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. Their effectiveness in reducing carbon emissions and their distributional consequences are actively debated. One key reason for the ongoing debate is that quantitative answers regarding the reduction-redistribution trade-offs of such policies remain limited. Looking at the emissions of household consumption, 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. Our results for the reduction-redistribution trade-off show that a percentage subsidy for carbon-neutral consumption effectively reduces emissions by targeting high-income households. If the subsidy is financed by a progressive income tax, it yields a policy mix that leads to rapid emission reductions and a majority of households supporting its distributional effects.

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 policy 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 to this question 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 11 percent of household expenditures. We also confirm the 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 will 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 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 of a percentage subsidy for the modern commitment good increases the speed of adoption the most and generates a majority of winners if it is financed by a progressive income tax. Non-progressive taxes instead 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 450 euros per year and net transfers for high-income households of up to 650 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 a strong reduction in emissions with one out of five households adopting the modern carbon-neutral consumption good 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. We also study a policy that is popular in the public debate and that combines a carbon tax to increase the user cost of commitment consumption with transfer payments to counteract redistributive effects from higher taxes on carbon emissions. 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. To match the same reduction in carbon emissions, the tax has to be 2.7-times higher than in the baseline case and will yields annual transfers of 2,000 Euros per household or 82 billion Euros at the level of the German macroeconomy. Such an high carbon tax would also have effects on inflation rates. We find that the price level would increase on average by 4.9pp and by 5.3pp for low-income households in case of the high carbon tax. By contrast, the percentage subsidy will lower the average price level by 0.2pp.

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). They show that consumption commitments constitute a considerable share of household's consumption and are important to explain their consumption behavior. 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 trade-off between reducing carbon emissions 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 based on a structural model.

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) evaluate 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 U.S. economy. They find that the optimal policy differs substantially between the two groups. Households in the current steady state prefer uniform, lump-sum rebates, while households in the future steady state prefer reducing existing distortionary taxes. 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 their 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 trade-off. We also summarize our extensive sensitivity analysis that we provide in the Appendix B. 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 percent 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.

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 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 compute 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.[2]

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

[2] Adjusting consumption for underreporting increases carbon footprints along the entire income distribution. Carbon emissions increase on average by 11 percent but changes are hump-shaped along the income distribution with an increase at the bottom and the top of 7 percent and 8 percent respectively. The share of consumption commitments increases on average from 37 percent to 40 percent when accounting for underreporting what further increases the role of consumption commitments for emissions.

We will rely on the EVS 2018 data as our main data for the empirical analysis and for calibrating the model. For the calibration, we will supplement the EVS data with data from the *RWI-GRECS: German Residential Energy Consumption Survey*, short GRECS.[3]

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 and heating systems. 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 the specific commitment property of these goods that households need to consume a certain amount of the 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.[4]

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).[5] We find that a household in the first quintile emits around 8 tons of carbon 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 having on average more family members. But even when we consider per-capita equivalent emissions (yellow bars), carbon footprints still increase substantially along the income distribution. 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 control for potential life-cycle effects. But after taking out age effects, we find only a negligible effect on per-capita emissions (black bars).

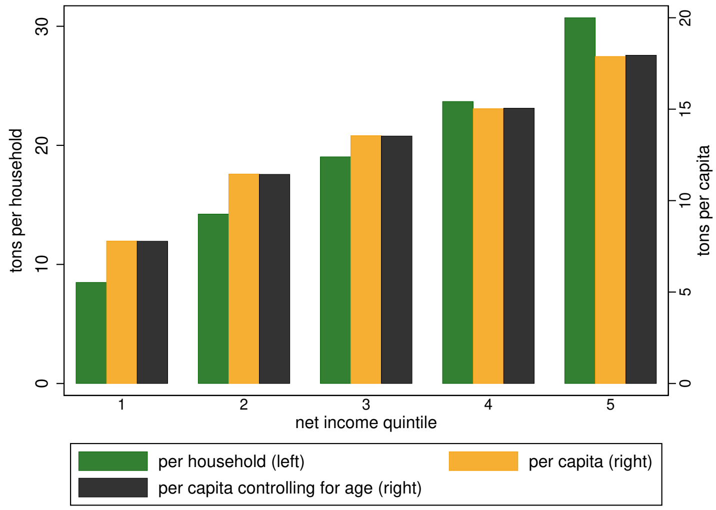
Figure 2 explores the role of consumption commitments for the carbon emissions of households from Figure 1. We find that on average around 35 percent of total household emissions are generated by commitment goods (yellow bars), while consumption commitments account for only 10 to 13 percent of household expenditures (black bars). Hence, consumption commitments account for

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

[4]There is no separate information in the EVS data on expenditures for heating systems but they are subsumed in housing investments. As buying a new heating system is very infrequent, we abstract from the expenditures for heating systems in our empirical analysis. Our results constitute therefore a lower bound on the expenditure of commitment consumption.

[5]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).

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

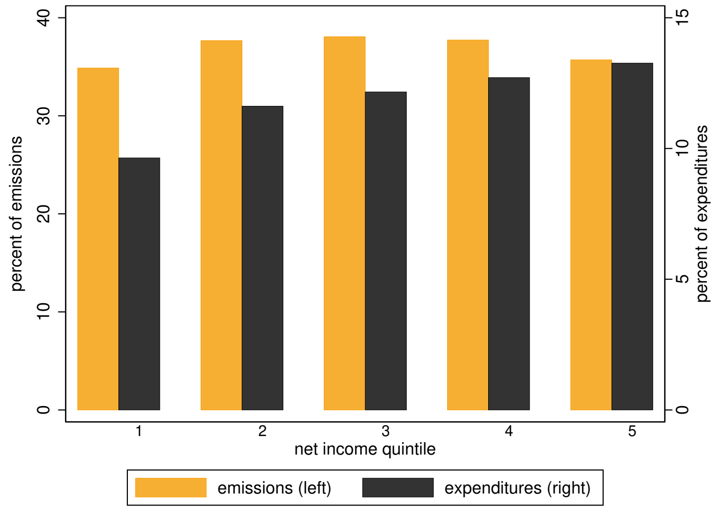


Notes: This figure depicts the average level of carbon emissions of households for different income quintiles. Per capita measures are computed based on the modified OECD scale. Household size is computed as the sum of weights of household members. The first adult member has a weight of 1.0, the second adult member of 0.5, and each child has a weight of 0.3. The results that control for age remove the effect of a quadratic age polynomial. Results are based on 2018 EVS data.

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 of expenditure 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 shares in 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 17.2 percent of total emissions and the top 25%, account for almost 40 percent of all emissions. By contrast, the bottom 25% of households account for only 12 percent of total emissions and thereby for less than a third of the emissions of the top 25% of households. A 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 subsidies for high-income households to adjust their consumption are financed 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. We will discuss the empirical evidence that provides support for this fact of faster adoption with income in the calibration section (Section 3.3).

Figure 2: Share of emissions and expenditures from consumption commitments by income



Notes: This figure shows the share of total emissions and total expenditures for consumption commitments by income quintile. See text for details on the definition of consumption commitments. Results based on 2018 EVS data.

Table 1 also reports differences in carbon emissions by (permanent) income by looking at households with different 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 percent 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 our grouping of households by education to capture permanent income differences is conservative as there is still substantial overlap in terms of income between the two education groups. Our quantitative results therefore likely constitute a lower bound of the redistributive effects of climate policies as they will rely on the proxy of 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

Table 1: Income and emission shares

	bottom 25%	25%-50%	50%-75%	top 25%	top 10%
emission share	12.0	20.9	28.5	38.6	17.2
income share	8.9	17.3	26.7	47.1	24.5
		no college	college		
income share		53.6	46.4		
population share		65.8	34.2		
emission level (in tons)		17.7	21.9		

Notes: Income shares and emission shares for different households groups. Upper part of the table shows income and expenditure shares for different income groups. Lower part shows income and expenditure shares for college and non-college households and the level of emissions in tons. Results are based on 2018 EVS data.

support the adoption process to modern commitment goods and with respect to their distributive effects. We will provide an extensive sensitivity analysis with respect to key modelling choices.

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 $\tilde{\mathbf{y}}_j$.

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). The parameters governing the luxurious good utility are θ^m and ψ^m. This luxurious good utility aligns the model with the empirical literature that finds that modern commitment goods are consumed to a much higher extent by high-income households (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 that are also long lasting but are not associated with user costs. 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 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

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

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 θ determines the strength of the life-cycle savings motive and the parameter Ω governs the importance of social security wealth for retirement.[6] Both parameters will be calibrated to match life-cycle wealth accumulation.

[6]The functional form follows De Nardi et al. (2010) who use it to model utility from bequests. The parameter Ω could therefore alternatively be interpreted as determining the strength of a bequest motive.

3.2 Recursive formulation of the dynamic decision problem

Each period the household makes a consumption-saving decision and an adjustment decision for its commitment good. 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

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

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

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

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

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

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. At the final stage consumption takes place.

3.3 Calibration

The goal of the calibration is to provide a quantitative laboratory to explore the reduction-redistribution trade-off of different climate 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 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 interpreted 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. Average household income in the model provides a normalization and is set to 48,609 Euro in line with the EVS data. 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.[7] 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 $\omega = 1.84$.[8] 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 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.

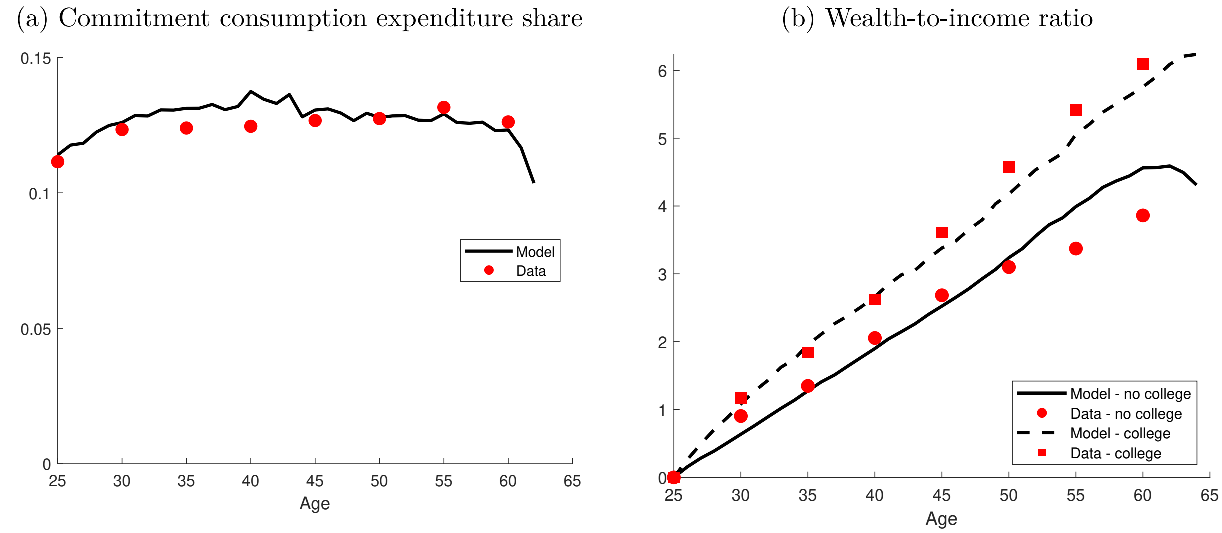
The remaining eleven parameters are calibrated within the model to match corresponding data moments. Six of these parameters, μ, κ, θ^m, β, Ω, and θ are calibrated to the initial steady state in 2018. The weight on utility from commitment consumption μ is calibrated to match the share of carbon emissions from consumption commitments generated by college households relative to all

[7] 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.

[8] 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 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 percent and heating systems of 18 percent.

households. In the 2018 EVS data, the share of carbon emissions from consumption commitments from college households is 36.6 percent. 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. To calibrate the weight on the luxurious good utility for the modern commitment good θ^m, we target the costs (purchase price and flow costs) of the commitment good as share of total household expenditure.

Figure 3: Life-cycle profiles from consumption-saving decision



Notes: The figure shows the model fit for the consumption commitment expenditure share and the wealth-to-income profiles for college and non-college households. Data shown as red dots and squares in 5-year age bins. Model simulation shown as black lines. Consumption commitment expenditure share shown as fraction of total household expenditure. Data from 2018 EVS data.

We calibrate the time discount factor β and the parameters of the utility function of wealth in retirement Ω and θ 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 figure shows that the model mechanism matches closely the untargeted life-cycle evolution of both income groups.

The remaining five parameters, μ_a, μ_x, σ_a, σ_x, and ψ^m 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 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 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.[9] Lastly, we calibrate the curvature of the luxurious utility function for modern commitment goods ψ^m to the ratio of modern adjustments made by high-income households (college households) relative to low-income households (non-college households). For this target, we rely on estimates for Norway in 2016 (Figenbaum and Kolbenstvedt, 2016) for electric cars and own estimates using the GRECS dataset for heat pumps. Figenbaum and Kolbenstvedt (2016) report 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 data 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. We summarize the calibrated model parameters in Table 2.

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 of the modern consumption good 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

[9]Another widely used measure in the literature is the percentage increase in purchases for modern commitment goods if prices decrease by 1,000 Euro. We find that purchases would increase by around five percent, which is well in line with the literature. Studying 32 European countries between 2010 and 2017 Münzel et al. (2019) find that sales shares for electric vehicles increase by five to seven percent and Clinton and Steinberg (2019) find an increase of around seven percent in electric vehicle registrations per capita in the United States between 2010 and 2014. We take this as further support for our calibration.

