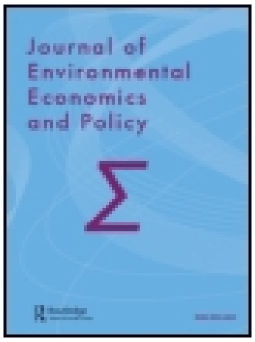

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Preferences for coastal adaptation to climate change: evidence from a choice experiment

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ABSTRACT

Climate change adaptation is essential for coastal areas. This paper adds to the limited evidence on the trade-offs people are willing to make concerning coastal adaptation strategies along an entire coast of a state (Baltic Sea coast of Mecklenburg-Western Pomerania). The trade-offs are conceptualised in a choice experiment in terms of six attributes: the extent of beach nourishment, dyke heightening, cliff protection, access to dunes, realignment of dykes and dunes, and cost in terms of a coastal protection levy. The attributes were selected and designed in close cooperation, among others, with governmental decision-makers. Accounting for preference heterogeneity, we identified three latent groups among the participants of a nationwide online survey in Germany. Respondents who prefer extensive changes, respondents who are willing to pay only for an increase in dyke height, and respondents who are unwilling to cover additional expenses for adaptation. The aggregated welfare measures indicate that an adaptation scenario *Recreation* ranks highest followed by *Safety* and *Nature*. However, the scenarios do not represent unequivocal alternatives and provide essential insights into peoples' preferences not only to policymakers and the administration in the case study region.

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Adaptation strategies; choice experiment; climate change; coastal protection

1. Introduction

For coastal areas adaptation to climate change is essential. Coastal areas are highly populated, accommodate significant amounts of economic assets and provide essential ecosystem services. In Europe, for example, one-third of the population lives within 50 km of the coast generating over 30% of the total EU GDP.[1] Climate change poses a significant threat to these areas. Even if greenhouse gas emissions would be limited to well below 2°C, the IPCC (2019) projects a rise in sea level over the twenty-first century in the range of 0.29–0.59 m compared to the period 1971–2015.[2] In the future, more and stronger storm surges than before are to be expected.

Coastal adaptation, however, is not only an engineering challenge (Gopalakrishnan, Landry, and Smith 2018). At its core, it is also an economic question about a societies' willingness to use scarce resources for adjusting and improving coastal protection. Decisions on which adaptation measures to implement and to what extent require costly trade-offs (Johnston, Makriyannis, and Whelchel 2018). Not all objectives may be achieved simultaneously due to financial constraints but also because of competing goals. One may argue, for example, against the protection of cliffs as their

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erosion is a natural process. Seen from a recreational perspective though, protecting cliffs allows preserving hiking and cycling trails running along with them. Further, a managed realignment of dykes and dunes, which is the deliberate removal of coastal protection measures further inland, would restrict land use options but could benefit nature by providing new habitats for flora and fauna. It is therefore essential to reflect the potential welfare changes of adaptation options societies would face.

How people evaluate trade-offs in coastal management options has been investigated in a couple of studies employing stated preference techniques. To a large extent, these relate to measures taken at local study sites. Several of them focus on coastal erosion providing useful findings for decision-makers, not necessarily considering adaptation to climate change (e.g. Matthews, Scarpa, and Marsh 2017a, 2017b; Marzetti et al. 2016). Studies that address adaptation to climate change, the focus of our analysis, also mostly refer to local study sites and focus on either single (e.g. Remoundou et al. 2015; Dachary-Bernard, Rey-Valette, and Rulleau 2018; Liski, Koetse, and Metzger 2019) or sets of adaptation measures (e.g. Rulleau and Rey-Valette 2013, 2017; Johnston, Makriyannis, and Whelchel 2018; Chen, Swallow, and Yue 2020; Landry, Shonkwiler, and Whitehead 2020; Oliveira and Pinto 2020). Remoundou et al. (2015), for example, study preferences for maintaining beaches in the Santander Bay area, Northern Spain, in their current state through nourishments. Marzetti and Disegna (2009) include beach nourishment as an artificial defence measure at Lido di Dante, a coastal tourist resort in Italy. Liski, Koetse, and Metzger (2019) investigate the impact of deliberative interventions on preferences for realignment as an adaptation strategy for the Inner Forth Estuary in Scotland. Dachary-Bernard, Rey-Valette, and Rulleau (2019) study preferences depending on risk perception for modalities of realignment schemes (timing, size and consultation process of the population) of both coastal and hinterland residents around Béziers, France.

Turning to studies that analyse sets of measures, Rulleau and Rey-Valette (2013, 2017) focus on long-term adaptation measures for local study sites in France. Residents face the choice between moving seafront property further inland and seawalls (Rulleau and Rey-Valette 2017), tourists are surveyed regarding their perceptions of different adaptation measures (i.e. nourishment, breakwaters, dykes, and seawalls). Rulleau and Rey-Valette (2013) and Johnston, Makriyannis, and Whelchel (2018) investigate trade-offs people in Waterford and Old Saybrook, Connecticut, United States, are willing to make between conservation of coastal assets and effects on other ecosystem services. Chen, Swallow, and Yue (2020) compare preferences for conventionally engineered seawalls and nature-based protections identified as living shoreline for residents of the Eastern Shore of Virginia, United States. Landry, Shonkwiler, and Whitehead (2020) analyse preferences for coastal erosion management of North Carolina's beaches, United States, including nourishment, armouring of the coastline and realignment. Oliveira and Pinto (2020) investigate users' preferences over alternative options of coastal erosion management at Praia da Amorosa, North of Portugal, including lighter interventions (palisades, gangways) and heavy infrastructures (rockfills, seawalls, groynes).

