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The opportunity cost of delaying climate action: Peatland restoration and resilience to climate change

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ABSTRACT

Ecosystem restoration and, in particular, peatland restoration, are considered a promising greenhouse gas (GHG) mitigation strategy to move towards net zero emissions. To remain within acceptable limits for projected warming scenarios, inaction with respect to GHG mitigation in the short term implies a need for even larger removals of GHGs in the longer term, which can be conceptualized as a 'mitigation debt'. This paper explores the economic implications of delaying GHG mitigation through ecosystem restoration using data of a large survey (N = 1377) that included a choice experiment to elicit the public's willingness to pay (WTP) for peatland restoration in Scotland, UK. The valuation specifically considers the interaction between the timing of restoration action and long-term ecosystem resilience. We find that respondents have a substantial WTP for peatland restoration. Importantly, we find considerable benefits for early restoration action (up to £191 million annually in our case study), which is linked to an increased resilience of peatlands under future climate change. This demonstrates that delaying restoration and thus accumulating a mitigation debt has an important opportunity cost that substantially decreases the related economic benefits. Attitudes towards climate change and climate change beliefs are found to explain variation in the public's WTP. Our research strengthens the economic argument for not delaying climate change mitigation through ecosystem restoration, demonstrating that the mitigation debt also translates into a welfare loss. To fully realise the potential benefits associated with immediate mitigation using peatland restoration, however, more needs to be understood about the mechanisms that facilitate large-scale implementation in practice.

1. Introduction

Ecosystem restoration plays an important role as a greenhouse gas (GHG) removal strategy to move towards achieving net zero emission targets (Griscom et al., 2017; Leifeld et al., 2019; Veldman et al., 2019). It is now clear that inaction with respect to GHG mitigation in the short term implies a need for even larger removals of GHGs later in this century to remain within acceptable limits for projected warming scenarios (IPCC, 2018). This difference in GHG removals can be conceptualized as a 'mitigation debt'. Furthermore, delays in efforts to reduce land degradation and to promote ecosystem restoration could result in irreversible impacts on some ecosystems. This is expected to substantially increase GHG emissions in the longer term (IPCC, 2019). Climate change therefore imposes additional stress on ecosystems that can undermine the long-term success of restoration efforts (Timpane-Padgham et al., 2017).

Peatlands represent an enormous carbon store. Atmospheric CO_2 emissions originating from peatlands contribute 3.5% of anthropogenic GHG emissions worldwide (IPCC, 2014), and the loss of all peatlands globally could increase emissions by 75% (Evans et al., 2017). As opposed to degraded peatlands, which can emit GHGs at high rates, intact or growing peatlands reduce the concentration of GHGs in the atmosphere over time (they act as a carbon sink). If no action is taken, the land system globally may remain a net carbon source throughout the

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Table 1
Choice experiment attributes and levels.

Attribute label	Description	Levels
C2050	Change (increase) in the share of peatlands that will be in good condition by 2050 (i.e., the extent of restoration undertaken) relative to business as usual scenario, in %. This describes the extent or scope of restoration undertaken	0,10,20,30,40
TIME	Time period when restoration measures will be in place in the period between 2017 and 2050 (and, associated with that, how much peatlands will be left in good condition by 2080 under a more severe or less severe climate change scenario)	Early (2017–2027), Midway (2028–2038), Late (2039–2050)
COST	Annual cost (tax towards Peatland Trust fund) up to 2050, in GBP per household	0,10,25,50,75,150,250

21st century (Humpenöder et al., 2020). In recognition of the substantial potential that peatland restoration offers to support GHG mitigation (Leifeld and Menichetti, 2018), the past decade has seen a surge of science and policy interest in peatland restoration across the globe (e.g., Artz et al., 2012; Badiou et al., 2011; Bain et al., 2011; Hansson and Dargusch, 2017; HM Government, 2018).

Peatlands are found on every continent, but can differ considerably in type and composition. Blanket bogs are restricted to cool, wet and typically oceanic climate. The UK's blanket bogs are the largest terrestrial carbon store in the UK (Clark et al., 2010; Evans et al., 2006) and represent 10%–15% of their total global extent (Wallage et al., 2006) with an area of approximately 1.5 million ha (BRIG, 2011). The bioclimatic space for blanket bogs is likely to shrink driven by warmer summers expected as a consequence of climate change (Gallego-Sala et al., 2010; Gallego-Sala and Prentice, 2013; Ferretto et al., 2019), which is likely to impose stress that will slow down carbon accumulation where peatlands cease to be carbon sinks (Gallego-Sala and Prentice, 2013; Ise et al., 2008).

Ferretto et al. (2019) find that by as early as 2050, the majority of carbon currently stored in UK blanket bogs will be at risk of loss, and that this risk is aggravated considerably by 2080. This does not mean that all bogs would be lost. Because of non-linearity of the biophysical relationships within the system, changes in peatlands may be slowed down or accelerated over time (Page and Baird 2016). Importantly, however, the "starting" ecological condition in which peatlands are affects how they will respond to climate change. Peatlands with a healthy cover of peat moss (*Sphagnum* spp.), and thus a natural hydrological regime, are anticipated to buffer seasonal oscillations and show overall greater resilience to gradual changes in the climate (Alshammari et al., 2020; Gallego-Sala and Prentice, 2013; Lindsay, 2010). Conversely, peatland sites that are in poor ecological condition, i.e., sites that are continually degrading, display comparatively less water storage capacities and are expected to be more susceptible to future climate change (e.g., Turetsky et al., 2015). This also implies that early (rather than delayed) restoration of degraded sites increases their robustness against future climate change, because such sites will have had more time to restore their vegetation cover and ecological functioning (see Swindles et al., 2019).

The above suggests that early restoration action can increase the chance of restoration success and long-term resilience of peatland ecosystems, following a broad definition of resilience as a system's ability to maintain its functioning if exposed to shocks (Walker et al., 2010). From a policy maker's perspective, this points to the possibility of opportunity costs and thus likely economic welfare losses associated with delaying restoration efforts. The economic welfare consequences of delaying restoration action do not simply relate to delaying an otherwise equal stream of costs and benefits over time. Rather, timing of restoration *affects* the stream of costs and benefits that arises over time. In other words, the impacts of timing of restoration action are not only related to accruing a defined sum of costs and benefits sooner or later, but also concern potential differences in the amount of costs and benefits realised at different points in time. We argue that this reasoning applies to many types of ecosystem restoration contexts, and beyond that is also of relevance for those interventions into natural systems that are characterised by non-linear system dynamics related to climate effects. An example are coral reefs (Côté and Darling, 2010). Consequently, economic appraisals related to ecosystem restoration efforts and other interventions in natural systems should account for trade-offs between early and late investments and corresponding long-term consequences. A number of economic appraisals of peatland restoration exist (Glenk and Martin-Ortega, 2018; Grammatikopoulou et al., 2020; Juutinen et al., 2020; Moxey and Moran, 2014; Wichmann et al., 2016). We are not aware of empirical studies that consider the interrelationships between short-term (in)action related to restoration and long-term consequences for ecosystem resilience in the face of climate change. This study, which draws on a choice experiment survey conducted in Scotland, is therefore the first to provide estimates of the welfare impacts of decisions regarding the timing of ecosystem restoration as an important GHG mitigation strategy. The choice experiment uses a hypothetical peatland restoration programme in which one of the attributes quantifies the *extent* of blanket bog restoration effort by 2050. A second attribute captures preferences for timing of restoration action, which is correlated with the resilience of restored peatlands under climate change by 2080. Via inclusion of a monetary (cost) attribute, the analysis allows the quantification of welfare effects of delaying restoration action.

2. Methods and data

2.1. Survey structure

Choice experiments are a survey-based stated preference method that can be used to quantify welfare effects associated with environmental change. The survey instrument used in this study comprised four sections. Section one provided an introduction to peatlands, peatland restoration, the role of peatlands in the provision of ecosystem services and the possible futures for peatlands in the face of climate change (with and without restoration). The second section comprised the choice experiment and a series of debriefing questions related to respondents' choices, for example regarding potential protest motives for serial non-participation. The third section covered a series of attitudinal questions, including attitudes towards climate change. The final section asked for socio-demographic characteristics of respondents.