Table 2: Calibrated parameters

Symbol	Description	Value	Source/Target
σ	Risk aversion	1.5	
r	Interest rate	0.02	
ϕ_{col}	Share of college graduates	0.342	EVS (2018)
ω	Price premium modern good	1.84	See text
δ	Cut in flow costs with modern good	0.226	See text
ρ_{rs}	Resale value	0.262	See text
p_o	Prob. depreciation old good	0.3254	Schloter (2022)
p_m	Prob. depreciation modern good	0.4349	Schloter (2022)
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	Weight commit. consumption	0.29	Share emissions college
κ	Share flow costs commitment size	0.171	Share flow costs to total commit. costs
θ_m	Weight modern commit. consump.	0.89	Share commit. to total consumption
β	Discount rate	0.986	Average WTI-ratio
Ω	Importance of social security wealth	11	Diff. bequests college/non-college
θ	Life-cycle savings motive	61	Average WTI-ratio at death
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
ψ_m	Curvature modern commit. consump.	1.4	Ratio modern good college/non-college

Notes: This table presents the calibrated model parameters. Uppar part shows parameters set based on external sources. Lower part shows internally calibrated parameters. Column *symbol* reports the parameter and column *value* the calibrated value.

modern commitment good and receive subsidies.[10] If there is heterogeneity in the semi-elasticities, this implies that the group with the larger semi-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 semi-elasticities are increasing with age for high-income households and that they are hump-shaped in age for low-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

[10] 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.

between low- and high-income households regarding the range of semi-elasticities. Older low-income households show about the same semi-elasticity as 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 for 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	0.01	0.05	0.07	0.12	0.05	0.12

Notes: This table shows the semi-elasticity in percentage points for the modern commitment good for different age and income groups. Semi-elasticity reported as the percentage point increase of households purchasing the modern commitment good after a one percent decrease in the price of the good. First row reports age of household in the model, second row reports permanent income group z, and bottom row the value for the semi-elasticity from the model.

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 49, 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.

4 Policy experiments

We will now use the calibrated model to study different policy mixes with respect to their 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 that increasing the speed of the transition to low carbon emissions requires that high-income households with larger carbon footprints receive sufficiently strong financial incentives for adjusting. On the redistribution side, because of heterogeneous adoption rates, such a policy is likely to result in net transfers from low-adjusting low-income households to high-adjusting high-income households. Our policy analysis will therefore explore different policy mixes of subsidies for modern technologies and financing options. We will quantify the present value of net transfers at the household level for the different policy mixes as our measure of political support for a policy to see which policy mixes satisfy the political economy constraint that they find majority support among today's electorate (support of the median voter).

Our policy experiments start from an initial steady state in which only the old commitment good exists and which we calibrate to the year 2018.[11] 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 constant policy mix in place. We will always focus the analysis on the group of households that are (economically) alive when the policy is introduced and follow these households over time. In Appendix B.4, we show how transition dynamics are affected if young (newborn) households enter the economy during the transition period. Although we find that the dynamics will change quantitatively, the conclusions of the policy analysis will remain unchanged. We opt for the focus on the currently alive households to allow for an informative comparison of policy mixes. Including newborn households will lead to intergenerational transfers that will differ across policy mixes and that will, therefore, render the comparison of the policy mixes uninformative.

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 A5 shows the baseline price scenario for the modern composite commitment good, as well as the slower

[11]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.

convergence scenario. Appendix Figure A6 shows the price scenarios for cars and heat pumps separately. We report the results of the analysis for the more conservative price scenario in Appendix B.2.

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. 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

$$\sum_{t=2024}^{2043} \frac{1}{(1+r)^{t-2024}} \tau_y \int_i y_{i,t} di = \sum_{t=2024}^{2043} \frac{1}{(1+r)^{t-2024}} \pi_1 \int_i \zeta_{i,t} \tilde{x}_{i,t+1} di \tag{7}$$

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

$$\sum_{t=2024}^{2043} \frac{1}{(1+r)^{t-2024}} \tau_y \int_i y_{i,t} di = \sum_{t=2024}^{2043} \frac{1}{(1+r)^{t-2024}} \pi_2 \int_i \zeta_{i,t} di \tag{8}$$

where π_2 denotes the lump-sum tax for buying a modern commitment good ($\zeta_{i,t} = 1$). As now the subsidy is lump sum, the right-hand side becomes independent of the size of the modern commitment good $x_{i,t}$.

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 on top of the subsidy for the modern good further increase 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. In this case, the reduction of carbon emissions will only result from higher user costs of the old commitment good and redistribution comes from the lump-sum transfer of tax revenue of the carbon tax.

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 between 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. By 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

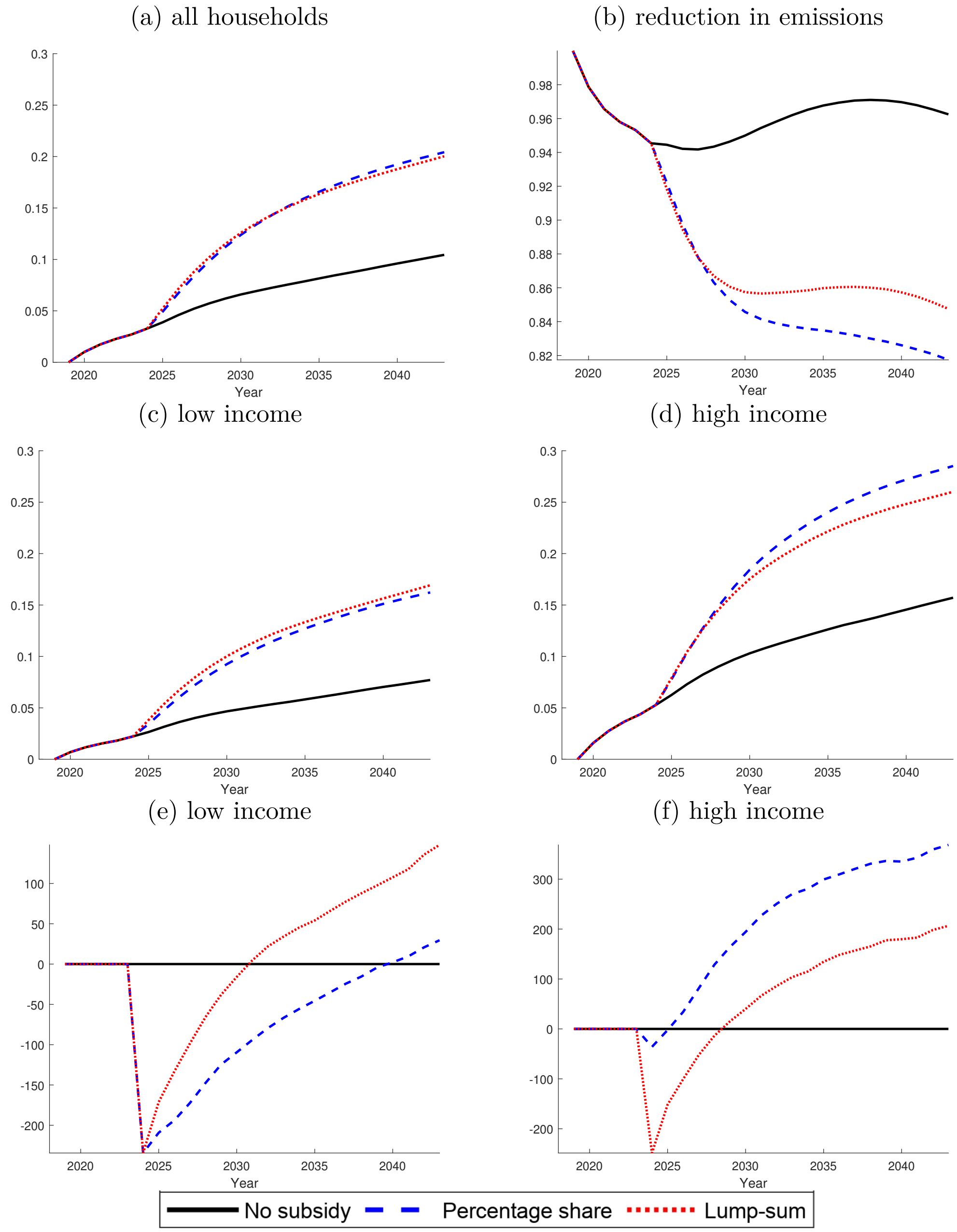
$$E_m^L = (1-\phi)[\omega x' - \rho_{rs}x] + \phi[\omega(x' - \rho_{rs}x)] - \min\{\pi_2, \omega x'\}$$

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 determine 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.[12] We then determine the linear income tax τ_y so that the government runs a balanced budget over the entire transition period (equation (8)). This approach yields a tax rate $\tau_y = 0.011$. To make the proportional subsidy comparable, we set $\pi_1 = 0.253$ which implies again that the government runs a balanced budget at the same income tax rate (equation (7)).

[12] 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. Note that the subsidy for the composite good is higher than the individual subsidies. This is due to the difference in adjustment frequencies that enter also our aggregation of cars and heating systems. We aggregate the sum of all subsides received over an average adjustment period so that we get a sum that is higher than the two individual subsidies. We proceed equivalently for the aggregation throughout. The level of the subsidy constitutes a free parameter that we discipline in this way and results will not depend on its exact level.

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



Notes: Panel (a) shows the share of households with modern commitment goods along the transition path for percentage and lump-sum subsidy and in the case with no subsidy. Panel (b) shows the reduction in carbon emissions along the transition for percentage and lump-sum subsidy and in the case with no subsidy. Carbon emissions only come from old consumption commitment goods and are assumed to be proportional to the size of the old commitment good. Panels (c) and (d) show the share of households with a modern consumption commitment good from panel (a) for low- and high-income households. Panels (e) and (f) show the annual net transfers along the transition period for the different subsidy specifications and for low- and high-income households. Net transfers are the difference between subsidies and taxes paid and are in Euros 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 10 percent of households have a modern commitment good at the end of the transition in 2043.[13] Second, in case of a lump-sum subsidy, we find a substantial increase of the adoption rate to around 20 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 size of the old commitment consumption of an adopting household as we assume that the modern commitment good has zero emissions independent of its size. Hence, the larger the old commitment good of the household adjusting to the modern commitment good, the larger is the reduction in carbon emissions. For the lump-sum subsidy, we now find with 15 percent a roughly 3pp smaller reduction in emissions compared to the 18 percent reduction of the percentage subsidy. By contrast, without any subsidy the reduction is only 4 percent. We observe that the reduction paths for the lump-sum subsidy and the no-subsidy case become non-monotone around 2030 and that the percentage subsidy case flattens out. The reason are the life-cycle dynamics of the cohort of households alive at the beginning of the transition period. As the households become older, they want to consume larger commitment goods. As only a fraction of households will buy the modern good, many will still buy the old commitment good, thereby, exerting upward pressure on the consumption level of the old commitment good and the associated emissions over time.

Two observations explain the difference between the change in households adopting the modern good and the change in emissions. First, the emission reduction initially exceeds the share of households adopting the modern commitment good as high-income households who more strongly adopt had higher emissions as they consume more of the old commitment good (Section 2). Over time, the life-cycle effect leads to increasing average emissions even at constant shares of adjusting households as all households consume larger commitment goods in an aging population. 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 leads to a stronger reduction of emissions under the percentage subsidy compared to the lump-sum subsidy.

The difference in adoption rates between 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.

[13]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 A1, 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.

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 existing 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 on average higher. This stronger adoption of high-income, high-emission households makes the percentage subsidy the more effective policy for reducing carbon emissions.

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 typically net-transfer recipients, while low-income households are on average typically 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 show below, these time paths are such that their present values are negative for a majority of households. Hence, they will not satisfy the political economy constraint of having a majority of net recipients.

In general, we see for both policies that net transfers increase along the transition path. 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 0.6 percent of annual net household income.

4.2 Different financing schemes

The results show that both 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 more 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. In Appendix B.1, we present the corresponding results for the lump-sum subsidy. For this analysis, we fix the percentage subsidy on the modern commitment good at $\pi_1 = 0.253$ 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 introduce two tax rates for low- and high-income households and set the difference of tax rates to 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

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

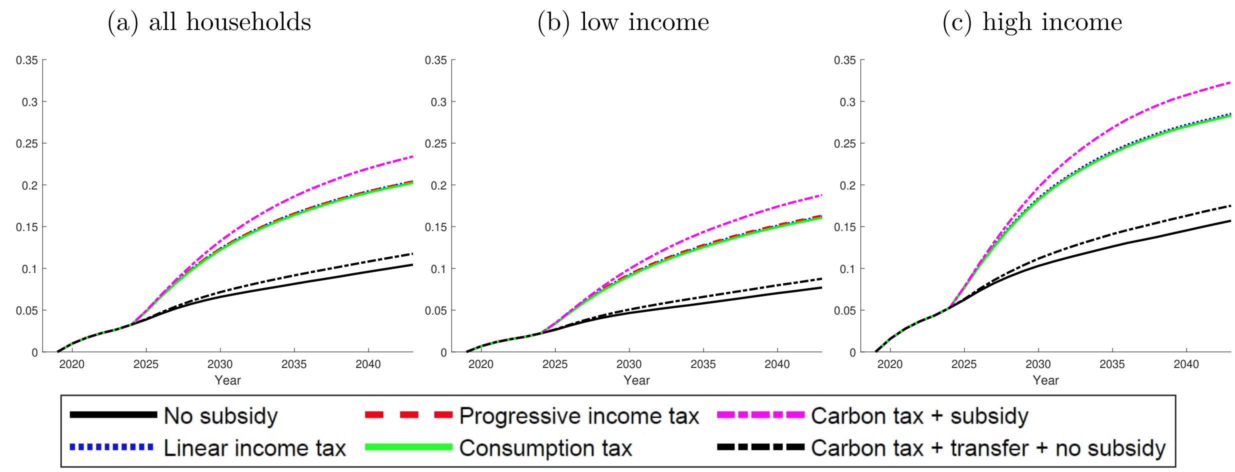
and differs depending on if the adjustment is to the old commitment good associated with costs E_o^P or to the modern commitment good associated with costs E_m^P. If there is no adjustment of the commitment good E_i^P drops from the constraint. The consumption tax τ_c applies to consumption c, flow expenditures 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 $\tau_y = 0.011$, a progressive tax of $\tau_y^l = 0.005$ and $\tau_y^h = 0.018$ for low-income (τ_y^l) and high-income (τ_y^h) households respectively, a consumption tax $\tau_c = 0.012$, and a carbon tax $\tau_o = 0.215$.[14] For the carbon tax, we also evaluate a policy mix where instead of financing a subsidy for the modern commitment good the tax revenue from the carbon tax will be redistributed as a lump-sum transfer among all households (Carbon tax + transfer + no subsidy).

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 schemes to be small. An exception is the financing of the subsidy by a carbon tax (carbon tax + subsidy) that further speeds up the adoption by 3pp at the end of the transition period. In the case of the carbon tax financing transfers but no subsidy, we only get 1.3pp more households adopting

[14]To translate this tax rate in a carbon price note that about 11 percent 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 40,200 Euros, the 21.5 percent tax on the flow costs therefore corresponds to a carbon price of around 127 Euros per ton of carbon emissions. A carbon price of 127 Euros is substantially higher than the current carbon price of 45 Euros in Germany in 2024.

