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Carbon Tax, Labour Market Segregation, and Inequality

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A rapid transition to low-carbon production is essential for climate mitigation, but its economic costs and benefits are not evenly shared. This paper studies how carbon pricing affects workers of different skills when clean and dirty energy sectors differ in their skill intensity. We extend a dynamic multi-sector environmental growth model in the spirit of Golosov et al. (2014) by introducing high- and low-skill households and a production structure in which clean energy is relatively high-skill intensive and dirty energy relatively low-skill intensive. We show that a Pigouvian carbon tax decentralizes the first-best allocation by internalizing the external cost of emissions, yet it is not distributionally neutral: the induced reallocation of capital and labour toward clean production raises the skill premium and can reduce welfare for the low-skill household. Numerical simulations calibrated to the U.S. economy confirm that aggregate welfare gains coexist with significant welfare losses for low-skill households, raising concerns about the political acceptability of such policies.

Keywords
climate policy, carbon tax, transition risks, inequality, labour market transitions

JEL Codes
E30, E32, E43, E51, E52, G18, Q58, H23

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Carbon Tax, Labour Market Segregation, and Inequality

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December 30, 2025

Abstract

A rapid transition to low-carbon production is essential for climate mitigation, but its economic costs and benefits are not evenly shared. This paper studies how carbon pricing affects workers of different skills when clean and dirty energy sectors differ in their skill intensity. We extend a dynamic multi-sector environmental growth model in the spirit of Golosov et al. (2014) by introducing high- and low-skill households and a production structure in which clean energy is relatively high-skill intensive and dirty energy relatively low-skill intensive. We show that a Pigouvian carbon tax decentralizes the first-best allocation by internalizing the external cost of emissions, yet it is not distributionally neutral: the induced reallocation of capital and labour toward clean production raises the skill premium and can reduce welfare for the low-skill household. Numerical simulations calibrated to the U.S. economy confirm that aggregate welfare gains coexist with significant welfare losses for low-skill households, raising concerns about the political acceptability of such policies.

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1 Introduction

Climate change represents one of the most pressing challenges faced by global society, with profound implications for long-term welfare, economic growth, and intergenerational equity. A broad consensus in economics holds that carbon pricing is among the most effective ways to address this problem, because it directly internalizes the external cost of greenhouse-gas emissions (e.g. Nordhaus, 2013). At the same time, the political feasibility and social sustainability of carbon taxes hinge on who bears the costs and who receives the benefits. Indeed, mounting evidence suggests that the burden of climate policy is not evenly shared across households, industries, and regions in the economy, with heterogeneous effects on both the demand and the supply sides (Drupp et al., 2025). Understanding these distributional consequences is therefore essential for evaluating carbon pricing as a policy instrument.

One important source of heterogeneity operates through the labour market. A substantial share of the energy workforce remains employed in carbon-intensive activities (IEA, 2024), and decarbonization requires large reallocations of workers away from polluting production and toward cleaner industries. Yet such reallocations are rarely frictionless. Skills acquired in carbon-intensive jobs may be imperfectly transferable to clean jobs, and clean occupations tend to be more skill-intensive than their dirty counterparts (Vona et al., 2018, Sato et al., 2023). Consistent with this, transitions from polluting to cleaner firms are particularly difficult for less-educated workers (Bluedorn et al., 2023). Moreover, the diffusion of new clean technologies often requires complementary, occupation-specific human capital (Popp et al., 2024). These patterns raise a concern that carbon pricing may interact with sectoral skill differences in a way that amplifies wage inequality and creates "just transition" tensions, even when the policy is efficiency-improving in aggregate.

In this paper, we develop an environmental dynamic general equilibrium model to study how carbon taxation interacts with skill heterogeneity and sectoral differences in skill intensity. In particular, we build a multi-sector environmental growth model in the spirit of Golosov et al. (2014). A competitive final-good sector combines clean and dirty energy inputs, and dirty energy production generates emissions that cumulate into a stock and reduce productivity through a climate-damage function. Our main departure is to introduce two worker types: high-skill and low-skill workers organized into two representative households. Both energy sectors use both skill types, but the dirty sector is relatively low-skill intensive while the clean sector is relatively high-skill intensive.

In the absence of climate policy, dirty energy is privately too cheap because its future climate damages are not priced. The decentralized economy therefore overuses dirty energy and allocates too much capital and labour to dirty production relative to the social optimum.

We show that efficiency can be restored by a Pigouvian carbon tax on dirty energy that equals the external marginal cost of emissions, i.e. the discounted present value of future productivity losses induced by a marginal increase in dirty output today.

While this policy allows the government to reach the efficient allocation, our central point is that this not distributionally neutral across households. By raising the effective price of dirty energy, the carbon tax induces substitution toward clean energy and reallocates both capital and labour across sectors. When clean production is relatively high-skill intensive, this reallocation changes relative factor demands and therefore affects the skill premium. Even with perfect mobility across sectors within each skill group, the transition can generate asymmetric wage pressures: low-skill labour is more exposed to contractions in dirty production, while high-skill labour benefits relatively more from the expansion of clean production. Hence, a carbon tax can increase wage inequality along the transition, despite improving aggregate welfare.

We illustrate these mechanisms numerically using a calibration loosely aligned with the US economy. The simulation highlights a simple but policy-relevant trade-off. The optimal carbon tax increases aggregate welfare by reducing climate damages, but it can lower welfare for the low-skill household when revenues are rebated uniformly, because the gains from lower future damages do not fully offset the low-skill group's relative wage losses during the transition. At the same time, the model clarifies a route to a 'just transition' without sacrificing efficiency: revenue recycling matters. A sufficiently progressive rebate of carbon-tax revenues can compensate the low-skill household for transitional wage losses while preserving the aggregate efficiency gains of carbon pricing. This underscores that the design of carbon dividends is an important component of policy, and that the appropriate recycling rule depends on the structure of sectoral labour demand and skill intensities.

More broadly, the paper bridges theory and evidence by offering a tractable dynamic framework in which sectoral differences in skill intensity mediate both the efficiency and the distributional effects of carbon taxation. Ignoring these labour market channels can lead to overly optimistic conclusions about the ease of decarbonization and the distributional neutrality of carbon pricing.

The remainder of this paper proceeds as follows. Section 2 reviews previous literature. Section 3 sets up the model, while Section 4 describes the socially optimal allocation and how this can be replicated in the decentralised equilibrium though a carbon tax. Section 5 presents numerical illustrations. Finally, Section 6 concludes.

