensions. First, they estimate carbon footprints for an average household and at at the group level for eleven income groups. We impute carbon emissions of consumption at the household level which allows for a flexible aggregation of households. Second, they correct for expenditure underreporting in the EVS data. We also report results corrected for expenditure underreporting as robustness but find differences to be negligible for our analysis. We therefore abstain from this adjustment in our baseline analysis.

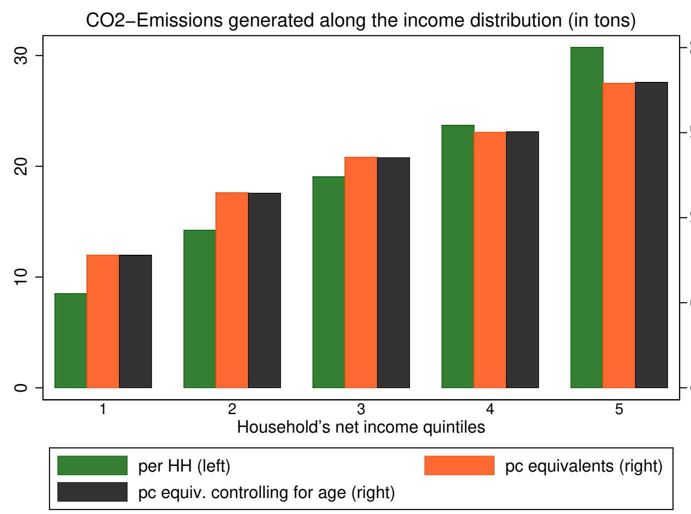
We will rely on the EVS 2018 data as our main data for the empirical analysis and for calibrating the model. In addition, we will use data from the *RWI-GRECS: German Residential Energy Consumption Survey*, short GRECS, when calibrating the model.[2]

[1] For more information see Stadler et al. (2018).

[2] The GRECS data are provided by the RWI – Leibniz-Institut für Wirtschaftsforschung. For more information see RWI and Forsa (2015).

In our empirical analysis, we distinguish between commitment and other consumption goods. This concept of consumption commitments was studied in a series of papers by Chetty and Szeidl (Chetty and Szeidl (2007); Chetty and Szeidl (2016)). While their definition includes shelter, cars (excluding gas and maintenance), apparel, furniture, appliances, and health insurance, we depart from this definition in two ways. First, we focus on those consumption commitments which are mostly affected by climate policies, for example, cars, heating systems, and large appliances. Second, we add the complements of these consumption goods, like gasoline for cars and natural gas or oil for heating systems to commitment consumption. This definition captures that households need to consume a certain amount of these complements in order to make use of the commitment good itself. Specifically, we consider the expenditure for consumption commitments with carbon emissions including cars, motor bikes, fuels, gas, liquid fuels, coal, wood, and other solid fuels and large appliances.

Figure 1: Household's annual carbon emissions along the income distribution (in tons)



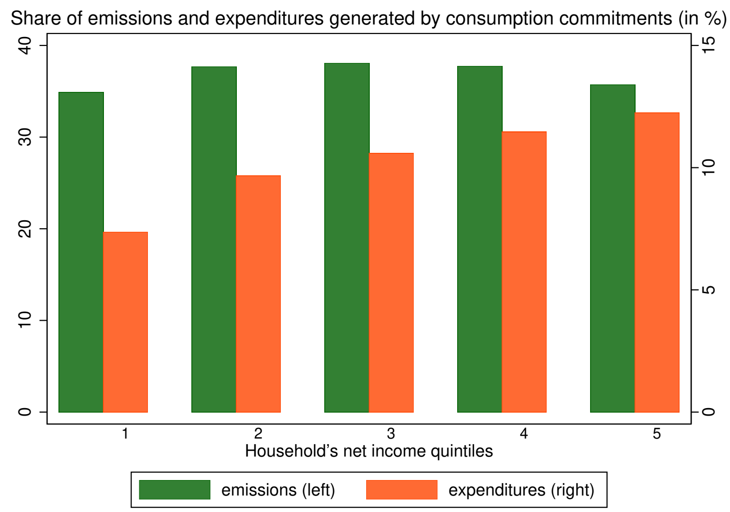
Notes: This figure depicts the average level of carbon emissions of households along the income dimension. Per capita equivalence measures are computed based on the OECD-modified scale. According to this definition the first adult is assigned a weight of 1.0, while the second adult and each child are assigned values of 0.5 and 0.3, respectively. The third specification controls for a linear and a quadratic age component.

Figure 1 depicts the carbon footprint of households along the net household income distribution in Germany in 2018. The figure corroborates the finding from the empirical literature that carbon footprints are increasing along the income distribution (green bars).[3] We find that a household in the first quintile emits around 8 tons each year while a household in the fifth quintile emits around 31 tons, an increase by a factor of almost four. This difference is partly explained by richer households

[3]This observation has been shown for Germany (Hardadi et al., 2021; Miehe et al., 2016), as well as for other European (Duarte et al., 2012; Isaksen and Narbel, 2017; Kerkhof et al., 2008) and non-European countries (Perobelli et al., 2015; Wiedenhofer et al., 2017).

having on average more family members. When we consider per-capita equivalent emissions, carbon footprints still increase substantially along the income distribution (orange bars). Households in the first quintile consume per capita around 8 tons, whereas a member of a household in the fifth quintile emits more than twice as much. The imputation of carbon emissions at the household level allows us further to also control for potential life-cycle effects. After taking out age effects, we find only a negligible effect on per-capita emissions (black bars).

Figure 2: Share of emissions and expenditures caused by consumption commitments along income distribution



Notes: This figure plots the share of household's emissions and expenditures which are caused by consumption commitments.

Figure 2 explores the role of consumption commitments for the carbon emissions of households from Figure 1. We find that on average around 35 percent of total household emissions are generated by commitment goods, while consumption commitments account for only 9 to 12 percent of household expenditures. Hence, consumption commitments account for three times their expenditure share in emissions. This high emissions per Euro of expenditure make them a prime candidate for policies aiming at reducing carbon emissions of households. This fact of high carbon emissions per Euro for commitment consumption is robust along the income distribution, which is remarkable given the high degree of heterogeneity in total carbon footprints across income groups.

In Table 1, we look at emission shares of household groups by income by reporting the share of total emissions. The numbers are striking and point to the key reduction-redistribution trade-off. We find that the top 10% of the income distribution account for 18.5% of total emissions and the top 25%, account for more than 40% of all emissions. By contrast, the bottom 25% of households account with 12% of total emissions for less than a third of the emissions of the top 25% of households. A

Table 1: Income and emission shares

	bottom 25%	25%-50%	50%-75%	top 25%	top 10%
emission share	11.6	19.7	28.2	40.5	18.5
income share	8.5	16.1	25.7	49.8	26.8
		no college	college		
income share		53.6	46.4		
population share		65.8	34.2		
emission level (in tons)		16.8	21.7		

Notes: Income share and emission shares for different households groups. Upper part of the table shows shares for different income groups. Lower part shows shares for college and non-college households and the level of emissions in tons.

policy to reduce carbon emissions will therefore be particularly effective in reducing emissions if it provides incentives for high-income households to adjust their consumption. Yet, if these subsidies are financed broadly with taxes on all households, then the distributional consequences of such policies will lead to redistribution from a majority of poorer households to high-income households. This redistribution will be further exacerbated if high-income households adopt the subsidized carbon-neutral technologies earlier in the transition process.

Table 1 also reports differences in carbon emission by (permanent) income by looking at households by the educational attainment of the household head. We split households by educational attainment into college and non-college households. In the quantitative model, we will use education as an observable characteristic to group households by permanent income into high- and low-income households. Consistent with this idea, Table 1 shows that although college households account for only about a third of the population, they receive almost half of all income. Regarding emissions, the high-income college households emit around 22 tons per household and therefore almost 25% more carbon than low-income non-college households with less than 18 tons per household. Emissions of 22 tons put college households on average in the fourth quintile of the income distribution (Figure 1). It is important to note that grouping households by education to capture permanent income differences is conservative as there is still substantial overlap in terms of income between education groups. Our quantitative results therefore likely constitute a lower bound of the redistributive effects of climate policies as they rely on educational attainment to describe (permanent) income differences.

3 Model

This section develops a quantitative life-cycle model with commitment goods and ex-ante permanent income heterogeneity of households. We will calibrate this model to today's economy and use it to simulate the transition process over 25 years to compare different climate policies in their ability to support the adaption process to modern commitment goods and with respect to their distributive effects.

3.1 Environment

We describe the model environment for a single household. Each household will be a member of a cohort of households that consists of a continuum of measure one of households. A household enters the economy and starts working at age $j = 1$ and lives for J periods. Households differ ex ante in their permanent productivity type z and face idiosyncratic productivity risk while working. Financial markets are incomplete as households can only trade a single risk-free financial asset a with per period return r that is subject to a no borrowing constraint ($a \geq 0$). The idiosyncratic income of a household of type z at age j is given by $y_{zj} = z_j \times \exp(\tilde{y}_j)$ where z_j is the deterministic life-cycle component that differs across the two ability types and $\tilde{y}_j$ is the stochastic idiosyncratic component that consists of a persistent and a transitory element, denoted η and ν, respectively:

$$\begin{aligned} \tilde{y}_j &= \eta_j + \nu_j, \\ \eta_j &= \rho\eta_{j-1} + \gamma_j \text{ with } \eta_0 = 0, \end{aligned} \tag{1}$$

where $\nu_j \sim \mathcal{N}\left(0, \sigma_\nu^2\right)$ and $\gamma_j \sim \mathcal{N}\left(0, \sigma_\gamma^2\right)$ are the idiosyncratic i.i.d. shocks and ρ denotes the persistence parameter. To simplify notation, we combine the realizations of η_j and ν_j in a vector $\mathbf{\tilde{y}}$.

Households derive utility from three types of consumption goods. First, there is a standard consumption good, denoted c, which households can freely adjust in every period. Additionally, there are two commitment goods, an old and a modern commitment good, denoted x^o and x^m, respectively. Households can in each period only consume the old or the modern commitment good. All commitment goods generate utility with utility weight μ. Modern commitment goods generate additional utility which consist of two parts. The first part is that modern commitment goods are luxury goods and yield utility as bequests in De Nardi et al. (2010). This is necessary as the empirical literature finds that modern commitment goods are consumed to a much higher extent by high-income groups (Axsen et al., 2018; Figenbaum and Kolbenstvedt, 2016; Hardman et al., 2016; Hardman and Tal, 2016; Westin et al., 2018). The second utility component is a size-independent utility flow μ_x from the modern consumption commitment good that we further discuss below. The period utility of a household from consuming c_t and x_t^i with $i \in \{o, m\}$ is

$$u(c_t, x_t^i) = \frac{[c_t/\lambda_j]^{1-\sigma}}{1-\sigma} + \mu \frac{[x_t^i/\lambda_j]^{1-\sigma}}{1-\sigma} + \phi \left[\theta^m \frac{[x_t^m + \psi^m]^{1-\sigma}}{1-\sigma} + \mu_x \right] \tag{2}$$

where λ_j captures household size and is age specific and ϕ describes whether a household consumes a modern ($\phi = 1$) or an old ($\phi = 0$) commitment good. It is important to note that the additional utility flow for modern commitment goods affects the trade off between old and modern commitment goods but not generally the trade off between commitment and non-commitment consumption.

Both commitment goods require per-period flow costs κ proportional to the stock of the commitment good x that households commit to when buying the good. We allow the price of the modern commitment good to differ from the price of the old commitment good. Initially, we assume that the price of the modern commitment good is higher than the price of the old commitment good. We denote this price premium by ω. We will let this price premium change during the transition period capturing technological progress. Regarding per-period costs, we assume that modern commitment goods have lower flow costs. The reduction is denoted by δ, so that flow costs for a level x of the modern commitment good are $(1-\delta)\kappa x$ and κx for the old commitment good. These committed flow costs for consuming the good distinguish the commitment good from durable consumption goods. Both assumptions are motivated by empirical studies which we employ for calibrating these parameters. Thus, the budget constraint of a household who does not adjust its level of the commitment good is

$$y_t + (1+r)a_t = c_t + a_{t+1} + (1 - \phi\delta)\kappa x_t$$

where c_t denotes consumption for the standard consumption good, y_t denotes current income, a_t wealth in period t, and the last term on the right-hand side denotes the flow costs for commitment good x_t depending on whether it is a modern ($\phi = 1$) or old commitment good ($\phi = 0$). For a household adjusting the commitment good, the budget constraint becomes

$$y_t + (1+r)a_t = c_t + a_{t+1} + (1 - \phi\delta)\kappa x_t + E_i$$

where E_i denotes the net costs associated with adjusting the commitment good that differ depending on whether the household buys an old $i = o$ or a modern $i = m$ commitment good. Net costs comprise the costs of the purchased commitment good net of the resale value of the previously owned commitment good x. The resale value of the modern commitment good is $\rho_{rs}\omega x$, i.e., if $\phi = 1$, and of the old commitment good it is $\rho_{rs}x$ ($\phi = 0$) with $\rho_{rs} \in (0, 1)$ being the discount factor for the resale value relative to the purchasing price. The net costs are then

$$\begin{aligned} E_o &= (1-\phi)(\tilde{x}' - \rho_{rs}x) + \phi(\tilde{x}' - \rho_{rs}\omega x) \\ E_m &= (1-\phi)(\omega\tilde{x}' - \rho_{rs}x) + \phi\omega(\tilde{x}' - \rho_{rs}x) \end{aligned}$$

where $\tilde{x}'$ denotes the purchased quantity of the commitment good. Finally, we allow for depreciation shocks to the commitment good so that the law of motion becomes

$$x' = x - \xi_\phi \qquad \text{and} \qquad x' = \tilde{x}' - \xi_\phi \qquad \phi \in \{o, m\} \tag{3}$$

with depreciation shock ξ_ϕ that hits with probability p_ϕ and it is zero otherwise. The size of the positive shock ξ_ϕ differs for the old and modern commitment good $\phi \in \{o, m\}$. The depreciation shock happens after the adjusting the commitment good so that the adjusted commitment good $\tilde{x}'$ is still subject to the shock. In case of no adjustment, it is the current stock x of the commitment good that is subject to the shock.