Figure 5: Share of households with modern consumption commitments

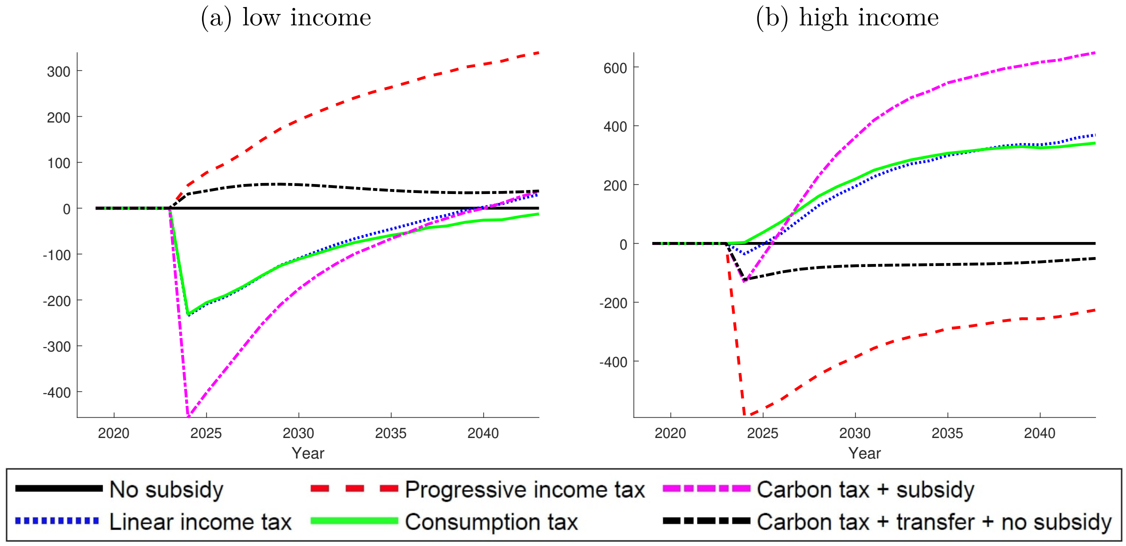


Notes: This figure shows the share of households with the modern commitment good along the transition path for different policy mixes. The left panel shows the share among all households, the middle panel shows the share for low-income households, and the right panel shows the share for high-income households. The policy mix is the combination of a percentage subsidy on the modern commitment good in combination with different financing schemes. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but rebates tax revenues back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

the modern consumption good relative to the baseline without any policy. 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 2.5pp. With the exception of the carbon tax, the differences between the other financing schemes are negligible. For high-income households, the difference in adoption rates between the carbon tax and the other financing schemes is with 4pp larger. Among the other financing schemes, the progressive tax leads to the least adjustment but again the differences are negligible. If the objective function were to maximize adoption rates without political economy constraints, then a percentage subsidy financed by a carbon tax would be the best policy across the considered policy mixes but as we will see this policy does not satisfy the political economy constraint that a majority of households support it because of its redistributive consequences.

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 will 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 22 percent leads to only 12 percent of households consuming the modern commitment good in contrast to the case with a percentage subsidy where the share is almost twice as high. The reason for the low adoption rate under the carbon tax is not simply its low level. The 22 percent tax on the expenditures for the flow costs of the old commitment good corresponds to a carbon price of 127 Euros per ton of emissions (see footnote 14). This price is about three times the current carbon price in Germany and within the range of estimates for carbon prices in the EU by 2030. Yet, the user cost are still small compared to the purchase price. The tax increases the flow user cost only by 4pp which provides a weaker incentive than a direct subsidy for the purchase of the modern commitment good. The policy taxes the consumption of most households that still consume the old commitment good but does not provide targeted incentives for substitution. A large part of the reduction in emissions will consequently not come from households buying modern goods but from consuming less of the old commitment good. In Appendix B.3, we study a policy mix with even higher carbon taxes that are rebated back as transfers. We find that in this case the effect of lower consumption of the old commitment good accounts for over two-thirds of the emission reduction from the policy.

Figure 6: Annual net transfers



Notes: This figure shows the annual net transfers of different policy mixes. Left panel shows transfers for low-income households and right panel shows transfers for high-income households. Transfers are in Euros per year. The different policy mixes combine a percentage subsidy for the purchase price of the modern commitment good with different financing instruments. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but rebates tax revenues back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

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. The reason for the increasing time path of net transfers is the 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 exceed on average 330 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 almost 600 Euros. Over time, their net transfer reduces but remains sizable and negative at 230 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 consequently they have to pay more of the carbon tax. They buy smaller 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 mix of a percentage subsidy with carbon taxes. In the year of the introduction, their negative net transfer is over 450 Euros, it declines quickly over time and only towards the end of the transition period, it turns positive. 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 640 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 roughly similar negative net transfers. Hence, the policy has the qualitative redistribution pattern as the progressive tax financing option. In Appendix B.3, we show that increasing the carbon tax will lead to higher transfers and the redistribution pattern further converge.

We find consistently 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 budget constraint rules out transfers across generations. Any debt-financed policy could make the current generation financially better off by financing transfers by higher debt levels as in our framework Ricardian equivalence does not hold. 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

So far, the analysis has shown that subsidizing the adoption of carbon-neutral commitment consumption goods can lead to a doubling of the reduction of carbon emissions relative to a baseline without policy. 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 households at the introduction of the policy is zero so that we get a direct measure of redistribution within the electorate 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 or the median voter has a positive present value of transfers.

Importantly, these net transfers are not the entire welfare effect of the different 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 quantify 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 currently alive households and rule out intergenerational transfers, for example, by debt financing. 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 different policies mixes uninformative.

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.

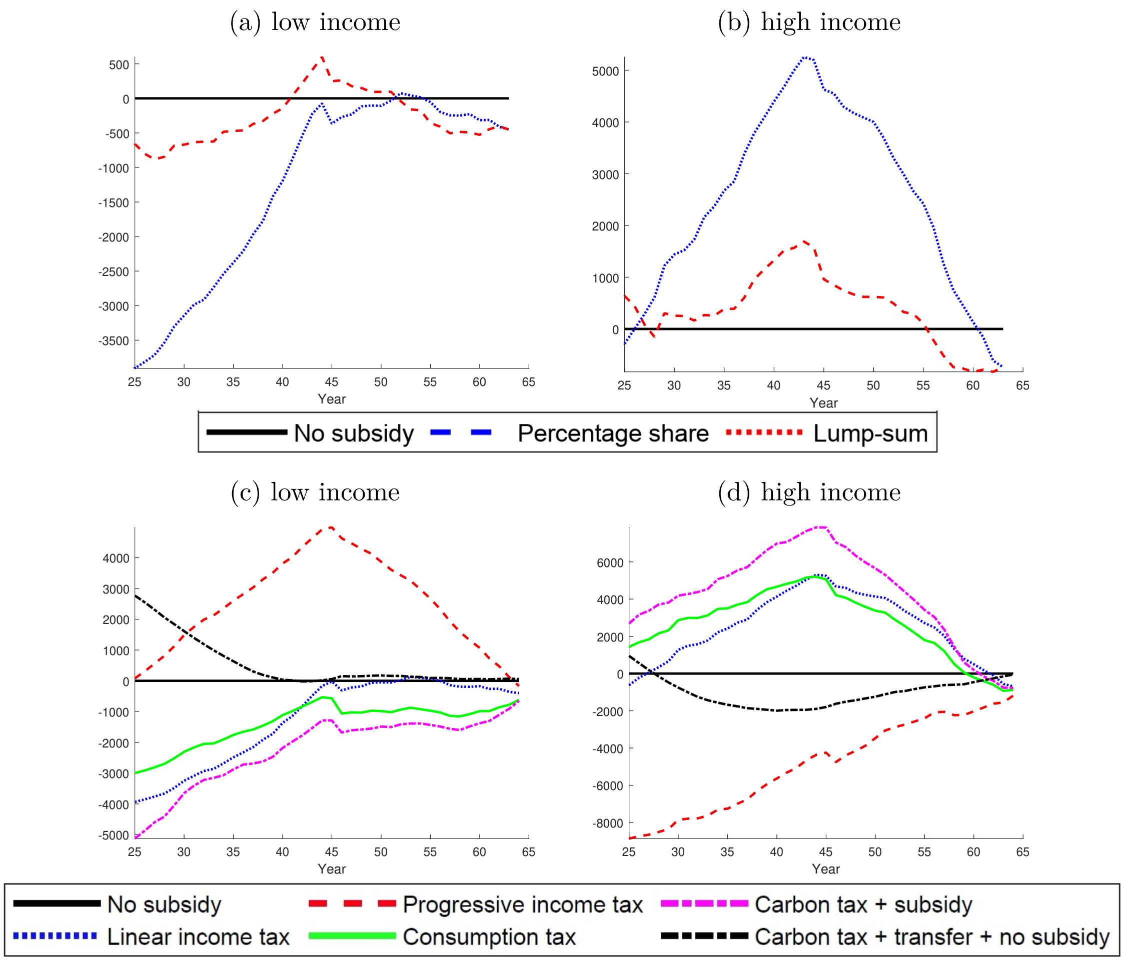
The top row of Figure 7 shows the age profile separately for low- and high-income households of the present value of net transfers for the linear income tax in combination with the two subsidy policies. Annual net transfers in Figure 4 did not yet allow for a direct conclusion on the distributional consequences of the policy mix especially with lump-sum subsidy because they show an increasing time path of net transfers with a flipping sign in the middle of the transition. Looking at the net present value, the lump-sum subsidy (red dashed line) shows qualitatively similar pattern for low- and high-income households. We find that the age profiles of the net present values increase up to age 45 and decrease afterwards. The levels differ 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 present value of transfers of about 900 Euros and high-income middle-age households receive a positive present value of net transfers of up to 1,700 Euros. Aggregating support across households, i.e. summing across households with positive net present value across and within age groups, Table 4 shows that this policy mix will not find a majority with only 45 percent of households having a positive present value of net transfers.[15]

Looking at the age profiles for the percentage subsidy in Figure 7 (blue dotted line), 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 is almost 4,000 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 5,200 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 7.7 percent 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, the distributional consequences of a policy undermine the support for this climate policy despite its effectiveness in reducing emissions.

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 but no subsidy. Qualitatively, we find the same distribution 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 path into account. By contrast, the linear tax, the consumption tax, and the carbon tax financing a percentage subsidy 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. It is mainly high-income households who 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).

[15]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: This figure shows the present value of net transfers of the different policy mixes by age and income group. Left panels show transfers for low-income households and right panels show transfers for high-income households. Transfers are in Euros and have been discounted at the interest rate r. Top row show policy mix of a linear income tax and a percentage and lump-sum subsidy for the purchase of the modern commitment good. Bottom row shows policy mixes that combine the percentage subsidy for the purchase price of the modern commitment good with different financing instruments. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but rebates tax revenues back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

Table 4 shows the results for 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. Less than a third of households support these policy mixes. The linear income tax has support of only slightly above one third. 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 little to the financing of the subsidy. As a consequence, we find that almost all low-income households support this policy mix. 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	7.7%	87.2%	34.9%
Lump-sum	income, linear	28.2%	76.9%	44.8%
Percent	income, progressive	97.4%	0.0%	64.1%
Percent	consumption	0.0%	87.2%	29.8%
Percent	carbon tax	0.0%	89.7%	30.6%
Transfer	carbon tax	94.9%	7.7%	65.1%

Notes: Share of households with positive present value of net transfers for different policy mixes. The shares are computed using the empirical shares of the two income groups of 34.2 percent (high income) and 65.8 percent (low income) and for a uniform age distribution. First column reports specification of subsidy, second column specification of financing instrument of the considered policy mix. The subsidy case *transfer* indicates the case when tax revenues are rebated back as lump-sum transfers. Columns *low income* and *high income* report shares among low-income and high-income households and column *total* show aggregated share among all households.

A further policy-relevant dimension of climate policies is their effect on inflation. A carbon tax will increase the price of the flow consumption costs for all households who consume the old commitment good whereas subsidies decrease the price of the modern commitment good.[16] A concern for monetary policy will therefore be the different effects of the policy mixes on inflation. We find that the carbon-tax-and-transfer policy will lead to a 1.8pp increase in the price level whereas the percentage subsidy will lead to a 0.2pp decline of the price level. The effect on the price level will be with 4.9pp substantially larger if we consider carbon taxes that reduce emissions as much as the percentage subsidy (Appendix B.3). We also find heterogeneity of the price increase across households. For the carbon-tax-and-transfer policy, we find an increase of 2.0pp for low-income households and of 1.6pp for high-income households. The difference increases to 1pp in case of the higher carbon tax with a price increase of 5.3pp for low-income households and 4.3pp for high-income

[16]We consider a one-time increase of the carbon tax which will have one-time effect on the price level. A gradual introduction would lead to a persistent effect on inflation.

households. We also find differences across income groups for the percentage subsidy but they are smaller with price level declines of 0.1pp and 0.2pp for low-income and high-income households, respectively.

In summary, our analysis of the reduction-redistribution trade-off shows that different financing schemes for a percentage subsidy 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 our analysis provides an explanation for why some policy mixes may find little support among large segments of the electorate although they could be effective in reducing emissions. 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.