2.2. Choice experiment survey design

In choice experiment surveys, respondents repeatedly choose their preferred alternative from a set of alternatives, the choice set or choice task. Each of the alternatives of a choice set is characterised by a number of attributes, which vary across alternatives and choice sets following an experimental design (Adamowicz et al., 1998). In this study, choice sets contained three alternatives; two alternatives each describing the

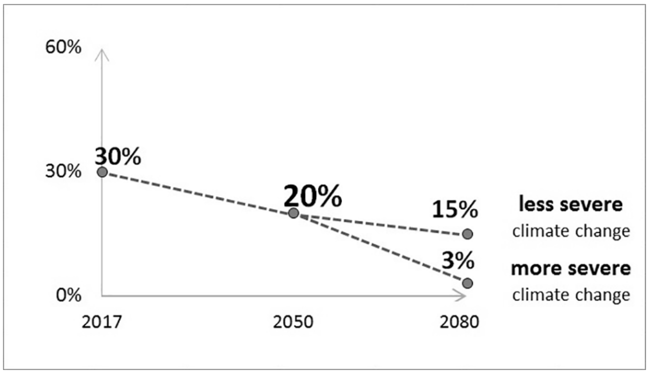

Fig. 1. Description of changes in the share of peatlands in good ecological condition over time (now, by 2050, by 2080) in the business as usual scenario under climate change. Based on focus group discussions undertaken with members of the general public for pre-test purposes, a simplified linear depiction of the change in the share of peatlands in good condition over time was found to be more comprehensible than an arguably more accurate, yet also more complex, non-linear step-wise pattern to depict changes in good ecological condition over time.

Table 2
Percentage of the increase in peatlands in good condition (achieved by 2050) that would be retained by 2080 as a result of different timing of restoration and climate change scenarios.

	Early	Midway	Late
More severe climate change	80%	50%	20%
Less severe climate change	95%	90%	85%

outcomes and characteristics of a hypothetical peatland restoration programme, and a third alternative representing a business as usual (BAU) situation with no additional peatland restoration. Each alternative was described by three attributes. The first attribute (*C2050*) reflects the share of peatlands in good ecological condition by 2050 as a result of the restoration programme. The second attribute (*TIME*) refers to the timing of restoration between 2017 and 2050. The third attribute (*COST*) was framed as a household tax payment towards a hypothetical Peatland Trust fund to finance implement a restoration programme that would be in place up to 2050 (Table 1). Inclusion of this monetary attribute enables estimation of willingness to pay for changes in attributes (Adamowicz et al., 1998).

The first attribute (*C2050*) focuses on changes in the share of Scottish peatlands from bad to good condition by 2050. The year 2050 reflects the Scottish Government's long term ambition that "by 2050, Scotland's expanded peatlands will be thriving habitats and sustaining a diverse ecosystem" (Scottish Government, 2018, p.182).

The ecological conditions of peatlands (described in Appendix Fig. A.1) were associated with varying levels of ecosystem service provision related to climate change mitigation (GHG emissions), water quality improvement and changes to wildlife as important co-benefits of peatland restoration (Martin-Ortega et al., 2014; Glenk et al., 2014). The process of developing and describing these conditions and their suitability for use in assessments of public preferences for peatland restoration is explained in detail in Martin-Ortega et al. (2017) and was successfully employed in Glenk and Martin-Ortega (2018).

Since observed data on current and projected peatland extent and condition is lacking, we defined shares under the BAU alternative and plausible changes arising from restoration jointly with Scottish peatland experts. According to expert opinion, about 30% of peatlands may currently be classified to be in bad ecological condition (40% by 2050 given current land use trends), and 30% in good ecological condition (20% by 2050), with the remainder up to 100% comprising peatlands in intermediate condition. The four levels of the first attribute (*C2050*, as listed in Table 1) characterise the scale of peatland restoration efforts in the period up to 2050. This represents the net reduction of the share of peatlands in bad ecological condition and a corresponding increase in the share of peatlands in good ecological condition, while keeping the share of peatlands in intermediate condition unchanged. Specifically, the share of peatlands in good condition may increase by 10, 20, 30 or 40 percentage points over the BAU scenario as a result of restoration interventions. Respondents were informed that improvements in terms of ecosystem service provision will be clearly visible shortly after restoration, but that it may take decades to achieve complete restoration.

The second attribute—timing of restoration and long-term status of peatlands under climate change (*TIME*)— is of central interest for this paper and is thus presented in greater detail. The attribute describes when restoration will happen (early, midway or late in the period up to 2050), which will— together with the share of peatlands restored to good ecological condition by 2050 (*C2050*) —determine the share of peatlands that will remain in good ecological condition by 2080. Respondents are explained that "[…] *how much of the restored Scottish peatland areas will remain in good ecological condition once the programme ends (after 2050) will depend on when restoration has taken place in the lifetime of the programme; how much has been done until 2050;* [and] *how severe climate change will be* […]". We considered two climate change scenarios for the 2080 time horizon: a more severe scenario, in line with the A1FI scenario in the IPCC Special Report on Emission Scenarios (SRES), and a less severe scenario that would be more in line with the B1 scenario and impacts as described in UKCP09 (Murphy et al., 2009). This information was developed in close consultation with peatland experts. An example for the BAU scenario is displayed in Fig. 1.

In our survey design the share of peatlands in good ecological condition that is expected to be retained by 2080 is assumed to vary depending on the timing of restoration. Respondents were informed that "[…] *If restoration happens early in the programme, restored peatlands will be more robust to potential climate change effects. As a result, most of the restored peatlands will likely remain in good condition once the programme ends. If restoration happens late in the programme, restored peatlands will be more vulnerable to potential climate change effects and therefore a smaller share of the restored peatlands will remain in good condition once the programme ends*". Additionally, the share of peatlands that will remain in good ecological condition by 2080 was assumed to depend on the severity of climate change. As can be seen in Table 2, we assumed that between 20% and 80% of the restored peatlands (depending on timing of restoration) should be retained in good condition under a more severe climate change scenario. In a less severe climate change scenario, it was assumed that between 85% and 95% of restored peatlands could be maintained in good condition after restoration ends (with different percentages again applied depending on the timing of restoration). For the BAU scenario, it was assumed that the 2080 share of peatlands retained in good condition could be either 15% (under a more severe climate change scenario) or 75% (under a less severe climate change scenario) of the 2050 share (see Fig. 1). The outcomes of the restoration programme by 2080 are thus assumed to be correlated with timing of restoration, and therefore do not represent a separate attribute in its own right. Because of this confounding of attribute dimensions, we cannot fully disentangle preferences for timing of restoration and preferences for long-term resilience of peatlands. We will revisit this aspect in the discussion.

For the third attribute (COST), the payment vehicle was a household

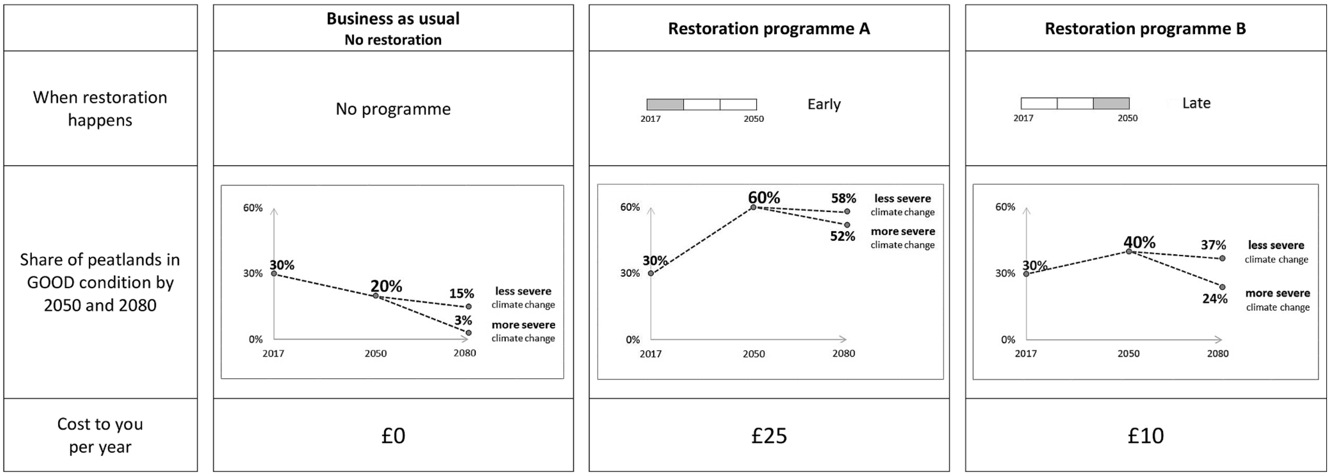

Fig. 2. Example choice task.