2 Literature Review

Our paper is part of a large literature that combines insight from environmental economics and macroeconomics to study the general equilibrium effects of climate policies on the economy. Among these, the standard framework is the dynamic integrated model of climate and the economy (DICE, e.g. Nordhaus, 2018). Embedding this into a dynamic stochastic general equilibrium model, Golosov et al. (2014) derived an analytical characterization of a simple formula for the marginal externality damage of carbon dioxide emissions, which can be used to calculate the optimal carbon tax. Since then, a large literature, summarised by Annicchiarico et al. (2022), has used environmental dynamic stochastic general equilibrium models (e-DSGE) to either compare the macroeconomic performances of different emission policies (see Fischer and Heutel, 2013, for an early literature review) or analyse the macro-financial consequences of climate policy (e.g. Diluiso et al., 2021, Carattini et al., 2023).

Whereas these papers use a representative agent framework, empirical evidence on the unequal impacts of climate policy have recently emerged. In particular, low-income groups are found to be disproportionately exposed to carbon pricing, both because they allocate a larger share of spending to energy and because they are more likely to work in sectors affected by the policy (Känzig, 2023). Relatedly, the concept of 'just transition', whereby policies are devised to secure workers' livelihoods during the transition towards more sustainable production processes, has entered the academic debate and the policy agenda (European Commission, 2021).

A few studies have thus started investigating this issue using theoretical and microfounded perspectives, like we do.[1,2] Among these, our paper is particularly close to Douenne et al. (2024), Ascari et al. (2025), and Belfiori et al. (2025). Douenne et al. (2024) study the optimal combination of carbon taxation and non-individualized lump-sum transfers or

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[1] Relatedly, different extensions to the DICE model have been proposed to model and analyse these unequal impacts. For example, Dennig et al. (2015) proposed the so-called nested inequalities climate-economy model (NICE), which divides each region into quintiles distributions of income and explicitly models the uneven within-country distribution of impacts to analyse how optimal global mitigation efforts are affected by inequality. Similarly, Gazzotti et al. (2021) used a regional integrated model of climate and the economy with more than fifty independent regions (RICE50+) to assess climate impacts, differentiating between rich and poor regions, and show that climate change is likely to increase economic inequality, even under welfare-maximizing policies.

[2] Other theoretical paper have also studied the unequal impacts of carbon policy from different perspectives, focusing on e.g. the equity-efficiency trade-off using a input-output model (Fremstad and Paul, 2019), the importance of considering Engel curves (Jacobs and van der Ploeg, 2019), the unequal impact of macro-financial policies mitigating transition risk (Comerford and Spiganti, 2023), the role of the carbon dividend for intergenerational equity (Fried et al., 2024), the geographical aspects (Labrousse and Perdereau, 2025), the difference in access to financial markets (Cantore et al., 2025), and the progressivity of the income tax system (Van Der Ploeg et al., 2025). However, these papers abstracts from the role of the labour market in shaping distributional and environmental outcomes.

taxes in a heterogeneous-agent setting where agents differ in their initial asset holdings and permanent productivity, generating persistent inequality in labour income. Belfiori et al. (2025) differ from Douenne et al. (2024) in focusing on the optimal combination of carbon taxes and transfers to internalise climate damages in the presence of inequality, rather than to address damages and inequality simultaneously. Ascari et al. (2025) develop a heterogeneous-agent model with non-homothetic preferences over energy and non-energy goods and calibrate it to European data to quantify the equity-efficiency trade-offs of different transition policies. We share with these papers an interest in the welfare consequences of the policy maker's access to individualised versus uniform rebates, and to unlimited transfers versus being limited to redistribute carbon dividends.

Nevertheless, our framework differs from this literature in one crucial respect: we explicitly model heterogeneity in sectoral skill intensity between clean and dirty production, and we highlight the labour market channel as a driver of distributional outcomes. Existing heterogeneous-agent macro-climate models generate unequal impacts through differences in consumption baskets, wealth, or permanent productivity, while abstracting from how climate policy changes equilibrium labour demand across sectors with different skill requirements. Yet empirical evidence suggests that this channel is central. Clean occupations are systematically more skill intensive than dirty occupations, and transitions from carbon-intensive to cleaner firms are particularly challenging for lower-educated workers (Vona et al., 2018, Borissov et al., 2019, Bluedorn et al., 2023, Rud et al., 2024). These findings align with US labour statistics: carbon-intensive energy industries employ a relatively larger share of operational occupations (e.g. construction, extraction, production, and installation), whereas clean energy sectors rely more heavily on managerial, engineering, and technical occupations (U.S. Bureau of Labor Statistics, 2023). By embedding such differences in sectoral skill intensity into a dynamic general-equilibrium model, we show how an efficient carbon tax can raise the skill premium during the transition and can generate welfare losses for low-skill households under uniform revenue recycling.

A small related literature considers labour market frictions in the context of carbon policy, though typically outside dynamic macro settings. For example, Hafstead and Williams III (2018) and Cavalcanti et al. (2024) study the incidence of carbon taxes with labour market frictions in static computational general-equilibrium frameworks. Our contribution is complementary: we focus on a dynamic environment with endogenous reallocation of capital and labour across clean and dirty sectors, and we isolate how sectoral differences in skill intensity interact with carbon pricing and revenue recycling to shape inequality and welfare.

Taken together, these strands of work underscore that the distributional incidence of climate policy is a first-order issue. Our contribution is to provide a parsimonious macro-climate framework in which the structure of labour demand, through sectoral differences in skill intensity, plays a central role in determining how the gains and losses from carbon pricing are shared, and to show how appropriately designed revenue recycling can support a just and politically feasible transition to a low-carbon economy.

3 Model

We consider a multi-sector closed economy in discrete and infinite time, indexed by $t = 0, 1, \ldots, \infty$. This economy consists of two representative households (indexed by h and l, respectively), a government, and three types of firms. It features a competitive final sector producing a homogeneous final good using two differentiated intermediate energy inputs, one clean and one dirty, and the two corresponding intermediate sectors producing energy inputs using capital, low-skill labour, and high-skill labour. Figure 1 gives an overview of the model between two time periods.