4.4 Sensitivity analysis

The current analysis considers already a variety of different policy mixes and studies their reduction-redistribution trade-offs. For the analysis, we restrict the set of policy mixes and have to make specific assumptions on the transition path over the next 25 years. In Appendix B, we provide an extensive analysis with respect to alternative policy mixes and assumptions on the transition path. We first demonstrate that the same conclusions about the reduction-redistribution trade-off arise when we consider the lump-sum subsidy instead of the percentage subsidy. We focus on the percentage subsidy in the main part as it is more effective in reducing carbon emissions as more high-income households adopt the modern commitment good under the percentage subsidy. We also discuss and show different assumptions on the price convergence of the modern commitment good over the transition period. In the main part, we consider a fast price convergence scenario but we find that the speed of convergence does not have any effect on the key conclusions of the reduction-redistribution trade-off. The results for the slower price convergence scenarios highlight however the important role of technological progress and innovations for the reduction of carbon emissions as they are quantitatively typically more important than policy interventions. We also study a policy mix of the carbon-tax-and-transfer policy with substantially higher carbon taxes. We set the carbon tax to achieve the same reduction of carbon emissions during the transition as the percentage subsidy with progressive taxes. The reduction of emissions are then identical by construction and we find that the redistributive effects also become more similar. Two important differences between the policy mixes however remain. The policy with the subsidy for buying the modern commitment good achieves the reduction of emissions by substituting consumption from the old to the modern commitment good. The high carbon tax reduces emissions mainly by reducing consumption of the old commitment good and has much lower adoption rates of the modern commitment good. Hence, the reduction in emissions comes mainly from lower consumption of old goods whereas it comes from substitution towards modern consumption goods in the case of the subsidy. The second difference is the fiscal budget of the two programs. The higher carbon tax implies annual lump-sum transfers of 2,000 Euros per year or almost 82 billion Euros at the level of the macroeconomy for the 41 million German households. The policy with the subsidy for the modern commitment good is also a large program but subsidies in the first year will account for less than a quarter with 19 billion Euros. Finally, we demonstrate how the inclusion of newborn generations will affect the distributional dynamics. In the main part of the analysis, we focused on the distributional dynamics only for households alive at the introduction of the policy. The reason is that the focus on this group allows for informative comparison across policy mixes. In general, we find that the conclusions from the main part regarding the reduction-redistribution trade-off are robust to alternative assumptions on policy mixes and transitional dynamics.

5 Conclusions

Policies to mitigate climate change are high on the policy agenda of governments around the world. Policies targeting households are of particular interest because the consumption of the household sector accounts for about two-thirds of total carbon emissions. We highlight that a key issue for any climate policy is its distributional consequences. We provide novel empirical facts on the importance of consumption commitments for carbon emissions of households and their heterogeneity in the population. Guided by this empirical evidence, we develop a quantitative life-cycle model with permanent income heterogeneity for the transition period after the introduction of modern, carbon-neutral consumption goods. We use the model to evaluate a variety of 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. We find that widely advocated carbon taxes have strong redistributive consequences, as low-income households are slower and less likely to adjust to modern consumption commitments. Progressive financing of a percentage 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 with large carbon footprints 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.

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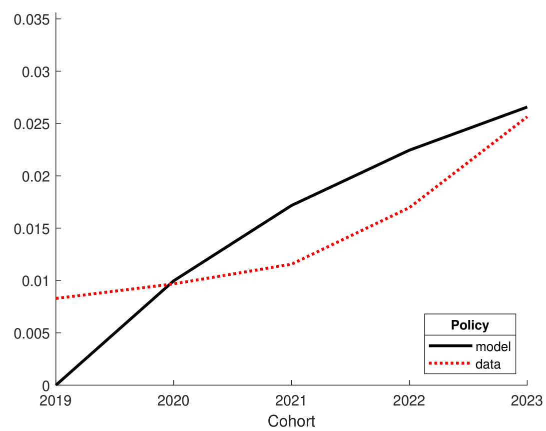
A Additional results

Figure A1 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 households with the modern commitment good of zero in 2019. Empirically, the share is already slightly positive by 2019. By 2020, we get, however, that the model has already converged to the adoption rate in the data and that after 2020 model and data show a close alignment in adoption rates increasing by about half a percentage point per year. We take this close alignment of adoption rates as further supporting evidence that the model provides a good framework to study the adoption dynamics of the modern commitment good.

Figure A1: 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 for the time period from 2019 to 2023.

B Sensitivity analysis

For the policy analysis in the main part of the paper, we focus on policy mixes that combine the percentage subsidy with different financing schemes. Here, we present the same policy experiments as in the main part for other policy mixes and different assumptions on price paths of the modern commitment good. In Section B.1, we report results for the lump-sum subsidy in combination with different financing schemes. In Section B.2, we show the reduction-redistribution trade-off for alternative assumptions on the price convergence of the modern commitment good. In the main part of the paper, we discuss a price scenario of fast convergence of prices. In Section B.2.1, we present the results for slower price convergence of the modern commitment good and in Section B.2.2, we show the case without any price convergence of the modern commitment good. Section B.3 discusses a policy mix of a carbon tax that finances transfers as in Section 4 (carbon tax +

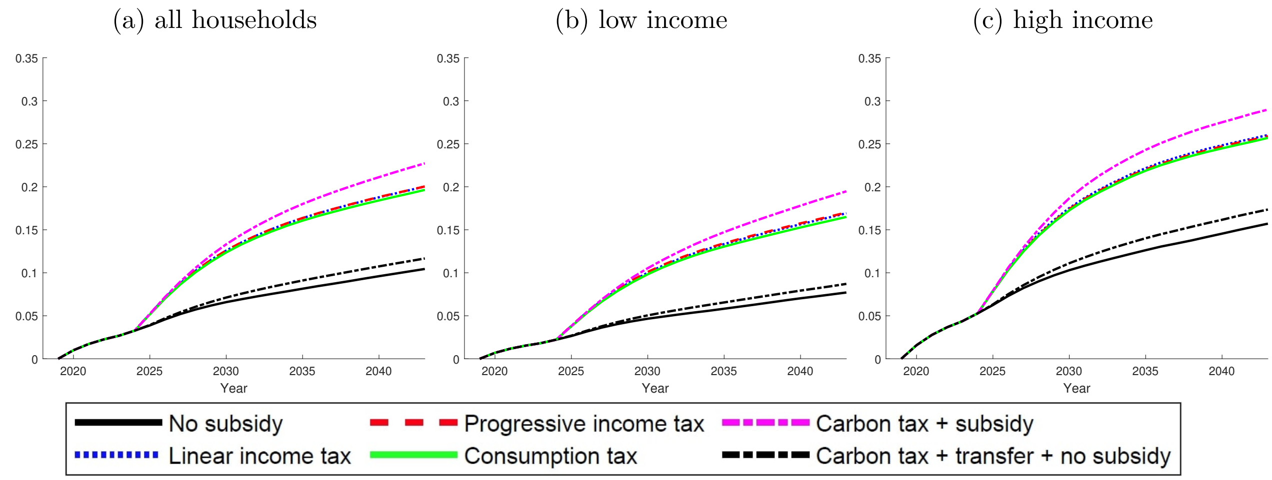
transfer + no subsidy) but instead of determining the tax to yield the same fiscal budget as in the case of the proportional subsidy, we now target the emission reduction by adjusting the carbon tax. In the main part, we saw that the carbon tax with the same fiscal budget yields only a small reduction in emissions. Tax receipts will as before be reimbursed lump-sum to households. Finally, we consider in Section B.4 the effect on the transition path if newborn cohorts enter the economy during the transition period and under the same policy that is in place for households initially alive. Importantly, policies will now no longer have a balanced budget and imply for entering cohorts that they are net recipients or contributors to the system depending on the specific policy. We discuss the results because of their macroeconomic relevance for the evolution of emissions but highlight the problem of comparability of policies with non-balanced budgets.

B.1 Results for lump-sum subsidy

In this section, we consider the policy experiment from Section 4.2 but now combine the lump-sum subsidy with different financing schemes. As in the main part, we first show the effect on adoption rates (reduction) and then discuss the distributional consequences (redistribution).

Figure A2 shows the adoption rates. We find that average adoption rates look very similar to the case of the percentage subsidy but they are on average lower. The combination with the different financing schemes yield the same pattern as in the case of the percentage subsidy. The financing of the subsidy by a carbon tax leads to the most adoption as the carbon tax provides additional substitution incentives. The results for the carbon-tax-and-transfer policy remain unaffected as no subsidy is paid for the modern commitment good. When looking across income groups, we see that the lower adoption rates mainly stem from the high-income households. Their adoption rates go down because of the smaller incentive to buy large modern commitment goods when the subsidy is lump-sum rather than proportional to the purchase price.

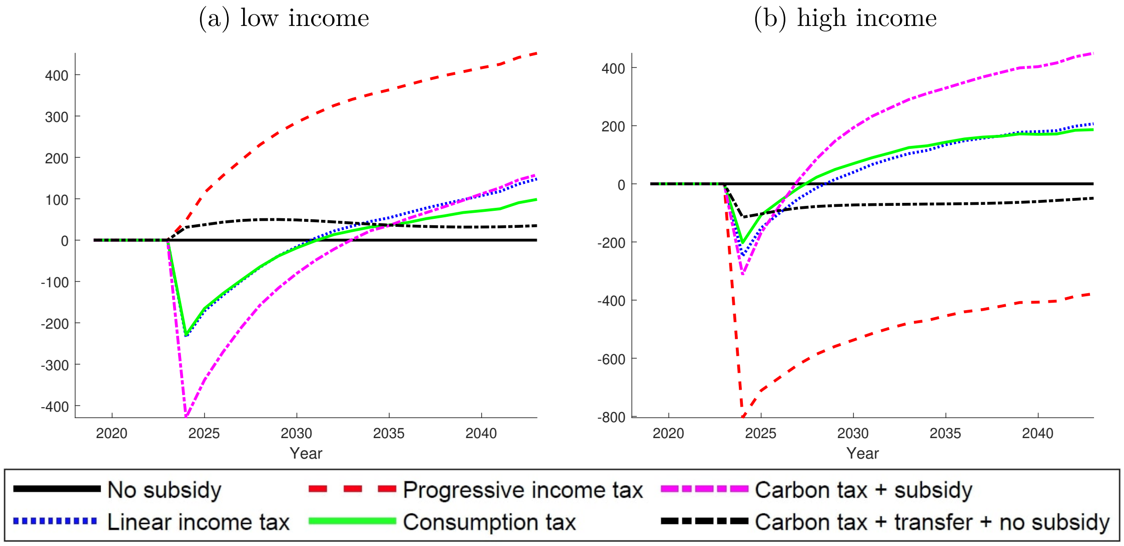
Figure A2: Share of households with modern consumption commitments with lump-sum subsidies



Notes: This figure shows the share of households with the modern commitment good along the transition path for different policy mixes. The left panel shows the share among all households, the middle panel shows the share for low-income households, and the right panel shows the share for high-income households. The policy mix is the combination of a lump-sum subsidy on the modern commitment good in combination with different financing schemes. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but rebates tax revenues back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

When we look at the annual net transfers during the transition, we find generally similar patterns as in the case of the percentage subsidy but levels of net transfers change and in particular net transfers increase for low-income households and decline for high-income households. In case of the linear income tax, we find that when combined with the percentage subsidy that low-income households have during the entire transition period with the exception of few years in the end of the transition negative net transfers. In case of the lump-sum subsidy, it becomes relatively more attractive for them to purchase the modern commitment good so that they receive more transfers and we find that already after 8 years of the transition period, their transfers turn positive. Yet, as we will see below the net present value remains negative for most of the households from this policy. If we look at the progressive income tax as a financing instrument, we find consistently that with the lump-sum subsidy high-income households receive less subsidies so that there are transfers from high-income to low-income households. In the year 2030, the negative net transfer with the lump-sum subsidy is almost 40 percent larger than in the case of the percentage subsidy.

Figure A3: Annual net transfers with lump-sum subsidies

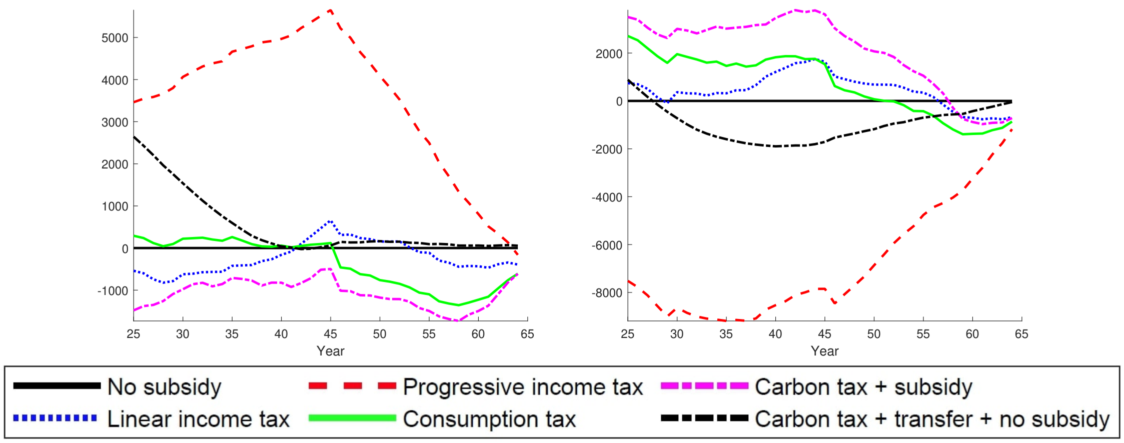


Notes: This figure shows the annual net transfers of different policy mixes. Left panel shows transfers for low-income households and right panel shows transfers for high-income households. Transfers are in Euros per year. The different policy mixes combine a lump-sum subsidy for the purchase price of the modern commitment good with different financing instruments. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but rebates tax revenues back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

In Figure A4, we report the present value of net transfers from the different policy mixes with the lump-sum subsidy. As before, results for the carbon-tax-and-transfer policy will not change relative to the results in the main part of the paper. Qualitatively, we get very similar conclusions compared to the case with the percentage subsidy. Yet, we find again that the lump-sum subsidy favors low-income households. We see this now most strongly for younger low-income households. For a 30-year-old low-income household, the average present value of net transfers in the case of a linear income tax is roughly cut by more than 80 percent from about 3250 Euros to around 620 Euros. We have seen in the main part that a progressive tax financing of the subsidy will lead to positive transfers for low-income households even if the subsidy is proportional to the value of the modern commitment good. If the subsidy becomes lump-sum, this further benefits the low-income households as their transfers increase. Yet, this comes at the cost of lower adoption rates as we have seen before. Hence, we find that generally the results for the reduction-redistribution trade-off are robust to what kind of subsidy is used but the percentage subsidy is more effective in increasing adoption rates and decreasing emissions as more of the high-income households with a large carbon footprint adjust their consumption choices.