We abstain from explicitly modelling retirement and bequests. To match life-cycle wealth accumulation, we add a reduced-form utility of wealth in retirement with the following functional form

$$v(w) = \theta \frac{(w + \psi)^{1-\sigma}}{1 - \sigma}$$

where w denotes wealth at entry into retirement that is the sum of household's financial wealth and the resale value of the commitment good the household owns in the last period. The parameter ψ governs the importance of social security wealth for retirement.

3.2 Recursive formulation of the dynamic decision problem

Each period the household makes a consumption-saving decision and an adjustment decision for its consumption commitment. Hence, households can either choose to not adjust the commitment good, to adjust and purchase the old commitment good, or to adjust and purchase the modern commitment good. We denote the value functions by V^{NA} (non adjusting), V^{OA} (adjusting to old commitment good), and V^{MA} (adjusting to modern commitment good). The value function V^{NA} is the solution to the following dynamic programming problem

$$\begin{aligned} V^{NA}(z, a, x, \phi, \tilde{\mathbf{y}}, j) \quad &= \quad \max_{\{a' \geq 0\}} \quad u(c, x) + \beta \, \mathbb{E} \left[V(z, a', x', \phi, \tilde{\mathbf{y}}', j+1) \mid \tilde{\mathbf{y}} \right] \\ s.t. \qquad & \quad y + (1 + r)a = c + a' + (1 - \phi\delta)\kappa x \\ & \quad x' = x - \xi_\phi \text{ and } \phi' = \phi \end{aligned} \tag{4}$$

The value function for adjusting to the old commitment good V^{OA} is the solution to the following dynamic programming problem

$$\begin{aligned}
V^{OA}(z,a,x,\phi,\tilde{\mathbf{y}},j) &= \max_{\{\widetilde{x}',a'\geq 0\}} \quad u(c,x)+\beta\,\mathbb{E}\left[V(z,a',x',\phi',\tilde{\mathbf{y}}',j+1)\mid\tilde{\mathbf{y}}\right] \\
s.t. \quad & y+(1+r)a = c+a'+(1-\phi\delta)\kappa x+E_o \\
& E_o=(1-\phi)(\tilde{x}'-\rho_{rs}x)+\phi(\tilde{x}'-\rho_{rs}\omega x) \\
& x'=\widetilde{x}'-\xi_o \text{ and } \phi'=0
\end{aligned} \tag{5}$$

and the value function for adjusting to the modern commitment good V^{MA} is

$$\begin{aligned}
V^{MA}(z,a,x,\phi,\tilde{\mathbf{y}},j) &= \max_{\{\widetilde{x}',a'\geq 0\}} \quad u(c,x)+\beta\,\mathbb{E}\left[V(z,a',x',\phi',\tilde{\mathbf{y}}',j+1)\mid\tilde{\mathbf{y}}\right] \\
s.t. \quad & y+(1+r)a = c+a'+(1-\phi\delta)\kappa x+E_m \\
& E_m=(1-\phi)(\omega\tilde{x}'-\rho_{rs}x)+\phi\omega(\tilde{x}'-\rho_{rs}x) \\
& x'=\widetilde{x}'-\xi_m \text{ and } \phi'=1
\end{aligned} \tag{6}$$

We further assume that the individual adjustment decision of each household depends on two preference shocks, denoted ϵ_a and ϵ_x. For tractability, we assume that shocks are logistically distributed with mean μ_a (μ_x) and standard deviation σ_a (σ_x). While the first shock ϵ_a determines whether or not the household adjusts its commitment good consumption, the second shock ϵ_x determines whether the household buys a modern commitment good conditional on adjusting. In case of adjusting to the modern commitment good, the household will receive the flow utility μ_x permanently while consuming the modern good (see equation (2)). Note, that households do not know the realization of ϵ_x when deciding whether or not to adjust. The decision process of each period consists therefore of four stages. First, households enter the period with their state variables from last period, observe the realizations of the transitory and persistent income shocks and solve the contingent decision problem for all three possible adjustment decisions. Second, households observe the first preference shock ϵ_a and decide whether or not to adjust the commitment good. If households decide to adjust the commitment good, they enter the third stage, observe ϵ_x, and decide if they adjust to the old or modern good. Thus, the two discrete choice problems of the household are

$$\begin{aligned}
V(z,a,x,\phi,\tilde{\mathbf{y}},j) &= \max\{\mathbb{E}\left[V^{NA}(z,a,x,\phi,\tilde{\mathbf{y}},j)\right],\mathbb{E}\left[V^{A}(z,a,x,\phi,\tilde{\mathbf{y}},j)\right]+\epsilon_a\} \\
V^{A}(z,a,x,\phi,\tilde{\mathbf{y}},j) &= \max\{\mathbb{E}\left[V^{OA}(z,a,x,\phi,\tilde{\mathbf{y}},j)\right],\mathbb{E}\left[V^{MA}(z,a,x,\phi,\tilde{\mathbf{y}},j)\right]+\epsilon_x\},
\end{aligned}$$

where expectations are with respect to the income process, the depreciation shock, and, in the first case, also with respect to the second preference shock ϵ_x.

3.3 Calibration

The goal of the calibration is to provide a quantitative laboratory to explore the reduction-redistribution trade-off of different policy mixes. The model is calibrated to match the current status quo and we demonstrate its consistency with available evidence on household adjustment patterns for commitment goods. We set some parameters externally and calibrate a second set of parameters internally.

We set one period in the model to match one year in the data. Households enter the economy at age 25 and live for 40 years until they exit the model with certainty at age 64 ($J = 40$). Household enter the economy and without any wealth but they are endowed with the lowest level of their parents' commitment good that can be old or modern and is changing during the transition period. Through the lens of the model, this initial endowment can be interpretied as receiving an inter-vivo transfer or inheriting a used commitment good. The coefficient of relative risk aversion and the interest rate are set to standard values $\sigma = 1.5$ and $r = 2\%$. The two ability types z are calibrated to education groups as two observable permanent income types in the EVS data. We assign a household to an education group depending on whether the main earner of a household has a college degree. The share of college households is 34.2 percent and we calibrate the deterministic life-cycle profile of income $\{z_j\}_{j=1}^{J}$ to net household income. For the idiosyncratic shock process, we use estimates from Fehr et al. (2013) for the persistence parameter ρ and the variance of the transitory shock σ_γ^2.[4] We calibrate the variance of the persistent shock σ_ν^2 to match the Gini-coefficient for net household income.

We use a grid for the commitment good with five logarithmic spaced grid points. In line with the empirical analysis, we interpret the commitment good as a composite of cars and heating systems. As around two-thirds of all commitment adjustments are car purchases and since two-thirds of total flow costs generated by commitment goods are caused by cars, we use a weight of two-thirds for cars and one-third for heating systems. For the price premium ω, we use evidence from Holland et al. (2021) for the US car market for a premium of 63 percent. This estimate is well in line with other studies looking at European countries, including Germany (Lévay et al., 2017). For heating systems, estimates from German heating installing firms suggest a price difference for old and modern systems with a price of 10,000 Euro for old heating systems (oil, gas) and 28,125 Euro for modern systems (heat pump) (Statista, 2023). Combining these price premia for cars and heating systems of 63 percent and 181 percent and taking into account adjustment frequencies results in a price premium parameter $\omega = 1.84$.[5] While the price premia for electric cars are relatively homogeneous across countries, the operating costs vary substantially. For Germany, Lévay et al. (2017) estimate a

[4] Fehr et al. (2013) estimate parameters for three income groups. As we assume the idiosyncratic part to be independent of the ability type, we take their estimate for the middle income group for both types.

[5] In order to match the overall adjustment costs, we need to not only take into account the adjustment costs for each item but also the adjustment frequency. Hence, we weight cars and heating systems by both components to

reduction in fuel costs of 25 percent for battery electric vehicles (BEV) and of 3 percent for plug-in hybrid electric vehicles (PHEV) relative to traditional internal combustion engine (ICE) vehicles. These reductions are relatively small compared to other European countries and are the result of the high electricity prices in Germany. Since the number of BEVs and PHEVs are roughly the same in Germany, we take the average of both estimates to arrive at an estimate of 14 percent for the reduction in flow costs when using electric cars. For heating systems, a large price comparison portal for energy reports a cost reduction of 39 percent (Verivox, 2023). Combining the two estimates, we get $\delta = 0.226$. For the resale value of the commitment good, we follow Gilmore and Lave (2013) who find average resale values for cars of around 40 percent. Assuming that heating systems do not have any resale value, we set $\rho_{rs} = 0.262$. As the grid for the commitment good is logarithmically spaced, combining the relative difference between two grid points of 32 percent with the annual depreciation rates found in Schloter (2022) gives us annual depreciation probabilities of $p_o = 0.325$ and $p_m = 0.435$, respectively.

The remaining 11 parameters are calibrated within the model to match closely corresponding data moments. Six of these parameters, μ, θ_m, β, λ, ψ, and κ are calibrated to the initial steady state in 2018. The remaining five parameters are calibrated to match the parameters of the adjustment process to modern commitment goods using the most recent evidence for 2023. The means of the preference shocks μ_a and μ_x are calibrated to match the share of households who adjust their commitment consumption over the life-cycle and the share of adjustments to modern goods. As corresponding data moments, we use data from the German Federal Motor Transport Authority (*Kraftfahrtsbundesamt*) for cars and the Federal Association of the Heating Industry (*Bundesverband der Deutschen Heizungsindustrie*) for heating systems. The weight on utility from commitment consumption μ is calibrated to match the share of carbon emissions from consumption commitments generated by college households relative to all households. In the 2018 EVS data, the share of carbon emissions from consumption commitments from college households is 36.6%. The flow cost parameter κ is calibrated to match the share of flow costs to the total expenditures for commitment consumption also from the EVS data.

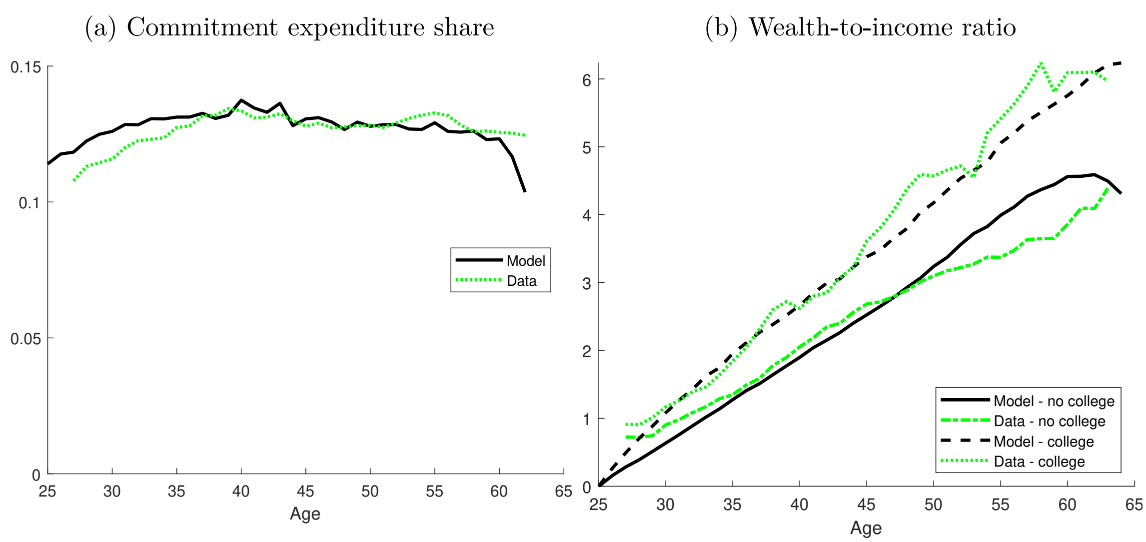
The parameters governing the variance of the preference shocks σ_a and σ_x are set to match the price elasticities of modern and old commitment goods. Fridstrøm and Østli (2021) provide estimates for own-price and cross-price elasticities of cars with different powertrains. We target their estimates for battery electric vehicles and plug-in hybrid vehicles in Norway in 2016 for the own-price elasticity of the modern commitment good in the model. Norway in 2016 is very comparable to Germany in 2022 regarding the market share of electric cars, the cumulative market shares of battery electric vehicles and plug-in hybrid vehicles was 29 percent in Norway in 2016 very similar to 31 percent in Germany in 2022. Fridstrøm and Østli (2021) estimate the elasticities of battery electric and

derive the aggregate price premium. Using the average adjustment frequency of 12 years for cars and 23 years for heating systems, we arrive at an effective weight for cars of 82% and heating systems of 18%.

plug-in hybrid vehicles to be -0.99 and -1.72, respectively. We average these estimates to compare them to the model. To compute the model equivalent, we mimic their strategy and simulate a 10 percent price increase for the modern commitment good holding all other prices constant. We find that our model matches the targeted elasticity of -1.4 exactly.

To calibrate the parameters θ^m and ψ^m of the luxurious good utility for the modern commitment good, we target the costs (purchase price and flow costs) of the commitment good as share of total household expenditure and the ratio of modern adjustments made by high-income households (college households) relative to low-income households (non-college households). For these targets, we have to rely on estimates for Norway in 2016 (Figenbaum and Kolbenstvedt, 2016) for electric cars and own estimates using the GRECS dataset from the RWI for heat pumps. Figenbaum and Kolbenstvedt (2016) reports that 77 percent of electric cars are bought by college graduates and we find in the GRECS data that college households are around 58 percent more likely to buy a heat pump. Our estimate of a smaller gradient in income for heat-pumps relative to electric cars is also consistent with evidence in Davis (2023) for the US. The calibration target is the combined estimate from Figenbaum and Kolbenstvedt (2016) for electric cars and the estimate based on the GRECS-dataset for heat pumps. We get a ratio of modern commitments bought by college- relative to non-college households of 2.7. Our calibration matches this target exactly.

Figure 3: Life-cycle consumption-saving decision



Notes: The empirical moments result from own computations based on the EVS (2018) dataset.