Table 3
Results of mixed logit (MXL) models in WTP space.

	MXL1 C2050 discrete		MXL2 C2050 linear		MXL3 C2050 quadratic	
	coef.	*t-ratio*	*coef.*	*t-ratio*	*coef.*	*t-ratio*
Mean parameters						
ASC – BAU	−0.278	−23.97	−0.254	−20.57	−0.169	−15.38
C2050 – 20%	0.412	15.58				
C2050 – 30%	0.713	17.54				
C2050 – 40%	0.784	19.86				
C2050 – linear			0.027	16.88	0.074	12.85
C2050 – squared					−0.009	−8.67
TIME – EARLY	0.753	21.52	0.744	22.17	0.778	21.52
TIME – MIDWAY	0.465	15.54	0.459	22.32	0.471	15.87
COST	1.069	20.67	0.966	20.52	1.061	20.87
Standard deviation terms						
ASC – BAU	0.219	19.13	0.174	9.13	0.124	9.59
C2050 – 20%	0.379	10.00				
C2050 – 30%	0.857	14.12				
C2050 – 40%	1.038	16.57				
C2050 – linear			0.036	14.46	0.074	14.62
C2050 – squared					0.007	7.11
TIME – EARLY	0.807	18.58	0.814	8.60	0.858	18.01
TIME – MIDWAY	0.461	15.43	0.460	5.25	0.487	14.36
COST	1.359	19.34	1.278	17.68	1.279	20.47
Log-L	−6999.71		−7037.41		−7022.60	
Rho square	0.406		0.398		0.400	

Note: The cost attribute was re-scaled and entered the model as 1/100 of the values in GBP shown on choice cards. The squared term of C2050 was scaled by 1/10, and the ASC by the factor 10.

Table 4
Principal component analysis of climate change attitudes: rotated factors scores.

Item #	Item	Principal component 1 (PC1)	Principal component 2 (PC2)
1	There is not much point in reducing the climate change contribution of Scotland as long as other countries don't seem to care much	**0.433**	0.015
2	If the climate is changing, it is due to fluctuations in the climate that naturally occur	**0.469**	0.083
3	Before the big industries start to take climate change seriously, people like me shouldn't be expected to do much about it	**0.450**	0.077
4	It is absolutely certain that climate change is occurring now	0.048	**0.561**
5	Climate change is mainly due to natural causes, not human activities	**0.443**	0.002
6	I feel deeply concerned about climate change and its possible impacts	0.022	**0.560**
7	I think more action is urgently needed to tackle climate change	−0.015	**0.534**
8	I believe that claims about climate change and its possible impacts have been greatly exaggerated	**0.352**	**−0.157**
9	I do not believe that climate change will harm me and my loved ones	**0.258**	**−0.221**

Note: Factor loadings that distinguish components shown in **bold**.

annual tax, in place until 2050, to fund a *Peatland Trust,* which would be managed by an independent body of scientists, government agencies, farmer and land owner organisations, nature conservation and community representatives. Survey participants were informed that all households in Scotland would have to pay such a tax. The highest level of the cost attribute was set at £250, based on the process of cost vector selection in an earlier survey on peatland restoration detailed in Glenk et al. (2019), drawing on a rule of thumb referred to in Mørkbak et al. (2010).

The three attributes (*C2050*; *TIME*; *COST*) varied across unlabelled alternatives and choice tasks following an experimental design. For this study, we employed a Bayesian D-efficient design that allows for the estimation of all main effects and second-order interaction effects between the attributes. The priors used to inform the construction of the experimental design were based on the results of Conditional Logit models estimated from data collected as part of a pilot study (with N = 93 respondents that were not included in the main survey). The design comprised of 48 choice sets, which were allocated to six blocks so that each respondent faced eight choice tasks. Respondents were randomly allocated to a block of choice tasks. The order of choice questions within each block was again randomised. Prior to completing the choice experiment, respondents received a budget reminder and a single opt-

Table 5
Regression results of conditional WTP estimates for *TIME* and *C2050* on individual specific characteristics.

	TIME				C2050			
	CC attitudes – no controls	CC attitudes – with controls	CC beliefs – no controls	CC beliefs – with controls	CC attitudes – no controls	CC attitudes – with controls	CC beliefs – no controls	CC beliefs – with controls
PC1	−2.90 ***	−3.35 ***			−8.82 ***	−10.41 ***		
PC2	7.75 ***	7.62 ***			13.09 ***	12.85 ***		
CCTEMP			5.80 ***	6.22 ***			8.74 ***	10.17 ***
CCCERT			1.83 ***	1.68 **			3.83 ***	3.27 **
C80_MID	−30.67 ***	−30.67 ***	−30.73 ***	−30.73 ***				
AGE		0.18 **		0.12		0.58 ***		0.37 **
FEMALE		−5.73 *		−4.48		−17.30 ***		−13.00 **
EDU0		0.80		0.14		2.87		−1.03
EDU3		−0.15		3.90		9.79		13.52 **
CITY		−0.83		0.02		−2.92		−0.33
PEAT_SOME		−4.03		−6.21 **		−5.89		−9.13
PEAT_LOT		4.35		2.31		0.44		−5.97
MEMBER		12.97 ***		15.44 ***		20.08 ***		26.19 ***
CONSTANT	77.66 ***	71.40 ***	57.79 ***	52.13 ***	92.79 ***	71.13 ***	56.88 ***	40.05 ***
R^2	0.09	0.11	0.03	0.05	0.10	0.13	0.02	0.05
N	1,327	1,327	1,330	1,330	1,327	1,327	1,330	1,330

Note: standard errors in parentheses. *,**,*** indicates significance at 10%, 5%, 1% level; the reported R^2 for the WTP estimates for time is between respondents.

out reminder (Whitehead and Blomquist, 1995; Ladenburg and Olsen, 2014). A typical choice task is shown in Fig. 2.

It is to be noted that the above described choice experiment design does not include spatial aspects in relation to ecosystem service delivery. Peatland ecosystem services are spatially distributed and therefore their values can be expected to be spatially defined (Glenk et al. 2014). Spatial heterogeneity of preferences for peatland restoration in Scotland was the object of a previous similar investigation using a different sample and survey that did not focus on temporal aspects, but shared the same peatland condition description (Faccioli et al., 2020). This study showed that the Scottish population has heterogeneous spatial preferences for peatland restoration, which, however, differ from the use value/distance decay effects conventionally identified in the valuation literature (Bateman et al., 2006; Glenk et al., 2020). We decided against including such spatial aspects in the design of the present study to avoid increasing the cognitive burden for respondents. We did, however, show a map of Scotland illustrating where peatlands are located as part of the background information on peatlands and their restoration in Scotland. We also indicated that peatlands cover about a 20% of Scotland's surface. Respondents were asked to state, with reference to the map of peatlands in Scotland, if there were "no or few", "some" or "a lot of" peatlands near their place of residence (within 25 miles). This question was aimed at providing a spatial framing for participants, but does not specifically address spatial heterogeneity of ecosystem service provision.

2.3. Attitudinal questions

Climate change attitudes were assessed based on a scale used in Glenk and Colombo (2011) with additional statements included from Capstick et al. (2015) and Corner et al. (2012). Specifically, respondents were asked about their level of agreement and disagreement (4 point Likert scale: completely disagree – somewhat disagree – somewhat agree – completely agree) with nine statements related to climate change concern and the need for action to counteract climate change, listed in Table 4. The order of items was randomised across respondents.

We also included two questions on beliefs regarding the extent of future climate change. Specifically, we asked respondents by how much they believe average annual temperature will have increased in Scotland by 2080 (on a scale from +0.5 degrees Celsius to +5 degrees Celsius), and how certain they are about their response (from 1: completely uncertain to 10: completely certain). Prior to asking these questions, we informed respondents that annual mean temperature in Scotland had increased by approximately 1 °C over the past 30 years.