Figure A4: Present value of net transfers of policy mixes across age and income groups - lump sum subsidy

(a) low income (b) high income



Notes: This figure shows the present value of net transfers of the different policy mixes by age and income group. Left panel shows transfers for low-income households and right panel shows transfers for high-income households. Transfers are in Euros per year and have been discounted at the interest rate r. The different policy mixes combine a lump-sum subsidy for the purchase price of the modern commitment good with different financing instruments. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but rebates tax revenues back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

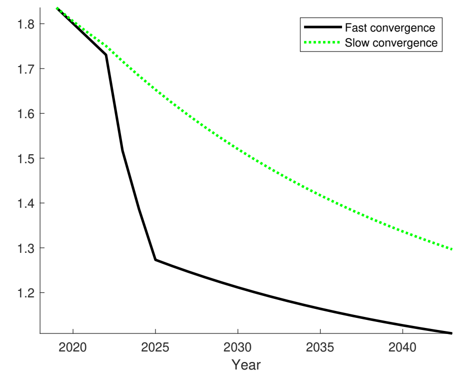
B.2 Results for different price convergence paths

This section presents the results for different convergence paths of the price premium for modern commitment goods over the transition period. We first discuss the different price convergence scenarios including the price convergence path for our baseline results from Section 4. In Section B.2.1, we then show a sensitivity analysis with results for a slow price convergence path and in Section B.2.2, we show results for a scenario without any price convergence over time.

Figure A5 shows the aggregated path for the price premium of the composite commitment good in the model that underlies the policy experiment in Section 4. We see that the fast convergence path shows a particularly strong convergence of prices until the year 2025 (black solid line). 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 (see below). The non-zero price premium and the ongoing convergence after 2025 is only a result of the convergence of the price for heating systems. The green dotted line shows the alternative scenario of a slow price convergence over time that we consider in Appendix B.2.1.

Figure A6 decomposes the composite price dynamics and shows the separate paths for price premia for electric cars and heating systems that we aggregate to the price premium ω in Figure A5.

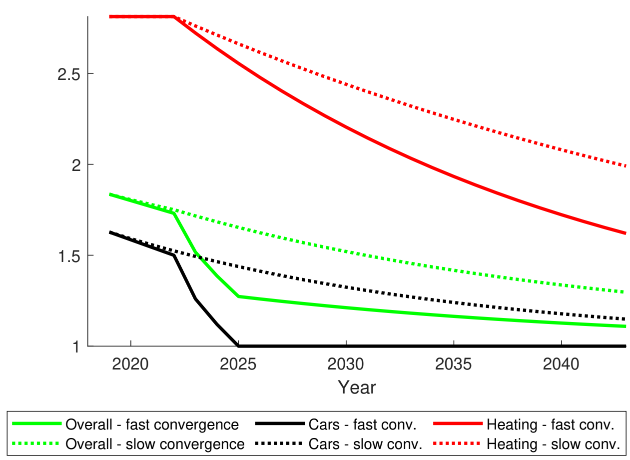
Figure A5: Price for modern commitment goods relative of old commitment goods



Notes: This figure plots the price paths for modern commitment good relative to old commitment good. The solid black line shows the baseline scenario that is used in the main part of the paper. The green dotted line shows the slower convergence path for which results are shown in Appendix Section B.2.1.

Aggregation weights combine expenditure shares and adjustment frequency to get a composite commitment good (see footnote 8). 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 that under the fast convergence scenario the price premium for cars has disappeared by 2025. This convergence explains the kink in the aggregated time series in Figure A5 in the year 2025.

Figure A6: Price for modern commitment goods relative of old commitment goods



Notes: This figure shows the price paths for the modern modern commitment goods relative to old commitment goods separately for cars and heating system and for the aggregated composite good. The solid lines describe the baseline scenario that is used in the main part of the paper. The dotted lines show the slower convergence scenario for which results are shown in Appendix Section B.2.1.

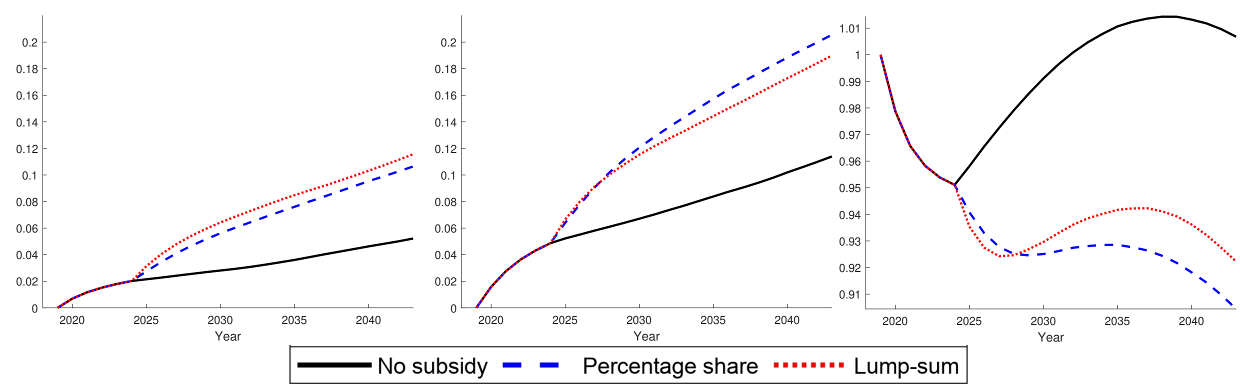
Modern heating systems start with a substantially higher initial price premium and price convergence is predicted to be much slower compared to cars so that even at the end of the transition period, there is still a large price premium of the modern over the old commitment good.

B.2.1 Slow price convergence

Figure A7 presents results for the three policy scenarios from Section 4.1 under the slow price convergence scenario. It shows 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 path. As prices for modern commitment good convergence at a slower rate to those of the old commitment good, we find that the share of households with a modern commitment good to be smaller and consequently the reduction in carbon emission to be lower compared to the baseline scenario. We find that on average adoption rates are about two-thirds of our baseline scenario but that there are no qualitative differences in transition paths if the price convergence is slower. Looking at the reduction of emissions, we find that the slower price convergence is too weak to counteract the life-cycle effect of the aging cohort that arises in the model as we are following the initial cohort of households. With a lower price reduction, their life-cycle increase of consumption of the old commitment good leads even to an increase of emissions over time. We see this effect also for the cases with the subsidy in place but the subsidy mitigates the effect and leads only in the case of the lump-sum subsidy to a non-monotonicity starting in year 2030.

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

(a) low income (b) high income (c) Reduction in emissions

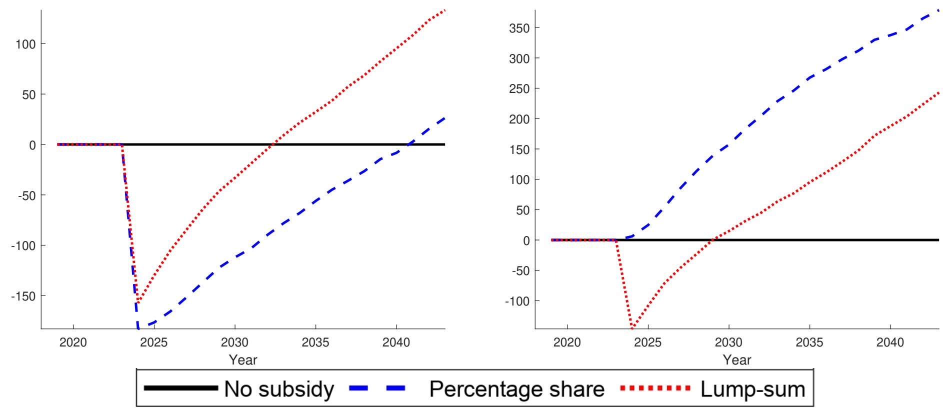


Notes: Panels (a) and (b) show the share of households with modern commitment goods along the transition path for percentage and lump-sum subsidy and in the case with no subsidy for low- and high-income households for slow price convergence. Panel (c) shows the reduction in carbon emissions along the transition for percentage and lump-sum subsidy and in the case with no subsidy for slow price convergence. Carbon emissions only come from old consumption commitment goods and are assumed to be proportional to the size of the old commitment good.

Figure A8 shows the annual net transfers under the slow price convergence scenario. We find qualitative the same pattern as in Section 4.1. There will be redistribution from low-income to high-income households and the redistribution is stronger under the percentage subsidy. On average, there is less redistribution because fewer modern commitment goods are bought so that fewer subsidies are paid out.

Figure A8: Annual net transfers for slow price convergence

(a) low income (b) high income

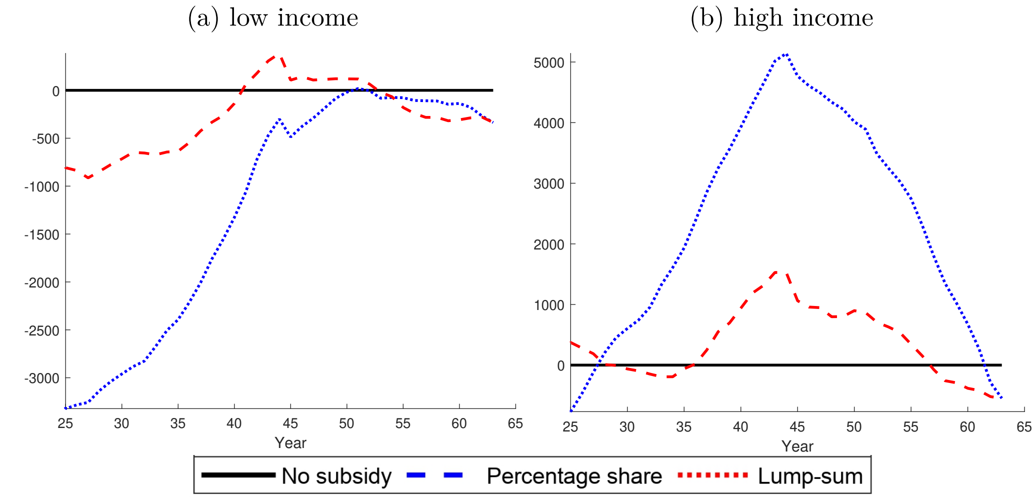


Notes: This figure shows the annual net transfers along the transition period for the different subsidy specifications and for low- and high-income households in case of slow price convergence of the modern and the old commitment good. Net transfers are the difference between subsidies and taxes paid and are in Euros per year.

Figure A9 shows the corresponding present value of net transfers for low- and high-income households by age in the case of slower price convergence of the modern commitment good. Qualitatively, we find the same results as under the fast convergence scenario. Quantitatively, we get that the heterogeneity of the present values of transfers across age groups is smaller than in the fast price convergence scenario.

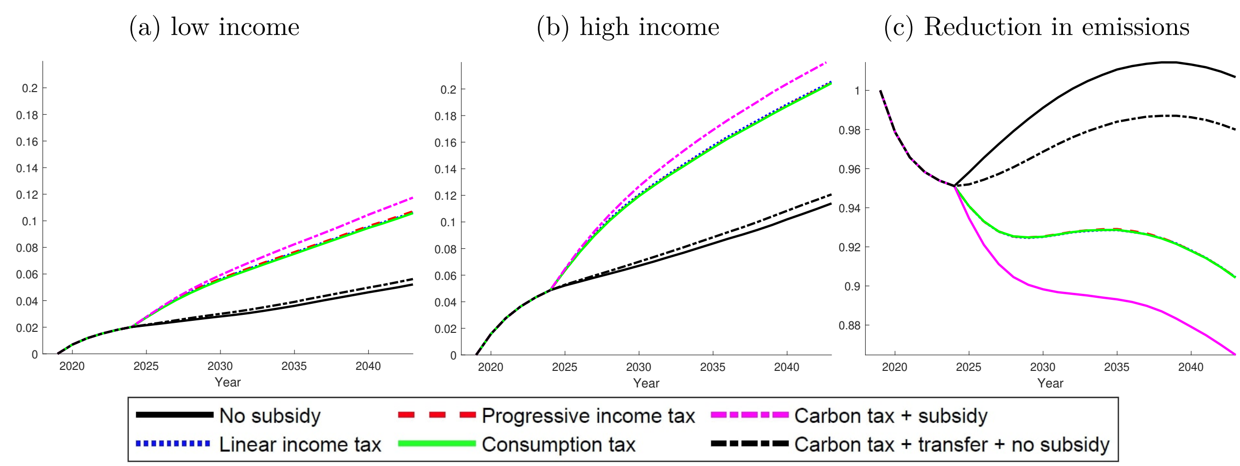
As in the analysis in the main part of the paper, we combine in the next step the percentage subsidy with different financing seems to further explore the reduction-redistribution trade-off. Figures A10, A11, and A12 present the corresponding results to Section 4.2 for the financing side under the slow price convergence scenario. Qualitatively, we find results to have similar redistribution patterns and that the differences in the speed of adjustment under slow price convergence mainly affects results quantitatively. Most notably, we find that the present value of net transfers becomes less negative for high-income mid-age households under progressive financing with slower price convergence. The reason is that with a smaller program size overall because of lower adoption rates, also tax rates decline so that there will be less redistribution. Based on these results, we conclude that our findings on the reduction-redistribution trade-off are robust to the assumptions on the speed of price convergence.

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



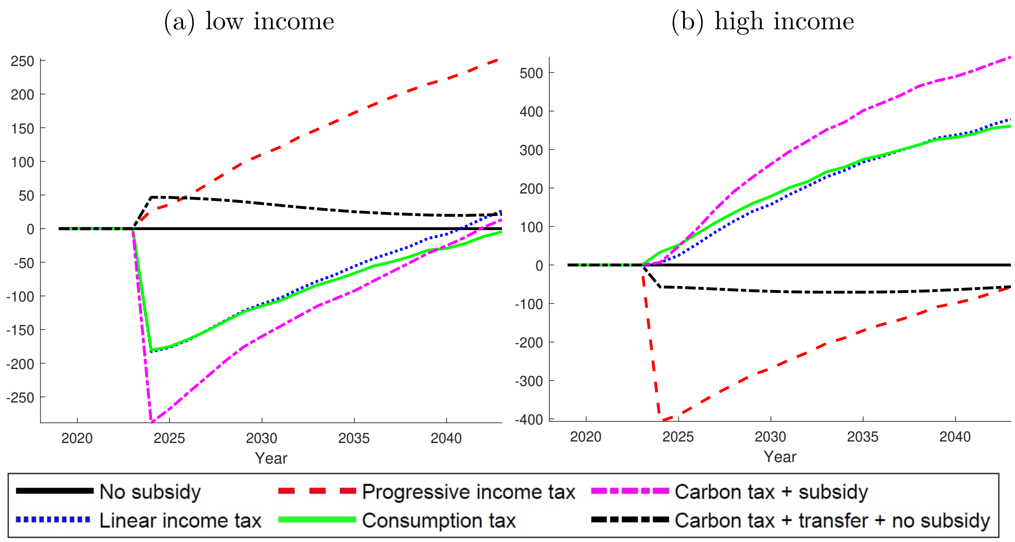
Notes: This figure shows the present value of net transfers of the different policy mixes by age and income group in the case of slow price convergence. Left panel shows transfers for low-income households and right panel shows transfers for high-income households. Transfers are in Euros and have been discounted at the interest rate r. The policy mixes combine a linear income tax with a percentage and lump-sum subsidy for the purchase of the modern commitment good. The subsidies for both policy mixes are set to have a balanced budget over the transition period.