Against this background, this paper contributes to the literature in at least four different ways. First, we add to the limited evidence on the trade-offs people are willing to make when it comes to climate change adaptation along coasts. For Germany, to the best of our knowledge, this is the first study eliciting individual preferences. Second, we aim at assessing the benefits of different adaptation measures along an entire coast and not only for certain sections or single locations. The Baltic Sea coast of Mecklenburg-Western Pomerania (MWP) serves as an example. If the sea level on this coast continues to rise at about the same rate as the global average in the future, Baltic storm surges could reach 30–90 cm higher by the end of the century simply because of the higher starting level. Storm surges, which are classified as very severe events today and currently occur about every 50 years, would then return at much shorter intervals (Meinke et al. 2014). As climate continues to change and impacts to increase, rising investments are required to keep up with the changes. Adaptation along the coast in MWP requires different measures at different sections of the coast, including, e.g. dykes, beach nourishments and groynes, which are embedded in our study. Third, unlike in other countries, coastal protection is a national task in Germany, delegated to the coastal states, and limited to the protection of settlements. At present, 70% of the expenses for coastal protection are financed by the national government, while 30% are covered by the coastal states' government (StALU 2009). This regulation is part of the joint task 'Improvement of Agricultural Structure and Coastal Protection' (GAK), an agreement between the federation and the states in Germany. The GAK is the most important national funding instrument in Germany for agriculture, forestry, and coastal protection, among others (BMEL 2020). Its budget, which was for coastal protection in MWP about €17 Mio for the year 2019 (BMEL 2020), is the result of a political negotiation process that does not take into account the individual preferences of citizens.

The fact that coastal protection under the GAK is financed not only by the coastal states in Germany, but all federal states, implies that also people who live far away from the coast or do not visit it contribute through their taxes to its protection. Their preferences should, therefore, be taken into account when deciding about adaptation to climate change. We do so by surveying the whole of Germany. Fourth, investigating preferences and their heterogeneity across a society will provide valuable insights for policy makers on future funding in Germany. We employ a choice experiment (CE) to investigate people's preferences for coastal adaptation options (Holmes, Adamowicz, and Carlsson 2017) as CEs enable to assess a range of adaptation strategies and provide richer information for decision making than other valuation approaches. This proves to be particularly suitable for our study as results are intended to support decision maker in politics and administration in the state of MWP. Adaptation measures were developed in cooperation with coastal engineers and in consultation with the responsible authority for coastal protection in MWP (Staatliches Amt für Landwirtschaft und Umwelt Mittleres Mecklenburg) to ensure that results would in fact be meaningful for decision making.

2. The study area

The German Baltic Sea coast of MWP is characterised by its distinctive bodden-type bays which are brackish water bodies forming lagoons. These bays are separated from the open sea by the islands Rügen, Usedom and the peninsula Fischland-Darss-Zingst. The coastline stretches over 1945 km in total, of which the outer coast amounts to 377 km and the considerably longer inner coast to 1568 km (Figure 1). The majority of coastal protection structures are implemented at the outer coast because of its direct exposure to coastal hazards (StALU 2009). About one-half of the outer coast is subject to flooding, while about one-third is protected by coastal structures. In the event of a storm surge comparable to that of 1872, an area of 1080 km^2 at the inner and outer coast would be flooded and about 200,000 residents directly affected if no defensive measures were taken.

On the outer coast, protection focuses on protecting flat coasts, which are prone to both flooding and erosion, and account for about 80% of the length of the coast. There, primarily dykes and dunes are employed which operate as a system together with groynes and sand nourishments. Cliffs are only exceptionally protected. This is because long stretches of the coastline in MWP are so-called graded shorelines *(Ausgleichsküste)* (StALU 2009). Sediments of the cliffs are carried away and transported along the shoreline disembarking at flat coasts. Any disruption of this natural process by the prevention of abrasion will raise the need for intervention at flat coastal stretches. A lack of sediment will emerge and will necessitate further sand nourishments. As priority is given to the protection of settlements by the Water Act, the statutory basis for coastal protection in MWP, the federal state of MWP is legally not obliged to protect cliffs as settlements are uncommon in these areas (LWaG 1992).

3. Method

A central element of designing a CE is to decide on the number and types of alternatives and to select the attributes and associated levels that describe these. The choice tasks in the present survey

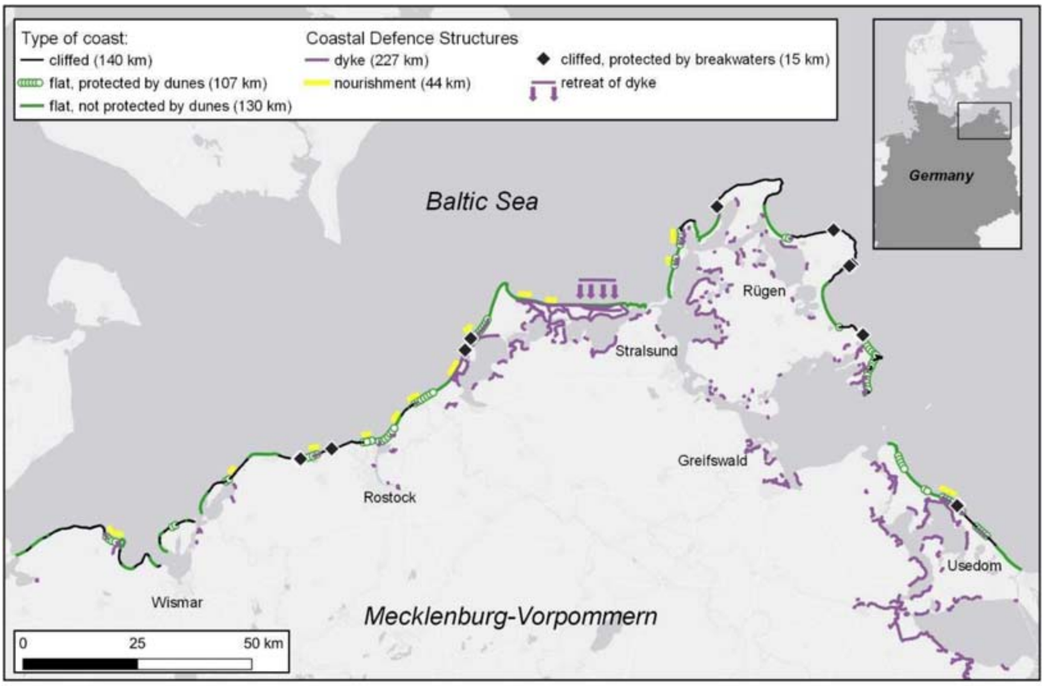


Figure 1. Map showing the coast of MWP and the coastal defence structures. Note: type of coast refers to the outer coast. Image courtesy of J. Tiede (LUH), based on data provided by StALU.