2.4. Survey implementation

The survey was implemented online (self-completion) using a professional market research company with 1813 adult Scottish citizens between July and August 2017. Of these, we use choice data on most preferred alternatives of a sample of 1377 respondents, excluding 436 respondents who were exposed to a different survey version with alternative attribute framing. As is common in stated preference studies, the survey employed a split sample design to test for effects of varying elicitation formats and attribute framing. We do not use the sub-sample with alternative attribute framing in this paper, and use 'best' choices from three sub-samples of common elicitation formats (best only; best-worst; best-next best). Respondents were randomly allocated to different survey versions. Potential effects of elicitation formats are not focus of this paper and will be investigated elsewhere. Initial analysis suggests that the general conclusions of the paper, which focuses on preferences for timing of restoration, are supported irrespective of the elicitation format. A quota-based approach was used to sample from an online panel with age and gender as 'hard' quotas. The final sample used for analysis was representative of the population of Scotland in terms of gender and age. There are statistically significant but relatively small deviations in terms of residence in rural or urban areas. In terms of educational attainment, higher educational levels are slightly over-represented (see Appendix Table A.1).

2.5. Econometric approach

2.5.1. Choice model

Following random utility theory, the utility function is characterised by the attributes of the experimental design in a linear and additive fashion, in addition to a random error term ε. The utility function U for respondent n and alternative i in choice task t can then be written as:

$$U_{nit} = -\alpha_n p_{nit} + \boldsymbol{\beta}_n^{'} \boldsymbol{x}_{nit} + \varepsilon_{nit} \quad (1)$$

where α, **β** are parameters to be estimated for the attributes describing the changes in the area of peatland condition resulting from restoration and the timing when peatland restoration efforts should take place $\times$, and a cost attribute p. The random error term ε is assumed to be identically and independently distributed (*iid*) and related to the choice probability with a Gumbel distribution with error variance $\text{Var}(\varepsilon_{ni}) = \mu_n^2(\pi^2/6)$. μ_n denotes a respondent specific scale factor.

By dividing Eq. (1) by μ_n, we derive a scale-free utility function with a new error term that is constant across respondents (Train and Weeks, 2005):

$$U_{nit} = -(\alpha_n/\mu_n)p_{nit} + (\boldsymbol{\beta}_n/\mu_n)^{'}\boldsymbol{x}_{nit} + \varepsilon_{nit} \tag{2}$$

where ε_{nit} is *iid* with constant error variance $\pi^2/6$. If $\gamma_n = \alpha_n/\mu_n$ and $\boldsymbol{c}_n = \boldsymbol{\beta}_n/\mu_n$ are parameters to be estimated, a model in preference space is derived (Train and Weeks, 2005). Re-specification of the utility function in WTP space allows direct estimation of the distributions of marginal willingness to pay (WTP) for non-monetary attribute effects. Because marginal WTP for changes in the share of peatland condition and timing of restoration is $\boldsymbol{w}_n = \boldsymbol{c}_n/\gamma_n$, the utility function in WTP space is:

$$U_{nit} = -\gamma_n p_{nit} + (\gamma_n \boldsymbol{w}_n)^{'}\boldsymbol{x}_{nit} + \varepsilon_{nit} \tag{3}$$

Let the sequence of choices over T_n choice tasks for respondent n be defined as $\boldsymbol{y}_n = \langle i_{n1}, i_{n2}, \cdots, i_{nT_n}\rangle$. The mixed logit (MXL) model enables estimation of heterogeneity across respondents by allowing γ_n and $\boldsymbol{w}_n$ to deviate from the population means following a random distribution. The unconditional choice probability of respondent n's sequence of choices ($\boldsymbol{y}_n$over $T_n$choice tasks) is:

$$\Pr(\boldsymbol{y}_n|\gamma_n, \boldsymbol{w}_n) = \int \prod_{t_1=1}^{T_n} \frac{\exp(-\gamma_n p_{nit} + (\gamma_n \boldsymbol{w}_n)^{'}\boldsymbol{x}_{nit})}{\sum_{j=1}^{J}\exp(-\gamma_n p_{njt} + (\gamma_n \boldsymbol{w}_n)^{'}\boldsymbol{x}_{njt})} f(\boldsymbol{\eta}_n|\boldsymbol{\Omega})d\boldsymbol{\eta}_n \tag{4}$$

where $f(\boldsymbol{\eta}_n|\boldsymbol{\Omega})$ is the joint density of the parameter vector for cost and non-monetary attributes, $[\gamma_n, \boldsymbol{w}_n]$, $\boldsymbol{\eta}_n$ is the vector comprised of the random parameters, and $\boldsymbol{\Omega}$ denotes the parameters of these distributions (e.g. the mean and variance). The integral in Eq. (4) does not have a closed form and thus requires approximation through simulation (Train, 2003), which was based on 10,000 (scrambled) Sobol draws (Sobol, 1967). A large number of Sobol draws is recommended to reduce simulation error, see e.g. Czajkowski and Budziński (2019). While exact numerical findings differ, our main findings are robust to changes in the number of draws, from a minimum of 1000 draws to the 10,000 draws used in the final analysis. In the estimation, we allow for correlation of all random parameters (full covariance). Starting values for the model with full covariance are derived from a model with uncorrelated coefficients (Hess and Train 2017). To ensure positivity of the marginal utility of income, the cost attribute parameter is assumed to follow a log-normal distribution. The marginal WTP coefficients of the remaining non-monetary attribute effects, and of an alternative specific constant (ASC) for the business as usual (BAU) option, are assumed to follow a normal distribution. 95% confidence intervals are estimated using the Delta method (Greene, 2008).

2.5.2. Analysis of preference heterogeneity based on conditional WTP estimates

To investigate preference heterogeneity, we also analyse whether climate change attitudes and beliefs and selected individual characteristics have a systematic influence on WTP estimates. Towards this aim, we derive 'individual-specific' WTP values for each sampled respondent based on individual conditional distributions based on the MXL model. Making use of Bayes' theorem, the expected value of marginal WTP for individual n can be approximated by simulation (Train, 2003). A discrete approximation of respondent n's conditional means may be written as

$$\widehat{E_n(\boldsymbol{w})} = \frac{\sum_{r=1}^{R} L(\boldsymbol{y}_n|\boldsymbol{w}_r)\boldsymbol{w}_r}{\sum_{r=1}^{R} L(\boldsymbol{y}_n|\boldsymbol{w}_r)} \tag{5}$$

where $\boldsymbol{w}_r$ are independent and multi-dimensional draws from$f(\boldsymbol{\eta}|\boldsymbol{\Omega})$ (the joint density of the attribute parameter vector) and $L(\boldsymbol{y}_n|\boldsymbol{w}_r)$ is the probability of observing the sequence of choices $\boldsymbol{y}_n$ with a specific $\boldsymbol{w}_r$. The estimation of the choice models and of conditional WTP were performed using the *Apollo* package in R (Hess and Palma, 2019). The conditional WTP estimates subsequently serve as dependent variables in regressions, with climate change attitudes and beliefs as well as individual characteristics serving as independent variables.

To derive suitable regressors related to climate change attitudes, we use a principal component analysis (PCA) with subsequent *varimax* rotation of factors to derive scores for attitudinal items organized in a number of components, identified as those components with an eigenvalue of one or higher. The varimax rotation makes the components easier to interpret and implies that the loadings remain orthogonal, although after rotation the components are no longer uncorrelated. Using a subset of the principal components as regressors in linear regressions as opposed to considering item scores themselves is appealing as it may reduce issues caused by multi-collinearity (Jolliffe, 1986).

The conditional estimates of WTP follow a distribution (Hess, 2010) and the Apollo package provides a measure of the conditional standard deviation. We use information on both means and standard deviations of conditional WTP estimates to fit a weighted ordinary least squares regression for the attribute reflecting changes in the share of peatlands in good condition by 2050 (C2050). The weights used are equal to the inverse of the squared individual-specific conditional standard deviations (the variance) so that WTP values that were estimated more precisely are given greater weight than the less precise ones. An unweighted analysis gives very similar results. We also employ a random effects panel model for the attribute reflecting timing of implementation, and associated long term implications for peatland resilience in the face of climate change (*TIME*). In the random effects model, we specify a pseudo-panel based on stacking individual WTP estimates for two attribute levels (Yao et al., 2014). Consequently, an indicator of one of the attribute levels also enters the model in addition to attitudes, beliefs and individual characteristics.