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



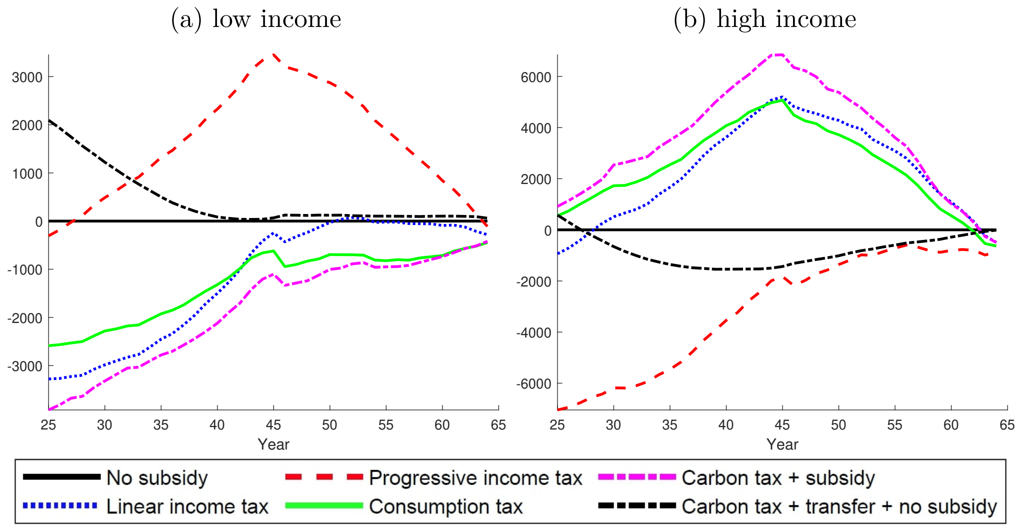
Notes: This figure shows for the case of slow price convergence the share of households with the modern commitment good along the transition path for different policy mixes and the reduction in carbon emissions. The left panel shows the share for low-income households and the middle panel shows the share for high-income households. The right panel shows the reduction in emissions. Carbon emissions only come from old consumption commitment goods and are assumed to be proportional to the size of the old commitment good. The policy mix is the combination of a percentage subsidy on the modern commitment good in combination with different financing schemes. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but rebates tax revenues back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

Figure A11: Annual net transfers for slow price convergence



Notes: This figure shows for the case of slow price convergence the annual net transfers of different policy mixes. Left panel shows transfers for low-income households and right panel shows transfers for high-income households. Transfers are in Euros per year. The different policy mixes combine a percentage subsidy for the purchase price of the modern commitment good with different financing instruments. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but rebates tax revenues back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

Figure A12: Present value of net transfers of policy mixes across age and income groups for slow price convergence



Notes: This figure shows the present value of net transfers of the different policy mixes by age and income group in the case of slow price convergence. Left panel shows transfers for low-income households and right panel shows transfers for high-income households. Transfers are in Euros and have been discounted at the interest rate r. The different policy mixes combine a percentage subsidy for the purchase price of the modern commitment good with different financing instruments. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but rebates tax revenues back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

B.2.2 No price convergence

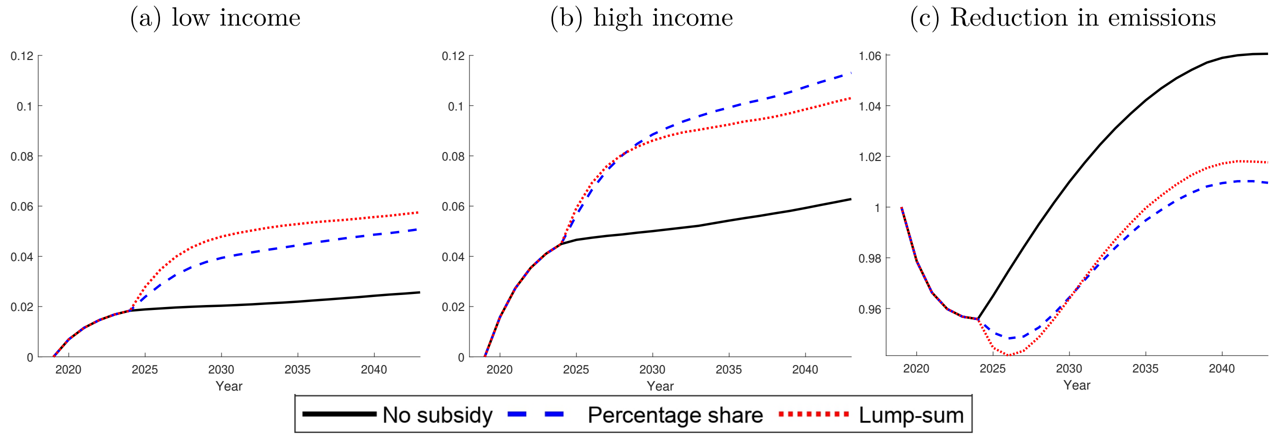
Finally, we also report results for a scenario without any price convergence between the modern and the old commitment good. We consider this an unlikely scenario given the available data on price dynamics, yet, we think it is an instructive scenario to study as it takes out all effects of exogenous price dynamics for the transition period. In the case without a relative price decline, we will still see that there are positive adoption rates of the modern commitment good. There are two reasons for these positive adoption rates. First, there will always be adoption of the modern commitment good after its introduction in the model in 2019 because of its different utility value (equation (2)) and the life-cycle dynamics of consumption. Second, if additional subsidies are introduced, then this will further increase demand for the modern commitment good at a constant price differential to the old commitment good.

Figure A13 presents the share of households with modern commitment goods and the reduction in emissions under the no price change scenario. Not surprisingly, we find that the share of households with modern commitment goods and the reduction in emissions is smaller than in the fast and the slow price convergence scenario. Despite the constant price difference between the modern and the old commitment good, we find a reduction of emissions at the end of the transition period of 8 percent. The reduction is 15 percent under the slow convergence scenario and 25 percent under the fast convergence scenario. The adoption rate of 8 percent in the no price convergence scenario in contrast to the 25 percent adoption rate in the fast price convergence scenario shows that competition and technological progress are important drivers of adoption rates over time and policy will only act on top of these developments.

Figures A14 and A15 depict the annual net transfers and the present value of net transfers of the two subsidies. We find that annual transfers are negative for most of the transition period for low-income households and positive for most of the transition period for high-income households. This is different to the price scenarios before where net transfers in case of the lump-sum subsidy turned positive for both groups much earlier in the transition process. Absent falling prices, adoption rates for low-income households remain however low. For low-income households, the present value of net transfers remains negative in the case of the lump-sum subsidy around age 40 and until age 50 for the percentage subsidy. After these ages, the values remain at zero or only slightly above. For high-income households, we find that even in the absence of price convergence adoption rates are high enough to lead to substantial positive present values of net transfers at most ages. For both subsidies, the present value is highest between age 40 and 45 and only negative in the first 5 years respectively 10 years of the life cycle depending on the subsidy specification.

Figures A16, A17, and A18 show the results for the percentage subsidy with different financing instruments in the case of no price convergence. Looking at the share of households with the modern commitment good in Figure A16, we find that adoption rates vary only little with the financing

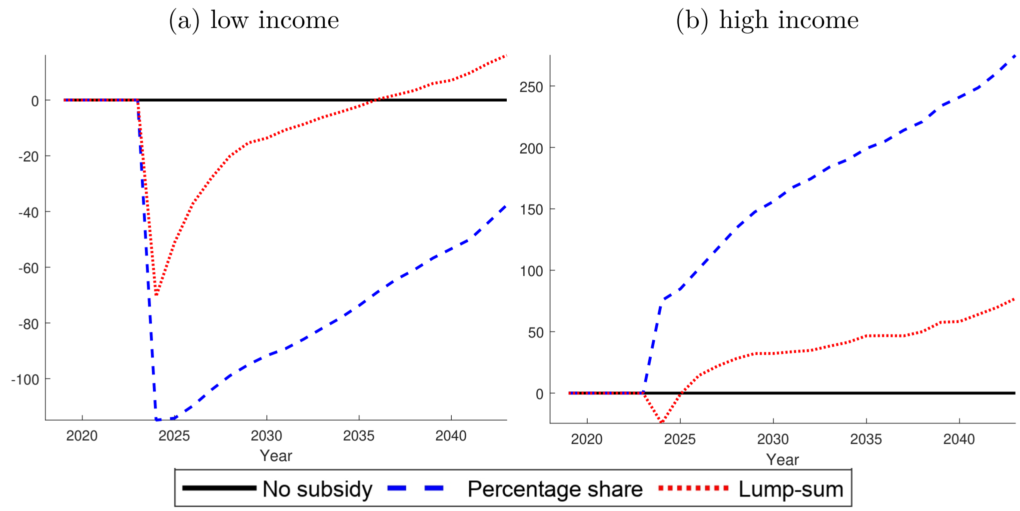
Figure A13: Share of households with modern commitment good by income and reduction in carbon emissions for no price convergence



Notes: Panels (a) and (b) show the share of households with modern commitment goods along the transition path for percentage and lump-sum subsidy and in the case with no subsidy for low- and high-income households for no price convergence. Panel (c) shows the reduction in carbon emissions along the transition for percentage and lump-sum subsidy and in the case with no subsidy for no price convergence. Carbon emissions only come from old consumption commitment goods and are assumed to be proportional to the size of the old commitment good.

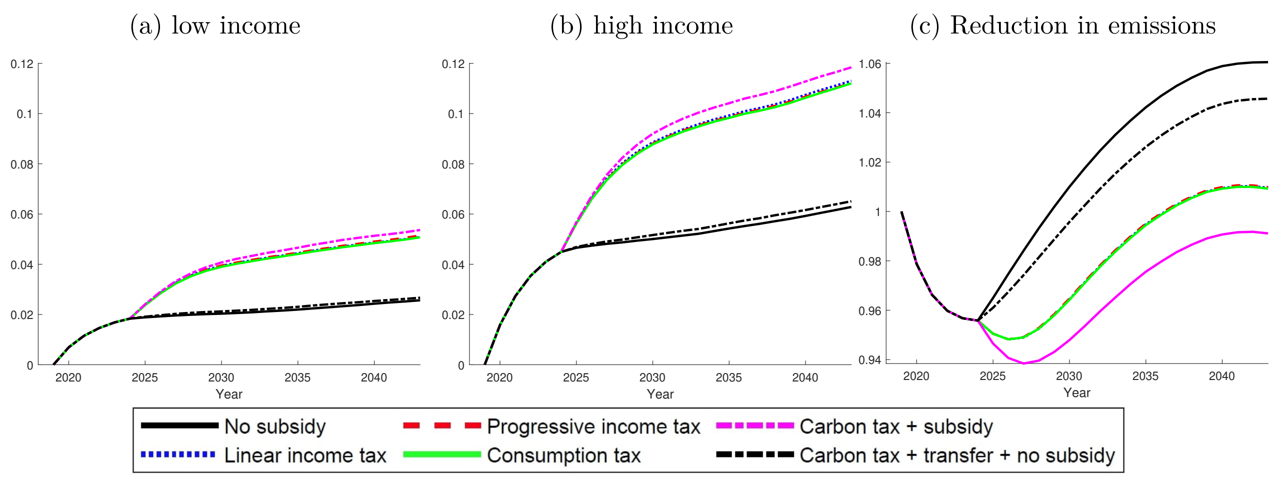
instrument. The only financing instrument that makes a difference is the carbon tax that provides an additional incentive to buy the modern commitment good.

Figure A14: Annual net transfers for no price convergence



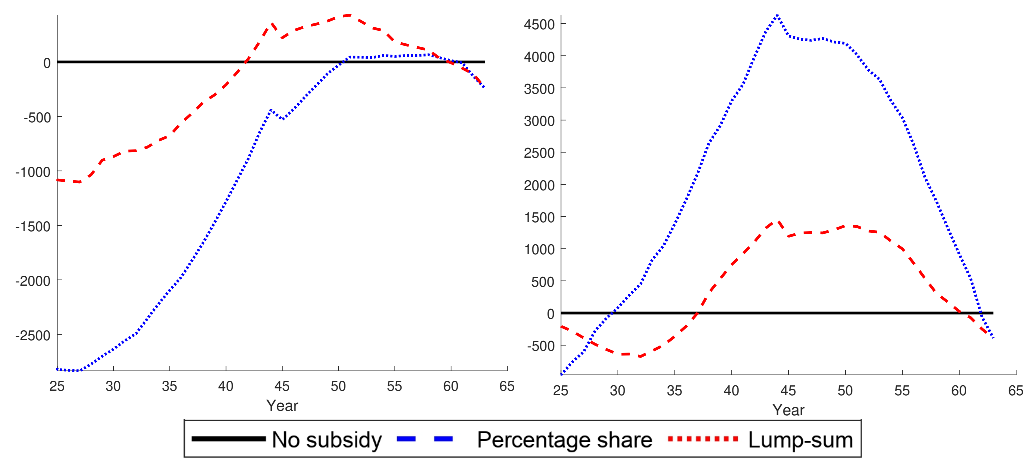
Notes: This figure shows the annual net transfers along the transition period for the different subsidy specifications and for low- and high-income households in case of no price convergence of the modern and the old commitment good. Net transfers are the difference between subsidies and taxes paid and are in Euros per year.