(Figure 2) provided individuals with three distinct types of alternatives. They could choose among two hypothetical alternatives (*Adaptation A and B*), the alternative to go ahead with the present set of protection measures (*Present measures*) or the alternative to go ahead with the present budget (*Present budget*). These types of alternatives are meant to reflect the basic options people in Germany have with respect to coastal adaptation.

Describing them in reversed order, the alternative *Present budget* reflects that individuals might not be willing to pay additionally for future adaptation. This implies that it would not be possible to maintain the current level of measures as costs will increase in the future. The alternative *Present measures* reflects that individuals might prefer to maintain today's measures and are willing to pay more for this compared to what people in Germany pay on average today for coastal protection. Finally, the two generic alternatives *Adaptation A* and *Adaptation B* reflect that individuals prefer to not only maintain the current conditions but to carry out further measures to adapt the coast to potential future changes. Each alternative implies a change in an attribute level of at least one of the non-monetary attributes and incurs also payments that are generally higher than those for the alternative *Present measures*.

The attributes aim at representing dimensions of adaptation that are crucial for future coastal protection in MWP. Adaptation measures considered here are confined to the outer coast because climate change is expected to impact here first. They and the associated attribute levels were selected based on literature reviews and expert interviews, especially with representatives from the responsible authority for coastal protection in MWP (Staatliches Amt für Landwirtschaft und Umwelt Mittleres Mecklenburg). The attributes and pictograms, developed to make them more recognisable for respondents, were tested in a series of focus groups in four cities of MWP (Schwerin, Rostock, Stralsund, Greifswald) in October 2019. Participants were randomly drawn from the populations living in and around those cities. The invitation as well as the moderation of the focus groups was conducted by the survey company that was also responsible for the main survey. On average, If only the following alternatives would be available: Which alternative would you prefer? Please choose one of the alternatives. If the payment associated with an alternative is above that amount of money you are actually willing to pay, please reconsider your choice.

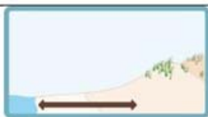
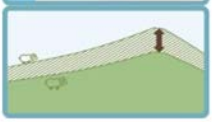
		Adaptation A	Adaptation B	Present measures	Present budget
Beach nourishment (44 km total)		40 m width	60 m width	40 m width	20 m width
Dyke heightening (227 km total)		75 cm height	75 cm height	50 cm height	25 cm height
Access to dunes		Yes. Over a distance of 20 km	Yes. Over a distance of 10 km	No	No
Protection of cliffs		30 km distance	45 km distance	15 km distance	15 km distance
Realignment of dykes and dunes		3 spots (45 km^2)	1 spot (15 km^2)	1 spot (15 km^2)	1 spot (15 km^2)
My payment		110 €	300 €	15 €	no payment
I choose		☐	☐	☐	☐

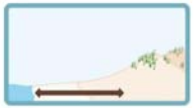
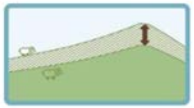
Figure 2. Example choice task with opt-out reminder.

between eight to ten people participated in each focus group. After the series of focus groups, the attributes and pictograms were revised.

The final set of attributes is presented in Table 1. The first two, *beach nourishment* and *dyke heightening*, directly relate to coastal protection. Both are coastal protection measures regularly applied in MWP. Beach nourishment is used at flat coasts and sections protected by dunes. Due to erosion, it must be repeated every few years. The responsible office generally aims at an average beach width of 40 m after a nourishment. The attribute's levels reflect that in future, the average width could be maintained or either increased to 60 m or decreased to 20 m. In order to account for future sea-level-rise in the Baltic Sea, dykes are currently adjusted in height by an extra 50 cm upon renewal (StALU 2012). The levels of this attribute include to maintain this practice, to increase the extension to 75 cm or decrease it to 25 cm.

The next attributes (access to dunes and protection of cliffs) concern recreational opportunities. First, dunes are crucial for coastal protection at the coast of MWP. To stabilise them and maintain their safety capacity, they are generally planted with beach grass. To protect the vegetation, people are usually not allowed to trespass, including walking and sunbathing. These activities are, however, popular among beach users. The attribute access to dunes offers the opportunity to use limited parts of the dunes for recreational purposes if people are willing to pay for the higher effort needed to restore the vegetation. Second, cliffs that characterise features of the coast in MWP are subject to

Table 1. Attributes and attribute levels.

Attribute	Pictogram	Description	Attribute levels
Beach nourishment (44 km total)		Wider beaches and higher dunes offer better protection for the land behind. Despite the use of groynes, sand is currently being washed up along the coast on 13 sections with a total length of 44 km. To maintain this condition, this process must be repeated every few years. In the future, beach nourishments may also be necessary on further sections. Usually the beach is about 40 m wide after a nourishment. However, less or more sand could also be used for nourishment.	Beach width of: 20 m **40 m** 60 m
Dyke heightening (227 km total)		Dykes protect the land behind them from flooding. In order to meet future requirements for coastal protection, dykes are currently being heightened by 50 cm during scheduled maintenance. However, this increase could also be lower or higher.	Height of: 25 cm **50 cm** 75 cm
Access to dunes		The stability of dunes is increased by planting, especially with beach grass. It also acts as a natural sand catcher. Walking on dunes can impair these functions and is therefore not allowed. In selected sections where dunes are of less importance for coastal protection and where this is compatible with nature conservation, access could be allowed in the future. There, dunes would then have to be maintained more comprehensively. This would involve additional costs.	Length of: **0 km** 6 km 15 km 28 km
Protection of cliffs		The sea continuously erodes parts of the cliffs and shifts the coastline. Breakwaters and seawalls can slow down this process. They are currently used in 10 sections where settlements are endangered by the demolition of cliffs. As a result. 15 km of the cliffs are currently fortified. Further sections could be fortified, for example to preserve coastal cycle or hiking paths for a longer period.	Length of: **15 km** 30 km 45 km
Realignment of dykes and dunes		At selected spots along the coast, the protection line (dykes and dunes) could be moved to the hinterland. There, natural bays and wetlands are created which provide habitats for typical coastal animal and plant species. Access to the areas would be restricted and existing cycle and hiking paths would have to be relocated. The safety of settlements would not be endangered at any time. So far, one major realignment has been implemented on the Zingst peninsula (about 15 km^2 or 1500 ha). Similar projects would be conceivable in other parts of the coast.	**1 spot (15 km^2)** 2 spots (30 km^2) 3 spots (45 km^2)
Payment		The existing coastal protection in Germany is financed jointly by the federal government and the coastal states from taxes. For further measures in Mecklenburg-Western Pomerania, a new coastal protection levy would have to be charged per household nationwide from 2021 on. It would have to be paid annually for the next 10 years. After this period, the measures would be reassessed, and a decision would be made on further financing.	**0 €**, 5 / 10 / 15 € (PM) 8 / 20 / 35 / 70 / 110 / 190 € (A_B)