We calibrate the parameters of the utility function of wealth in retirement θ and ψ and the time discount factor β to match the average wealth-to-income ratio, the average difference between college and non-college households of the wealth-to-income ratio, and the average wealth-to-income ratio at the end of working life ($J = 40$) from the EVS data. Figure 3 shows the model fit for life-cycle profiles of two dimensions of the consumption-saving decision. Figure 3a shows the expenditure share for commitment goods over the life cycle from model and data. In both cases, we see little life-cycle variation around the mean. Figure 3b shows the wealth-to-income ratios for low- and high-income households. The calibration matches the average life-cycle profile and the unconditional income-group difference, but the figures show that the model mechanism matches closely the untargeted life-cycle evolution of both income groups. We summarize the calibrated model parameters in Table 2.

Table 2: Calibrated parameters

Symbol	Description	Value	Source/Target
γ	Risk aversion	1.5	
r	Interest rate	0.02	
ϕ_{col}	Share of college graduates	0.342	EVS (2018)
p_o	Prob. depreciation old good	0.3254	Schloter (2022)
p_m	Prob. depreciation modern good	0.4349	Schloter (2022)
ω	Price premium modern good	1.84	See text
ρ_{rs}	Resale value	0.262	See text
δ	Cut in flow costs with modern good	0.226	See text
ρ	Persistence of income shock	0.957	Fehr et al. (2013)
σ_γ^2	Variance transitory income shock	0.084	Fehr et al. (2013)
	Internally calibrated parameters		
σ_v^2	Variance of persistent income shock	0.025	Gini-coefficient net household income
μ_a	Mean of first preference shock	-0.769	Share of households adjusting
μ_x	Mean of second preference shock	0.813	Share of modern to total adjustments
σ_a	Scale parameter first pref. shock	0.31	Elasticity of old good
σ_x	Scale parameter second pref. shock	0.35	Elasticity of modern good
μ	Weight commit. consumption	0.29	Share emissions college
ψ_m	Curvature modern commit. consump.	1.4	Ratio modern good college/non-college
θ_m	Weight modern commit. consump.	0.89	Share commit. to total consumption
β	Discount rate	0.986	Average WTI-ratio
λ	Weight on bequests	61	Average WTI-ratio at death
ψ	Curvature of bequests	11	Diff. bequests college/non-college
κ	Share flow costs commitment size	0.171	Share flow costs to total commit. costs

Notes: This table presents the calibrated model parameters.

In our calibration, we target the average own-price elasticities. The moment of interest for the redistributive effects of climate policies are, however, the semi-elasticities as they determine the adjustment level in response to a price change, for example, from introducing a subsidy. A larger semi elasticity means that more households will adjust to the modern commitment good and receive subsidies.[6] If there is heterogeneity in the semi-elasticities, this implies that the group with the larger elasticity will receive more of a newly introduced subsidy because of a stronger adoption of the modern commitment good. Table 3 reports the semi-elasticities for different income and age groups. Regarding the variation with age, we find that the elasticities are increasing with age for low-income households and that they are hump-shaped in age for high-income households. The on average higher elasticities among older households imply that there will be a redistribution from the currently young households to older households during a transition period after a subsidy will be introduced. Conditional on age, we find that high-income households are more price sensitive. More importantly, there is hardly any overlap between low- and high-income households regarding the range of elasticities. Older low-income households show about the same semi-elasticity than high-income young households. This pattern implies that there will be redistribution of climate policies from low- to high-income households once the government introduces subsidies conditional on adopting the modern commitment good.

Table 3: Model heterogeneity

Age (years)	30	30	45	45	55	55
Income group	low	high	low	high	low	high
Semi-elasticity of modern good	0.018	0.035	0.026	0.053	0.036	0.038

Notes: This table shows the semi-elasticity of modern commitment goods for different age and income groups.

A further important moment for redistribution during a transition period is the average adjustment age to modern technologies. We therefore evaluate whether our model is able to match at which age households adjust to the modern commitment good. There is only limited data on the age profile of households with modern commitment goods. For electric cars, empirical studies find the average age for electric car buyers to be between 43 and 53 years (Figenbaum and Kolbenstvedt, 2016; Lee et al., 2019; Westin et al., 2018). For heat pumps, the RWI data suggest that owners are on average around 42 years old. This evidence suggest that most of the modern commitment goods are bought by middle-aged household heads. In our model, the average age among those households who adjust to the modern commitment good is around 48, which is in line with what the empirical literature suggests. In the next section, we will use the calibrated model as laboratory to quantify the effects of different climate policies.

[6] Most of the adjustment will happen at the extensive margin given that only very few households have modern commitment goods at the start of the transition.

4 Policy experiments

This section compares different policy mixes with respect to the reduction-redistribution trade off, this means their ability to support the adoption process to modern commitment goods (reduction) and with respect to their allocation of net transfers (redistribution). The empirical analysis of Section 2 suggests already that a fast transition to low carbon emissions requires that high-income households receive sufficiently strong financial incentives for adjusting. On the redistribution side, such a policy will, because of heterogeneous adoption rates, likely result in net transfers from low-income to high-income households. Our policy analysis will therefore explore different policy mixes of subsidies for modern technologies and financing options. In Section 4.3, we will quantify the present value of net transfers at the household level as our measure of political support for a policy mix to see which policy mixes satisfy the political economy constraint that they find majority support among today's electorate.

Our policy experiments start from an initial steady state in which only the old commitment good exist and that we calibrate to the year 2018.[7] From this steady state, we compute a transition of 25 years during which the modern commitment good is available. For the first five years, we assume no governmental policy, thereafter, in year 2024, we assume that the government introduces a climate policy mix of a subsidy and a financing instrument. We rule out anticipation effects and simulate the economy for 20 years (until 2043) with a policy mix in place.

After the introduction of the modern commitment good, we also allow for technological progress that will lead to a relative price decline of the modern commitment good. This relative price decline will result in a decrease of the price differences ω between the modern and the old commitment good. A lower relative price of the modern commitment good will further speed up the adoption of the modern good. For our baseline economy, we follow the literature and assume that the price of the modern commitment good will converge over time to the price of the old commitment good (Holland et al., 2021). We take actual price developments for electric cars and heat pumps until 2022 and forecasts from 2023 onward until the end of the transition period. For electric cars, we take actual data and forecasts by the car rental company nextmove (Nextmove, 2023). For heat pumps, we observe no price changes until 2022. From there onward, we take as our baseline scenario the forecasts from LCP Delta who estimate prices to drop by 40 percent within 10 years (LCP Delta, 2021). We extrapolate this percentage price reduction over the entire transition period. We also compute a second more conservative price scenario with slower price convergence based on price forecasts for electric cars by Holland et al. (2021). For heat pumps, we also take the more conservative price scenario by LCP Delta of a reduction of 25 percent within 10 years. As before, we weight variables for electric cars and heat pumps to a composite good. Appendix Figure A1

[7]The share of electric cars and heat pumps on the stock of all cars and heating systems in 2018 were around 0.2 percent and 2.0 percent, respectively.

shows the baseline price scenario for the modern composite commitment good, as well as the slower convergence scenario. Appendix Figure A2 shows the price scenarios for cars and heat pumps separately. We report the results of the following analysis for the more conservative price scenario in Appendix B.

In the first step, we compare different specifications of price subsidies for the modern commitment good. Specifically, we consider a percentage subsidy on the purchase price and a lump-sum subsidy for the purchase of the modern commitment good. In both cases, the government imposes a linear income tax to finance the subsidy. In the second step, we will consider different financing options. These taxes will then be set such that the government has a balanced budget over the transition period for the current population. Hence, we rule out policies with transfers from or to future (unborn) generations as, in particular, any debt-financed policy for the current generation (transfers from future generations) could make a majority of households support any policy. Under this assumption, the government's budget constraint for the linear income tax with the percentage subsidy reads

$$\sum_{t=2019}^{2043} \tau_y \int_i y_{i,t} di = \sum_{t=2019}^{2043} \pi_1 \int_i \zeta_{i,t} x_{i,t+1} di \tag{7}$$

where $\zeta_{i,t}$ is an indicator function that is one if household i buys a modern commitment good in period t and τ_y and π_1 represent the linear income tax and the percentage subsidy, respectively. In case of the lump-sum tax, the budget constraint changes to

$$\sum_{t=2019}^{2043} \tau_y \int_i y_{i,t} di = \sum_{t=2019}^{2043} \pi_2 \int_i \zeta_{i,t} di \tag{8}$$

where π_2 denotes the lump-sum tax for buying a modern commitment good ($\zeta_{i,t} = 1$).

In the second step, we compare on the financing side a linear income tax, a progressive income tax, a consumption tax, and a tax on the flow cost of the old commitment good (carbon tax). By raising the user cost of the old commitment good, the carbon tax will also affect the speed of adopting the modern commitment good. We will also consider as a further and widely discussed policy option the introduction of a carbon tax that increases the user cost of the old commitment good but that will not be used to finance a subsidy for adopting the modern commitment good but where tax revenues will be redistributed as lump-sum transfers.

For each policy mix, we quantify the adoption of modern commitment goods and the financial consequences in terms of net transfers for the two permanent income groups and across age groups over the transition period. Looking at the distribution of net transfers, we will ask if any of the policy mixes has a majority of households with positive net transfers so that it would find majority support. Looking only at financial transfers, we abstract from any direct or indirect welfare costs of climate change that are important but that are challenging to quantify at the level of the individual household.

4.1 Subsidies for carbon reduction

Subsidies for the modern commitment good change the costs of adjusting to the modern commitment good E_m. We get in case of the proportional price subsidy π_1

$$E_m^P = (1-\phi)[(1-\pi_1)\omega x' - \rho_{rs}x] + \phi[\omega((1-\pi_1)x' - \rho_{rs}x)]$$

and in case of the lump-sum subsidy π_2, we get

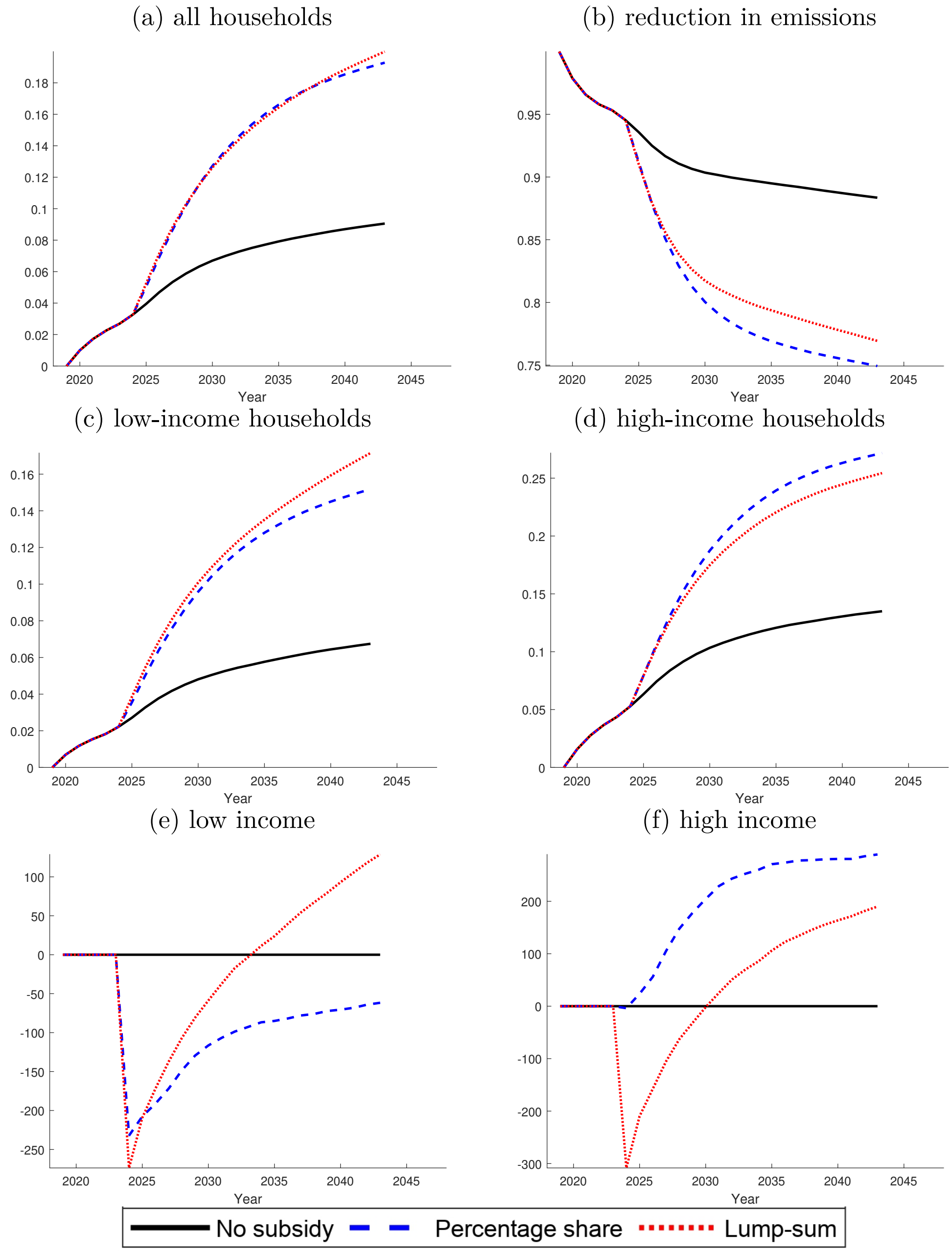
$$E_m^L = (1-\phi)[\omega x' - \rho_{rs}x] + \phi[\omega(x' - \rho_{rs}x)] - \min\{\pi_2, \omega x'\}$$

where we rule out that the subsidy π_2 exceeds the costs of the new commitment good $\omega x'$. In both cases, the subsidy is financed by a linear income tax τ_y on labor income, so that net labor income becomes $(1-\tau_y)y$. In case a household does not adjust or adjusts to the old commitment good, the budget constraints for this household only changes on the income side with labor income being $(1-\tau_y)y$.