Figure A16: Share of households with modern commitment good by income and reduction in carbon emissions for no price convergence



Notes: This figure shows for the case of no price convergence the share of households with the modern commitment good along the transition path for different policy mixes and the reduction in carbon emissions. The left panel shows the share for low-income households and the middle panel shows the share for high-income households. The right panel shows the reduction in emissions. Carbon emissions only come from old consumption commitment goods and are assumed to be proportional to the size of the old commitment good. The policy mix is the combination of a percentage subsidy on the modern commitment good in combination with different financing schemes. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but rebates tax revenues back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

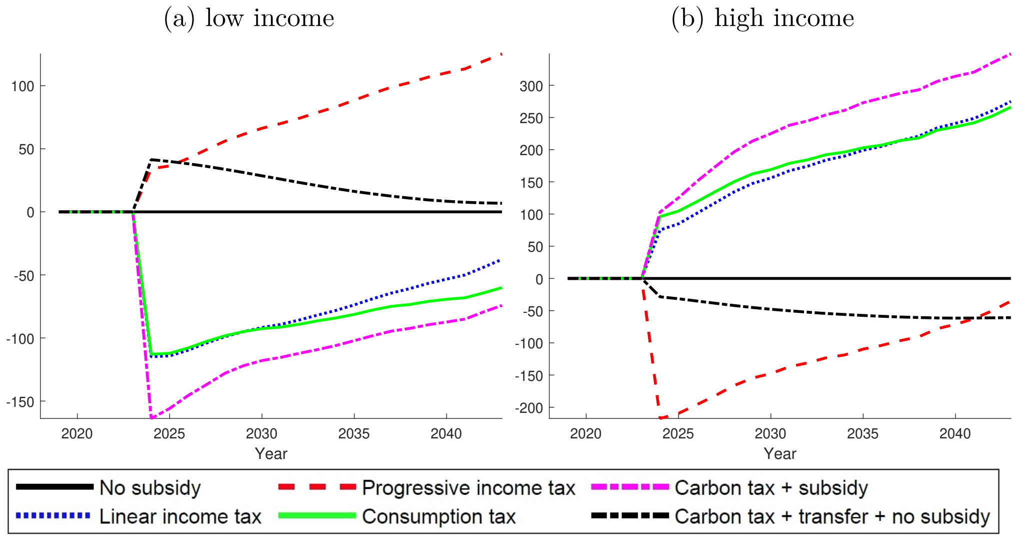
Figure A15: Present value of net transfers for different age groups and subsidies for no price convergence



Notes: This figure shows the present value of net transfers of the different policy mixes by age and income group in the case of no price convergence. Left panel shows transfers for low-income households and right panel shows transfers for high-income households. Transfers are in Euros and have been discounted at the interest rate r. The policy mixes combine a linear income tax with a percentage and lump-sum subsidy for the purchase of the modern commitment good. The subsidies for both policy mixes are set to have a balanced budget over the transition period.

Figure A17 shows the annual net transfers for the different policy mixes in case of no price convergence. The key difference to the baseline experiment is that adoption rates are lower as the modern commitment good maintains a higher price premium. We observe that the absolute size of annual transfers are smaller compared to the two price scenarios with price convergence, yet, we also see that the qualitative results remain unchanged. Only the financing of the subsidy by a progressive income tax or the carbon-tax-and-transfer policy without a subsidy yield positive net transfers for low-income households. The other policy mixes all lead to positive net transfers to high-income households. The time trend in transfers results from the life-cycle effect as we are only considering the cohort of households alive at the introduction of the policy.

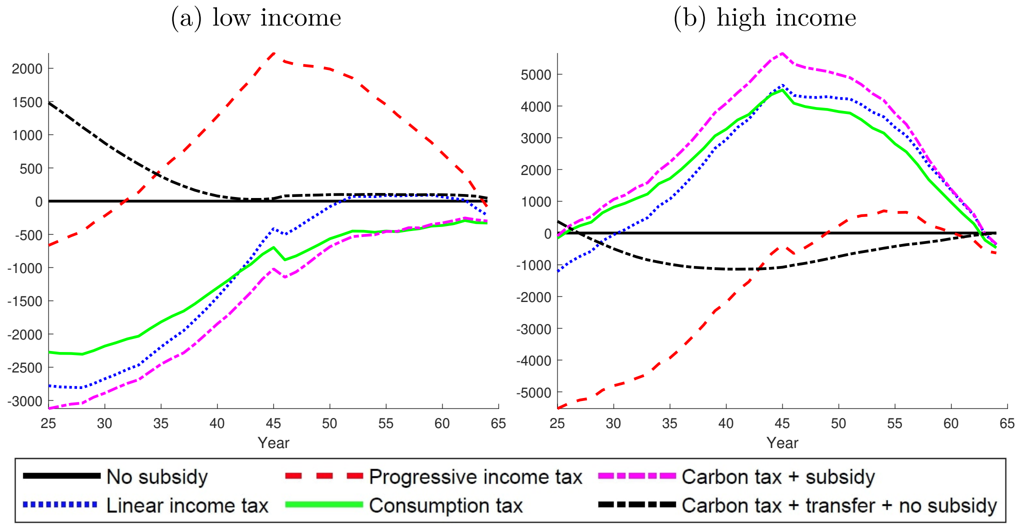
Figure A17: Annual net transfers for no price convergence



Notes: This figure shows for the case of no price convergence the annual net transfers of different policy mixes. Left panel shows transfers for low-income households and right panel shows transfers for high-income households. Transfers are in Euros per year. The different policy mixes combine a percentage subsidy for the purchase price of the modern commitment good with different financing instruments. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but rebates tax revenues back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

Figure A18 shows the net present value of transfers by age of the different policy mixes. We find our key results to be robust. The only policy that offers subsidies and thereby substantially increases adoption rates and that also implies positive net transfers for most low-income households is the policy mix with the progressive tax as a financing instrument.

Figure A18: Present value of net transfers of policy mixes across age and income groups for no price convergence

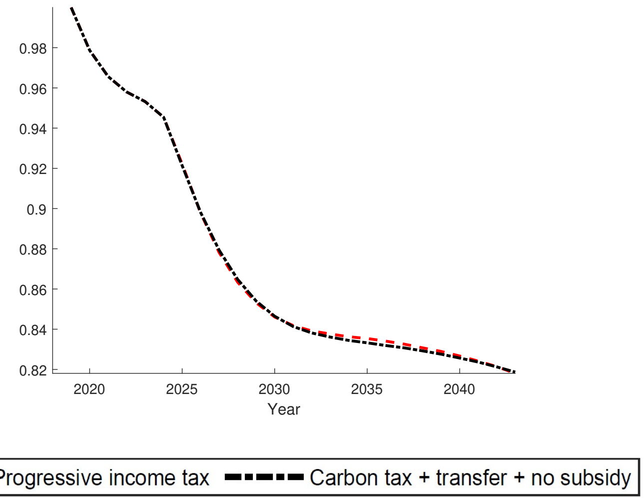


Notes: This figure shows the present value of net transfers of the different policy mixes by age and income group in the case of no price convergence. Left panel shows transfers for low-income households and right panel shows transfers for high-income households. Transfers are in Euros and have been discounted at the interest rate r. The different policy mixes combine a percentage subsidy for the purchase price of the modern commitment good with different financing instruments. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but rebates tax revenues back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

B.3 Results for higher carbon taxes

In Section 4, we construct all policy mixes so that they imply a balanced budget over the transition period for a given percentage subsidy. If we use the receipts of the carbon tax to finance lump-sum transfers instead of a subsidy, we find that only few households adjust to the modern commitment good (carbon tax + transfer + no subsidy). In this section, we therefore consider a carbon tax that we set to match the same reduction in carbon emissions as in the case of the percentage subsidy with progressive taxation. To match a 18 percent reduction of emissions, we need a carbon tax that is substantially higher. In Section 4, the carbon tax was 22 percent and it has to be increased to 58 percent to match the same reduction in emissions, hence, more than 2.5 times as high. This higher carbon tax corresponds to a carbon price of 342 Euros per ton that is six times its current level and the annual transfer per household that the tax finances are about 2,000 Euros per year. Figure A20 shows the reduction in carbon emissions with progressive tax and the percentage subsidy from Section 4 and the higher carbon tax.

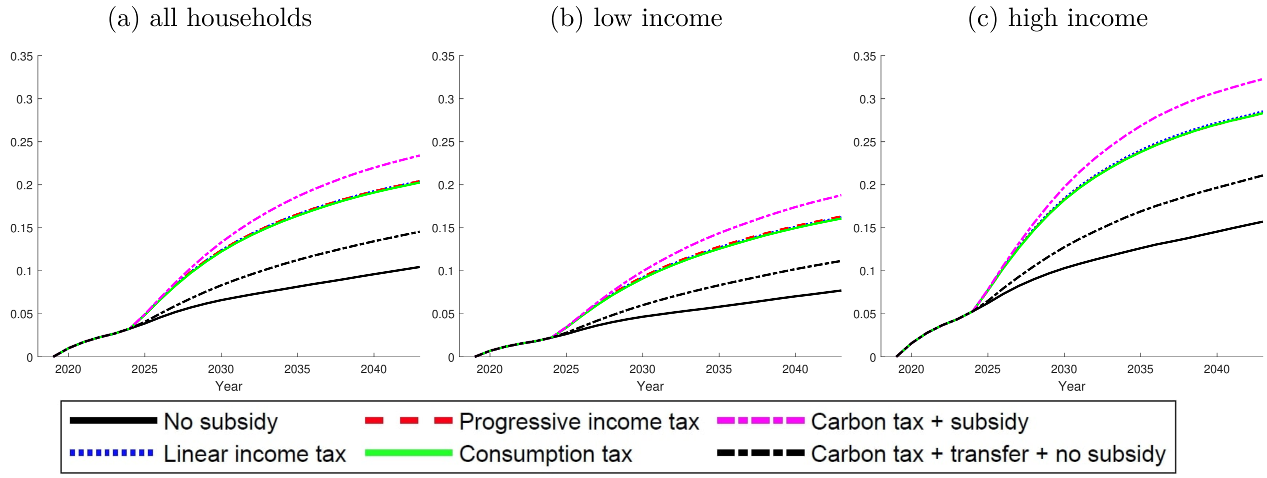
Figure A19: Emission reduction with higher carbon taxes



Notes: This figure depicts the reductions in carbon emissions when a progressive income tax finances a percentage subsidy and when a carbon tax revenues are rebated back to households as lump-sum transfers.

Figure A20 shows the share of households with the modern commitment good under the policies as in Section 4 and in case of the higher carbon tax (carbon tax + transfer + no subsidy). Although the carbon tax has been set to match the same reduction in emissions, the share of households with the modern commitment good increases only modestly over the no subsidy case. Surprisingly, the adoption rate remains low compared to the policies that yield the same reduction in emissions. The reason is that an important part of the reduction in emissions comes from households who still consume the old commitment good but who consume less of the good so that emissions fall because of less consumption of the old commitment good rather than substitution to the modern good. Compared to the no policy scenario, the reduction of emissions with higher carbon taxes is 14pp of which 10pp are accounted for by smaller commitment goods and only 4pp because of higher adoption rates.

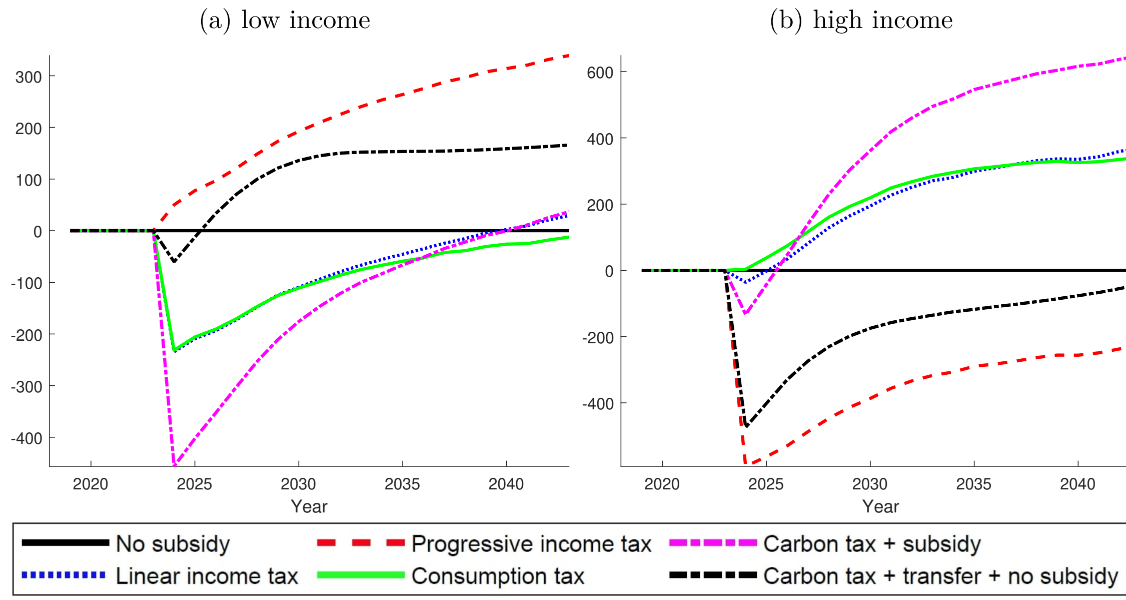
Figure A20: Share of households with modern consumption commitments with higher carbon tax



Notes: This figure shows the share of households with the modern commitment good along the transition path for different policy mixes. The left panel shows the share among all households, the middle panel shows the share for low-income households, and the right panel shows the share for high-income households. The policy mix is the combination of a percentage subsidy on the modern commitment good in combination with different financing schemes. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but a higher carbon tax where the tax revenues are rebated back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

Figure A21 shows the annual net transfers of the different policy mixes from Section 4 and for the case of the higher carbon tax. We find that the net transfers of the policy mix with the higher carbon tax converge to the policy mix of the progressive income tax with the percentage subsidy. The lump-sum transfer financed by the higher carbon taxes increases the progressivity of the tax and transfer system similar to the progressive tax system. While the two policy mixes appear similar with respect to the time path of average net transfers, we find that they still differ substantially in their distributional effects across age groups.