Note: Attribute levels in bold indicate current values.

constant erosion. This may threaten public infrastructure such as cycling and hiking trails along the cliffs. While this natural process cannot be stopped, measures such as breakwaters and bank walls can slow down this process. Currently, efforts to limit cliff erosion are implemented at various sections summing up to 15 km of the coastline. Technically, it would be possible to extend these measures to a total of 30 or 45 km of the coastline.

The fifth attribute considers the *realignment of dykes and dunes* at selected parts. This measure involves actively moving dykes and dunes into the hinterland creating new 'inter-tidal zones' between the sea and land which could be flooded. Doing so, new habitats for typical animal and plant species may arise. Realigning dykes and dunes may also be beneficial for coastal protection as it reduces the technical effort required to maintain the coastline. The realignment, however, does not include withdrawal of houses or settlements, as it is an explicit objective to protect inhabited areas (StALU 2009). So far, one realignment has been carried out on the Zingst peninsula creating a new inter-tidal zone of around 1500 ha. Dykes and dunes could be realigned, as reflected by the attribute levels, at one or two further locations. Finally, the monetary attribute was set up as a new coastal protection levy to be charged annually per household nationwide from 2021 on for the next 10 years. After this period, the measures would be reassessed and a decision would be made on further financing.

The attribute levels were constant for the alternatives *Present measures* and *Present budget* (Figure 1) on all choice tasks except for payment in the alternative *Present measures*. In this case, payment had three levels that were assigned to this alternative via the experimental design. For the two remaining alternatives (*Adaptation A* and *Adaptation B*) all attribute levels were allocated through the experimental design. It is based upon a Bayesian efficient design with uniform priors. Small prior values were employed to indicate the expected sign of the coefficients. For example, a negative sign for the cost coefficient was used. D-efficiency as design criterion was optimised for an MNL model under both random utility maximisation and random regret minimisation with equal weights (van Cranenburgh and Collins 2019). To allow for uncertainty in the prior values, 1000 Sobol draws were taken for each parameter prior. Overall, 48 choice tasks were created and blocked into four sequences of 12 choice tasks each.

The CE was embedded in a nationwide online survey. We informed participants that the funding is for coastal adaptation in the state of MWP. In the introduction to the CE, we also noted that further surveys would be carried out for the remaining coastal areas of Germany. This way, we wanted to point out that this survey is not meant to state preferences for coastal adaptation in other states as MWP. After requesting socio-demographics, which were used for the quota sampling, respondents were asked whether they visited the coast in Germany before the interview and how familiar they are with coastal protection measures. Afterwards, a map of MWP's coast (Figure 1) locating, among others, the current coastal protection measures were shown to all respondents. Measures comprise 227 km of dykes, 43.5 km of nourished beaches, 15 km of fortified cliffs, and the newly created inter-tidal area on the Zingst peninsula.

Next, we introduced the choice scenario by describing past sea-level-rise at the Baltic Sea coast in MWP and referring to the latest projections of the IPCC by 2050. We informed respondents that an increase in extreme weather events, especially storm surges, is expected. Therefore, coastal protection likely has to be increased. To make adjustments, authorities have to decide upon measures already today. It was also highlighted that climate change impacts are associated with a level of uncertainty even for experts.[3] Measures discussed in our application would be implemented gradually by 2050.[4] Respondents could then familiarise themselves with the dimensions of coastal adaptation we examine in this study (Table 1) before they faced the choice tasks. On each task, an opt-out reminder was employed (Ladenburg and Olsen 2014) instructing respondents to choose the zero-price alternative if they find the other alternatives too expensive. The device helps to mitigate the hypothetical bias inherent in stated preference surveys. The questionnaire ended with follow-up questions on attitudes and further requests for socio-demographics.

The finalised version of the survey instrument was implemented in spring 2020 after we administered a pilot study to about 50 individuals. As for the pilot, also the sample for the online survey was drawn from the panel provided by norstat, a company that relies exclusively on active participant recruitment. To get closer to a representation of the target population, we used quotas for age, gender, state of residence, and education. The latter, however, was defined by three broad categories to maintain some flexibility. The invitation to the survey was kept as neutral as possible to reduce the effects of respondent self-selection, i.e. it did not include information about the content.

3. Econometric modelling

Assuming that the researcher does not possess complete information regarding the preferences of individual n, random utility theory (McFadden's 1974) serves as the starting point for the econometric modelling. Accordingly, individual preferences are considered as the sum of a systematic (V) and a random ε component:

$$U_{ni} = V_{ni}(x_{ni}\beta) + \varepsilon_{ni} \tag{1}$$

with U_{ni} the true but unobservable utility associated with alternative i out of a set of available alternatives j, V_{ni} is the deterministic part that is a function of the attributes (x_{ni}) and ε_{ni} an unknown random part. The vector of coefficients (β) reflects the desirability of the attributes. Assuming that the error components are distributed independently and identically (IID) following a type 1 extreme value distribution, one gets the conditional logit (CL) model where the probability of individual n choosing alternative i is:

$$P_{ni} = \frac{\exp(\mu V_{ni})}{\sum_{j\epsilon C}\exp(\mu' V_{nj)}}. \tag{2}$$

The scale parameter μ is commonly normalised to 1. As the CL assumes same preferences across individuals, we additionally apply a latent class (LC) model (Hess 2014). It allows to capture unobserved heterogeneity in taste sensitivities by assuming that a finite number of a priori unknown segments exist in a population, each with different values for taste coefficients β. Using a probabilistic class allocation model, every individual is assumed to belong to each of the classes in the model with a certain probability π_s. This probability lies between 0 and 1 and sums to 1 across all classes. Applying the LC model requires the external specification of the number of classes. The common procedure is to sequentially estimate models with an increasing number of classes $s\ (s = 1, 2, 3, 4, \ldots, S)$ and to select the number of classes using information criteria such as the Bayesian Information Criteria (BIC) but also account for the significance of parameter estimates and the meaningfulness of the parameter signs (Scarpa, Thiene, and Tempesta 2007). To test for potential non-linearities in the attribute levels we applied likelihood-ratio tests.

