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Abstract: Carbon abatement decisions are usually based on the implausible assumption of constant social preference. This paper focuses on a specific case of market and non-market goods, and investigates the optimal climate policy when social preference for them is also changed by climate policy in the DICE model. The relative price of non-market goods grows over time due to increases in both relative scarcity and appreciation of it. Therefore, climbing relative price brings upward the social cost of carbon denominated in terms of market goods. Because abatement decision affects the valuation of non-market goods in the utility function, unlike previous climate-economy models, we solve the model iteratively by taking the obtained abatement rates from the last run as inputs in the current run. The results in baseline calibration advocate a more stringent climate policy, where endogenous social preference to climate policy raises the social cost of carbon further by roughly 12%-18% this century. Moreover, neglecting changing social preference leads to an underestimate of non-market goods damages by 15%. Our results support that climate policy is self-reinforced if it favors more expensive consumption type.

Key words: integrated assessment model, endogenous preference, Preprint submitted to arXiv January 29, 2024 non-market goods, social cost of carbon, dynamic decision making

Endogenous preference for non-market goods in carbon abatement decision

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Abstract

Carbon abatement decisions are usually based on the implausible assumption of constant social preference. This paper focuses on a speci c case of market and non-market goods, and investigates the optimal climate policy when social preference for them is also changed by climate policy in the DICE model. The relative price of non-market goods grows over time due to increases in both relative scarcity and appreciation of it. Therefore, climbing relative price brings upward the social cost of carbon denominated in terms of market goods. Because abatement (abatemen4)-250(are)-249(ui9n(upicy)-2--e)-249(implausible)-

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1. Introduction

Climate change not only adversely impacts economic production, but also impairs non-market goods such as human health, clean water, biodiversity, etc (Nordhaus, 1991; Tol, 2009; Belval and Thompson, 2023). Optimal abatement decisions based on damage estimates should factor in both market goods and non-market goods. However, valuing non-market goods is inherently difficult, as it requires careful consideration of preferences, whose expression is endogenously determined in the complex climate-economy system. Furthermore, climate policy, like many other policies, can potentially influence social preferences (Bowles and Polania-Reyes, 2012; Mattauch et al., 2022). This changes the value of non-market goods, and in turn affects the recommended climate policy. Thus, this paper investigates the optimal abatement decision in an integrated assessment model ("IAM" hereafter) when such policy alters social preferences for non-market goods.

By differentiating market from non-market goods, a strand of IAMs literature (Tol, 1994; Hasselmann, 1999; Hoel and Sterner, 2007; Drupp and Hänsel, 2021; Bastien-Olvera and Moore, 2021) consistently advocates a more stringent abatement policy. Market goods are growing overtime, whereas the absolute amount of some non-market goods are roughly stable (or even decreasing owing to, say, climate change) over the long run. The relative scarcity of non-market goods raises their price, and non-market goods are increasingly valuable. As climate change proceeds, increasing values of non-market goods can be associated with more expensive climate damages. Thus, it is recommended to adopt a stricter abatement policy based on cost-benefit analysis. Specifically, Drupp and Hänsel (2021) concludes that accounting for the rising price of non-market goods leads to a social cost of carbon about 50% higher than Nordhaus suggested (Nordhaus, 2018).

One assumption underneath this line of modelling is the fixed social preference structure. By virtue of this, one can readily derive the relative price of non-market goods and assess the implications for optimal climate policy. However, as climate change is a long-run issue, social preferences need not be fixed. Beckage et al. (2022) and Stern et al. (2022) criticized that IAMs fail to account for endogenous preference. Hence, the carbon price recommended by these models lack credibility. Peng et al. (2021) note that public opinion about climate policy is partly shaped by the success or failure of past climate policy, and that this feedback is currently lacking in IAMs. Public opinion is an expression of social preference.

Endogenous preferences are generally assumed away in the broader climate management literature, two notable exceptions being Konc et al. (2021) and Mattauch et al. (2022). Konc et al. (2021) examined the level of carbon tax when consumers' preferences for products with different carbon intensities are influenced by peers in a social network. Mattauch et al. (2022) investigated how to adjust carbon taxes in a static context when they crowd-in or -out social preference between dirty and clean consumption varieties. Both studies use examples of consumption with distinct carbon intensity. Their focus is not on valuing climate damages in climate policy. Their analysis is static.