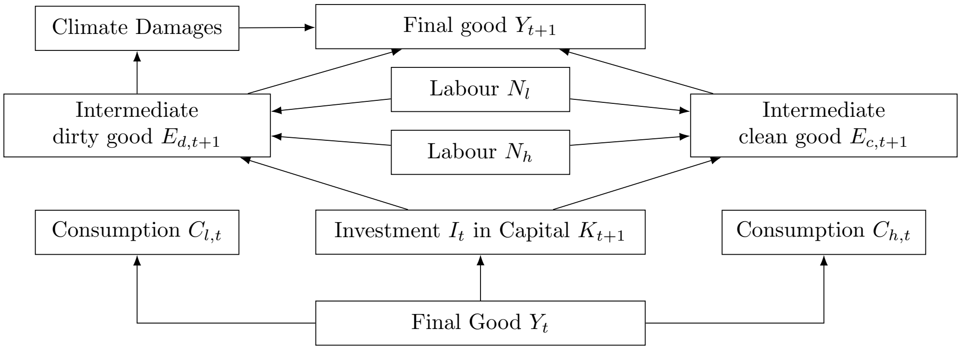

Figure 1: Overview of the model

3.1 Households

There are two households, indexed by $i = \{h, l\}$, denoting high-skill (h) and low-skill (l). Household i has a continuum of members of total size N_i. Workers in each household i are endowed with one unit of labour in each period, which they supply inelastically to intermediate good firms. Wages are returned to the respective household. The representative household of type i derives utility from household consumption $C_{i,t}$. The net present value of lifetime utility of the representative household of type i is

$$\sum_{t=0}^{\infty} \beta^t \frac{C_{i,t}^{1-\sigma} - 1}{1 - \sigma}, \tag{1}$$

where $\beta \in (0,1)$ is the discount factor and $\sigma > 0$ is the inverse of the elasticity of intertemporal substitution; for simplicity, both parameters are common across households.

Labour is perfectly mobile across sectors within each skill group, which means that in equilibrium an agent from household i must receive the same wage $W_{i,t}$ independently of the sector where she is employed. Each household then receives household-specific wage bills $W_{i,t}N_i$ and lump-sum transfers $T_{i,t}$ from the government (negative values denote taxes). Households can save by investing in capital $K_{i,t}$. Since this is rented out freely across sectors,[3] a no-arbitrage condition implies that the rental rate R_t must be unique between sectors and households. The flow budget constraint of each household is then

$$C_{i,t} + I_{i,t} = W_{i,t}N_i + R_t K_{i,t} + T_{i,t}, \tag{2}$$

where $I_{i,t}$ is investment in capital by household i at time t. Since capital depreciates at rate $\delta \in [0,1]$ between periods, the law of motion of household's capital reads

$$K_{i,t+1} = I_{i,t} + (1-\delta)\, K_{i,t}. \tag{3}$$

Each household chooses the stream of consumption and investment $\{C_{i,t}, I_{i,t}\}_{t=0}^{\infty}$ to maximize lifetime utility (1), subject to the flow budget constraint (2), the law of motion of capital (3), a transversality condition, and given initial capital holding $K_{i,0}$. Combining the first-order conditions (FOCs), one obtains the usual Euler equation for intertemporal allocation between consumption and investment,

$$\left(\frac{C_{i,t}}{C_{i,t+1}}\right)^{-\sigma} = \beta \left[R_{t+1} + (1-\delta)\right]. \tag{4}$$

In deciding whether to invest or consume an additional unit of income, household i compares current marginal utility with the net present value of future marginal utility. Note that, since the right-hand side of (4) is the same across households, the rate of change in consumption (on the left-hand side) will also be the same across households in equilibrium.

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[3] We follow Golosov et al. (2014) in assuming that agents invest in generic capital across periods and are then free to allocate this capital across sectors within period. Conversely, models with a more business-cycle perspective (e.g. Diluiso et al., 2021, Carattini et al., 2023) usually assume that capital is sector-specific. Sector-specific capitals require a higher carbon tax to disincentivise dirty capital accumulation early on, which would strengthen the conclusions of our model.

3.2 Final Good Production

Households consume a unique final good Y_t. This is produced competitively by a representative firm combining dirty and clean energy inputs, $E_{d,t}$ and $E_{c,t}$, according to the following constant elasticity of substitution (CES) technology,

$$Y_t = [1 - D(Z_t)]\, A_t \left[E_{d,t}^{(\epsilon-1)/\epsilon} + E_{c,t}^{(\epsilon-1)/\epsilon}\right]^{\epsilon/(\epsilon-1)}, \tag{5}$$

where $\epsilon > 1$ is the elasticity of substitution between dirty and clean inputs, A_t is the exogenous total factor productivity of the final sector, and $D(Z_t)$ is a damage function capturing the effect of cumulative emissions Z_t on productivity, in the spirit of the dynamic integrated climate-economy model (Nordhaus, 2018). Cumulative carbon emissions are given by

$$Z_t \equiv \hat{Z} + \sum_{k=0}^{t} E_{d,k}, \tag{6}$$

where $\hat{Z}$ is the pre-industrial stock of emissions and emission intensity is normalised to one.

The FOCs of the final good producer imply that the relative demands for the intermediate inputs are inversely related to their prices,

$$\frac{E_{d,t}}{E_{c,t}} = \left(\frac{P_{d,t}}{P_{c,t}}\right)^{-\epsilon}. \tag{7}$$

Without loss of generality, we normalise the price of the final good to one at each date.

3.3 Carbon Emissions and Energy Goods Production

A representative firm in each sector $s \in \{c, d\}$ produces competitively the energy good $E_{s,t}$, using labour and generic capital. We denote with $K_{s,t}$ the amount of generic capital employed in sector s at time t. Whereas clean energy production does not create carbon emissions, the production of the dirty input entails carbon emissions as a negative externality, so that the representative dirty firm may be subject to a carbon tax τ_t imposed by the government.

Both types of firms operate a constant returns to scale technology,

$$E_{s,t} = A_{s,t} K_{s,t}^{\alpha_s} N_{s,t}^{1-\alpha_s}, \tag{8}$$

where $\alpha_s \in (0, 1)$ is the capital share, $A_{s,t}$ denotes sector-specific total factor productivity, and $N_{s,t}$ is a CES composite of high-skill $H_{s,t}$ and low-skill $L_{s,t}$ labour,

$$N_{s,t} = \left[\gamma_s H_{s,t}^{(\epsilon_s-1)/\epsilon_s} + (1-\gamma_s)\, L_{s,t}^{(\epsilon_s-1)/\epsilon_s}\right]^{\epsilon_s/(\epsilon_s-1)}, \tag{9}$$

where ϵ_s is the elasticity of substitution and $\gamma_s \in [0,1]$ is the share parameter.