Changes in welfare due to a marginal change in a given attribute can be expressed through the marginal willingness to pay (mWTP) measure. It is defined as the maximum amount of income an individual is willing to pay in exchange for an improvement in the level of a given attribute provided. In an LC model, the mWTP is calculated separately for each segment s with the class-specific coefficient of the attribute of interest and the class-specific coefficient of the cost attribute representing the marginal utility of income as follows: mWTP $= \beta_{s\_attribute}/\beta_{s\_money}$. Note that we estimate two different cost parameters to capture potentially different cost sensitivities associated with the different alternatives. As non-marginal welfare measure, we calculate the compensating variation for coastal adaptation strategies, i.e. combinations of attribute levels, using weighted WTP measures. It is calculated following Hanemann (1984) as:

$$CS_n = -\frac{1}{\beta \text{cost}_n}\left[\ln \sum_n \exp V_n^1 - \ln \sum_n \exp V_n^0\right], \quad (3)$$

where CS is the compensating surplus welfare measure, β_{cost} is the marginal utility of income and V_n^0 and V_n^1 represents the nth individuals' indirect utility functions before and after the change under consideration.

4. Results

4.1 Sample characteristics

Overall, responses from 1878 individuals aged 18 or above were useable for data analysis. The descriptive statistics for the sample and the target population (Table 2) indicate that respondents are on average slightly younger and the household size slightly bigger compared to the target population of Germany. Net household income per month is on average EUR 438 higher in the sample population, a finding that is not uncommon for online surveys (e.g. Lindhjem and Navrud 2011). For gender and residence in a coastal state (Bremen, Hamburg, Lower Saxony, MWP or Schleswig-Holstein), the sample population resembles the target population. The majority of people (82%) had visited the German Sea coast prior to the survey (Table 2). More than half of the sample had even visited both, the North and the Baltic Sea coast (52%). The figures point out that visiting the German Sea coast is popular among people living in Germany.

4.2 Preferences for coastal adaptation measures

From the CL model results, we can infer that two attributes, dyke heightening and costs, are mainly driving the choices (Table 3). Assuming all respondents have the same preferences, as the CL model does, raising dyke heights is highly positively significant. Respondents are in favour of higher dykes as a measure to adapt to the consequences of climate change. The other non-monetary attributes are not statistically significant at the 5%-level; access to dunes is close, however. Thus, these attributes do not seem to address important aspects to all respondents and hence do not systematically influence the stated choices. Both cost attributes (Payment_PM and Payment_A_B) are highly

Table 2. Descriptive statistics.

	Sample population		Target population (Germany)[a]
	n = 1878		83 Mio. in 2019
Characteristics	mean	std. dev	Mean
Age (years)	48.86	16.46	52.70
Female (%)	50.85		50.70
Higher education (%)[b]	36.94		33.50
Household income[c] (€ per month)	2533.78	1454.10	2155.90
People per household (number)	2.23	1.28	2.00
Resident in a coastal state (%)	17.25		18.10
Residents in MWP (%)	2.10		2.00
Recreational visits to the German Sea coast			
only to the North Sea (% yes)	15.10		
only to the Baltic Sea (% yes)	15.02		
to the North and Baltic Sea (% yes)	51.60		

[a]Data is taken from https://www.destatis.de and https://ec.europa.eu/eurostat (last retrieved September 15, 2020). Average age includes people aged 15 and above. Income refers to the year 2018; Age, education and household size refers to 2019.
[b]Defined as education level that is required to study at a university.
[c]Due to missing disclosures and some implausible responses to this question the statistics for household income are based on 1552 responses within the range of €450 to €10,000.

Table 3. Estimates from conditional (CL) and LC logit model.

	CL		LC					
			Class1		Class2		Class3	
Label			*Dykes*		*Improve*		*No payments*	
	100		39		38		23	
Sample size (in%)	Coeff.	|*z*-val.|	Coeff.	|*z*-val.|	Coeff.	|*z*-val.|	Coeff.	|*z*-val.|
Beach nourishment (per metre)								
40 => 20 m	−0.081	2.14	−0.389	3.71	−0.001	0.01	0.615	2.08
40 => 60 m	−0.035	0.94	−0.350	3.77	0.172	3.24	−0.159	0.56
Dyke heightening (per centimetre)	0.004	6.76	0.006	4.39	0.006	7.97	−0.017	3.93
Access to dunes (yes)	−0.002	1.88	−0.022	6.81	0.017	10.96	−0.032	3.76
Cliff protection (per kilometre)	−0.001	0.75	−0.012	5.01	0.008	6.29	−0.022	3.04
Realignment of dikes and dunes (per spot)								
1 spot => 2 spots	−0.050	1.51	−0.174	2.01	0.267	6.02	−0.720	2.79
1 spot => 3 spots	0.032	1.11	−0.328	3.92	0.445	11.38	−1.197	5.18
Payment_PM (in €)	−0.022	6.05	−0.044	6.04	0.043	5.58	−0.203	11.91
Payment_A_B (in €)	−0.009	29.30	−0.040	20.54	−0.005	13.40	−0.020	5.97
ASC_A	−0.064	1.11	0.352	2.75	1.102	11.11	−1.169	3.09
ASC_B	−0.019	0.32	0.493	3.83	1.117	11.22	−1.250	3.29
ASC_PM	Reference							
ASC_PB	−0.385	6.89	−2.174	16.11	−1.597	11.74	−0.325	0.90

Note: $N = 1878$.

significant and have the expected negative sign. On average, respondents prefer alternatives with lower payments. However, the cost sensitivity is lower for the adaptation alternatives, indicating that respondents who are in favour of these alternatives are willing to pay more. The alternative specific constants (ASC) shown in the lower part of Table 3 separate the alternatives' effects. As a reference, the ASC for the alternative *Present measures* is fixed. The parameter for the alternative *Present budget* (ASC_PB) is negative and highly significant, indicating that on average respondents do not prefer this alternative over the alternative *Present measures* for reasons that are not captured by the attributes. This result suggests that respondents want to keep today's actions even if this is associated with a higher payment.