3. Results

3.1. Choice analysis and WTP estimates

Out of the 1377 respondents, information on choices were incomplete for eight respondents. Ninety eight respondents chose the business as usual option in all choice sets. Among these, 38 revealed protest motives based on responses to a dedicated debriefing question. These respondents were dropped from subsequent analysis with the rest kept as genuine zero answers following best practice (Dziegielewska and Mendelsohn, 2007), resulting in a final sample of 1331 respondents.

Table 3 reports model estimates of three MXL models estimated in the WTP space. For comparison, we also report results of three conditional logit models (CL1, CL2 and CL3, Appendix Table A.2). MXL1 models utility for discrete levels of *C2050* by including dummy variables for attribute levels representing 20%, 30% and 40% increase in the share of peatlands in good condition by 2050, relative to the omitted category, 10%. The results clearly show that as the share of peatlands in good condition by 2050 increases, marginal utility decreases. This indicates a possible non-linear relationship in line with diminishing marginal

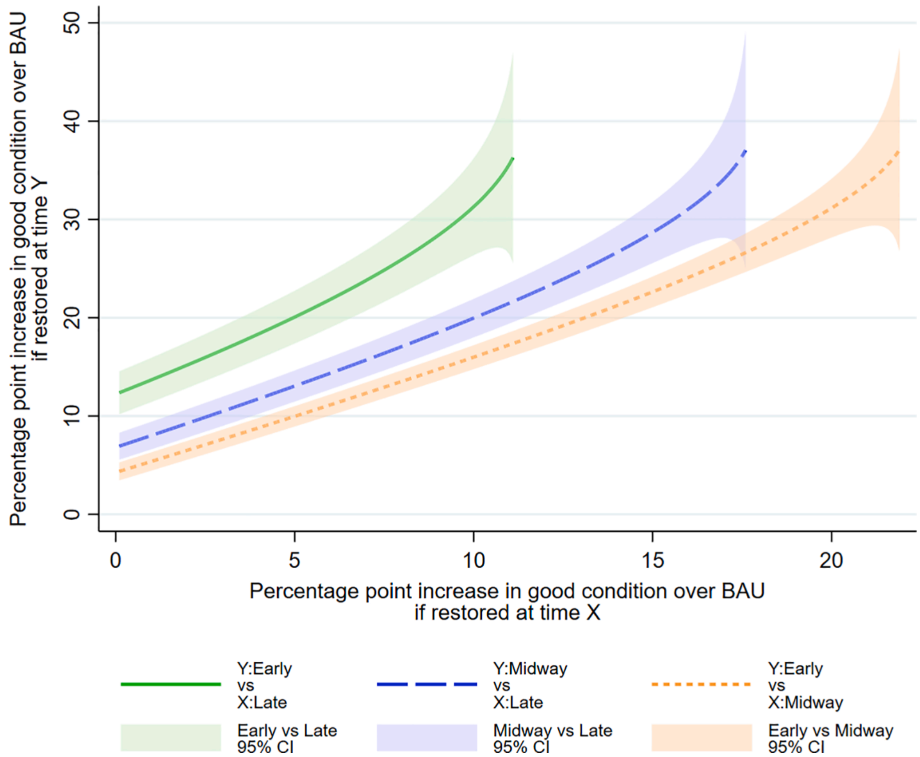

Fig. 3. Trade-off between timing of restoration and scope of restoration (percentage increase of peatlands in good condition by 2050 over the BAU scenario), keeping benefits constant.

utility. The non-linear relationship is captured in MXL3 via a quadratic specification of *C2050*. Because we are interested in estimating the rate of substitution between timing (*TIME*) and scope (*C2050*) over the whole spectrum of restoration efforts, we have to model *C2050* continuously. Among the continuous specifications of C2050, the quadratic specification represents a significant improvement in goodness of fit over the linear specification (Likelihood Ratio test statistic 29.62; df = 7; p = 0.000). We therefore use MXL3 in what follows for estimations of WTP and rates of substitution between timing and scope of restoration, and to derive conditional WTP estimates that are used to explore factors explaining heterogeneity in WTP. We note that among the three models (MXL1-MXL3), MXL1 has superior goodness of fit. Because WTP estimates are very similar between MXL1 and MXL3, relying on the continuous quadratic specification of *C2050* in MXL3 does not affect the main findings of this article.

Results show that marginal WTP is positive but decreases as *C2050* increases. The estimated threshold where marginal WTP would turn zero in the MXL model with a quadratic term is 40.4%; this is outside the observed range for *C2050* of increases in shares in good condition relative to the BAU. In terms of magnitude of mean WTP, a 10% increase in the share of peatlands in good condition over the BAU is valued at £65.03 (95% confidence interval: [£55.72; £74.35]) per household and year, a 20% increase is estimated to yield £111.68 [£96.94; £126.42] per household and year. Corresponding estimates for a 30% and 40% increase are £139.93 [£123.35; £156.51] and £149.8 [£134.08; £165.52], respectively.

A central objective of this paper is to investigate preferences for timing of restoration, which have consequences for the resilience of peatlands in the longer term. All models consistently show a preference for earlier timing of restoration efforts (*TIME*) relative to delaying restoration efforts to the last decade in the period up to 2050. In terms of WTP as derived from the MXL model, restoring early (2017–2027) rather than late (2039–2050) is associated with an estimated annual mean WTP of £77.76 [£70.68; £84.85] per household per year. The corresponding value for restoring midway (2028–2038) is £47.06 [£41.25; £52.87]. Aggregating these estimates over all 2.46 million Scottish households yields average benefits of £191 million for restoring in the period 2017–2027 rather than 2039–2050, and £116 million for restoring in the period 2028–2038 rather than 2039–2050. This clearly shows that there are significant welfare gains to be obtained from earlier rather than later restoration. Or, put in other words, there exists an opportunity cost of delaying restoration that translates into a decrease in economic welfare.

This can also be illustrated by exploring the trade-offs between preferences for timing of restoration (*TIME*) and for scope of restoration (*C2050*), summarised in the following question: to obtain the overall same benefits from restoration, how much additional restoration could be achieved if restoration took place earlier rather than later? Because we obtain a quadratic utility surface for *C2050*, the marginal rate of substitution between *TIME* and *C2050* is not constant over the share of peatlands in good ecological condition in 2050. Therefore, the welfare equivalent share of peatlands in good condition $R_{t_{YvsX}}$ that could be achieved by restoring at time t_Y rather than at time t_X where $Y = 1{,}2$ and $X = 2{,}3$ and $Y < X$ can be estimated from MXL model coefficients ω by solving for the solution of the quadratic formula that lies within the attribute range of *C2050* as follows:

$$R_{t_{YvsX}} = \frac{-100\omega_{C2050} + \sqrt{(100\omega_{C2050})^2 - 4\left(10\omega_{C2050_{squared}}\left(100(\omega_{t_Y} - \omega_{t_X}) - 100\omega_{C2050} \times R_{t_X} - 10\omega_{C2050_{squared}} \times {R_{t_X}}^2\right)\right)}}{\left(2\left(10\omega_{C2050\_squared}\right)\right)} \quad (6)$$

The results of such an analysis are graphically shown in Fig. 3 illustrating the trade-off between timing and scope of restoration effort. For example, increasing the share of peatlands in good ecological condition over the BAU by 10% through restoration taking place 'late' (2039–2050) is equivalent in benefit terms to an increase of 20.1% if restoration was in place in the period between 2028 and 2038 (midway), and an increase of 31.6% if restoration was carried out immediately after the programme starts (2017–2027). Again, this shows that delaying restoration has an opportunity cost that can be expressed in terms of forgone increases in the scope of restoration to achieve the same benefit. Overall, the results of the choice experiment clearly support early investments in peatland restoration to meet emission reduction targets and to reduce the implications of accumulating a 'mitigation debt'.