The functional form in (9) is quite general and can thus capture different cases that might be of interest. For example, when workers with different skill levels are perfect substitute ($\epsilon_s \to \infty$) and the share parameters are equal ($\gamma_s = 0.5$), high- and low-skill workers have identical wages, allowing the model to encompass the baseline case of no wage inequality (e.g. Golosov et al., 2014). Conversely, when $\epsilon_s \to 1$, the labour aggregator in (9) simplifies to a Cobb-Douglas function with factor shares for high- and low-skill labour equal to γ_s and $1-\gamma_s$, respectively. Then, the parametrization $\gamma_c = 1-\gamma_d = 1$ represents the extreme case in which labour markets are fully segregated, with all high-skill workers permanently employed in the clean sector and all low-skill workers forever in the dirty sector. Yet another, perhaps more empirically relevant, parametrization involves $\epsilon_s \to 1$ and $1 > \gamma_c > \gamma_d > 0$, which implies that the clean sector hires a greater proportion of high-skill workers than the dirty sector, which in turn relies proportionally more on low-skill workers (as documented by e.g. Vona et al., 2018, Sato et al., 2023).

At the beginning of period t, firms in the dirty and clean sectors rent capital $K_{s,t}$ from households and hire workers $H_{s,t}$ and $L_{s,t}$. After production takes place, firms return capital and interest at rate R_t and pay wage bills $W_{h,t}H_{s,t}$ and $W_{l,t}L_{s,t}$. The representative firms in the dirty and clean sectors choose capital $K_{s,t}$ and labours $H_{s,t}$ and $L_{s,t}$ to maximize profits,

$$(P_{d,t} - \tau_t)\, E_{d,t} - W_{h,t}H_{d,t} - W_{l,t}L_{d,t} - R_t K_{d,t}, \tag{10a}$$

$$P_{c,t}E_{c,t} - W_{h,t}H_{c,t} - W_{l,t}L_{c,t} - R_t K_{c,t}, \tag{10b}$$

subject to the technology constraint in (8) and (9), and taking prices (including the carbon tax) and productivities as given. The representative dirty firm then chooses labour and capital according to the following FOCs,

$$W_{h,t} = (P_{d,t} - \tau_t)\, \frac{\partial E_{d,t}}{\partial H_{d,t}}, \tag{11a}$$

$$W_{l,t} = (P_{d,t} - \tau_t)\, \frac{\partial E_{d,t}}{\partial L_{d,t}}, \tag{11b}$$

$$R_t = (P_{d,t} - \tau_t)\, \frac{\partial E_{d,t}}{\partial K_{d,t}}. \tag{11c}$$

The representative clean energy firm does not emit, and it is thus not subject to climate policy; it then chooses labour and capital to satisfy

$$W_{h,t} = P_{c,t} \frac{\partial E_{c,t}}{\partial H_{c,t}}, \tag{12a}$$

$$W_{l,t} = P_{c,t} \frac{\partial E_{c,t}}{\partial L_{c,t}}, \tag{12b}$$

$$R_t = P_{c,t} \frac{\partial E_{c,t}}{\partial K_{c,t}}. \tag{12c}$$

Capital and labour markets clearing conditions entail $\sum_s K_{s,t} = \sum_i K_{i,t}$, $\sum_s L_{s,t} = N_l$, and $\sum_s H_{s,t} = N_h$ for all t.

3.4 Government

The government runs a balanced budget: it sets a sequence of carbon taxes $\{\tau_t\}_{t=0}^{\infty}$, collects revenues, and immediately transfers them to households, i.e. $\sum_i T_{i,t} = \tau_t E_{d,t}$. It has full commitment. Under laissez-faire, the government does not impose a climate policy, and thus $T_t = 0 \ \forall t$. In the rest of the paper, we focus on a constant split of the carbon dividends among the two households and we indicate with $\xi \in (0, 1)$ the share of the tax rebate in each period going to the l household. For example, under a uniform rebate scheme, $\xi = N_l / (N_h + N_l)$.

4 Equilibrium

Given a sequence of carbon taxes $\{\tau_t\}_{t=0}^{\infty}$, a constant split of tax revenues ξ, exogenous productivities $\{A_t, A_{d,t}, A_{c,t}\}_{t=0}^{\infty}$, and initial capital holdings $\{K_{h,0}, K_{l,0}\}$, a decentralised equilibrium is a sequence of prices $\{R_t, P_{d,t}, P_{c,t}, W_{h,t}, W_{l,t}\}_{t=0}^{\infty}$ and quantities $\{Y_t, E_{d,t}, E_{c,t}, C_{h,t}, C_{l,t}, I_{h,t}, I_{l,t}, K_{d,t}, K_{c,t}, K_{h,t}, K_{l,t}, H_{d,t}, H_{c,t}, L_{d,t}, L_{c,t}, T_{h,t}, T_{l,t}, Z_t\}_{t=0}^{\infty}$ such that households make optimal consumption and investment choices in accordance with the Euler's equations in (4), the representative energy firms demand labours and capital according to the FOCs in (11) and (12), the representative final good firm chooses energy inputs according to (7); all markets (the final good market, the intermediate energy goods markets, the markets for capital, and the labour markets) clear; cumulative emissions evolve according to (6); and the government runs a balanced budget.

In the rest of this section, we first derive the first-best allocation, i.e. the solution to the maximization problem of a social planner who can directly choose allocations without passing through markets. This allocation internalises the negative externality of carbon emissions, optimally managing the trade-off between productivity losses (deriving from emissions due to dirty energy production) and consumption losses (following reduced output due to limitations to dirty energy production). Then, we show how the first-best allocation can be implemented in the decentralised equilibrium by a government which optimally sets the stream of carbon taxes.

4.1 Socially Optimal Allocation

The production of dirty energy contributes to cumulative emissions according to (6) and thus to damages to the productivity of the final sector. While this is not internalised by markets in the absence of targeted policies, this environmental externality must be corrected in the socially optimal allocation.

Formally, the maximization problem of the benevolent social planner is to choose the stream of aggregate investment in capital $\{I_t\}_{t=0}^{\infty}$, the input allocations $\{K_{d,t}, K_{c,t}, H_{d,t}, H_{c,t}, L_{d,t}, L_{c,t}\}_{t=0}^{\infty}$, and the stream of consumption of the two households $\{C_{h,t}, C_{l,t}\}_{t=0}^{\infty}$ to maximize the following social welfare function,

$$\theta \sum_{t=0}^{\infty} \beta^t \frac{C_{l,t}^{1-\sigma} - 1}{1-\sigma} + (1-\theta) \sum_{t=0}^{\infty} \beta^t \frac{C_{h,t}^{1-\sigma} - 1}{1-\sigma}, \tag{13}$$

where $\theta \in [0,1]$ is a relative Pareto weight attached to household l. The maximization is subject to the technological constraints (5), (8), and (9), the law of motion of cumulative emissions (6), the law of motion of aggregate capital $K_{t+1} = I_t + (1-\delta) K_t$, the feasibility conditions for each good and service (akin the market clearing in the decentralized set-up), and an aggregate resource constraint $Y_t = C_t + I_t$, where $C_t \equiv C_{h,t} + C_{l,t}$ is aggregate consumption.