The LC model, which we use to capture unobserved taste heterogeneity among respondents, provides a more nuanced picture. Testing models with an increasing number of classes, the information criteria indicated that a 3-class segmentation best represents the underlying unobserved taste heterogeneity. In class 1 (named *dykes* group), all parameters are statistically significant but the parameter for *dyke heightening* is the only one with a positive sign.[5] Individuals who are likely to be in class 1 prefer to increase the height of dykes but are unwilling to give up money for a change in any other attribute compared to *Present measures*, the reference alternative. Even extended beaches are not valued positively as a measure to protect the land. An explanation for this might be that those respondents perceive beaches to be more crucial for recreation than for coastal protection. The same reasoning may apply to the attributes *access to dunes* and *cliff protection*.

In the second class, named *improvement* group, the results are different. All attribute parameters are positive and significant, indicating that respondents, who are likely to be in this class, prefer extensive changes compared to the reference situation *Present measures*. Broader beaches, higher dykes, access to dunes, cliff protection on longer sections and more locations where dykes are realigned are preferred. Another distinct group of respondents is specified by class 3 (named *No payments* group). Respondents more likely to belong to this class do not prefer any changes in relation to the reference situation, except for smaller beaches. They even do not choose higher dyke levels if that would entail to give up money. It is worth emphasising that the parameter of ASC_PB,

Table 4. Descriptive statistics across classes.

Label	Class 1 *Dykes*	Class 2 *Improve*	Class 3 *No payment*	
Sample size (in %)	39	38	23	Test of sign. differences[1]
Individual characteristics				
Age (years)[a]	50.14	46.28	51.07	5%
Female (%)[b]	53.50	48.05	51.40	no
Higher education (%)[b]	39.18	39.64	28.43	5%
Household income (€ per month)[a]	2513.47	2679.86	2306.56	5%
Household size[1]	2.18	2.32	2.16	no
Resident in a coastal state (%)[b]	18.33	17.15	15.56	no
Resident in MWP (%)[c]	30.00	37.50	32.50	no
Recreational visits to the German Sea coast				
only to the North Sea (% yes)[b]	14.50	17.15	12.50	10%
only to the Baltic Sea (% yes)[b]	14.91	13.69	17.45	no
to the North and Baltic Sea (% yes)[b]	54.04	53.94	43.39	5%
Perception of climate change				
Climate change already present (% yes)[b]	35.16	33.47	28.30	10%

[a]Kruskal-Wallis test.
[b]Chi-square test.
[c]Note that overall, only 40 respondents are from MWP.

representing the alternative *Presents budget*, has a positive sign for this class. Against the reference alternative *Present measures*, respondents prefer the alternative *Present budget,* as they are not willing to spend more money than they already do today.

To gain further insights into the taste heterogeneity, we characterise each class by reporting descriptive statistics and testing for significant differences. We use common characteristics such as age, gender, income and place of residence in a coastal state, residence in MWP, visits to the North and/or Baltic Sea, and respondent's perceptions of whether the impacts of climate change are already present (Table 4). Starting with the first set of characteristics, respondents assigned to the *Improve* class are on average close to four years younger than those in the other two classes. Gender shares do not differ, but higher education (level required to enter university) and household income. Those in the class *No payments* are less likely to have a higher education degree and the lowest average income. In contrast, those in the class *Improve* have on average the highest income. Household size slightly varies, but differences are not statistically significant. Place of residence in a coastal state in Germany is not associated with class membership. The same is true for residency in MWP. The fact that a respondent has visited the German coast, however, is significant, albeit weakly. The fact that more individuals in the third class had seen only the Baltic Sea might indicate that these people tend to come from the states that belonged to the former GDR. For them, the Baltic Sea was an important holiday destination, but travel distances were of course shorter. Respondents not willing to pay for adaptation have on average visited the coast less frequently. Another considerable difference can be observed regarding whether climate change impacts are already present in Germany. Among respondents in class 3 (*No payments* group), a share of 28% perceive impacts of climate change to be noticeable while the percentage is higher in class 1 and class 2 with 35% and 33%, respectively.

4.3 Willingness to pay for coastal adaptation

The marginal WTP estimates, reported by class and as a weighted average across classes, reflect the preference patterns (Table 5). Increases in dyke height result in positive WTPs in Class 1 and Class 2 with those in the former being substantially lower; confidence intervals do not overlap. Class 3 members would experience clear dis-utilities for attribute levels other than those of the alternative *Present budget*. The weighted average across classes (Table 5, last column) is based only on the statistically significant marginal WTP estimates. It is positive overall due to the marginal estimates of Class 2. As the units of measurement differ, we cannot compare the WTP estimates for marginal

Table 5. Marginal WTP estimates (in €/year/household) by class and weighted average.

Label Sample size (in%)	Class 1 Dykes 39	Class 2 Improve 38	Class 3 No payments 23	Weighted average
Beach nourishment				
40 m => 20 m	−9.75	−0.04	31.10	−3.80
	(−14.60/−4.90)	(−19.20/19.11)	(−1.97/64.17)	(−5.59/−1.91)
40 m => 60 m	−8.77	33.70	−8.03	9.72
	(−13.20/−4.34)	(10.56/56.84)	(−35.38/19.31)	(0.59/18.85)
Dyke heightening	0.15	1.17	−0.84	0.33
(per centimetre)	(0.8/0.21)	(0.82/1.51)	(−1.31/−0.37)	(0.16/0.50)
Access to dunes	−0.55	3.39	−1.62	0.74
(per kilometre)	(−0.74/−0.37)	(2.59/4.18)	(−2.60/−0.63)	(0.37/1.13)
Cliff protection	−0.30	1.58	−1.10	0.25
(per kilometre)	(−0.43/−0.17)	(1.01/2.14)	(−1.86/−0.33)	(−0.02/0.54)
Realignment of dikes and dunes				
1 spot => 2 spots	−4.36	52.43	−36.36	10.75
	(−0.77/−0.05)	(35.14/69.72)	(−67.52/−5.20)	(1.05/20.44)
1 spot => 3 spots	−8.23	87.25	−60.55	17.50
	(−12.69/−3.77)	(66.67/107.83)	(−90.33/−30.77)	(7.04/27.96)