Figure A21: Annual net transfers with higher carbon tax



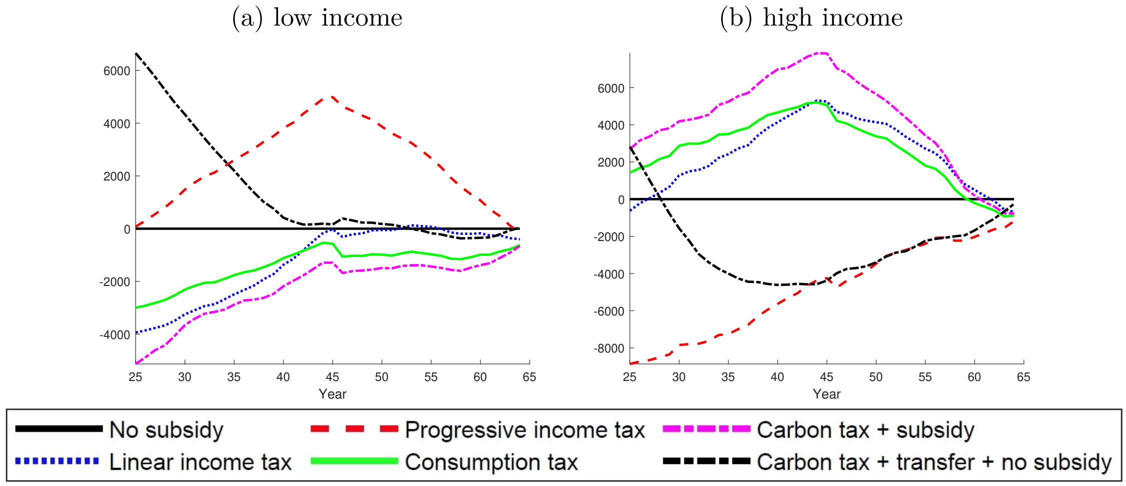
Notes: This figure shows the annual net transfers of different policy mixes. Left panel shows transfers for low-income households and right panel shows transfers for high-income households. Transfers are in Euros per year. The different policy mixes combine a percentage subsidy for the purchase price of the modern commitment good with different financing instruments. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but a higher carbon tax where the tax revenues are rebated back to households as lump-sum transfers. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

Figure A22 shows the present value of net transfers by age group. Comparing the carbon-tax-and-transfer policy without a subsidy to the progressive income tax with percentage subsidy shows very different distributional consequences by age among low-income households. The same qualitative pattern already arises in the case of the lower carbon tax but at a substantially smaller scale (Figure 7). We find the progressive income tax with a percentage subsidy to be particularly attractive for mid-age low-income households who adopt to the modern commitment good and receive the subsidy but pay low taxes. By contrast, the carbon-tax-and-transfer policy is most attractive for young low-income households who consume little of the old commitment good, pay little carbon taxes, and receive the full lump-sum transfer. Hence, the carbon-tax-and-transfer policy redistributes mainly to households who consume little of the commitment good or reduce their consumption whereas the subsidy policy redistributes to households who change to consuming the modern commitment good. Hence, whereas the carbon tax policy reduces consumption for most households because of the increase in user costs, the policy of a progressive tax to finance a subsidy leads to more substitution because of increased substitution incentives.

For high-income households, we find the corresponding pattern. The carbon-tax-and-transfer policy leads to the largest negative present values for mid-age households who consume the old commitment good. The youngest high-income households receive slightly positive net transfers as they reduce their consumption of the old commitment good, pay little carbon taxes, and receive the transfers financed by the carbon tax. With the progressive income tax to finance a subsidy, we find that the present value is always negative but that net transfers are the least negative for those households who are most likely to adopt to the modern commitment good, the older high-income households. The group with the largest negative present value are the high-income young households as they receive little of the subsidy as they are buying less of the modern commitment good but they contribute to the financing of the subsidy program by paying the higher progressive tax rate.

In summary, a substantially higher carbon tax that is rebated as lump-sum transfer could be an alternative to a progressive tax policy financing a percentage subsidy. The policies differ however in the mechanism how the reduction of emissions is achieved. Whereas the higher carbon tax achieves a large part of the reduction by reducing consumption of the old commitment good by higher user costs, the subsidy policy financed by a progressive tax provides incentives for substitution so that higher adoption rates of the modern commitment good lead to the reduction of emissions. These differences in mechanism show up in the very different distributional consequences along the age dimension of these policies. Importantly, the two policies also differ in their fiscal budget. The higher carbon tax policy will at the level of the macroeconomy lead to transfers of about 82 billion Euros per year given 41 million households in Germany. This budget corresponds to 20 percent of the current German federal budget. The progressive tax policy is substantially smaller but would still be a large fiscal program with about 19 billion Euros of subsidies in the first year of the program.

Figure A22: Present value of net transfers of policy mixes across age and income groups with higher carbon tax



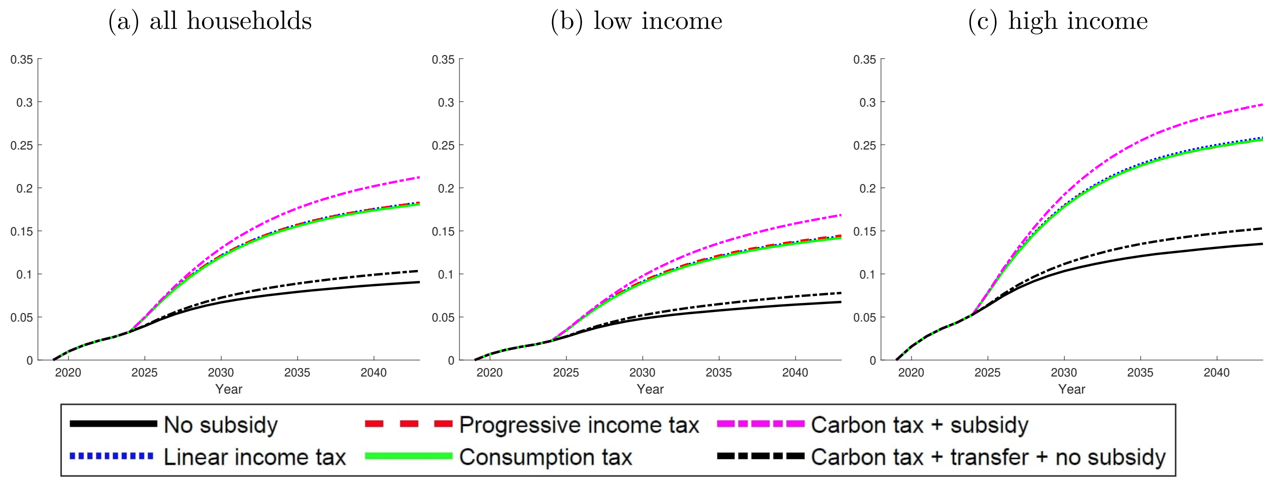
Notes: This figure shows the present value of net transfers of the different policy mixes by age and income group. Left panel shows transfers for low-income households and right panel shows transfers for high-income households. Transfers are in Euros per year and have been discounted at the interest rate r. The different policy mixes combine a percentage subsidy for the purchase price of the modern commitment good with different financing instruments. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but a higher carbon tax where the tax revenues are rebated back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

B.4 Entering newborn cohorts during the transition

In Section 4, we discuss the transition dynamics for the group of households alive a the introduction of the policy. We abstract from young cohorts entering the model at later points during the transition to allow for a transparent comparison. Here, we show results with newborn households entering the model during the transition. We keep the taxes, transfers, and subsidies as before what implies that the policies typically do not have a balanced budget over the transition period but that the newborn cohorts are either net recipients or net contributors. Figure A23 shows the adoption rates with newborn households. The key qualitative difference is that the entry of new cohorts will remove the life-cycle effect on the transitional dynamics as now the age structure remains constant over the transition period. As young households are less likely to buy the modern commitment good, we find that there is a negative effect on adoption rates but the effects are overall very small. In case of the percentage subsidy financed by a progressive tax, the average adoption rate at the end of the transition period declines by 2pp from 20 percent to 18 percent.

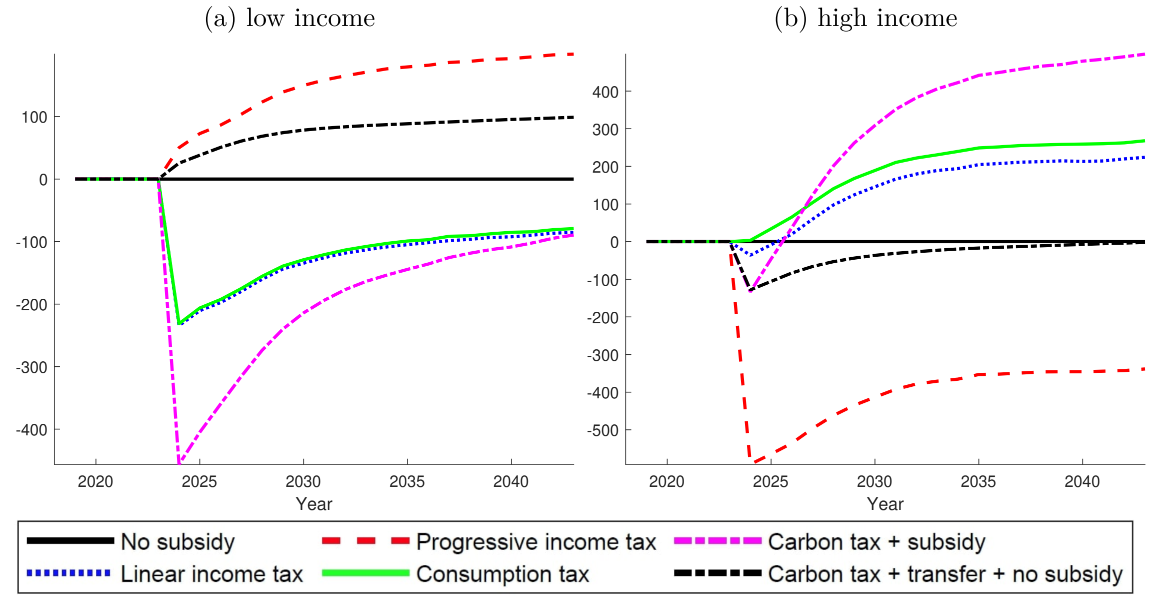
Figure A24 shows the time path of net transfers. We find overall effects to be small. In the first years of the transition period, the effect on average transfers is negligible. At the end of the transition, when the life-cycle effect in the baseline model becomes strongest, we find that including newborn generations stabilizes the redistribution pattern around their level of 2035.

Figure A23: Share of households with modern consumption commitments by income and reduction in carbon emissions with newborn cohorts



Notes: This figure shows for the case with newborn cohorts the share of households with the modern commitment good along the transition path for different policy mixes and the reduction in carbon emissions. The left panel shows the share for low-income households and the middle panel shows the share for high-income households. The right panel shows the reduction in emissions. Carbon emissions only come from old consumption commitment goods and are assumed to be proportional to the size of the old commitment good. The policy mix is the combination of a percentage subsidy on the modern commitment good in combination with different financing schemes. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but rebates tax revenues back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

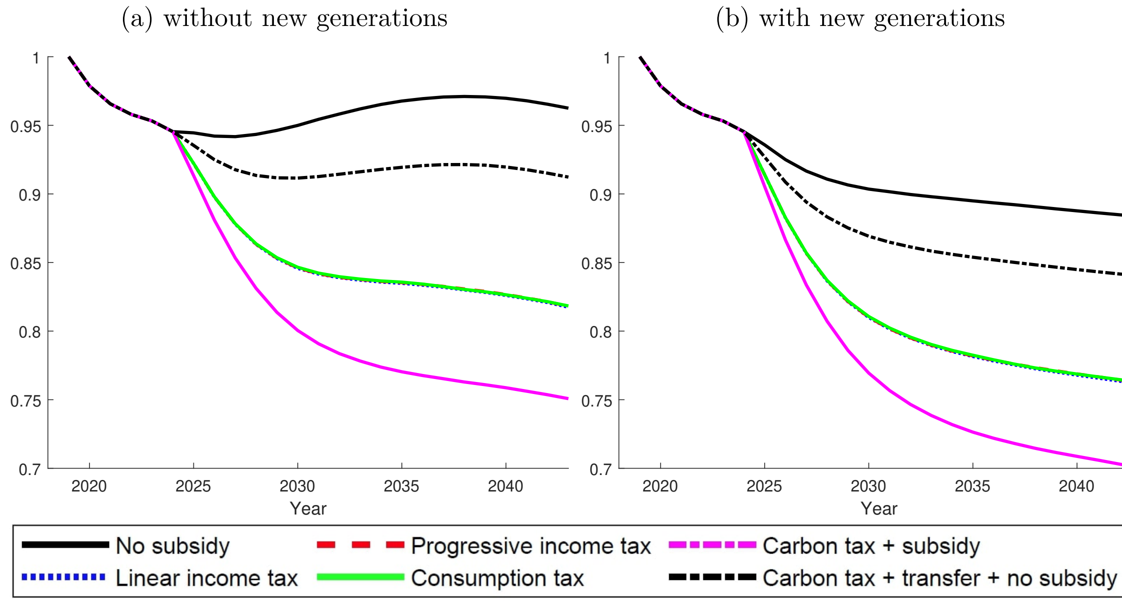
Figure A24: Annual net transfers with newborn cohorts



Notes: This figure shows for the case with newborn cohorts the annual net transfers of different policy mixes. Left panel shows transfers for low-income households and right panel shows transfers for high-income households. Transfers are in Euros per year. The different policy mixes combine a percentage subsidy for the purchase price of the modern commitment good with different financing instruments. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but rebates tax revenues back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.

Finally, Figure A25 compares the reduction of emissions from Section 4 to the reduction of emissions if also young households enter during the transition period. The life-cycle effect in the case without new generations leads to higher emissions in the second half of the transition period. When new generations enter during the transition period, we find a smooth decline of emissions for all policy mixes.

Figure A25: Reduction in emissions with newborn cohorts



Notes: This figure shows the reduction in carbon emissions along the transition for different policy mixes. Left panel shows the case without newborn cohorts and right panel shows the case with newborn cohorts. The different policy mixes combine a percentage subsidy for the purchase price of the modern commitment good with different financing instruments. The carbon tax + transfer + no subsidy policy mix includes no subsidy for the modern commitment good but rebates tax revenues back to households as lump-sum transfer. Tax rates for all policy mixes are set to have a balanced budget over the transition period.