The FOCs for consumptions imply

$$\nu_{rc,t} = \theta C_{l,t}^{-\sigma} = (1-\theta) C_{h,t}^{-\sigma}, \tag{14}$$

where $\nu_{rc,t}$ is the Lagrangian multiplier associated to the resource constraint at time t. Since $\nu_{rc,t}$ is also equal to the shadow value of one unit of the final good, equation (14) means that, at the social optimum, the planner equalises the shadow value of the final good to the marginal utility of consumption of each household, weighted by their Pareto weights.

Moreover, by differentiating the Lagrangian by K_{t+1}, one obtains the following FOC for aggregate capital accumulation,

$$\frac{\nu_{rc,t}}{\nu_{rc,t+1}} = \beta \left[\frac{\partial Y_{t+1}}{\partial K_{t+1}} + (1-\delta) \right]. \tag{15}$$

By then combining (14) and (15), we obtain the Euler equations describing the optimal intertemporal choices between aggregate investment and households' consumption,

$$\left(\frac{C_{l,t}}{C_{l,t+1}} \right)^{-\sigma} = \left(\frac{C_{h,t}}{C_{h,t+1}} \right)^{-\sigma} = \beta \left[\frac{\partial Y_{t+1}}{\partial K_{t+1}} + (1-\delta) \right]. \tag{16}$$

Note that the Pareto weights disappear and so the optimal change in consumption over time is equal across households. Thus, the Euler equations in (16) must also hold in aggregate terms and the left-hand sides can be substituted in terms of aggregate consumption, $(C_t/C_{t+1})^{-\sigma}$. Given that the utility functions are iso-elastic, the socially optimal allocation can be obtained by first choosing aggregate consumption C_t according to an aggregate Euler equation, and then distributing consumption to households. Indeed, by combining the FOCs with the aggregate resource constraint, the socially optimal levels of consumption in each period can be expressed as the following functions of aggregate consumption, welfare weights, and relative risk aversion,

$$C_{l,t} = \frac{\left(\frac{\theta}{1-\theta}\right)^{\frac{1}{\sigma}} (Y_t - I_t)}{1 + \left(\frac{\theta}{1-\theta}\right)^{\frac{1}{\sigma}}} \tag{17a}$$

$$C_{h,t} = \frac{Y_t - I_t}{1 + \left(\frac{\theta}{1-\theta}\right)^{\frac{1}{\sigma}}}. \tag{17b}$$

We consider a government with no access to lump-sum transfers across households, and thus redistribution can only occur through the revenues generated by the climate policy (i.e. the carbon dividends). Indeed, our main focus is on the feedback effect between carbon tax, labour market, and inequality, rather than whether climate consideration can coexist with a social desire to reduce inequality. We thus ex ante reduce the social planner's concern for redistribution: instead of focusing on comparing the social planner's allocations for different Pareto weights θ, we consider a planner with Negishi's (1960) weights, similar to Belfiori et al. (2025). These weights are endogenously set to be consistent with the income distribution determined by market wages, capital earnings, and rebate scheme. In other words, the decentralized competitive allocation can be mapped to a socially optimal one where the welfare weights are functions of relative market incomes.[4] Nevertheless, we explore in Section

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[4] Operationally, one must first solve for the optimal allocation for an initial guess of $\theta \in [0, 1]$. Second,

5 how the carbon tax dividends should be distributed across households to increase the acceptability of climate taxation.

At first sight, the social planner's Euler equation in (16) looks identical to the ones in (4) from the decentralised economy. However, the marginal contribution of capital to output $\partial Y_{t+1}/\partial K_{t+1}$ in the first-best allocation will generally differ from the rental rate of capital R_{t+1} in a decentralised allocation without an optimal carbon policy, as the negative effects of dirty production on productivity through climate damages would not be taken into account by individual agents. Conversely, in the first-best allocation, the social planner internalizes the climate externality.

To highlight this, let $\nu_{s,t}$ be the Lagrange multiplier associated with energy production of type s in period t, so that the ratio $\nu_{s,t}/\nu_{rc,t}$ becomes the shadow price of the intermediate input at time t (expressed in relative terms to the shadow value of one unit of the final good). Then, the FOCs with respect to $E_{s,t}$ read

$$\frac{\nu_{d,t}}{\nu_{rc,t}} = \frac{\partial Y_t}{\partial E_{d,t}} - \sum_{j=0}^{\infty} \frac{\beta^j \nu_{z,t+j}}{\nu_{rc,t}} \tag{18a}$$

$$\frac{\nu_{c,t}}{\nu_{rc,t}} = \frac{\partial Y_t}{\partial E_{c,t}}, \tag{18b}$$

where $\nu_{z,t}$ denotes the Lagrange multiplier associated with the evolution of cumulative carbon emissions in (6). In a laissez-faire equilibrium (i.e. a decentralised equilibrium with no carbon policy), firms would simply equalise the marginal product of each energy good to its price: private marginal benefits would equalise private marginal costs. Whereas this is the same in the socially optimal allocation for clean energy in (18b), for dirty energy the social planner must also consider the external marginal cost, represented by the last term in (18a). Combining the FOC with respect to Z_t with (18a), the socially optimal choice of the dirty intermediate input $E_{d,t}$ can be indeed expressed as

$$\frac{\nu_{d,t}}{\nu_{rc,t}} = \frac{\partial Y_t}{\partial E_{d,t}} + \sum_{j=0}^{\infty} \frac{\beta^j \nu_{rc,t+j}}{\nu_{rc,t}} \frac{Y_{t+j}}{1 - D(Z_{t+j})} \frac{dD(Z_{t+j})}{dZ_{t+j}}, \tag{19}$$

which makes it explicit that this external marginal cost is represented by the net present value (in terms of shadow prices of the final good) of all future climate damages to productivity caused by a marginal increase in the production of one unit of dirty energy today.

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given the optimal allocation, one must reconstruct the decentralized economy (that is, the set of prices that supports the optimal allocation) and check whether the resulting net present value of lifetime wealth of each household is consistent with their consumption path. If not, the initial guess of θ is updated and the steps replicated until convergence.