changes directly. For example, the weighted average marginal WTP for an additional metre of beach nourished is €0.18 per household while it is €13.37 per household for one more spot where dikes and dunes are realigned. Comparing our WTP estimates to actual spending would be misleading, as actual expenditure does not take into account the preferences of citizens; rather, the budget is the result of negotiations at the government level. Further, our DCE captures changes in coastal adaptation beyond current measures (status quo). For example, a beach is currently about 40 m wide after nourishment. In the future, beach nourishments may be necessary on additional sections, and more sand may also be needed.

We now turn to non-marginal welfare measures for overall changes. The scenarios *Safety*, *Recreation*, and *Nature* (Table 6) differ at least in one attribute from the current situation (*Present measures*). In Scenario 1 (*Safety*), which focuses on better protection of the land behind, we increase beach widths by 20 m and dyke height by 25 cm compared to today. Scenario 2 (*Recreation*) addresses changes that are associated with the recreational use of the Baltic Sea in MWP. Changes relate to beach width, which is increased to 60 m as in Scenario 1, to access to dunes on stretches of overall 28 km length, and cliff protection on another 30 km of coastline. Finally, Scenario 3 (*Nature*) captures nature protection. Two additional spots where dykes and dunes are realigned would

Table 6. Welfare measure for different adaptation strategies (in €/year/household).

	As today	Scenario 1 *Safety*	Scenario 2 *Recreation*	Scenario 3 *Nature*	Scenario 4 *Maximum*
Beach nourishment (per metre)	40 m	**60 m**	**60 m**	40 m	**60 m**
Dyke heightening (per centimetre)	50 cm	**75 cm**	50 cm	50 cm	**75 cm**
Access to dunes (for access)	no	no	**yes (28 km)**	no	**yes (28 km)**
Cliff protection (per kilometre)	15 km	15 km	**45 km**	15 km	**45 km**
Realignment of dikes and dunes (spots)	1 spot	1 spot	1 spot	**3 spots**	**3 spots**
CS in € per year per household[a]		21.05	43.95	15.09	66.12
		(11.21/30.88)	(18.79/69.11)	(6.57/27.61)	(41.27/90.97)
CS in mio € across households		874	1824	626	2744

Note: Welfare measures were calculated without incorporating marginal WTP estimates for the ASCs. In bold are the highest attribute levels.
[a]In brackets are the 95% confidence intervals.

establish new inter-tidal areas that would serve the conservation of species typical for these habitats. In Scenario 4 (*Maximum*), all attribute levels are at their maximum values.

Note, however, that the assignment of attribute level changes to adaptation scenarios is not unambiguous. Having a more expansive beach, for example, could serve both safety and recreation. Thus, streamlining is used to demonstrate the implications for welfare measures. On another note, welfare measures are calculated without including the ASCs. The literature is not clear on whether they reflect an inherent part of welfare and including them would have increased welfare measures substantially. Thus, a CS of about €44 per household/year for *Recreation* is the highest among the three scenarios, followed by *Safety* (about €21) and *Nature* (about €15). In case all attribute levels are set to their highest levels, the overall welfare gain would on average equal €66.

Aggregating the welfare measures across Germany, we multiply the CS values with the number of households in Germany. At the end of 2019, the total number of households in Germany was about 41.5 million.[6] The 95% confidence intervals calculated for each of the welfare measures partially overlap, indicating that they are statistically not significantly different from each other. When we use the mean estimates for aggregation, however, the absolute differences become meaningful. The welfare effect is most considerable for Scenario 2 *Recreation* that amounts to €1.8 billion. Next, *Safety* follows with €874 million, while *Nature* results in €626 million. Interpreting these measures requires, however, to keep in mind that households with higher incomes are overrepresented. Using as a simple weight the ratio between the mean income in the target population and the mean value for the sample, which results in a value of 0.85, we get a CS per year and household of €17.9, €37.4, €13.7, and €56.3 for the four scenarios in Table 6.

5. Discussion and conclusion

Adaptation to climate change is becoming increasingly crucial for coastal areas. They are often particularly vulnerable to the consequences of climate change, as sea levels continue to rise with more and stronger storm surges. As Gopalakrishnan, Landry, and Smith (2018) point out, there is a long list of unvalued or undervalued coastal amenities and ecosystem services affected by climate change adaptation. Having information on how people assess trade-offs between alternative coastal protection modes thus supports decision making on adaptation strategies. This paper adds to the limited evidence about such trade-offs. We use a CE and focus on adaptation to climate change along the entire coast of MWP, Germany. The trade-offs are conceptualised in the CE in terms of six attributes: the extent of beach nourishment, dyke heightening, cliff protection, access to dunes, realignment of dykes and dunes and cost in terms of a coastal protection levy.

Accounting for taste heterogeneity among respondents identified three preference classes. Respondents in the first class (39% of the sample) are willing to pay for an increase in dyke height but are not ready to give up money for a change in any other attribute. This preference might reflect peoples' understanding of the consequences of climate change-induced sea-level rise, i.e. higher dykes are needed to protect the hinterland. While we vary the height of existing dykes, other studies consider length. Johnston, Makriyannis, and Whelchel (2018) include the attributes dyke length (they name it seawalls) and whether an emphasis is put on large-scale hardening of the shoreline in their CE. Varying height or length are of course two different ways of looking at adjustments of protection measures and preferences may differ accordingly.

Nevertheless, as Matthews, Scarpa, and Marsh (2017a, 2017b) find invariance to scale regarding dyke length, this suggests that some way of comparison may be allowed. In contrast to our and the results by Matthews, Scarpa, and Marsh (2017a, 2017b), Johnston, Makriyannis, and Whelchel (2018) do not find any statistically significant direct WTP for dykes. While Johnston, Makriyannis, and Whelchel (2018) looked at the planning of new dykes, we looked at changes of existing ones which might explain the difference. Of course, apart from differences in survey design, comparability is further limited by varying, among others, site characteristics or sampling design.