To set the level of subsidies, we use recently introduced subsidies in Germany for electric cars and heat pumps that set the lump-sum subsidy to a maximum of $\pi_2 = 12,795$ Euros.[8] We then determine the linear income tax τ_y so that the government runs a balanced budget over the entire transition period. This approach yields a tax rate $\tau_y = 0.012$. To make the proportional subsidy comparable, we set $\pi_1 = 0.271$ which implies again that the government runs a balanced budget at the same income tax rate.

[8]We take subsidies of 4,500 Euro and 10,000 Euro for electric cars and heat pumps, respectively, and aggregate them with the respective weights.

Figure 4: Share of households with modern consumption commitment good, reduction of emissions, and annual net transfers



Notes: Panel (a) shows the share of households with modern commitment goods along the transition for both types of subsidies and without any subsidy. Panel (b) shows the reductions in carbon emissions for both subsidy types along the transition. We assume that carbon emissions are proportional to the size of the commitment good. Panels (c) and (d) show the share of households with a modern consumption commitment good along the transition for both types of subsidies and without any subsidy for low- and high-income households. Panels (e) and (f) show the annual net transfers along the transition period for both educational groups and both subsidies. Net transfers are the difference between subsidies and taxes paid and are in Euro per year.

Figure 4a shows the share of households consuming the modern commitment good along the transition for three scenarios. First, the scenario without any subsidy, where we get that around 9 percent of households have a modern commitment good at the end of the transition in 2043.[9] Second, in case of a lump-sum subsidy, we find a substantial increase of the adoption rate to around 19 percent at the end of the transition. We find a similar household share in case of the proportional subsidy. Figure 4b shows that the two subsidy policies differ however in their implied reduction of emissions over time. The reduction of emissions only depends on the amount of the old commitment consumption of an adopting household as we assume that the modern commitment good has zero emissions independent of its size. For the lump-sum subsidy, we now find with 23% a roughly 10% smaller reduction in emissions compared to the 25% reduction of the percentage subsidy. By contrast, without any subsidy the reduction is only 12%. Two observations explain the difference between the change in household and emission shares. First, the emission share exceeds the share of households adopting the modern commitment good as high-income households who more strongly adopt caused higher emissions from consuming more of the old commitment good. Second, the percentage subsidy is more attractive for high-income households in general because they consume larger commitment goods and therefore adjust more under a percentage price subsidy. This stronger adjustment of high-income households shifts the composition of adjusting households towards high-income households which further contributes to a stronger reduction of emissions compared to the lump-sum subsidy.

The difference in adoption rates across income groups can be seen in Figures 4c and 4d that show the share of households with modern commitment goods among low- and high-income households. Two observations are important from this comparison. First, we see that the share of households with a modern commitment good is higher and increases more in its level for high-income households consistent with empirical estimates (Axsen et al., 2018; Figenbaum and Kolbenstvedt, 2016; Hardman et al., 2016; Hardman and Tal, 2016; Westin et al., 2018). This implies that also a larger fraction of the subsidy will go to high-income households. Second, the difference between the adoption rates with the price and lump-sum subsidy reverses between high-income and low-income households. Whereas low-income households adopt more under the lump-sum subsidy, high-income households react more to the percentage subsidy as their expenditure for the commitment good are higher. This stronger adoption of high-income, high-emission households makes the percentage subsidy the more effective policy for reducing carbon emissions.

[9] The scenario without a subsidy allows us to further validate the quantitative predictions of the model regarding the speed of adjustment and therefore justify its use for a quantitative policy analysis. The general challenge is that the available evidence on adjustment paths is necessarily scarce. In Appendix Figure A3, we compare the first four years of the transition from 2019 to 2022 for which data exist. We find that the model matches the speed of adoption well. Both model and data yield a roughly 0.5pp annual adoption rate of the modern commitment good after 2020. We take this evidence as further support for the quantitative predictions of the model.

The differences in the adoption of the modern commitment good under the two subsidy policies also implies that the policies will differ in their distributional consequences. We compute the average net transfers for both policies in each year of the transition as the average subsidies net of the average income taxes paid for high- and low-income households. Figures 4e and 4f show that for the percentage subsidy high-income households are on average net-transfer recipients, while low-income households are on average net contributors to the policy. For the lump-sum subsidy, the pattern is less clear. Both income groups have a steeply increasing net transfer profile over time that flips sign in the middle of the transition period. As we will see below, these time paths are such that their present values are negative for a majority of households.

In general, we see for both policies net transfers to increase along the transition. This increase is driven by the falling price path of the modern commitment good along the transition, which increases the share of households consuming the modern commitment good and thus the share of households receiving the subsidy. The increase in net transfers is stronger for lump-sum subsidies as their level is independent of the price of the modern commitment good, i.e., transfers stay constant over the transition period. Quantitatively, the annual net transfers per household are sizeable and amount to up to positive or negative 300 Euros in some years, which corresponds to around one percent of annual net households income.

4.2 Different financing schemes

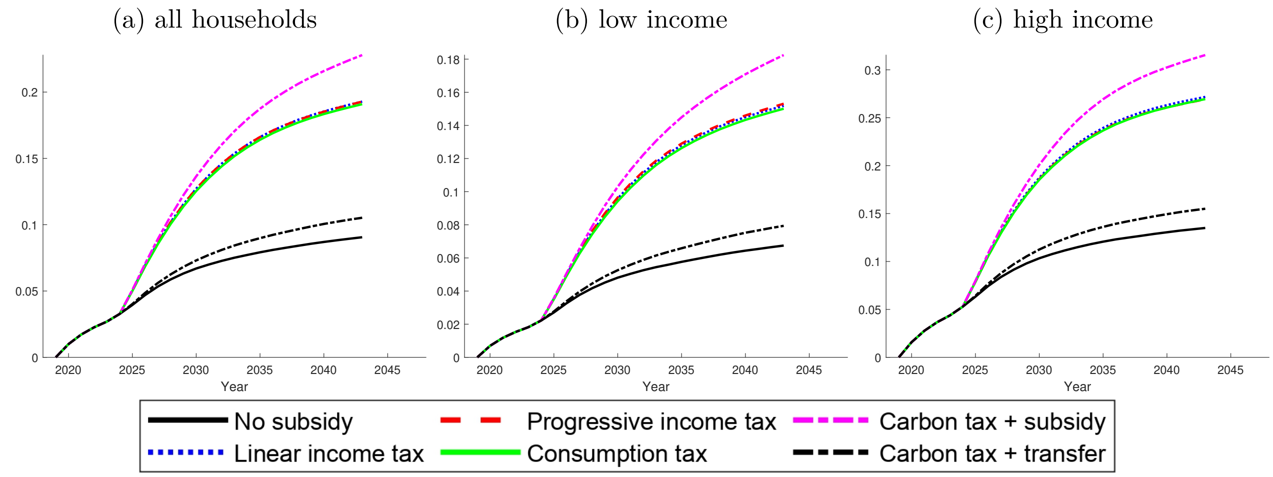
The results show that all subsidy policies lead to large net transfers and therefore potential redistribution along the transition if they are financed by a linear income tax. In the next step, we focus on the percentage subsidy that is most effective in reducing emissions and consider different financing schemes to explore if there is a policy mix with a similar reduction of emissions and redistribution pattern that will find majority support among households. For this analysis, we fix the percentage subsidy on the modern commitment good at $\pi_1 = 0.271$ and solve for each of the tax instruments for the tax rate to finance the subsidy with a balanced budget over the transition. The baseline is the case of a linear income tax. Second, we consider a progressive income tax. For the progressive tax, we match the empirical observation that the low-income group accounts for 16 percent of total labor income tax revenues in Germany. Third, we consider a consumption tax on all consumption goods. For the consumption tax, the budget constraint in case of adjusting the commitment good becomes

$$\begin{aligned}
y + (1+r)a &= (1+\tau_c)c + a' + (1+\tau_c)((1-\phi)\kappa x + \phi(1-\delta)\kappa x) + E_i^P \qquad i \in \{o, m\} \\
E_o^P &= (1-\phi)((1+\tau_c)\tilde{x}' - \rho_{rs}x) + \phi((1+\tau_c)\tilde{x}' - \rho_{rs}\omega x) \\
E_m^P &= (1-\phi)((1+\tau_c)(1-\pi_1)\omega\tilde{x}' - \rho_{rs}x) + \phi\omega((1+\tau_c)(1-\pi_1)\tilde{x}' - \rho_{rs}x)
\end{aligned}$$

and differs depending on if the adjustment is to the old commitment good associated with costs E_o^P or to the modern commitment good associated with costs E_m^P. If there is no adjustment of the commitment good E_i^P drops from the constraint. The consumption tax τ_c applies to consumption c, flow expenditures κx, and new commitment goods $\tilde{x}'$. Finally, we consider a tax on the user cost of the old commitment good, which is a carbon tax through the lens of the model. The flow cost in case of consuming the old commitment good ($\phi = 0$) are $(1+\tau_o)\kappa x$ where τ_o denotes the carbon tax and user costs are $(1-\delta)\kappa x$ in case of the modern commitment good ($\phi = 1$) where no tax needs to be paid.

Setting each of the four tax rates such that the government runs a balanced budget over the transition period implies a linear tax rate of $\tau_y = 0.012$, a progressive tax of $\tau_y^l = 0.006$ and $\tau_y^h = 0.019$ for low-income (τ_y^l) and high-income (τ_y^h) households respectively, a consumption tax $\tau_c = 0.013$, and a carbon tax $\tau_o = 0.24$.[10] For the carbon tax, we also evaluate the policy mix where the tax revenue from the carbon tax will be redistributed as a lump-sum transfer among all households.

Figure 5: Share of households with modern consumption commitments



Notes: This figure depicts that share of households with a modern commitment good. The left panel shows all households, the middle panel low-income households, and the right panel high-income households. The policy is a percentage subsidy of 27.1 percent on the modern commitment good in combination with different financing schemes.

In the first step, we explore how, in the case of the percentage subsidy, the different financing policies affect the adoption of the modern commitment good. Figure 5a shows the adoption of the modern commitment good across all households. On average, we find differences across financing

[10]To translate this tax rate in a carbon price note that about 11% of household expenditures are for commitment goods and two-thirds of these costs are flow costs for commitment consumption. Based on the data from Section 2, the flow consumption of the commitment good leads to 5 tons of carbon emissions. Given average household expenditures of 48,000 Euros, the 24% tax on the flow costs therefore corresponds to a carbon price of 170 Euros per ton of carbon emissions. A carbon price of 170 Euros is substantially higher than the current carbon price of 45 Euros in Germany in 2024.

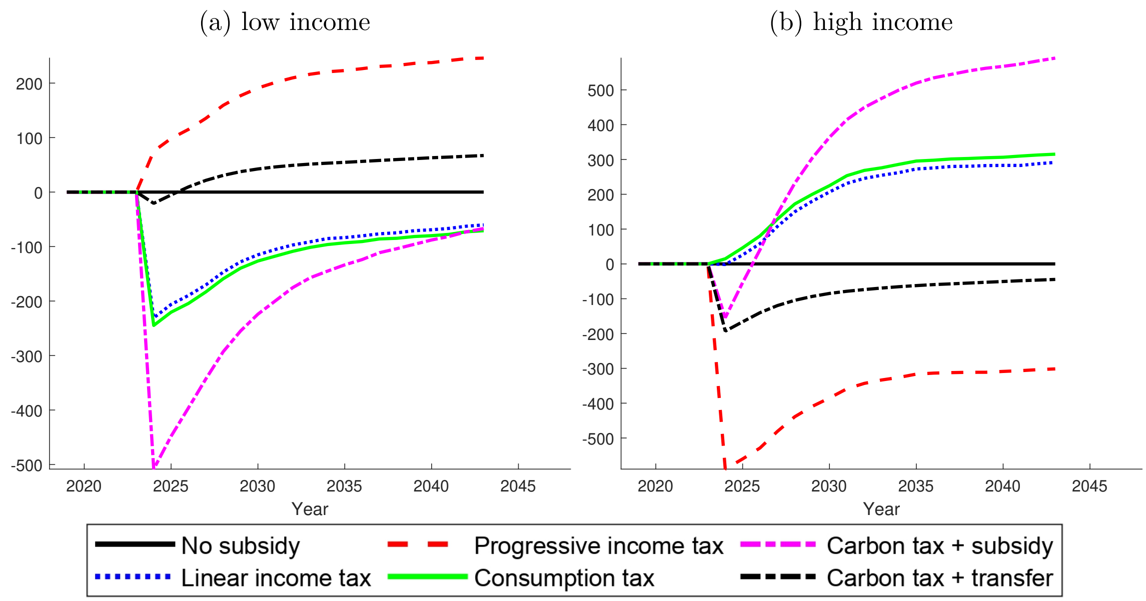
schemes to be small. An exception is the financing of the subsidy by a carbon tax that further speeds up the adoption by 3.5pp at the end of the transition period. Looking across income groups in Figures 5b and 5c, we find that for low-income households the consumption tax leads to the least adjustment and the carbon tax leads to the most adjustment but the difference at the end of the transition is only 2.8pp. For high-income households, the differences in adoption rates are with 4.4pp larger. The progressive tax leads to the least adjustment and the carbon tax leads to the most adjustment. The lower adoption rate for high-income households under the progressive tax comes from the negative income effect as the modern good is a luxurious good. By contrast, the carbon tax leads to more adoption because of its additional substitution effect as it increases the user costs of the old commitment good.

Finally, when we look at the policy where the carbon tax finances lump-sum transfers to households, we find that adoption rates are an order of magnitude smaller than with any of the subsidy policies. The reason is that in case of the carbon tax, it is only the differences in user costs that induce households to change consumption and there is no additional incentive from subsidies for acquiring the modern commitment good. At the end of the transition period, the carbon tax that increases the user costs for the old commitment good by 24% leads to only 10% of households consuming the modern commitment good in contrast to the case with a percentage subsidy where the share is more than twice as high. The reason for the low adoption rate under the carbon tax is not simply its low level. The 24% tax on the expenditures for the flow costs of the old commitment good corresponds to a carbon price of 170 Euros per ton of emissions (see footnote 10). This price is more than three times the current carbon price in Germany and within the range of estimates for carbon prices in the EU by 2030.