Regarding the split of capital between the two sectors, by combining the FOCs with respect to $K_{s,t}$, one obtains that at the optimum the social planner must equalise their marginal contribution to output, i.e.

$$\frac{\nu_{d,t}}{\nu_{rc,t}}\frac{\partial E_{d,t}}{\partial K_{d,t}} = \frac{\nu_{c,t}}{\nu_{rc,t}}\frac{\partial E_{c,t}}{\partial K_{c,t}}, \tag{20}$$

where the left-hand side includes the marginal damage as in (19). Likewise, high- and low-skill workers are optimally allocated to the two sectors to equalise their marginal contribution to final output, taking into account the marginal damages of allocating more workers to the dirty sector,

$$\frac{\nu_{d,t}}{\nu_{rc,t}}\frac{\partial E_{d,t}}{\partial L_{d,t}} = \frac{\nu_{c,t}}{\nu_{rc,t}}\frac{\partial E_{c,t}}{\partial L_{c,t}} \tag{21a}$$

$$\frac{\nu_{d,t}}{\nu_{rc,t}}\frac{\partial E_{d,t}}{\partial H_{d,t}} = \frac{\nu_{c,t}}{\nu_{rc,t}}\frac{\partial E_{c,t}}{\partial H_{c,t}}. \tag{21b}$$

4.2 The Ramsey Problem

Here, we describe the Ramsey problem, that is the maximization problem of a government that wants to implement the socially optimal allocation of Section 4.1 through a stream of carbon taxes $\{\tau_t\}_{t=0}^{\infty}$ on the supply of dirty energy, subject to implementability. Indeed, the allocation must be a competitive equilibrium given $\{\tau_t\}_{t=0}^{\infty}$, i.e. consistent with: (i) households' optimal consumption and saving decisions; (ii) firms' profit-maximizing choices in the final-good sector and in the two energy sectors; (iii) the government budget constraint; (iv) the absence of lump-sum transfers between representative households; and (v) market-clearing in goods, capital, and labour markets.

In a decentralized equilibrium, the dirty firm chooses capital according to (11c), which can be rewritten as

$$R_t\left(\frac{\partial K_{d,t}}{\partial E_{d,t}}\right) = P_{d,t} - \tau_t. \tag{22}$$

The left-hand side is the intermediate energy firm's private marginal cost of producing one extra unit of dirty energy $E_{d,t}$; conversely, the right-hand side is the after-tax price of its output. By comparing this privately optimal condition with the socially optimal choice in (19), it follows that the Ramsey tax that decentralizes the first-best allocation is the Pigouvian tax

$$\tau_t = \sum_{j=0}^{\infty}\beta^j\frac{\nu_{rc,t+j}}{\nu_{rc,t}}\,\frac{Y_{t+j}}{1-D(Z_{t+j})}\,\frac{dD(Z_{t+j})}{dZ_{t+j}}. \tag{23}$$

This τ_t aligns private and social marginal incentives in dirty production.

Moreover, combining the first-order conditions for capital in the dirty (11c) and clean (12c) energy sectors implies the private arbitrage condition

$$(P_{d,t} - \tau_t)\frac{\partial E_{d,t}}{\partial K_{d,t}} \;=\; P_{c,t}\frac{\partial E_{c,t}}{\partial K_{c,t}}. \tag{24}$$

When τ_t equals the Pigouvian wedge in (23), condition (24) coincides with the planner's optimal split of capital across sector in (20), whereby capital is reallocated until social marginal returns are equalized across clean and dirty energy.

Because workers are free to move across sectors, wages for each skill type must be equalized across sectors in a decentralised equilibrium. Combining private labour demands from (11) and (12), these must satisfy,

$$W_{h,t} = (P_{d,t} - \tau_t)\frac{\partial E_{d,t}}{\partial H_{d,t}} \;=\; P_{c,t}\frac{\partial E_{c,t}}{\partial H_{c,t}} \tag{25a}$$

$$W_{l,t} = (P_{d,t} - \tau_t)\frac{\partial E_{d,t}}{\partial L_{d,t}} \;=\; P_{c,t}\frac{\partial E_{c,t}}{\partial L_{c,t}}. \tag{25b}$$

Once again, when τ_t is given by (23), the after-tax price of dirty energy $P_{d,t} - \tau_t$ ensures that the private marginal products reflect the social marginal valuation of dirty energy. Hence, the Ramsey tax implements the socially optimal allocations of labour in (21).

Absent policy, dirty energy is privately too cheap because its future damage is not priced. The decentralized economy therefore overuses dirty energy and, as a consequence, allocates too much capital and labour toward dirty production relative to the social optimum. The carbon tax raises the user cost of dirty energy by exactly its external cost, inducing firms and the final-good producer to substitute toward clean energy. Through equilibrium input demands, this substitution reallocates both capital and labour from the dirty to the clean sector, reducing emissions and mitigating future productivity losses.

While the Ramsey policy allows the government to reach the efficient allocation, this is not distributionally neutral across households. Indeed, the tax changes the relative price of the two types of energy and therefore sectoral input demands, which, in turn, affects relative wages across skill types. Because clean and dirty energy firms employ workers of different types with different intensities, the induced labour reallocation creates asymmetric wage pressures across skill groups, even if labour is fully mobile across sectors. Moreover, the net impact on the welfare of the two households also depends on the tax revenues' rebate. We provide a numerical example to quantify these channels in Section 5.

5 Numerical Illustrations

In this section, we provide a numerical illustration of the model's mechanism. We calibrate parameters to broadly reflect the US economy in 2020, especially the clean/dirty energy mix and the skill composition of employment in each energy sector. The goal is not a quantitative fit, but a transparent example of how an optimal carbon tax reshapes sectoral input demands and, through skill intensities, affects wages and welfare across worker types.

5.1 Calibration

Calibrated parameters are in Table 1. Our initial period is calibrated to 2020 and our simulations run for 25 periods, with each period representing five years. The full span of our simulations thus goes from 2020 to 2145, although we will limit our analysis to the end of the century.[5] Unless otherwise noted, parameters are taken at an annual frequency and converted to the model period length using standard compounding.