This paper endogenizes social preferences in an IAM. We consider the specific case where climate policy affects the social preferences for non-market goods. Policy design can increase public awareness and valuation of non-market goods (e.g.: Christie et al., 2006; Kumar, 2012; Tonin, 2019).

The paper takes two steps. First, it theoretically shows how changing preferences influence the relative price of non-market goods. A CES form utility function is utilized with time-varying weights for market and non-market goods. Weights attached to each variety of goods are assumed to reflect the associated social preferences. In addition to scarcity, the relative price of non-market goods will increase further with changing social preferences. Second, it establishes a dynamic climate-economy model, based on the seminal DICE model (Nordhaus, 2018) and its augmented version by Drupp and Hänsel (2021), where social preferences are responsive to abatement policy (unlike the original models).

Notably, solving the proposed model is not as easy and direct as previous numerical decision exercises: Future preferences depend on current action while, as foresight is perfect, current action depends on future preferences. This decision process is lacking in previous climate-economy studies. This can be explained by two channels via which abatement policy affects social welfare. First, by reducing carbon emissions, global warming is curbed, and fewer climate damages materialize. Consequently, avoided damages serve to increase consumption levels of both market and non-market goods, but more so of the latter. Second, a hypothetical social planner is incentivized to attach a higher weight to the less expensive consumption type. However, this implies that a social planner can arbitrary decide social preference. The second channel is not only a moral issue, but also a matter of tractability in the real world. Thus, we need to rule out the second channel. To this end, we provide a novel solution method by iteration.

Numerical ndings support a more stringent abatement policy when social preference for non-market goods is enhanced by this policy itself. First, with endogenous preferences, although the time of achieving net-zero emissions remains the same, unabated carbon emissions are greatly reduced before that (from 5.86 $GtCO_2$ to 1.29 $GtCO_2$ in 2050). Second, changing social preference for non-market goods increases the social cost of carbon from 124 to 139 US\$/tCO_2 (by 12%) in 2020, and from 1981 to 2331 US\$/tCO_2 (by 18%) in 2100. Third, by the end of this century, the model produces an optimal temperature rise of 2.5C, which is 0.80C lower than DICE-2016. Sensitivity analyses are broadly consistent with the baseline results.

Our model can also be applied to value non-market goods damages, which

2. Non-market goods valuation under time-varying preference

Our analyses below focus on two important concepts in climate economics and policy literature|relative price and social cost of carbon.

There is a representative household in the economy whose preference at time t is de ned as:

U

as:

$$RPE_t = \frac{d}{}$$

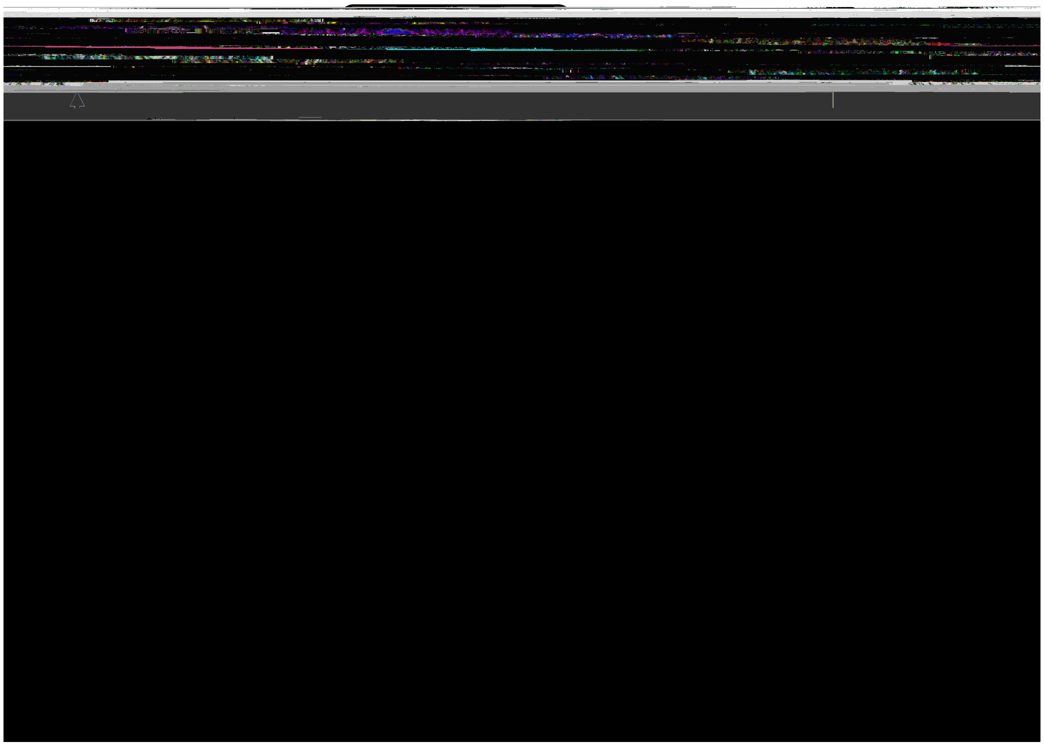

Figure 1: Framework

2018)[2], introduce the relative price effect due to relative scarcity following Drupp and Hänsel (2021), and then endogenize preferences. The framework of our model is presented in Figure 1. The yellow lines represent the new channel introduced in the model. In this section, we describe the main body of the model first, then introduce the calibration process, and conclude with the solution method.

3.1. Main body

The intertemporal welfare function is defined as:

$$U \quad \sum_{t=1}^{\ } P_t \frac{1}{(1+\ \ )^t}\frac{1}{1\ \ }\left[f(\ ;\ \ _t)E_t^{\frac{\ 1}{\ }} + (1\ \ \ f(\ ;\ \ _t))C_t^{\frac{\ 1}{\ }}\right]^{\frac{(1\ \ )}{\ 1}} \tag{5}$$

[2]The most recent version is DICE-2023 (Barrage and Nordhaus, 2023), but is still under revision at the moment. The core insight in this study would not change if we built on the latest version.

where P_t is the exogenous population at period t, C_t per capita consumption of market goods, the social time of preference, and the marginal utility of aggregate consumption.

$f(\ ;\ _t)$ is the weight attached to non-market goods, and is the counterpart of $_t$ in Equation (1). Di erent from $_t$, it speci es that social preference is in uenced by the abatement rate $_t$, in addition to the xed weight . Following Mattauch et al. (2022), we assume that the abatement rate exerts its impact in a linear form[3] so that:

$$f(\ ;\ _t) = \ + \ _t \tag{6}$$

where measures the extent to which the abatement rate in uences the preference for non-market goods. Previous studies (Christie et al., 2006; Kumar, 2012; Tonin, 2019) provided some evidence that proper policy designs lead to increased social appreciation of non-market goods. Motivated by these, we set > 0. This can be the case, for example, when part of revenues from abatement e orts are used in environment-related education or propaganda and consequently raise public appreciation of non-market goods. Alternatively, people may rationalize the carbon taxes that they pay by convincing themselves that they care more about climate change than they used to.

Global output net of climate damages and abatement costs is governed by:

$$Y_t = (1 \ \ _t) A_t K_t \ P_t^{1} \ /(1 + \ _t) \tag{7}$$

where A_t denotes total productivity level, K_t capital stock and P_t population. is the capital share. $_t$ is the abatement cost function, and $1/((1 + \ _t))$ measures the relative level of climate damages, both of which are fraction of aggregate economic output. Speci cally, $_t$ is given by a quadratic function:

$$_t = \ _1 T_t^2 \tag{8}$$

where T_t refers to atmospheric temperature change relative to preindustrial levels.

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[3] Bowles and Polania-Reyes (2012) studies alternatives to linearity. In addition, this paper is more interested in the long-term gradual changes in social preference and hence abstracts from climate-related decisions under uncertainty as Webster (2008). All this is deferred to future research.

In line with Hoel and Sterner (2007) and Drupp and Hänsel (2021), non-market goods cannot be directly produced à la market goods where $_t$ denotes the exogenously-given carbon intensity, i.e., carbon content per unit of gross economic output.

The DICE-2016 model[6] adopts equations of the carbon cycle including three reservoirs (carbon in the atmosphere L_t^{At}, the upper oceans and the biosphere L_t^{Up}, and the deep oceans L_t^{Lo}):

$$\begin{pmatrix} L_t^{At} \\ L_t^{Up} \\ L_t^{Lo} \end{pmatrix} = \begin{pmatrix} {}_{11} & {}_{21} & 0 \\ {}_{12} & {}_{22} & {}_{32} \\ 0 & {}_{23} & {}_{33} \end{pmatrix} \begin{pmatrix} L_{t-1}^{At} \\ L_{t-1}^{Up} \\ L_{t-1}^{Lo} \end{pmatrix} + \begin{pmatrix} M_t + M_t^{Land} \\ 0 \\ 0 \end{pmatrix}$$