While the effects on the emission reduction of the different financing schemes are overall modest, Figure 6 shows that the differences in redistribution vary strongly across the different financing schemes. Most strikingly, the direction of redistribution for the progressive tax flips the sign relative to the other financing schemes. Only the carbon tax that finances lump-sum transfers also yields a redistribution pattern that aligns qualitatively with that of progressive taxation but at a lower level. Except for these two policies, all other financing policies typically result in positive net transfers for high-income households and negative net transfers for low-income households along the transition. Considering the time path, we find transfers to be again increasing consistent with a falling price path of the modern commitment good over time.

In terms of transfer levels, we get net transfers to low-income households for the progressive tax in the final years of the transition that are on average 200 Euros per year. By contrast, high-income households receive negative net transfers under this policy because of its progressive financing. In the year of the introduction, their negative net transfer is more than 500 Euros. Over time, their net

Figure 6: Annual net transfers



Notes: This figure depicts the net governmental transfers of different policies to finance a 27.1 percent subsidy on the modern commitment good. Transfers are in Euros per year.

transfer reduces but remains sizable and negative at 300 Euros per year at the end of the transition period.

The polar opposite is the carbon tax to finance the percentage subsidy. Now, it is low-income households who mainly finance the policy. They are slower to adopt the modern commitment good and therefore they have to pay more of the carbon tax. They buy smaller and hence less expansive commitment goods and they buy the modern commitment good less often and therefore also receive less of the subsidy. Hence, they are worse off in both dimensions of a policy with a percentage subsidy. In the year of the introduction, their negative net transfer is 500 Euros, it declines quickly over time but even in the final year of the transition period, it remains at negative 100 Euros. High-income households are the receivers of these net transfers. Except for the initial periods when still many of them own the old commitment good and therefore have to pay carbon taxes, they receive positive transfers that increase to more than 500 Euros on average at the end of the transition period.

The policy mix of the carbon tax financing transfers leads to the least redistribution across income groups of all policies. For most of the transition, low-income households receive positive net transfers of less than 100 Euros and high-income households contribute with a slightly decreasing but always negative time path of net transfers. Hence, the policy has the qualitative redistribution pattern as the progressive tax financing option.

In general, we see again that net transfers increase over the transition period. By assumption, we restrict all policy mixes to have a balanced budget for the initial cross section of households so that net transfers across income groups net out to zero in the first period of the transition. This policy constraint rules out transfers across generations. The time path of net transfers shows however that all policies tend to yield surpluses today that will be spent in the later part of the transition period when prices have fallen and more households adjust to the modern commitment good. This time path therefore highlights a potentially important role also for intergenerational financial redistribution of climate policies.

4.3 Distributional effects

The analysis so far has shown that subsidizing the adoption of carbon-neutral commitment consumption goods leads to more than a doubling of the reduction of carbon emissions relative to a no-policy baseline. Yet, we have also seen that different financing options differ strongly in their net transfers across income groups. To assess the support for different policy mixes, we quantify in a final step the present value of net transfers of the different policy mixes. The budget balance requirement for the government implies that the sum of net transfers across all currently alive households is zero so that we get a direct measure of redistribution from the policy when considering the differences of present values across households. We assume that households who receive a positive net transfer support a policy mix whereas households with a negative present value of net transfers will not support it. Hence, we consider a policy to find support if a majority of households, i.e. the median voter, has a positive present value of transfers.

Importantly, these net transfers are not the entire welfare effect of the policies as they abstract from any other gains or losses associated with climate change. We abstain from including these additional welfare effects as they are hard to qunatify at the household level. Instead, we focus here on the economic decisions and transfers directly attributable to the individual household. Furthermore, we only consider the support of the policy among the currently alive households and we rule out intergenerational transfers. We restrict the policy mixes in this way as otherwise intergenerational transfers across policy mixes can and will differ. Such different intergenerational transfers to the current generation will render a direct comparison of the policies impossible.

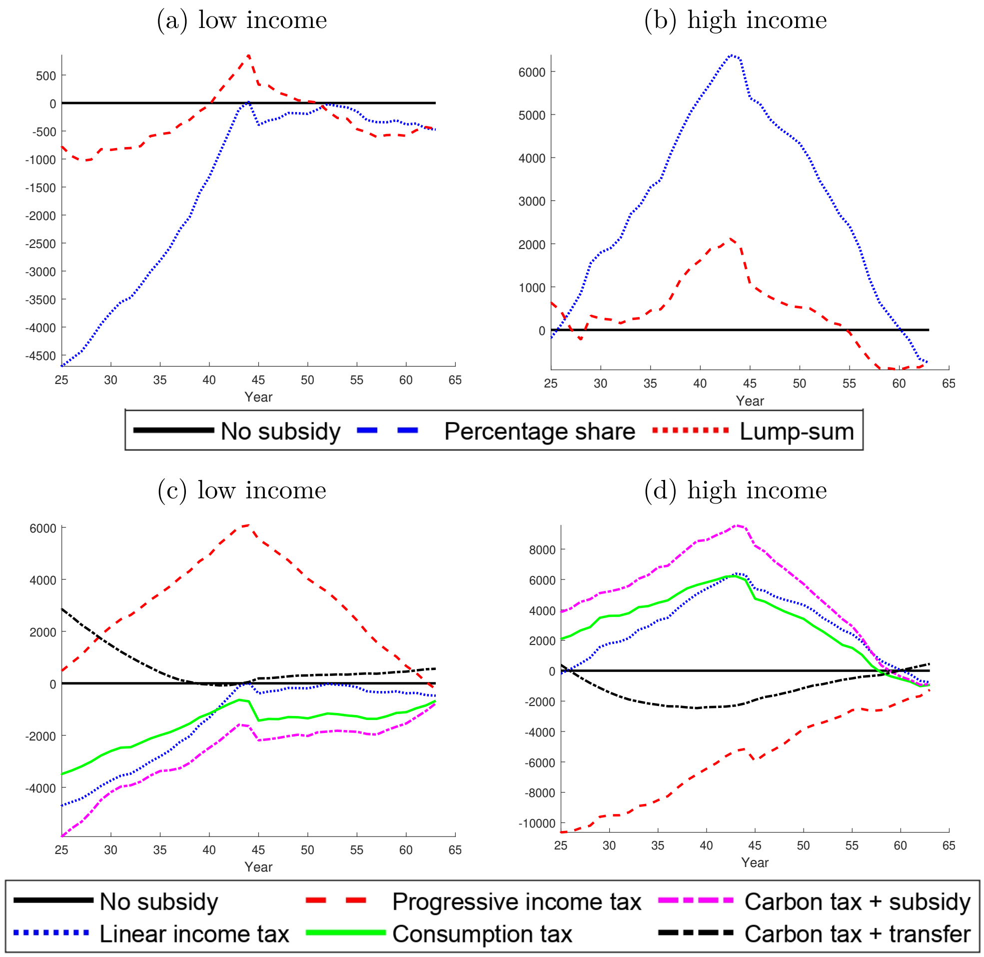
We compute net transfers for all households over the transition period. Households who are at most 45 years old when the policy is introduced (born 1978 or later) will live for the whole transition period. For the remaining households, we only consider the transfers until they leave the model for retirement. We report results by age and for the two permanent income groups. We proceed as before and first compare the policy mixes of the percentage and lump-sum subsidy with the linear income tax and in the second step, we compare the percentage subsidy with the different financing schemes. In this second step, we also discuss the carbon tax and transfer policy.

The top row of Figure 7 shows the age profile separately for low- and high-income households of the present value of net transfers for the linear income tax in combination with the two subsidy policies. The lump-sum subsidy shows qualitatively similar pattern for low- and high-income households. Annual net transfers in Figure 4 did not yet allow for a direct conclusion on the distributional consequences of this policy mix because they show an increasing time path of net transfers with a flipping sign in the middle of the transition. Looking now at the present values of the time paths for different age groups, we find that they increase up to age 45 and decrease afterwards. The level differs however across income groups. Whereas the present value is except for few age groups around age 45 always negative for low-income households, it is mainly positive for high-income households except for households 55 and older. In terms of net transfer levels, the youngest low-income households have the most negative net transfers of about 1,000 Euros and high-income middle-age households receive a positive present value of net transfers of up to 2,000 Euros. Aggregating support across households, Table 4 shows that this policy mix will not find a majority with only 44% of households having a positive present value of net transfers.[11]

Looking at the age profiles for the percentage subsidy in Figure 7, we find them to differ qualitatively and quantitatively. Young low-income households experience the largest negative net transfers and low-income households, in general, have on average negative net transfers. For the youngest low-income households, with the most negative transfers the present value exceeds 4,500 Euros. By contrast, the present value of net transfers is for almost all age groups of high-income households on average positive and it is substantial with up to 6,000 Euros for middle-age households. These results show that the percentage subsidy that reduces carbon emissions most effectively will not be supported by most low-income households if financed by a linear income tax. Table 4 shows that only 2.6% of low-income households will support the policy and in total the policy will find support only from about a third of the electorate. Hence, its distributional consequences undermine the support for this climate policy.

[11] We assume a uniform age distribution and the calibrated population shares of college and non-college households for the high- and low-income households.

Figure 7: Present value of net transfers of policy mixes across age and income groups



Notes: Figure shows the present value of net transfers of different policy mixes by age and income group. The top row shows different subsidies with a linear income tax. The bottom row shows different financing schemes for a percentage subsidy. The policy mix *carbon tax + transfer* does not include a subsidy but instead lump-sum transfers to households financed by a carbon tax.

The bottom row of Figure 7 shows the age profiles of net transfers for the different financing schemes from the previous section. It also shows the policy mix of a carbon tax financing a lump-sum transfer. Qualitatively, we find the same distributional patterns as for the annual net transfers in Figure 6. A financing of the percentage subsidy by a progressive income tax and the carbon tax and transfer policy lead to positive transfers for low-income households and negative transfers for high-income households even if we take the entire transition period into account. By contrast, the linear tax, the consumption tax, and the carbon tax all lead to a negative present value of net transfers for low-income households. Given that low-income households account for two-thirds of the population, these average numbers already suggest that these policies will not find support by a majority of households. High-income households typically support these policies as they benefit from the percentage subsidy but contribute less to its financing under these financing schemes so that the present value of net transfers is on average positive (except for some of the oldest households).

Table 4 shows the support of the different policy mixes when aggregated across households. As expected, we find that all policy mixes that lead on average to negative net transfers for low-income households also do not have a majority supporting them. The least support exists for the consumption and carbon taxes as financing tools that less than a third of households support. By contrast, the progressive income tax finds broad support with almost two-thirds of households supporting this policy. As we have seen, these are mainly low-income households who will adjust less to the modern commitment good but who will now also contribute less to the financing of the subsidy. Strikingly, we find that no high-income household will support the progressive financing option. On the other hand, no low-income household will support the carbon tax or consumption tax financing option. The other policy mix that finds broad support is the carbon tax financing transfers. Figure 7 shows that this policy, too, leads typically to positive present values of net transfers for low-income households and negative values for high-income households. Although the policy finds support by a majority of households, we have seen in Figure 5 that it will lead to little adoption of the modern commitment good and consequently is very ineffective in reducing carbon emissions.

Table 4: Share of households with positive present value of transfers from different policy mixes

Subsidy	Tax	low income	high income	total
Percent	income, linear	2.6%	89.7%	32.4%
Lump-sum	income, linear	28.2%	74.4%	44.0%
Percent	income, progressive	97.4%	0.0%	64.1%
Percent	consumption	0.0%	84.6%	28.9%
Percent	carbon tax	0.0%	87.2%	29.8%
Transfer	carbon tax	87.2%	15.3%	62.6%

Notes: The total share of households benefiting from the reform is computed by weighting the two income groups by their empirical shares of 0.342 and 0.658.

In summary, our analysis of the reduction-redistribution trade-off shows that different subsidy financing schemes have modest effects on adoption rates, but that there are large differences in the present value of net transfers. We abstract from any welfare gains from carbon reduction for the macroeconomy or specific groups of households, but provide an explanation for why some policy mixes may find little support among large segments of the electorate. Our results thus highlight the political economy constraints of climate policy when considering the transition period with heterogeneous adoption rates. High-income households are, on average, early adopters and thus net recipients of subsidies. To avoid deteriorating support for climate policy, the financing side of the policy must take heterogeneous adoption rates into account by relying on financing that redistributes to low-income households, such as a progressive income tax.

5 Conclusion

Policies to mitigate climate change are high on the political agenda, and policies targeting households are of particular interest because the household sector accounts for about two-thirds of total carbon emissions. A key issue for any climate policy is its distributional consequences. This paper evaluates different policy mixes with respect to their ability to reduce carbon emissions and their distributional consequences. We find that different policy mixes vary little in their ability to reduce carbon emissions, but differ widely in their distributional consequences. This conclusion results from a combination of novel empirical facts on the importance of consumption commitments for carbon emissions and a quantitative life-cycle model with permanent income heterogeneity for the transition period after the introduction of modern, carbon-neutral consumption goods.

Empirically, we first show that about 35 percent of total household emissions are generated by consumption that involves longer-term commitments. Cars, heating systems and their complements, oil and natural gas, are prime examples. Motivated by this empirical result, we build a quantitative life-cycle model with consumption commitments to evaluate different policy mixes in terms of their reduction-redistribution trade-off. We find that widely advocated carbon taxes have strong redistributive consequences, as low-income households are less likely to adjust to modern consumption commitments. Progressive financing of a price subsidy offers a policy mix that mitigates the redistributive consequences while still allowing for rapid adoption of carbon-neutral modern consumption goods. The main advantage of the percentage price subsidy is that it provides high incentives for high-income households to adopt modern consumption goods, but the progressive tax financing avoids the large fiscal burden on slowly adopting low-income households of other financing schemes, especially a carbon tax.

References

Axsen, Jonn, Josh Cairns, Nichole Dusyk, and Suzanne Goldberg (2018). "What drives the Pioneers? Applying lifestyle theory to early electric vehicle buyers in Canada". In: *Energy Research & Social Science* 44, pp. 17–30.