Table 1: Parameter Values

Description	Parameter	Value
Annual discount factor	β	0.985
Relative risk aversion	σ	1.5
Elasticity of substitution	ϵ	3
Capital shares	α_c, α_d	0.33
Annual depreciation rate	δ	10%
Initial productivities	$A_0, A_{c,0}, A_{d,0}$	10.38, 1, 1.6
Annual productivities growth	g, g_c, g_d	0%, 2%, 2%
Initial output	Y_0	20.93
Initial capital	$K_0, K_{h,0}, K_{l,0}$	5.46, 2.73, 2.73
Labour Endowment	N_l, N_h	0.6, 0.4
Labour Elasticity	ϵ_c, ϵ_d	1, 1
Labour Shares	γ_c, γ_d	0.6, 0.4
Damage parameter	μ	0.0008

First, we calibrate the preferences parameters. We set the annual discount factor to $\beta = 0.985$, consistent with Nordhaus (2017). The inverse of the elasticity of intertemporal substitution (equivalently, the constant relative risk aversion parameter) is set to $\sigma = 1.5$

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[5] In line with other environmental growth models (e.g. Golosov et al., 2014, Barrage, 2020, Douenne et al., 2024), we focus on the transition towards a decarbonised steady state. We assume that a backstop technology exogenously arises at the end of the last period, eliminating the negative externality stemming from dirty production from that period onward and locking the economy in a balanced growth path, which is then simulated for ten additional periods.

(Golosov et al., 2014), close to the value of 1.45 assumed in Nordhaus (2017) and the value of 2 that is commonly found in the empirical literature (see e.g. Kaplow, 2005).

Second, we consider the production side of the economy. We set the capital depreciation rate to 10% per year and the capital shares to $\alpha_c = \alpha_d = 0.33$. We assume that clean and dirty inputs are imperfect substitutes, and we set the elasticity of substitution between them to $\epsilon = 3$ (Acemoglu et al., 2012, Campiglio et al., 2024).[6] We match the initial total output to the 2020 US GDP (in trillions of 2020 USD), $Y_0 = 20.93$, and the initial rate of return of capital to 5% per year (Golosov et al., 2014) by choosing initial capital equal to $K_0 = 5.46$ and the initial value of the productivity of the final sector to $A_0 = 10.38$. Arbitrary, we split initial capital equally across households. We normalise the initial productivity of the clean energy sector to $A_{c,0} = 1$ and set the one of the dirty sector to $A_{d,0} = 1.6$ to approximately match the 2020 split between clean and dirty energy production in the US. The exogenous growth rates of productivities are based on Golosov et al. (2014) and Barrage (2020): the productivity of the final sector is constant, whereas those of the energy sectors grow at a constant rate equal to 2% per year.

We normalize the total labour force to one and set relative labour endowments N_l and N_h using employment counts from U.S. Bureau of Labor Statistics (2023). We classify energy industries into clean (renewables and nuclear) and dirty (fossil electricity, extraction, and fossil-based manufacturing) using U.S. Bureau of Labor Statistics's (2023) industry-by-occupation employment data. We define the low-skill group as predominantly manual and operational occupations and the high-skill group as predominantly managerial, technical, and professional occupations.[7] These data imply $N_l = 0.6$ and $N_h = 0.4$. Imposing a Cobb-Douglas skill aggregation within each sector ($\epsilon_c = \epsilon_d \to 1$), the resulting within-sector employment shares imply $\gamma_d = 0.4$ and $\gamma_c = 0.6$.

Finally, we calibrate the climate change module. Our damage function follows Golosov et al. (2014), $D(Z_t) \equiv 1 - \exp(-\mu Z_t)$. The intensity of damages μ is set to lead to damages approximately equal to 5% at an increase in global average temperature of 2 degree celsius relative to the pre-industrial period (Howard and Sterner, 2017).[8]

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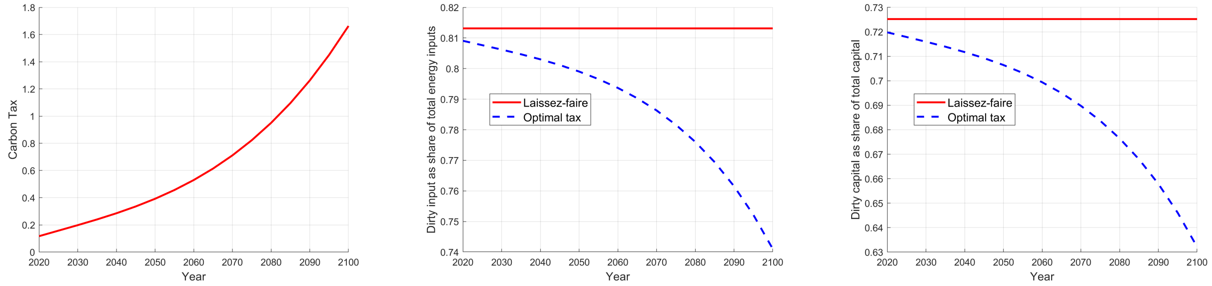
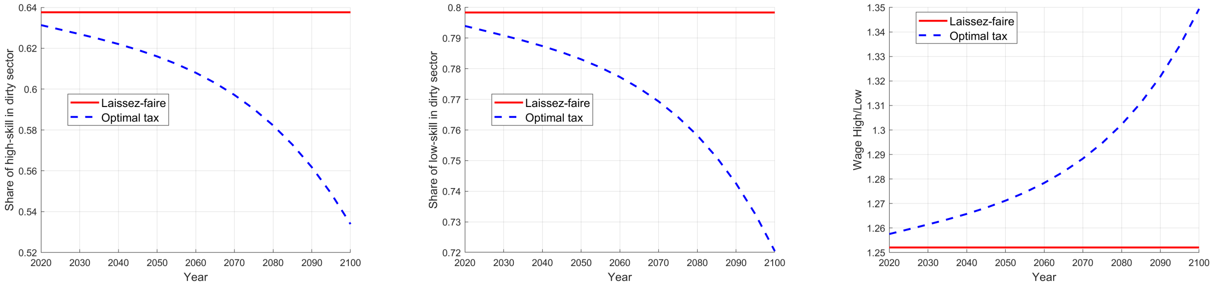
[6] Elasticities used in integrated assessment and macroeconomic models have ranged between 1 and 10. For example, Acemoglu et al. (2012) provide simulations for elasticities equal to 3 and 10, whereas Golosov et al. (2014) set it to approximately 1. Most empirical estimates range between 0.5 and 3 (e.g. Stern, 2012, Papageorgiou et al., 2017).

[7] We focus on the following industries: Solar, Wind, Hydro, and Nuclear, which we classify as clean, and Fossil electricity, Oil and Gas extraction, Coal mining, and Petroleum and coal products manufacturing, which we classify as dirty. Using Standard Occupational Classification, we consider part of the l households those workers in Construction and Extraction, Installation, Maintenance and Repair, Production, and Transportation and Material Moving; conversely, we define as part of the h household the sum of Management, Business and Financial, Computer and Mathematical, Architecture and Engineering, and Life, Physical, and Social Science.