substitution elasticity between two kinds of consumption is 0.5. Nordhaus (2018) aggregated both market and non-market damages in the DICE-2016 vintage, which totals 2.12% loss of GDP at a temperature rise of 3C. The share of non-market damage is a guess of 20%. By comparison, to account for the relative price effect, Drupp and Hänsel (2021) followed Sterner and Persson (2008) and assumed that non-market damage is comparable to market damages (50% for each). Namely, each damage in effect accounts for a GDP loss of 1.63%, and aggregate damage totals 3.26% at a temperature rise of 3 C. Recently, Barrage and Nordhaus (2023) revised the damage estimate to 3.12% of global output, based on the climate impact studies surveyed by Piontek et al. (2021) as well as additionally adding 1% for the impact of tipping point events (Dietz et al., 2021). This revision is generally consistent with Drupp and Hänsel (2021) from which we maintain $_1 = 0:00181$ and $_2 = 0:016$. The relative shares are close to the results by Tol (2022), who finds that 45.7% of total impacts are non-market.

Table 1: Some key parameters

Parameter	Note	Value
	Initial weight of NMG in utility function	0.1
	Substitution elasticity between MG and NMG	0.5
E_0	Initial monetary value of NMG (trillion 2005 USD)	77.74
$_1$	Damage coefficient on MG	0.0181
$_2$	Damage coefficient on NMG	0.016
	Ability of policies to alter social preference	0.02

Notes: MG is short for market goods, and NMG for non-market goods.

The most difficult parameter is the impact of abatement policies on social preference. Unfortunately, there are scant empirical studies for calibrating this parameter. In the baseline model, takes a guess value of 0.02, implying that a policy to reduce emissions by 10% fosters an increase in the share of non-market goods in total expenditures by 0.2%. In addition, we consider different values for sensitivity tests, ranging from 0 to 4%. In most cases, positive values are selected for to reflect the intuition that proper policy design raises social awareness of non-market goods. We also consider a specific case $= \quad 0:01$ in the sensitivity analysis to include an extreme case that carbon abatement policies, if implemented inappropriately, may incur people to resent preserving non-market goods.

Nordhaus (2018) calibrated the economic module such that annual GDP per capital growth averages 2.1% from 2015 to 2050, and 1.9% from 2050 to 2100. For the climate module, the mean warming is 3.1C for an equilibrium CO_2 doubling and the transient climate sensitivity is 1.7 C.

3.3. Decision problem and solution methods

We solve an optimal control decision problem that maximizes Equation (5) subject to constraints (6)-(16). However, note that the abatement rate $_t$ also appears in the utility function (5). Our understanding is **not** that a hypothetical social planner, by changing abatement policy, intentionally alters social preference. To see this, suppose for illustrative convenience that two types of consumption are prefect substitutes so that the instantaneous utility function can be rewritten to $U(c_t; E_t) = (\quad + \quad {}_t)(E_t \quad c_t) + c_t$. Two types of consumption are calibrated with the same value in the initial period. Also note that because market goods grow faster than non-market ones, it is then expected that $E_t \quad c_t \quad 0$. Because is positive by assumption, any increment in leads to declining utility directly. If is enough high, the hypothetical social planner will not be motivated to reduce carbon emission at all, because the direct utility loss from preference changes outweighs the utility gain due to avoided damages.

Therefore, instead, we solve the optimization problem as if preferences had always been like the new ones. That is, we solve the decision problem using the following iteration method:

Step 1 Run the optimal scenario in the DICE model that explicitly di erentiates market and non-market goods, and save a series of abatement rates in each period;

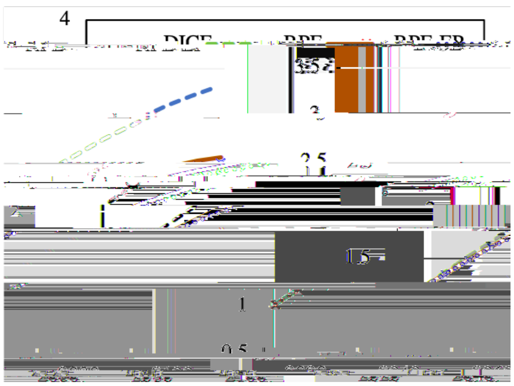
Step 2 Use the abatement rates obtained in Step 1 to calculate a series of new weights according to $f(\, ; \quad {}_t)$ for both market and non-market goods, re-run the model, and save the new abatement rates;

Step 3 Repeat Step 2 until the obtained abatement rates between two subsequent runs are almost identical.