For completeness, additional MXL model estimates of interest are the coefficient of the ASC for the business as usual alternative. The coefficient of the ASC is negative and significant, indicating that respondents had a tendency to prefer restoration alternatives over the BAU for reasons unrelated to the magnitude and timing of peatland restoration. The significant standard deviation coefficients point to the presence of considerable preference heterogeneity, which will be further explored in the following section.

3.2. Debriefing questions

After the choice experiment, we asked respondents a series of questions related to attributes in choice tasks and perceptions regarding the valuation scenario. This included questions on whether respondents always, sometimes or never considered (i) when restoration takes place up to 2050 (early, midway, late) and (ii) how much peatland is in good condition by 2080. Timing is reported to have been always considered by 33.3% of the sample, sometimes considered by 51.6% and never considered by 15.1%; while the amount of peatland in good condition is reported to have been always considered by 35.2% of the sample, sometimes considered by 54.8% and never considered by 10%. Thus, how much peatland is found in good condition in the long term has received at least as much attention when answering the valuation tasks as the aspect of timing itself. Additionally, when asked about whether restoration should be undertaken sooner to enjoy benefits earlier and whether restoration should be undertaken sooner to preserve them in the longer term, an overwhelming majority of respondents agreed with related statements. When asked on a 4 point Likert scale (1: completely disagree; 4: completely agree) whether "[…] *Scottish peatlands should be restored immediately to enjoy the benefits of peatland restoration earlier*", whether "[w]*e need to restore Scottish peatlands now to make sure they will not be at risk in the future*" and whether "[…] *it is important to preserve Scottish peatlands for future generations*", 91.2%, 94.6% and 96.8% somewhat agreed or completely agreed with these statements.

Concerning questions related to perceptions of the valuation scenario, 89% of respondents agreed or strongly agreed that the "peatland restoration alternatives presented in the choice situations were credible" to them, and 90% of respondents disagreed or strongly disagreed that they "didn't understand what [they] were supposed to do" in the choice tasks. Furthermore, 88% of respondents agreed or strongly agreed that "the results of surveys like this one can influence future decisions regarding peatland restoration in Scotland".

3.3. Factors explaining heterogeneity in WTP

Descriptive statistics of explanatory variables used in regressions of individual WTP to explore preference heterogeneity are reported in Appendix Table A.3. As a reminder, the dependent variables in the regressions are the conditional WTP estimates for *C2050* and *TIME*. The primary explanatory variables are related to climate change attitudes and beliefs. A further set of socio-demographic characteristics is added to regressions as a control of the robustness of the association of climate change attitudes and beliefs with WTP.

The principal component analysis of attitudinal variables extracts two factors with an eigenvalue greater than one that jointly explain 65% of variance in the responses to the nine Likert scale items. Rotated factor scores are reported in Table 4. The first component (PC1), which we denote "*hesitant scepticism*", is associated with items for which agreement suggests some form of climate scepticism, and items that suggest that a low perceived degree of a need to act against climate change, or of being impacted by climate change. The second component (PC2), which we label "*deep concern*", reflects certainty about the existence of climate change and an urgent need to do something about it.

In terms of beliefs regarding future climate change (*CCTEMP*), the mean expected temperature increase by 2080 as stated by respondents is 2.1 degrees Celsius. This suggests an average expectation of not meeting the target as stated in the Paris Agreement of keeping temperature rise below two degrees Celsius threshold above pre-industrial levels. It should be noted that in the survey we referred to Scotland only, while the Paris Agreement refers to global temperature rise. The average respondent is also found to be rather uncertain about their belief regarding future temperature rise (*CCCERT*) indicated by an average score of 4.3 on a 10 point scale where 10 reflects complete certainty. As may be expected, there are significant correlations between the extracted component scores for "*hesitant scepticism*" (PC1) and "*deep concern*" (PC2) and expected climate change increase (*CCTEMP*) and certainty (*CCCERT*). PC1 is negatively and significantly correlated with *CCTEMP* and *CCCERT*, while PC2 shows positive and significant correlations. We therefore only include either climate change attitudes (PC1 & PC2) or climate change beliefs (*CCTEMP* & *CCCERT*) as explanatory factors in regressions of WTP indicators, but do not enter them jointly in the regressions.

Table 5 reports results of the regressions. Overall, the explanatory power of models is low, suggesting a large degree of unobserved heterogeneity. Both components (PC1 & PC2) show a significant relationship with WTP for scope (*C2050*) and timing (*TIME*) of restoration. Specifically, a greater degree of scepticism is associated with lower WTP estimates, while increase in stated "*deep concern*" about climate change is related to an increase in WTP estimates. In terms of beliefs about climate change, a higher expected temperature increase and greater perceived certainty about the expected temperature effect are associated with greater WTP for both attributes (*C2050* and *TIME*). These associations remain significant even after inclusion of the range of socio-demographic control variables. These comprise of age, gender, education level, whether the respondent lives in a city, whether the respondent states to live close to peatlands or not, and if the respondent states to be member of environmental organization.

Before we continue with a discussion of main results, we briefly return to the issue of (stated) attendance to attributes, which is a likely factor impacting WTP, as found by numerous studies (Campbell et al., 2008; Glenk et al., 2015; Lew and Whitehead, 2020). While a detailed analysis of attribute non-attendance is beyond the scope of this study, we explored differences in WTP as a result of stated differences in attribute attendance using the conditional WTP estimates for *C2050* and *TIME_EARLY* (see 3.3.). WTP for *C2050*, evaluated at 25% increase in share of peatland in good condition, is £182, £109, and £42 depending on whether respondents stated to have always, sometimes or never attended to the attribute. The corresponding figures for *TIME_EARLY* are £106 (always), £70 (sometimes) and £43 (never). This shows that stated attribute non-attendance affects WTP in the expected *direction* (lower WTP if lower attendance), but not in terms of the expected *magnitude* of the effect. WTP estimates do not drop to zero (or close to zero) for respondents who stated to have never considered an attribute, while in theory that would be expected. This points to issues with identification of attribute non-attendance, possibly related to not understanding reasons underpinning non-attendance (Alemu et al., 2013) and concerns about the reliability of stated attribute non-attendance (Scarpa et al., 2013).

4. Discussion

This study is among the first to consider implications for ecosystem resilience in a stated preference environmental valuation framework. Ecosystem resilience is an important factor in ecosystem conservation and restoration decisions. It contributes to improve the capacity of ecosystems to cope with perturbations and withstand shifts towards more degraded ecological conditions. Therefore, fostering resilience of functioning ecosystems helps to safeguard their ability to provide valuable services to society (Gunderson and Holling, 2002; Allen et al., 2016). Despite its evident social relevance, demonstrated theoretically for example by Admiraal et al. (2013) or Baumgärtner and Strunz (2014), very little is known regarding the (monetary) value of environmental resilience in economic welfare terms (Dallimer et al., 2020). Only two empirical applications exist in the economic valuation literature have focused on people's preferences for resilient ecosystems (Vergano and Nunes, 2007; Scheufele and Bennett, 2012) and among these only Scheufele and Bennett (2012) studies people's preferences for resilient ecosystems. Our study contributes to this emerging literature by specifically referring to resilience of ecosystems under climate change in an economic valuation study.

Specifically, in the valuation scenario of this stated preference study, an explicit link is made between timing of interventions, in this case peatland restoration, and effects on long-term ecosystem resilience, i.e., that peatlands maintain their ecological condition and related functioning. We demonstrate that people have strong preferences for earlier restoration action, which is assumed to be related to a greater proportion of peatlands maintaining a good ecological condition in the longer term.

This outcome may be driven by at least three reasons guiding respondents' choices that are worth discussing here. First, reflecting their time preferences, in general people tend to prefer earlier consumption to later consumption (in this case, enjoy the benefits of restoration earlier rather than later). Amongst other things, this may reflect uncertainty about future consumption possibilities. Considerations of time preferences in environmental stated preference studies aiming at estimation of discount rates are consistent with such a finding (e.g., Bond et al., 2009; Viscusi et al., 2008; Meyer, 2013a; Meyer, 2013b; Lew, 2018; Vasquez-Lavín et al., 2019; Grammatikopoulou et al., 2020).