Chetty, Raj and Adam Szeidl (2007). "Consumption commitments and risk preferences". In: *The Quarterly Journal of Economics* 122.2, pp. 831–877.

— (2016). "Consumption commitments and habit formation". In: *Econometrica* 84.2, pp. 855–890.

Davis, Lucas W (June 2023). *The Economic Determinants of Heat Pump Adoption*. Working Paper 31344. National Bureau of Economic Research. DOI: 10.3386/w31344. URL: http://www.nber.org/papers/w31344.

De Nardi, Mariacristina, Eric French, and John B Jones (2010). "Why do the elderly save? The role of medical expenses". In: *Journal of political economy* 118.1, pp. 39–75.

Duarte, Rosa, Alfredo Mainar, and Julio Sánchez-Chóliz (2012). "Social groups and CO2 emissions in Spanish households". In: *Energy policy* 44, pp. 441–450.

Fehr, Hans, Manuel Kallweit, and Fabian Kindermann (2013). "Should pensions be progressive?" In: *European Economic Review* 63, pp. 94–116.

Figenbaum, Erik and Marika Kolbenstvedt (2016). "Learning from Norwegian battery electric and plug-in hybrid vehicle users". In.

Fridstrøm, Lasse and Vegard Østli (2021). "Direct and cross price elasticities of demand for gasoline, diesel, hybrid and battery electric cars: the case of Norway". In: *European Transport Research Review* 13.1, pp. 1–24.

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

— (2022). *Understanding the Inequality and Welfare Impacts of Carbon Tax Policies*. Tech. rep. Working Paper.

Gilmore, Elisabeth A and Lester B Lave (2013). "Comparing resale prices and total cost of ownership for gasoline, hybrid and diesel passenger cars and trucks". In: *Transport Policy* 27, pp. 200–208.

Glaeser, Edward L, Caitlin S Gorback, and James M Poterba (Dec. 2022). *How Regressive are Mobility-Related User Fees and Gasoline Taxes?* Working Paper 30746. National Bureau of Economic Research. DOI: 10.3386/w30746. URL: http://www.nber.org/papers/w30746.

Hardadi, Gilang, Alexander Buchholz, and Stefan Pauliuk (2021). "Implications of the distribution of German household environmental footprints across income groups for integrating environmental and social policy design". In: *Journal of Industrial Ecology* 25.1, pp. 95–113.

Hardman, Scott, Eric Shiu, and Robert Steinberger-Wilckens (2016). "Comparing high-end and low-end early adopters of battery electric vehicles". In: *Transportation Research Part A: Policy and Practice* 88, pp. 40–57.

Hardman, Scott and Gil Tal (2016). "Exploring the decision to adopt a high-end battery electric vehicle: role of financial and nonfinancial motivations". In: *Transportation Research Record* 2572.1, pp. 20–27.

Holland, Stephen P, Erin T Mansur, and Andrew J Yates (2021). "The electric vehicle transition and the economics of banning gasoline vehicles". In: *American Economic Journal: Economic Policy* 13.3, pp. 316–344.

Isaksen, Elisabeth T and Patrick A Narbel (2017). "A carbon footprint proportional to expenditure-A case for Norway?" In: *Ecological Economics* 131, pp. 152–165.

Känzig, Diego R (2021). "The unequal economic consequences of carbon pricing". In: *Available at SSRN 3786030*.

Kerkhof, Annemarie C, Henri C Moll, Eric Drissen, and Harry C Wilting (2008). "Taxation of multiple greenhouse gases and the effects on income distribution: A case study of the Netherlands". In: *Ecological Economics* 67.2, pp. 318–326.

Lanteri, Andrea and Adriano A Rampini (2023). "Financing the Adoption of Clean Technology". In.

LCP Delta (2021). *Heat pump costs projected to fall by 40 percent.* URL: https://delta.lcp.com/press-release/heat-pump-costs-projected-to-fall-by-40/.

Lee, Jae Hyun, Scott J Hardman, and Gil Tal (2019). "Who is buying electric vehicles in California? Characterising early adopter heterogeneity and forecasting market diffusion". In: *Energy Research & Social Science* 55, pp. 218–226.

Lévay, Petra Zsuzsa, Yannis Drossinos, and Christian Thiel (2017). "The effect of fiscal incentives on market penetration of electric vehicles: A pairwise comparison of total cost of ownership". In: *Energy Policy* 105, pp. 524–533.

Miehe, Robert, Rene Scheumann, Christopher M Jones, Daniel M Kammen, and Matthias Finkbeiner (2016). "Regional carbon footprints of households: a German case study". In: *Environment, Development and Sustainability* 18, pp. 577–591.

Nextmove (2023). *Preisverfall bei E-Autos?* URL: https://nextmove.de/preisverfall-bei-e-autos/?privacy=updated.

Ohlendorf, Nils, Michael Jakob, Jan Christoph Minx, Carsten Schröder, and Jan Christoph Steckel (2021). "Distributional impacts of carbon pricing: A meta-analysis". In: *Environmental and Resource Economics* 78.1, pp. 1–42.

Perobelli, Fernando Salgueiro, Weslem Rodrigues Faria, and Vinicius de Almeida Vale (2015). "The increase in Brazilian household income and its impact on CO2 emissions: Evidence for 2003 and 2009 from input–output tables". In: *Energy Economics* 52, pp. 228–239.

Postlewaite, Andrew, Larry Samuelson, and Dan Silverman (2008). "Consumption commitments and employment contracts". In: *The Review of Economic Studies* 75.2, pp. 559–578.

RWI and Forsa (2015). "The German Residential Energy Consumption Survey 2011-2013". In: *RWI Projektberichte*.

Santos, Cezar and David Weiss (2016). ""Why not settle down already?" a quantitative analysis of the delay in marriage". In: *International Economic Review* 57.2, pp. 425–452.

Schloter, Lukas (2022). "Empirical analysis of the depreciation of electric vehicles compared to gasoline vehicles". In: *Transport Policy* 126, pp. 268–279.

Segovia, Javier López (2021). "Consumption Commitments and Unemployment Insurance". In.

Shore, Stephen H and Todd Sinai (2010). "Commitment, risk, and consumption: do birds of a feather have bigger nests?" In: *The Review of Economics and Statistics* 92.2, pp. 408–424.

Stadler, Konstantin, Richard Wood, Tatyana Bulavskaya, Carl-Johan Södersten, Moana Simas, Sarah Schmidt, Arkaitz Usubiaga, José Acosta-Fernández, Jeroen Kuenen, Martin Bruckner, et al. (2018). "EXIOBASE 3: Developing a time series of detailed environmentally extended multi-regional input-output tables". In: *Journal of Industrial Ecology* 22.3, pp. 502–515.

Statista (2023). *Vergleich der Anschaffungskosten verschiedener Heizsysteme in Deutschland im Jahr 2022*. URL: https://de.statista.com/statistik/daten/studie/380742/umfrage/anschaffungskosten-verschiedener-heizsystem-in-deutschland/.

Verivox (2023). *Heizkostenvergleich: Wärmepumpe bis zu 39 Prozent günstiger als Erdgas*. URL: https://www.verivox.de/strom/nachrichten/heizkostenvergleich-waermepumpe-bis-zu-39-prozent-guenstiger-als-erdgas-1119298/.

Westin, Kerstin, Johan Jansson, and Annika Nordlund (2018). "The importance of socio-demographic characteristics, geographic setting, and attitudes for adoption of electric vehicles in Sweden". In: *Travel Behaviour and Society* 13, pp. 118–127.

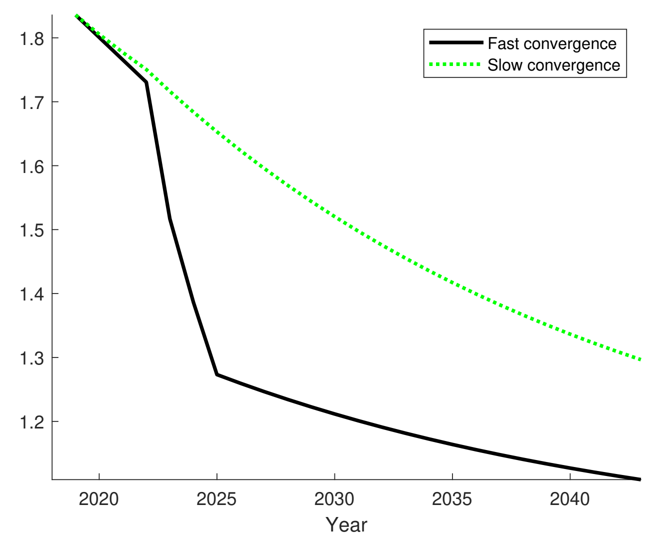
Wiedenhofer, Dominik, Dabo Guan, Zhu Liu, Jing Meng, Ning Zhang, and Yi-Ming Wei (2017). "Unequal household carbon footprints in China". In: *Nature Climate Change* 7.1, pp. 75–80.

A Additional results

This subsection presents further details on the price convergence of the modern and old commitment good that we assume for the transition period. We also report the fit of the model to the most recent data on the adoption of modern commitment goods.

Figure A1 shows the aggregated price path for the composite commitment good in the model that underlies the policy experiment in Section 4. We compute results for a fast and a slow convergence of the price premium ω of the modern commitment good. Section 4 shows results for the fast convergence. Results for the slow convergence are in Appendix B.1. We find that the fast convergence path shows a particularly strong convergence of prices until the year 2025. As we will further discuss below, the reason for this fast convergence is that prices for electric cars are predicted to converge very quickly so that there will be no price premium for electric cars after 2025. The non-zero price premium and the ongoing convergence is after 2025 only a result of the convergence of the price for heating systems.

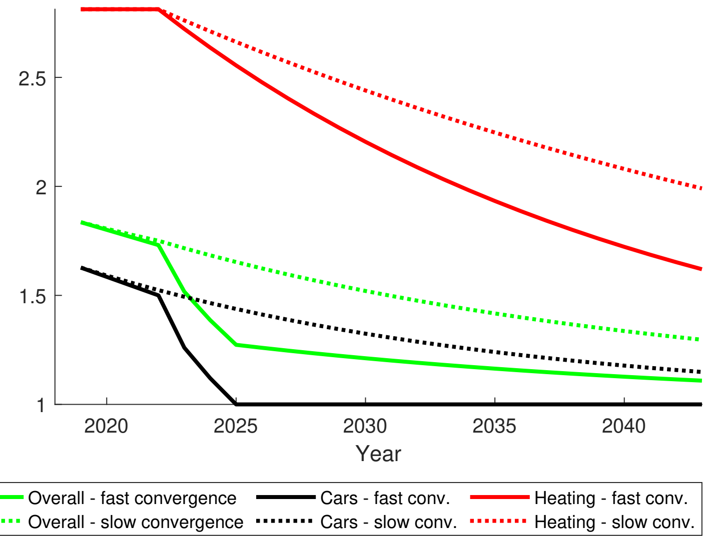
Figure A1: Price for modern commitment goods relative of old commitment goods



Notes: This figure plots the price paths for modern relative to old commitment goods. The solid black line describes the baseline scenario whereas the green dotted line describes the slower convergence, which we assume to evaluate the robustness of our results.

Figure A2 shows the separate paths for price premia for electric cars and heating systems that we aggregate to the price premium ω shown in Figure A1. Aggregation weights combine expenditure shares and adjustment frequency to get a composite commitment good (see footnote 5). We show for electric cars and heating systems a slow and fast convergence scenario that we aggregate accordingly for the composite commitment good. For electric cars, we observe the fast convergence until 2025 so that in the fast convergence scenario the price premium for cars has disappeared by 2025. This convergence explains the kink in the fast convergence scenario in Figure A1.

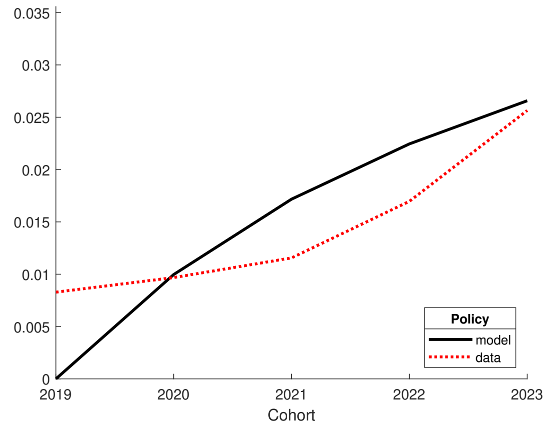
Figure A2: Price for modern commitment goods relative of old commitment goods



Notes: This figure plots the price paths for modern relative to old commitment goods. The solid lines describe the baseline scenario whereas the dotted lines describe slower convergence, which we assume to evaluate the robustness of our results.

Figure A3 compares the adoption rates for the modern commitment good after its introduction in the model and compares the path to the data. The model starts at a share of zero for modern good in 2019 whereas the share is already positive in the data. In year 2020, the model has already converged to the data and after that model and data show a close alignment in adoption rates increasing by about half a percentage point per year. We take this as further supporting evidence that the model matches the speed of adoption of the modern commitment good closely.

Figure A3: Comparison of adoption of modern commitment good with data



Notes: This figure shows the adoption of the modern commitment good after its introduction relative to data from 2019 to 2023.