For each run, the abatement rates appearing in the utility function are predetermined, so the model searches the optimal allocation as in the xed preferences situation. However, because the abatement rates obtained in each run are utilized as initial inputs in the next run, they reshape the social preference structure and are endogenous in the model. The computational method is based on presumption that the obtained abatement rate in each iteration will converge to its equilibrium level, which has been testi ed by numerical exercises in this study. For example, in our baseline calibration ($= 0.02$), the solutions stabilize after four iterations.

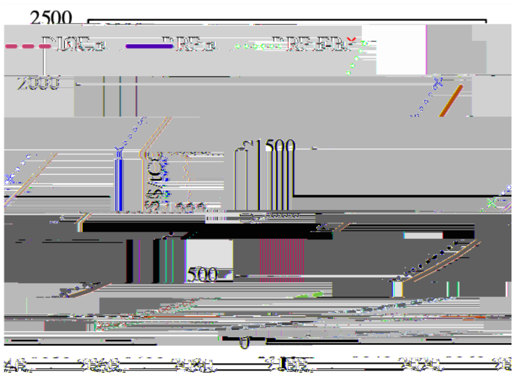
4. Quantitative results

We first present the numerical results where parameters are calibrated

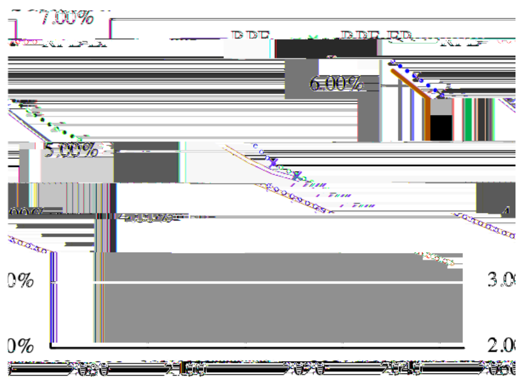


(a): Atmospheric temperature rise

(b): Industrial emissions



(c): Social cost of carbon



(d): Relative price e ect

Notes: The dashed blue line represents the DICE model for comparison. The solid green line describes the model augmented with the relative price e ect (RPE) as in Drupp and Hansel (2021). The dotted red line displays our model with both relative price e ect and endogenous preference (RPE-EP).

market goods[7] of 4.6 trillion US$ in 2050, and of 65.9 trillion US$ in 2100. By comparison, the market goods consumption derived from the model is 221.2 trillion US$ and 571.7 trillion US$, respectively. Thus, non-market goods damages are equivalent to a consumption loss in market goods by 2.1% and 11.5% in 2050 and 2100, respectively.

(a): Social cost of carbon 2020

in addition to the scarcity e ect, endogenous social preferences increases the relative price of non-market goods. The social cost of carbon increases correspondingly. Compared to xed social preference, the social cost of carbon is elevated by 54 US\$/tCO_2 to 445 US\$/tCO_2 in 2050, and by 350 US\$/tCO_2 to 2331 US\$/tCO_2 in 2100. If abatement policies are properly introduced to re ect these costs, the climate impact on non-market goods amounts to a consumption loss in market goods of 3.9 and 56.5 trillion US\$ in 2050 and 2100, respectively. If no such policies are implemented, however, non-market goods damages will almost triple in monetary value.

The paper focuses on the bene t end of climate governance. Nyborg et al. (2016) noted that social norms can be important in turning a vicious cycle into a virtuous cycle, or vice versa. In line with this spirit, Konc et al. (2021) and Mattauch et al. (2022) showed how social preference for products with di erent carbon intensity contributes to abatement. Recently, Besley and Persson (2023) further showed that changing social preference can be complementary to technological advances, fueling the net-zero transition. Although changes in social preferences are exogenous in their study, their results shed light on the previously-overlooked role of social preference favorable to deep carbon reduction. However, preference changes not only occur among goods with di erent pollution intensities, but also among those subject to di erent levels of climate damage. The former speaks to how much carbon we can abate, the latter governs how we value climate damages|that is the main focus of this study. Both of them matter to climate policy decisions.

There are three interesting avenues to explore along this paper. First, calibrating the preference response parameter entails empirical evidence that is currently lacking. To address this concern, our study performs sensitivity tests as a preliminary attempt. However, the impact of endogenous preferproduction, particularly in developing countries. All this is deferred to future research.

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