Respondents in the second class (38% of the sample) prefer extensive changes including broader beaches, higher dykes, more cliff protection, more realignments of dykes and dunes, and access to dunes. As there are no studies that investigated a similar set of measures, the comparability is limited. Studies focussing on beach size mostly focus on the maintenance of current beaches. Remoundou et al. (2015), for example, frame beach nourishment as an opportunity for recreation while we described wider beaches as an explicit coastal protection measure. Recreational opportunities would result from this as positive side effects. Marzetti and Disegna (2009) include beach nourishment as an artificial defence measure while Landry, Shonkwiler, and Whitehead (2020) compare different measures for coastal erosion management (nourishment, armouring, retreat). Due to their results, realignment ranks highest, followed by nourishment and armouring. Considering agricultural and industrial wasteland, Liski, Koetse, and Metzger (2019) find that respondents value realignment of these areas as an adaptation strategy positively. Both Dachary-Bernard, Rey-Valette, and Rulleau (2018) and Matthews, Scarpa, and Marsh (2017a, 2017b) go a step further and include the realignment of buildings in their studies. So far, the responsible state office of MWP does not consider realignment including the withdrawal of houses or settlements. If climate change progresses at high enough speed, this option might be considered, and it would be interesting to elicit preferences for realignment of inhabited land at the Baltic Sea Coast. In this context, one may argue from a more general perspective that the adaptation options evaluated in our study could be perceived as a short-term response to climate change, especially as it covers rather traditional measures (e.g. dykes and nourishments). These measures work only at the pace of delaying climate change-induced impacts. Against this backdrop, it is worth mentioning that we considered other soft adaptation options to be included in the CE, but, because we got to know that soft and hard measures cannot be applied interchangeably at the coast of MWP at a spot, dismissed the idea.

Respondents in the third class (23% of the sample) are not willing to cover any additional expenses preferring today's budget. Our results are in line with Chen, Swallow, and Yue (2020) who apply an LC model and identify a class of size 28% they label non-participant. Financing coastal protection is a national task in Germany, with 70% of the costs covered by the federal government. Therefore, decision-makers have to provide tax payers across Germany with a reasonable justification for the additional expenditure to be incurred. Interestingly, being an inhabitant of a coastal state does not differ across classes. An explanation for this might be that the Baltic Sea is a famous holiday destination for people across the whole of Germany, and thus people all over Germany feel attached to this coast. The figures show that more than 65% of the people interviewed have been visiting the Baltic Sea at least once.

Aggregating the mean WTP estimates to welfare measures for the whole population, the scenario *Recreation* ranks highest followed by *Safety* and *Nature*. The scenarios, however, do not represent unequivocal alternatives and are used here mainly for demonstration purposes. The CE approach allows combining all attribute levels providing a high degree of flexibility. Decision-makers can therefore compose their scenarios which can then be evaluated. At first glance, especially the aggregated figures seem large. However, the survey design aimed at being conservative by applying an opt-out reminder and explicitly offering the alternatives *Present budget* and *Present measures*, the former requiring no additional payments and the latter lower payments. Thus, we argue that the mean welfare estimates are of a reasonable order of magnitude. That the aggregated numbers are high is due to the large number of households that enter the calculation as we include all households in Germany. This is justified by (a) the current organisation of coastal protection funding and (b) by the high popularity of the Baltic Sea among people in Germany. Still, it needs to be considered that although we aimed at a representative sample of the German population and selected a panel provider that relies exclusively on active participant recruitment, our sample is biased towards more educated respondents and higher levels of income. To our knowledge, this is a problem not only for this study but many surveys relying on online panels. In order to account for this bias, we used a simple weight to adjust the welfare measures.

A further limitation is that the study leaves out sections of the German Sea coast, the Baltic Sea coast in Schleswig-Holstein and the North Sea coast. Not offering comparable adaptation options for the latter may have caused some people to state all their willingness to pay for the Baltic Sea coast in MWP because of the lack of alternatives. This may lead to an overestimation of the true WTP. Anticipating this potential embedding, we informed participants that other surveys would be conducted to record preferences for adaptation at coastal sections in other states. Whether this mitigated or even eliminated embedding can only be assessed in future studies. Another source for overestimating the true WTP could be the sole focus on coastal adaptation. If people would be offered a broad portfolio of adaptation options across Germany, some may state a different WTP for coastal adaptation measures. For example, people living further away from the coast might care more about adapting forests to climate change than coastal protection measures. Whether, and to what extent, we overestimate the actual WTP for coastal adaptation is again a topic for future studies.

Finally, the results suggest that citizens value certain adaptation strategies over other. The present results might therefore be also informative for decision-makers at different coasts at least in Europe. Only benefit transfer tests, however, would clarify to what extent preferences are similar across countries. Investigating this would require surveys about coastal climate adaptation along the coasts of other countries.

Notes

1. See https://ec.europa.eu/environment/iczm/state_coast.htm; last retrieved August 18, 2020.
2. According to the European Environmental Agency, the rise in relative sea level change along most of the European coastline is projected to be reasonably similar to the global average (https://www.eea.europa.eu/data-and-maps/indicators/sea-level-rise-6/assessment; last retrieved August 18, 2020).
3. Please note, that in Germany coastal protection planning by the state government is not based on avoided damage costs. To calculate the dimension of the required protection measures (e.g. dykes), the state government takes the design flood as a basis and adds a climate change extension (e.g. 50 cm for dykes). Although this should be sufficient to account for the uncertainty associated with climate change, we hypothesise that respondents may have preferences for either higher or lower extensions, which may depend on their risk aversion, among other factors.
4. Note that implemented structures may well provide protection after the time considered here. Due to the uncertainty of climate change, it may nevertheless be necessary to consider other adaptation pathways in the future.
5. We tested whether respondents had lexicographic preferences for this attribute. Across the whole sample, no respondent always selected an alternative with always the highest dyke extension level available on the choice task. A few respondents revealed this choice behaviour on 10 out of the 12 choices tasks, but all were willing to make trade-offs on some tasks.
6. Taken from https://www.destatis.de (last retrieved September 15, 2020).

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