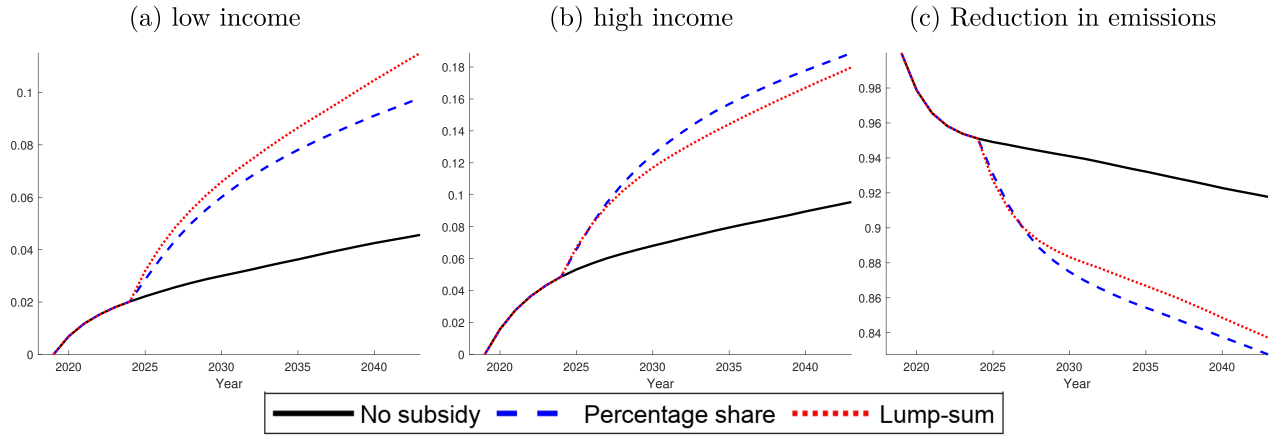
B Results for different price convergence paths of the modern commitment good

This section presents the results for different convergence paths of the price premium for modern commitment goods over the transition period. Section B.1 reports results for a slow price convergence , before presenting the results without any price convergence over time.

B.1 Slow price convergence

Figure A4 presents the share of households with modern commitment goods for the low- and high-income group, as well as the reduction in emissions along the transition period. As prices for modern commitment goods convergence at a slower rate to those of the old commitment good, we find that the shares of households with modern commitment goods and consequently the reduction in carbon emission to be slower compared to the baseline scenario. Qualitatively our baseline results are confirmed by this check.

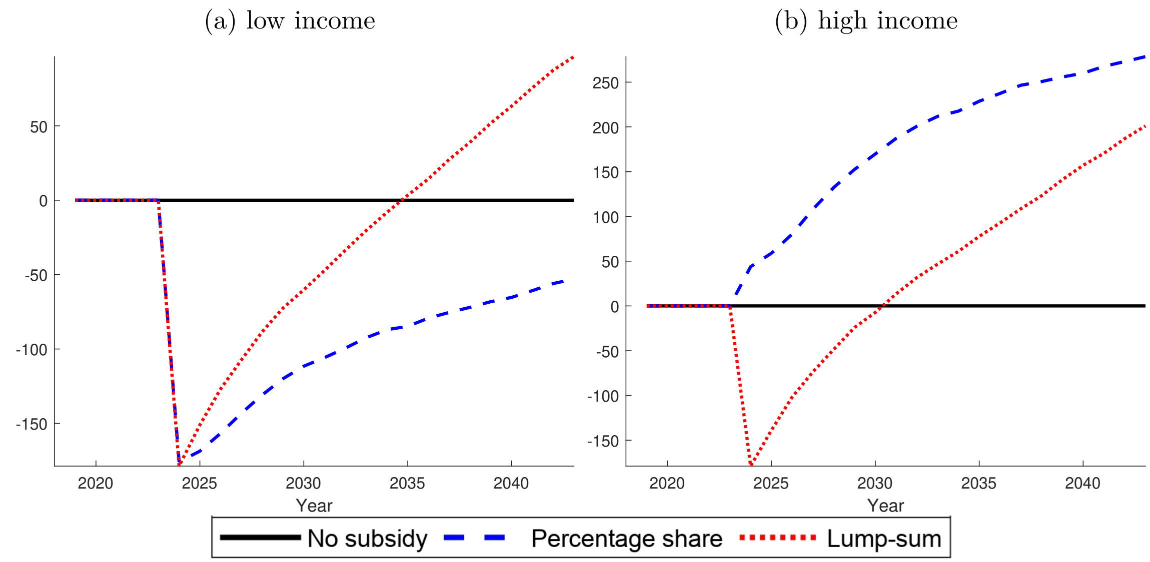
Figure A4: Share of households with modern commitment good by income and reduction in carbon emissions



Notes: Panel (a) and (b) plot the share of households with a modern consumption commitment good along the transition for both types of subsidies and without any subsidy for low- and high-income households. Panel (c) plots the reductions in carbon emissions for both subsidy types along the transition. We assume that carbon emissions are proportional to the size of the commitment good.

Figure A5 shows the annual net transfers under this price scenario. Redistribution from poor to rich is lower in this scenario as fewer modern goods are bought.

Figure A5: Annual net transfers

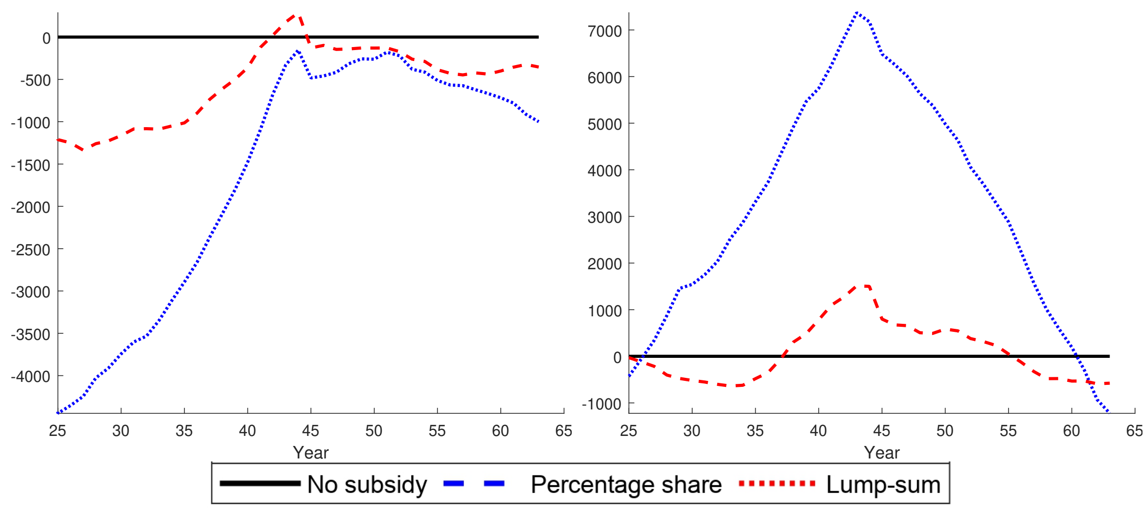


Notes: This figure depicts the net governmental transfers of different policies to finance a 24.6 percent subsidy on the modern commitment good under the scenario of the slow price convergence. Transfers are in Euros per year.

Figure A6 depicts the present value of net transfers for both income groups under the slower price convergence scenario. The heterogeneity of present values across age groups is smaller than in the fast price convergence scenario. As primarily old households buy modern commitment goods in both scenarios, this is consistent with the fact that the overall number of modern commitment goods bought decreases.

Figure A6: Present value of net transfers for different age groups and subsidies

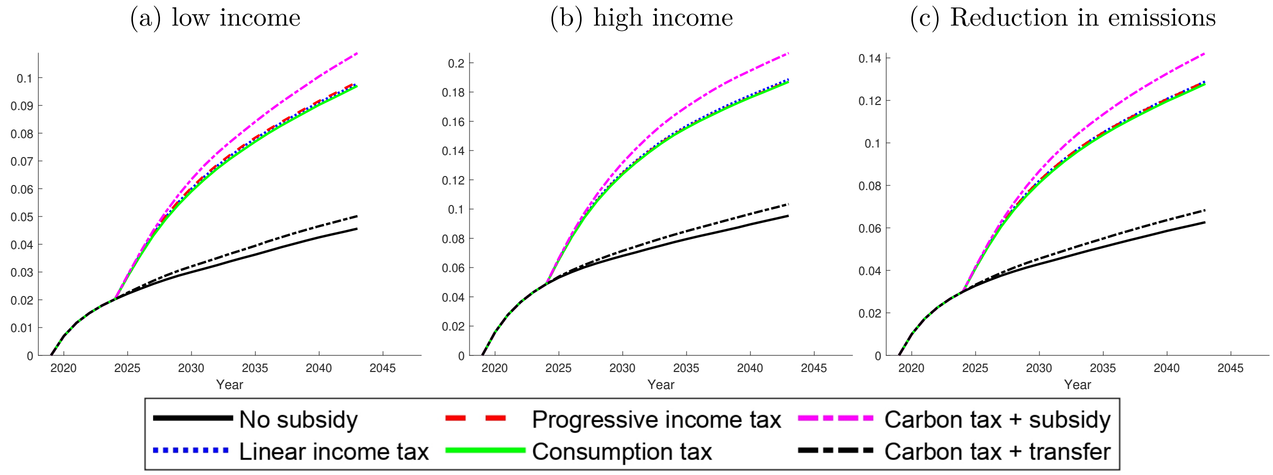
(a) low income (b) high income



Notes: These figures plot the aggregated net transfers of the policies.

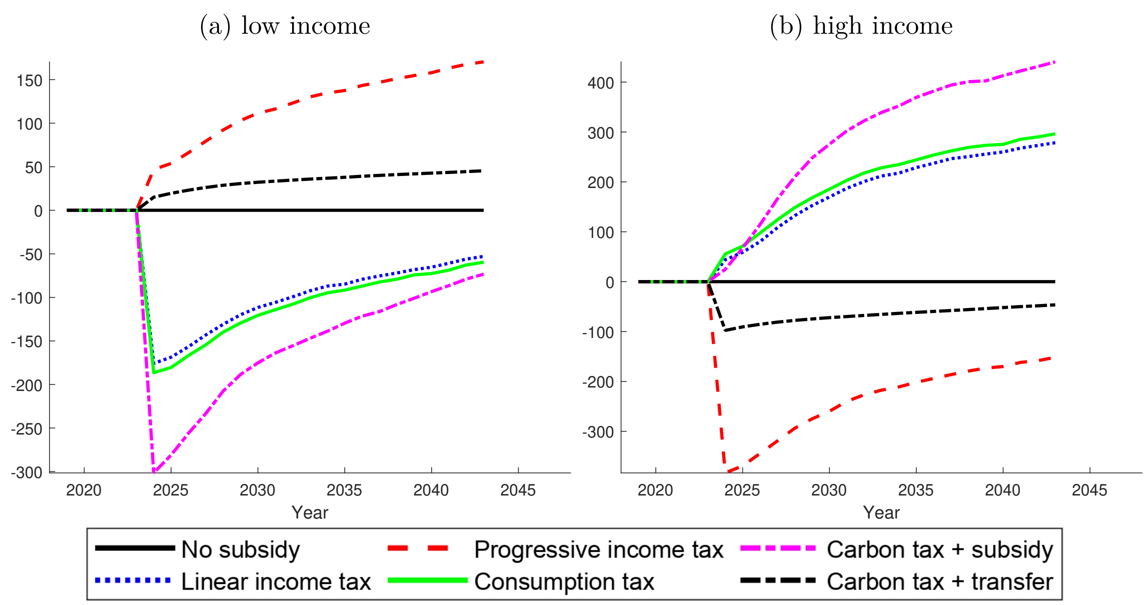
Figures A7, A8, and A9 present the results on the financing side under the slower price convergence scenario. Again, we observe the the net transfers in absolute terms are slower than in the faster price convergence scenario as fewer households buy modern commitment goods. Hence, we find that also the present value of net transfers is smaller in size.

Figure A7: Share of households with modern commitment good by income and reduction in carbon emissions



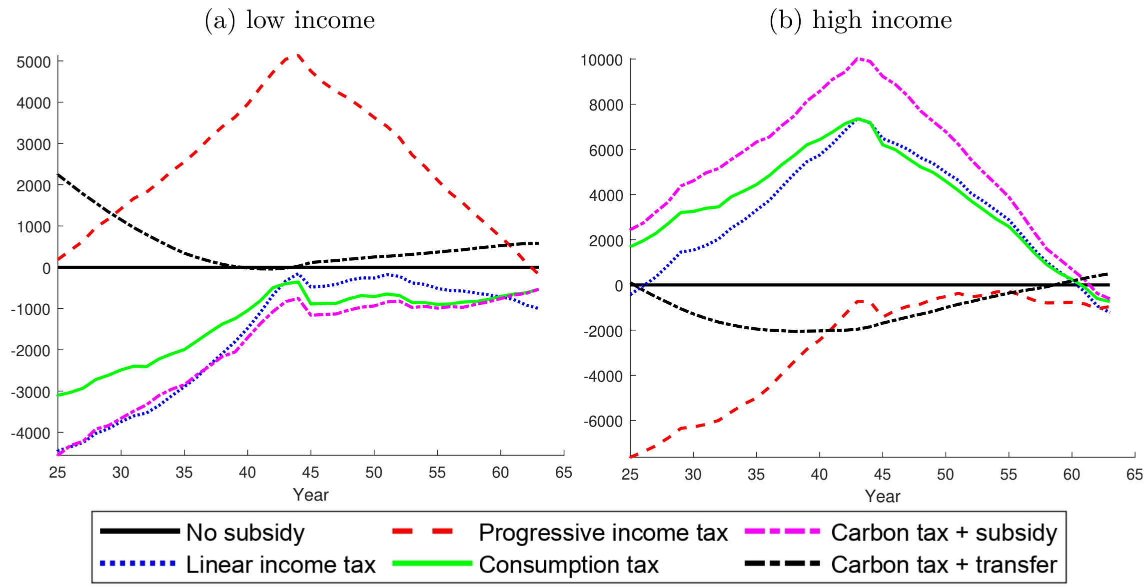
Notes: Panel (a) and (b) plot the share of households with a modern consumption commitment good along the transition for both types of subsidies and without any subsidy for low- and high-income households. Panel (c) plots the share of households with a modern consumption commitment good along the transition for all households.

Figure A8: Annual net transfers



Notes: This figure depicts the net governmental transfers of different policies to finance a 24.6 percent subsidy on the modern commitment good under the scenario of the slow price convergence. Transfers are in Euros per year.