[8] To rescale these figures within our calibration, we use the fact that the estimated remaining carbon



(a) Carbon Tax (b) Dirty energy share (c) Dirty capital share



(d) Dirty high-skill labour share (e) Dirty low-skill labour share (f) Wage ratio

Figure 2: Transitions

Notes. Transition dynamics under laissez-faire and the optimal carbon tax with uniform dividends.

5.2 Results

Figure 2 shows the equilibrium of our economy under the calibration of Section 5.1 and where the government imposes an optimal stream of carbon taxes on the production of the dirty intermediate input and redistribute carbon dividends uniformly across agents. Panel 2a plots the carbon tax τ_t; panel 2b plots the dirty energy share, $E_{d,t}/(E_{d,t}+E_{c,t})$; panel 2c plots the dirty capital share, $K_{d,t}/K_t$; panels 2d and 2e plot the share of workers employed in the dirty sector, $H_{d,t}/N_h$ and $L_{d,t}/N_l$; finally, panel 2f plots the skill premium, $W_{h,t}/W_{l,t}$.

The optimal carbon tax, shown in Panel 2a, grows slowly initially, before accelerating in the second part of the century. The rising path of the tax reflects the increasing marginal damages of cumulative emissions and the economy's growing need to reallocate resources from the dirty to the clean energy sector.

We compare our full model with a laissez-faire scenario, i.e. an economy with no climate policy, to draw out the consequences of policy and to underline that some workers may prefer the absence of carbon taxation. Under laissez-faire, the dirty energy input is privately too cheap because its future damages are not priced. In the full model, the optimal tax

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budget calculated from the beginning of 2020 to achieve a warming of 2°C with respect to the pre-industrial period with a 66% to 83% probability is approximately 1000GtCO$_2$ (IPCC, 2021, Table 5.8), whereas global CO$_2$ emissions are approximately 40Gt per year.

internalizes these damages and induces substitution toward clean energy (panel 2b). This reallocation reduces the dirty sector's demand for capital and labour, lowering the dirty shares of capital and employment over time (panels 2c–2e).

The carbon tax reduces the net-of-tax price received by dirty producers, lowering the marginal revenue product of labour in dirty production. Because the dirty sector is relatively low-skill intensive in our calibration ($\gamma_d < \gamma_c$), the induced contraction in dirty production depresses the equilibrium wage of low-skill labour more than that of high-skill labour. At the same time, expanding clean production raises labour demand disproportionately for high-skill workers, who are used more intensively in the clean sector. Together these forces increase the skill premium $W_{h,t}/W_{l,t}$ along the transition (panel 2f).

5.3 Welfare

Table 2 reports each household's discounted lifetime utility, evaluated under laissez-faire and under the optimal carbon tax, respectively.

	Laissez-faire	**Optimal Tax**
Low-skill Household	22.6815	22.6788
High-skill Household	22.2937	22.3125
Aggregate	22.5112	22.5167

Table 2: Welfare

The optimal carbon tax effectively mitigates the environmental externality by internalizing the social cost of emissions and thus it increases aggregate welfare (13), as shown in the last line of Table 2. The ensuing structural reallocation, however, comes with distributional consequences that penalise low-skill workers, who are employed by the dirty sector more intensively. Uniform (per-capita) rebates correspond to $\xi = N_l = 0.6$ in our calibration (that is, 60% of the tax revenues in every period are rebated to the low-skill household, with the remaining 40% going to the high-skill household). Under this scheme, the aggregate efficiency gains from pricing emissions are not large enough to offset the low-skill group's relative loss of labour income, so the low-skill household is worse off than under laissez-faire (first line of Table 2).

However, this distributional imbalance can be addressed with a non-uniform rebate scheme compensating the low-skill household for the wage losses induced by the carbon tax. For example, a modestly more progressive recycling of revenues of $\xi = 0.65$ is sufficient to leave the low-skill household indifferent between an economy under laissez-faire and one under the optimal climate policy, with the high-skill household still experiencing a welfare gain.

In other words, while the optimal carbon tax with uniform rebates exacerbates income inequality by disproportionately favouring high-skill workers, a non-uniform rebate scheme can ensure that the low-skill representative household enjoys at least the same welfare as in laissez-faire, while maintaining the efficiency benefits of the policy (and a welfare gain for the high-skill household).

6 Conclusions

Putting a price on carbon is essential to internalize the climate externality from dirty energy production. Yet carbon pricing is unlikely to be distributionally neutral: it changes relative input demands across sectors and therefore reshapes the labour market. This paper studies these interactions in a tractable dynamic general-equilibrium model with two energy sectors (clean and dirty), two skill groups, and a government that can implement an emissions tax and recycle the proceeds through lump-sum carbon dividends.

The central mechanism is straightforward. A Pigouvian carbon tax raises the user cost of dirty energy by its external cost, inducing substitution toward clean energy. Through firms' factor demands, this shift reallocates capital and labour away from dirty production and toward clean production, reducing cumulative emissions and future productivity losses. In aggregate, the policy is efficiency-improving.

However, the same reallocation generates distributional consequences when the clean and dirty sectors differ in their skill intensity. As the economy decarbonizes, demand shifts toward the clean sector, which absorbs high-skill labour more easily than low-skill labour. As a result, the skill premium rises along the transition. More broadly, carbon pricing can widen pre-existing wage inequality even when labour is perfectly mobile across sectors within each skill group. This highlights a key implication for 'just transition' debates: carbon taxation alone can deliver efficiency, but it risks increasing inequalities without complementary measures.

Our numerical illustration makes this point transparent. Under a uniform (per-capita) rebate of carbon-tax revenues, the aggregate gains from efficient carbon pricing are not sufficient to offset the relative loss of labour income borne by low-skill workers, who are more exposed to contractions in dirty production. In that case, the representative low-skill household is worse off than under laissez-faire, while the high-skill household benefits. The distributional imbalance can nonetheless be addressed without sacrificing efficiency. A modestly more progressive recycling rule makes the low-skill household indifferent between the optimal tax and laissez-faire, while preserving a welfare gain for the high-skill household. As a consequence, revenue recycling is a central component of the policy package that determines whether carbon pricing is politically and socially sustainable.

Several extensions would further enrich the analysis. First, allowing climate change to affect utility directly (in addition to productivity) would provide a more comprehensive welfare accounting. Second, introducing labour market frictions (such as costly sectoral mobility, unemployment risk, or skill depreciation) would bring the model closer to observed adjustment dynamics and sharpen the incidence of policy during the transition. Third, evaluating carbon taxes jointly with complementary measures such as reskilling programs, wage insurance, or targeted hiring subsidies could clarify how to best combine pricing and redistribution to achieve both environmental objectives and distributional fairness. We leave these directions for future work.

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