Second, because earlier restoration implies that benefits of restoration may be realised earlier, benefits accumulated over the lifetime of an individual are higher. A greater valuation would therefore not be an effect of time preference, but simply reflect the notion that people prefer to consume more of a normal good. To disentangle time preferences, previous studies therefore varied timing of the provision of goods and services, but kept the level of provision constant (Viscusi et al., 2008; Meyer, 2013a; Meyer, 2013b). While of academic interest, we argue that in many environmental valuation contexts, including peatland restoration, it is unrealistic to assume that environmental improvements can be "switched on" and "switched off" at any given time, for example due to time lags in the ecological response to changes in various ecosystems and conservation contexts (Watts et al., 2020; Mueller et al., 2015; Diefenderfer et al., 2021; Lira et al. 2019), and that doing so compromises the policy relevance of such studies. To illustrate, Viscusi et al. (2008, 201) proposed to respondents that "the government is considering several policies that would temporarily increase water quality in your region. Once the policy is in effect, the improvement lasts for five years, then water quality returns to its previous level." Meyer (2013a, 48) informed respondents that "[t]he water quality improvement ends five years after the cleanup is fulfilled". The approach used in these studies thus implies that benefits arising from interventions into complex ecosystems (lakes and rivers in the respondent's region in the USA (Viscusi et al., 2008) and water quality in the Minnesota River Basin (Meyer, 2013a; Meyer, 2013b)) can be "switched on" and "switched off" at a specific point in time.

Third, and importantly, respondents to our survey may have expressed a preference for early restoration based on reasons directly related to future resilience of peatlands under climate change. This includes motivations related to enhancing the potential for benefits to be enjoyed in the future (option value) and, potentially, considerations of the 'natural' protection that ecosystems can provide against disturbances (insurance value) (Dallimer et al. 2020). Respondents may also have other-regarding motives underpinning preferences, including inter-generational altruism (Jouvet et al., 2000). While this cannot be categorically established, results from choice experiment debriefing questions in the survey (Section 3.2) provide some grounds for accepting this as a plausible explanation. The majority stated to have always or sometimes considered how much peatland is in good condition by 2080 when evaluating the alternatives on choice cards, and expressed agreement with the importance of undertaking restoration sooner to preserve them in the longer term and for future generations. We also find that concern (scepticism) about climate change is associated with higher (lower) WTP for the attribute *TIME*, and that higher expected temperature increase due to climate change tends to increase WTP for this attribute (Section 3.3). Together, we believe that the above findings provide sufficient evidence to suggest that considerations of climate change and ecosystem resilience in the longer term did play an important role in respondents' valuations.

Irrespective of the reasons underpinning WTP for earlier peatland restoration efforts, our results demonstrate that there is an opportunity cost of delaying action, in this case of delaying peatland restoration. The overall implications for policy makers are evident. Delaying climate action may result in a substantial welfare loss relative to early initiatives. This means that—at least for the case of peatland restoration in Scotland—an enhanced emphasis that accelerates investment into climate change mitigation efforts is desirable from a societal point of view. Our results point to the welfare implications of, for example, a uniform distribution of investments in peatland restoration as opposed to accumulated investments in earlier time periods, or a long period of 'phasing in' before considerable scaling of restoration takes place. Further, our results also show that restoring earlier achieves greater scope of restoration (for equivalent welfare gains), thus contributing to greater emission reduction.

However, despite the implied urgency to scale restoration efforts in a short period of time, immediate large scale implementation of peatland restoration also needs to be mindful of restoration capacity and economic efficiency (i.e., costs of restoration). For example, to fully realise the potential, the capacity of suppliers of peatland restoration services must grow alongside potential demand, even if triggered by attractive public funding for restoration. There is also a value in growing experience with restoration over time to improve efficacy and efficiency of restoration. Both aspects help realise important economies of scale, i.e., decreasing per hectare restoration costs as efforts increase. It is especially important to realise potential economies of scale, because our findings suggest diminishing marginal benefits related to increasing scope of restoration. What also deserves further scrutiny is the impact of ongoing degradation in the absence of restoration measures on programme costs. Arguably, sites that are more heavily degraded more expensive to restore. In practical terms, policy makers may also see delaying investments as a strategy to hedge against risks associated with incomplete knowledge on effectiveness and costs of restoration. Overall, we therefore suggest that policy makers couple an enhanced emphasis on early investments with dedicated research to reduce such uncertainties, and with continued funding that support learning and innovation in restoration practice by landowners and restoration suppliers alike.

There are some limitations to our study design that are worth pointing out. First, even after careful pre-testing, we cannot rule out the possibility that some respondents may have struggled with the complexity of the information provided in choice tasks, possibly resorting to some decision heuristic. However, responses to debriefing questions regarding the valuation scenario (3.2) suggest that this was unlikely an issue for a large majority of respondents, who found scenarios credible and stated to not have struggled with answering the choice tasks. While exact numerical findings differ, our results are also robust to omitting respondents (10% of the sample) with stated difficulties to understand the choice tasks from the analysis.

Second, the long term impacts of climate change on peatlands are highly uncertain. We represented this uncertainty by providing respondents with two alternative endpoints depending on uncertainty regarding future climate change (i.e. less or more severe climate change), but did not consider other sources of uncertainty, for example regarding dynamic and possibly non-linear processes in ecosystem response to environmental stressors (Page and Baird, 2016). These uncertainties should be borne in mind when using our estimates of WTP to guide decision making.

Third, there is the limited availability of information on study participants' household income. Income information was not provided by about 25% of the sample. Relatively low response rates for income questions are not uncommon in social science surveys (Kim et al., 2007). Because of the limited availability of income information, it was not possible to explore whether and how WTP differs depending on income. Further, a logit regression with a dummy variable for missing income as the dependent variable finds systematic effects that suggest that younger, more highly educated respondents and females were less likely to provide income information in the survey. This may have consequences for the aggregation of the study values to population level because full representativeness based on the income distribution cannot be ensured. Nevertheless, mean marginal WTP estimates from our study clearly establish preferences for more and early peatland restoration for the average respondent.

5. Conclusions

Ecosystem restoration is a key strategy for the advancement of the global net zero emissions agenda. Delaying restoration action may not only result in further ecosystem degradation, but also negatively impact on ecosystem resilience, leading to substantial additional greenhouse gas (GHG) emissions that accelerate global warming. Relying on stated preference data from a choice experiment, this paper investigates the economic welfare impacts of delaying ecosystem restoration, using peatlands in Scotland as a case study.

Our results are unequivocal with respect to the economic benefits associated with the timing of restoration: there are significant welfare gains to be obtained from earlier rather than later restoration. This has important implications for GHG mitigation. It suggests that accumulating a 'mitigation debt' by delaying land-based GHG removals has a substantial opportunity cost that is independent of an increase in the magnitude of GHG removals over time required to keep climate change within acceptable limits. This opportunity cost can also be expressed as a trade-off between timing of restoration and scope of restoration. For a given benefit amount, more peatland area can be restored to good ecological condition, and thus a greater amount of GHG mitigation achieved, if restoration is implemented in the near future rather than later. However, in order to realise the benefits of early investment in peatland restoration, restoration programmes should be accompanied by efforts to reduce uncertainty in peatland restoration practice and to increase restoration capacity to benefit from economies of scale.

These results come at a time when major decisions are taken regarding planned investments in peatland restoration. Looking at our case study context, in Scotland alone the Scottish Government has since February 2020 committed an investment exceeding £250 million over the next ten years. Our research shows that the annual allocation of investments in within the multi-annual programme has significant consequences for the returns on investments. The global importance of our findings become evident when considering that CO_2 emissions from (almost) all drained peatlands in the world would have to be stopped to achieve climate-neutrality by 2050 as implied by the Paris Agreement (Günther et al., 2020).

Our study also provides grounds to hypothesise that public preference for earlier restoration might be related to ecosystem resilience considerations with respect to maintaining the ecosystem's natural capacity to resist and provide protection against disturbances. In this respect, future research could explore if preferences for timing of ecosystem restoration depend on the type of GHG mitigation strategy considered. Furthermore, similarly to understanding the impact of risk preferences on willingness to pay for environmental goods (Bartczak et al., 2017), further research could aim to investigate how individuals' rate of pure time preferences relates to willingness to pay for long-term ecosystem resilience.