Figure A9: Present value of net transfers for different age groups and subsidies

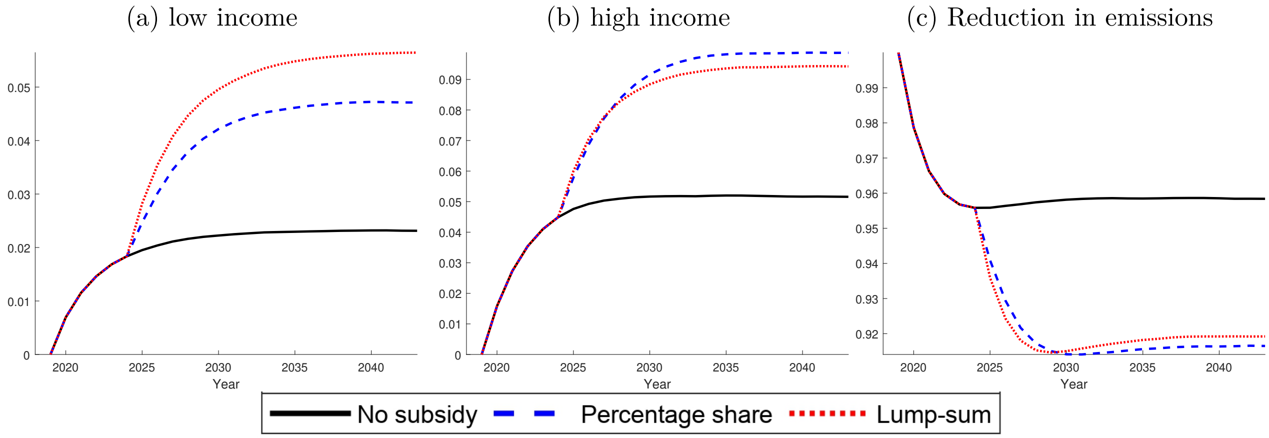


Notes: These figures plot the aggregated net transfers of the policies.

B.2 No price convergence

Lastly, this subsection presents our results without any price convergence implying that the price premium for modern commitment goods stays as in the initial steady state throughout the whole transition period. Figure A10 presents the share of households with modern commitment goods and the reduction in emission under the price scenario. Not surprisingly, we find that the share of households with modern commitment goods and the reduction in emissions to be smaller than in both price scenarios we presented before.

Figure A10: Share of households with modern commitment good by income and reduction in carbon emissions

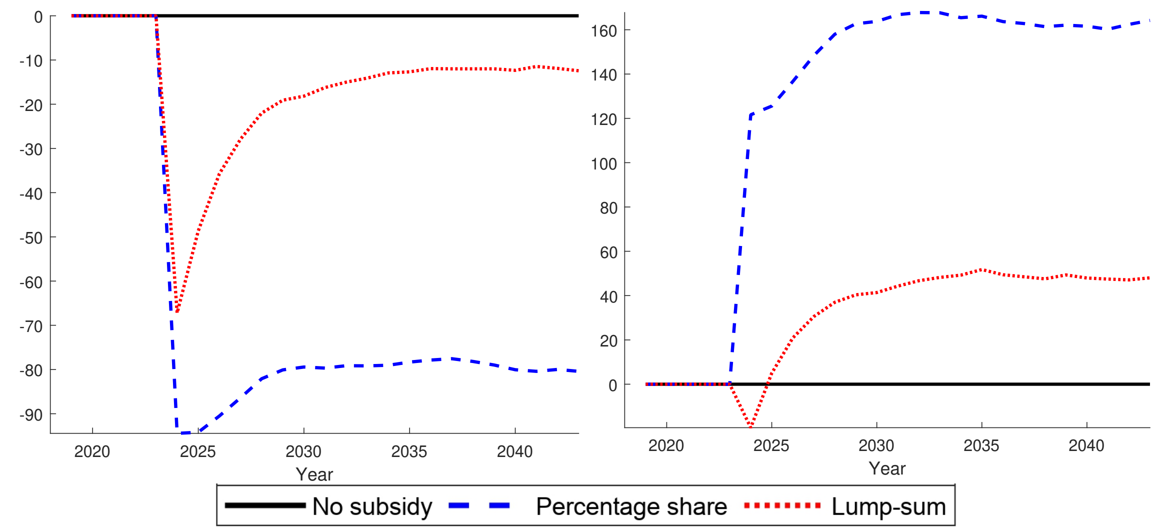


Notes: Panel (a) and (b) plot the share of households with a modern consumption commitment good along the transition for both types of subsidies and without any subsidy for low- and high-income households. Panel (c) plots the reductions in carbon emissions for both subsidy types along the transition. We assume that carbon emissions are proportional to the size of the commitment good.

Figures A11 and A12 depict the annual net transfers and the present value of net transfers of the two subsidies. Strikingly, we find that annual transfers are negative for low income households and positive for high income households for the whole transition period. This is different to the price scenarios before and can be explained by the fact that modern prices to not fall over the transition period which before increased the number of poor households adjusting to modern commitment goods.

Figure A11: Annual net transfers

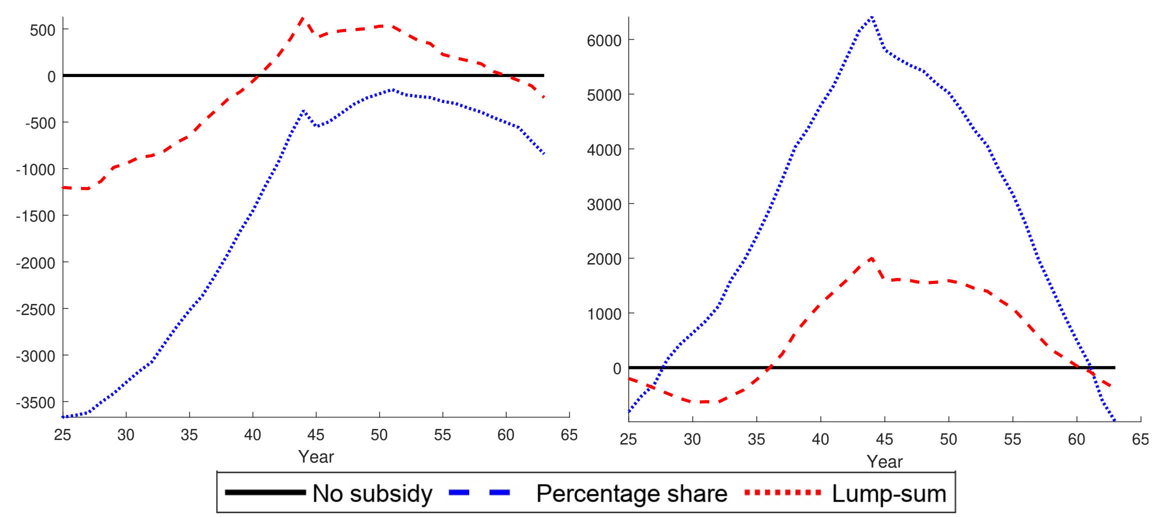
(a) low income (b) high income



Notes: This figure depicts the net governmental transfers of different policies to finance a 22.1 percent subsidy on the modern commitment good under the scenario of the slow price convergence. Transfers are in Euros per year.

Figure A12: Present value of net transfers for different age groups and subsidies

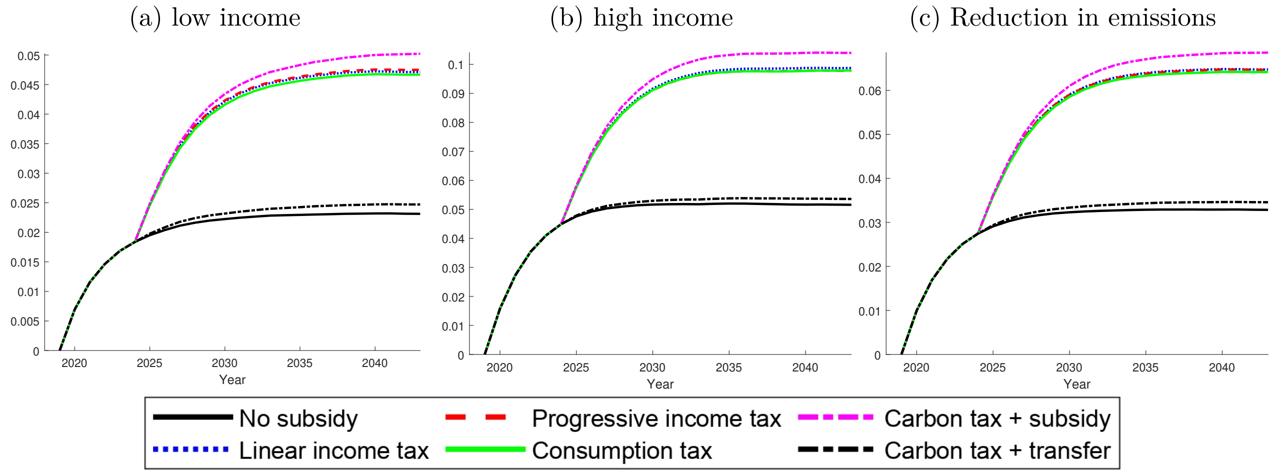
(a) low income (b) high income



Notes: These figures plot the aggregated net transfers of the policies.

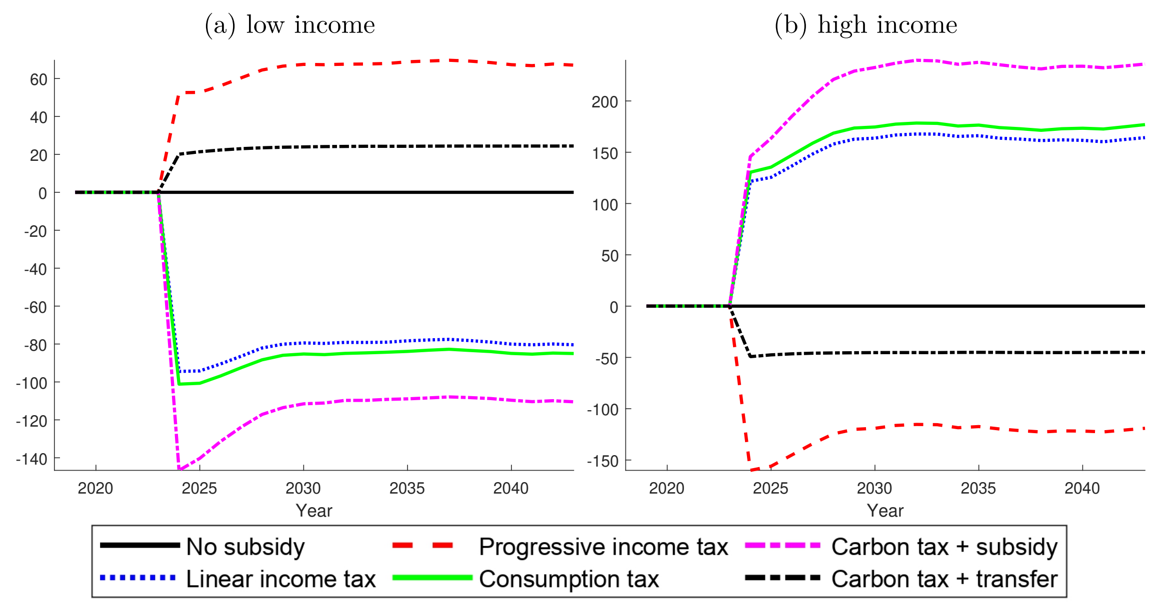
Lastly, Figures A13, A14, and A15 show the results on the financing side. We can observe that the absolute size of annual transfers are smaller compared to both price scenarios before, while the qualitative results remain unchanged.

Figure A13: Share of households with modern commitment good by income and reduction in carbon emissions



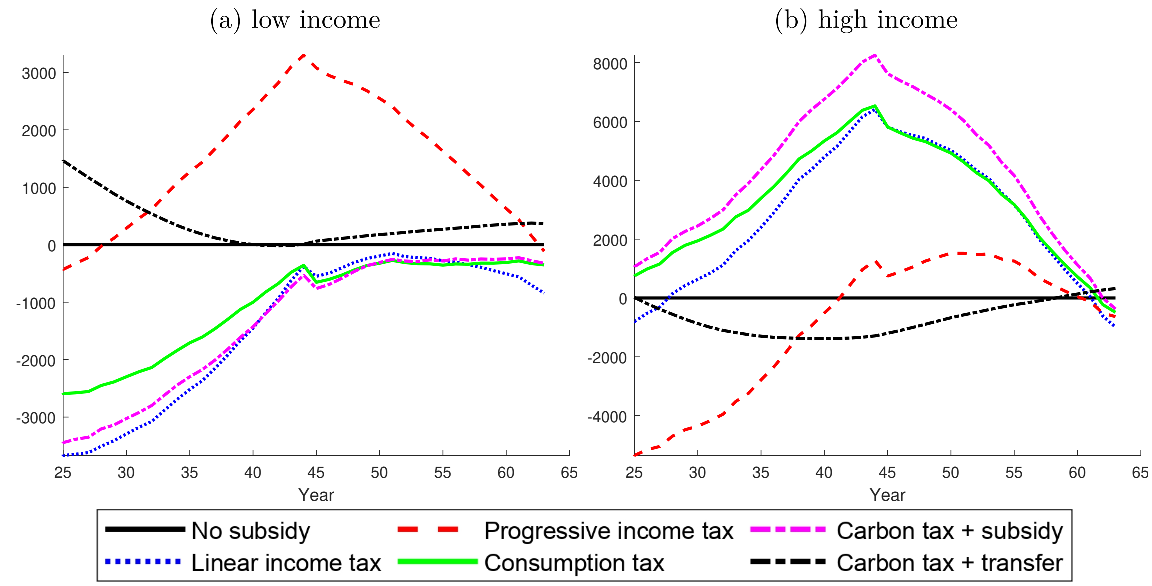
Notes: Panel (a) and (b) plot the share of households with a modern consumption commitment good along the transition for both types of subsidies and without any subsidy for low- and high-income households. Panel (c) plots the share of households with a modern consumption commitment good along the transition for all households.

Figure A14: Annual net transfers



Notes: This figure depicts the net governmental transfers of different policies to finance a 22.1 percent subsidy on the modern commitment good under the scenario of the slow price convergence. Transfers are in Euros per year.

Figure A15: Present value of net transfers for different age groups and subsidies



Notes: These figures plot the aggregated net transfers of the policies.