CRediT authorship contribution statement

Klaus Glenk: Conceptualization, Methodology, Data curation, Formal analysis, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Michela Faccioli:** Conceptualization, Methodology, Data curation, Writing - review & editing, Supervision, Project administration, Funding acquisition. **Julia Martin-Ortega:** Conceptualization, Methodology, Writing - review & editing, Supervision, Project administration, Funding acquisition. **Christoph Schulze:** Formal analysis, Writing - review & editing. **Jacqueline Potts:** Methodology, Formal analysis, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

CATEGORIES OF PEATLAND ECOLOGICAL CONDITION	ECOSYSTEM SERVICE REPRESENTATION	ACCOMPANYING NARRATIVES
 Good Ecological Condition		In good condition, there is plenty of water, so it is visible on the surface, slowly flowing through larger and smaller pools. You will see small grasses and especially the peat moss that grows well in wet conditions. The moss stores lots of water and makes the peatland appear in a typical red-green-brown mosaic. Peatlands in good condition continue to grow by adding more and more layers of peat. While growing, carbon is taken up from the atmosphere as carbon dioxide (CO_2) and stored as peat. Water that flows from peatlands that are in good ecological condition is usually clear and of good quality. This means less need for water treatment. The water quality is also good for fish living downstream, especially salmon and trout. Peatlands in good condition are home to various birds and wildlife species. This includes waterfowl and wading birds such as curlew, and predators such as hen harrier and red kite.
 Intermediate Ecological Condition		In peatlands in intermediate condition, water has been taken off the land by creating channels for drainage. This allows activities such as livestock grazing. Surface water is rarely visible. With less water on the land, taller plants can grow, like cotton grass, or small bushes like heather. Peatlands in this condition are not very colourful. However, if heather grows in the area and is in bloom, its purple colour stands out. Signs of bare peat start to appear as dark patches. Sometimes peatland of intermediate condition is burned regularly, to create conditions for grouse shooting. This leaves characteristic patterns of burned and unburned land in the landscape. Peatlands in intermediate condition have stopped growing. No additional peat layers are added. Instead, peat layers gradually shrink, releasing a moderate amount of carbon to the atmosphere, where it contributes to climate change. Water flowing from such peatlands can be of lower quality. Water can be slightly murky, especially after a heavy rainfall. This can affect the fish population downstream, including salmon and trout, and increase the need for water treatment. Peatlands in intermediate condition may still harbour some of the wildlife that is present in peatlands in good condition. However, it is less abundant and some of the wildlife may not be found any more. It is also more likely that you will see managed species such as deer, sheep and grouse.
 Bad Ecological Condition		Peatlands in bad condition have been drained for a longer time. The forces of water and wind (erosion) have now exposed larger areas of bare peat. Deep gullies and trenches are formed. Rarely any plant grows on the areas that are exposed. Patches of grasses or heather are still found on ‘islands’ in between exposed bare peat. The exposed bare peat areas will continue to grow, leaving less plant cover as protection on the surface. Peat will continue to be lost until the solid rock surface emerges. Peatlands in bad condition lose carbon at a high rate. They have turned into a severe ‘source’ of carbon to the atmosphere, where it contributes to climate change. Water that flows downstream is of bad quality. It is often murky and can be dark brown from soil components in the water, especially after heavy rainfall events. The bad water quality will affect fish downstream. It is not suitable for human consumption and therefore needs a lot of treatment. Peatlands in this condition are home to little wildlife. Not many plant and animal species can be found.

Fig. A1. Peatland ecological conditions and depictions of associated ecosystem service impacts (from Martin-Ortega et al. (2017)). These visual descriptions were accompanied by the narratives shown, that served as mechanisms for conveying (at least in part) the complexity of the ecosystem processes that led to the delivery of the ecosystem services in a way that the public could understand. The information contained in these narratives was presented to survey respondents in a step-wise interactive manner in the online tool, in which they could click on several parts of the landscape and display the relevant pieces of information.- The information and images shown in Fig. A.1 are open access under the conditions of the Creative Commons copyright and can be freely used by anyone who would like (see Martin-Ortega et al. (2017) for more details or download here www.see.leeds.ac.uk/peatland-modules/embeds/index.php). The images were drawn by Ximena Maier.

Table A1
Socio-demographic characteristics by split sample, compared to the Census statistics for the population in Scotland.

Characteristic	Sample	Population (Scotland) [a]	p-value
Gender			
Male	49%	49.0%	0.97
Female	51.1%	51.0%	0.97
Age			
18–24	11.6%	11.9%	0.69
25–44	33.0%	33.0%	0.97
45–64	33.8%	34.2%	0.78
≥ 65	21.6%	20.9%	0.54
Place of residence			
Rural	33.2%	30.1%	0.01
Urban	66.8%	69.9%	0.01
Education level attained [b]			
Level 0 (Lower secondary school)	20%	26.8%	0.00
Level 1 (Upper secondary school)	22.5%	23.1%	0.57
Level 2 (College)	11.8%	14.3%	0.01
Level 3 and above (University)	45.1%	36.0%	0.00
Prefer not to tell	0.7%		

Note: [a] Scotland Census 2011 data downloaded from: http://www.scotlandscensus.gov.uk/; [b] Some differences are worth noting regarding information on educational attainment derived from the Census versus in our study. The Census considers a population of 16 years of age or older, while we only included respondents of 18 years of age or older in our survey. In addition, there are some discrepancies in the education categories considered.

Table A2
Results of conditional logit (CL) models in WTP space.

	CL1 C2050 discrete		CL2 C2050 linear		CL3 C2050 quadratic	
	coef.	*t-ratio*	*coef.*	*t-ratio*	*coef.*	*t-ratio*
ASC – BAU	−0.147	−20.13	−0.129	−16.96	−0.119	−11.7
C2050 – 20%	0.194	5.53				
C2050 – 30%	0.464	9.15				
C2050 – 40%	0.556	10.82				
C2050 – linear			0.019	11.29	0.03	3.99
C2050 – squared					−0.002	−1.40
TIME – EARLY	0.555	12.5	0.541	12.32	0.547	12.46
TIME – MIDWAY	0.406	10.52	0.401	10.41	0.406	10.54
COST	0.989	25.46	0.990	25.52	0.991	25.48
Log-L	−9522.43		−9525.08		−9524.31	
Rho square	0.186		0.186		0.186	

Note: The cost attribute was re-scaled and entered the model as 1/100 of the values in GBP shown

Table A3
Descriptive statistics of explanatory variables used analysis of preference heterogeneity.

Label	Description	Mean	Std. Dev.	Min	Max	N
WTP2050	Conditional WTP estimates for C2050 attribute, evaluated at 25% increase in share of peatland in good condition	98.25	55.61	−39.82	277.76	1,331
WTP2080	Conditional WTP estimates for TIME attribute, stacked for the two levels EARLY and MIDWAY	37.2	25.03	−52.5	153.16	1,331
C80_MID	=1 if WTP2080 refers to estimate for TIME = MIDWAY	0.50	0.50	0	1	1,331
CCTEMP	Belief regarding temperature increase by 2080 (range of answer options: 0–5 degrees Celsius)	2.09	1.20	0	5	1,330
CCCERT	Certainty regarding CCTEMP on 10 point scale (1 = completely uncertain; 10 = completely certain)	4.31	2.25	1	10	1,330
PC1	Principal component 1 – “hesitant scepticism”	0	1.8	−3.04	5.58	1,327
PC2	Principal component 2 – “deep concern”	0	1.6	−5.24	2.54	1,327
AGE	Age in years	47.59	17.10	18	96	1,331
FEMALE	=1 if respondent is female	0.52	0.5	0	1	1,331
EDU0	=1 if education level is lower secondary school	0.2	0.4	0	1	1,331
EDU3	=1 if education level is university	0.45	0.5	0	1	1,331
CITY	=1 if respondents lives in cities, close to a city or larger towns	0.67	0.47	0	1	1,331
PEAT_SOME	=1 if respondent states to live close to some peatland	0.42	0.49	0	1	1,331
PEAT_LOT	=1 if respondent states to live close to lots of peatland	0.06	0.23	0	1	1,331
MEMBER	=1 if respondent states to be member of environmental organization	0.18	0.39	0	1	1,331

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