Three Essays on the Political Economy of Climate Change

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Dla mojej rodziny

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The thesis consists of the following three single-authored and unpublished contributions:

Rybicki, J. (2021). “The Influence of Migration on Mitigation - A Political Economy Approach”.
Rybicki, J. (2021). “The Political Economy of the German Climate Package and the Commuting Allowance”.
Rybicki, J. (2021). “The Influence of Weather on Climate Change Concerns - Evidence from Germany”.

Chapter 1

Introduction

The extent and complexity of climate change can hardly be described in a few words. However, for a large part of the scientific community, one thing is certain: the need to reduce greenhouse gas emissions quickly. Yet, we are still emitting too much compared to the economically optimal path. This thesis studies the political economy of climate change and contains three essays to understand this so-called emission gap. The emission gap can be analyzed at several levels, and the purpose of this introduction is to explain the levels and which level each essay may be assigned to. First, in Section 1.1, we begin at the global level where we discuss the general difference between the 1.5°C target that was set in the Paris Agreement and the current path. Then, in Section 1.2, we consider a smaller scale and show some examples of public responses to particular policies. Finally, Section 1.3 gives a brief summary for each essay and explains their relationship.

1.1 The 1.5 degrees Celsius target and warming projections

Paris Agreement, Article 2.1a:

"1. This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:
(a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of

climate change;" (United Nations Framework Convention on Climate Change (UNFCCC), 2015)

Even though the 1.5°C target is immutably written into the Paris Agreement, there exists some scientific debate whether the target is economically optimal. W. D. Nordhaus (2017) shows within his integrated assessment model (IAM) DICE[1] that a 3.5°C warming is an efficient target. In contrast, a target below this threshold would imply inefficiently high costs compared to the benefits. However, according to Hänsel et al. (2020), the 1.5°C target is optimal if updated parameters are used in the model. But if this debate is only a reaction to the 1.5°C target, the question arises of how this target was determined. Livingston and Rummukainen (2020) investigate this matter and show that it was first a purely political choice pushed by an alliance of small islands and least developed countries. Only later was it supported by climate scientists.

Nevertheless, only one country, namely The Gambia, is on track to fulfill this target. Most countries, including the European Union[2], head towards a 3°C world (Climate Action Tracker, 2021b). Germany's emission targets were also not compatible with the 1.5°C target. After the German Constitutional Court criticized in a ruling that the burden of reducing emissions had been shifted too far into the future, the government had to update them. Figure 1.1 shows the old and new targets, the current path, and the global least-cost paths, leading to a 1.5°C and 2°C warming, respectively.[3] We see that the current implemented policies and the old national targets for 2030 and 2040 are not enough to limit the warming to 1.5°C. But even the new targets are not optimal. The new target for 2030, which is an emission reduction of 65% compared to 1990, lies above the global least-cost pathway. According to the Climate Action Tracker (2021a) at least 69% would be needed. The new 2040 target and the planned neutrality target are compatible with the 1.5°C target. However, it remains to be determined how these targets will be achieved.

[1] Integrated assessment models extend macroeconomic growth models with climate change components, in most cases, greenhouse gas emission functions, temperature functions, and damage functions. One of the first IAMs, the Dynamic Integrated Climate-Economy model (DICE), was developed by W. Nordhaus (1993). However, those models are often criticized, e.g., for their parameter sensitivity (Pindyck, 2013).

[2] The European Union is treated as one country because the emission reduction goals are more and more delegated to the European Commission.

[3] At the time the report was published, the updated targets were just a proposal. Now, they are already approved by the parliament and the federal states (Bundesregierung, 2021).

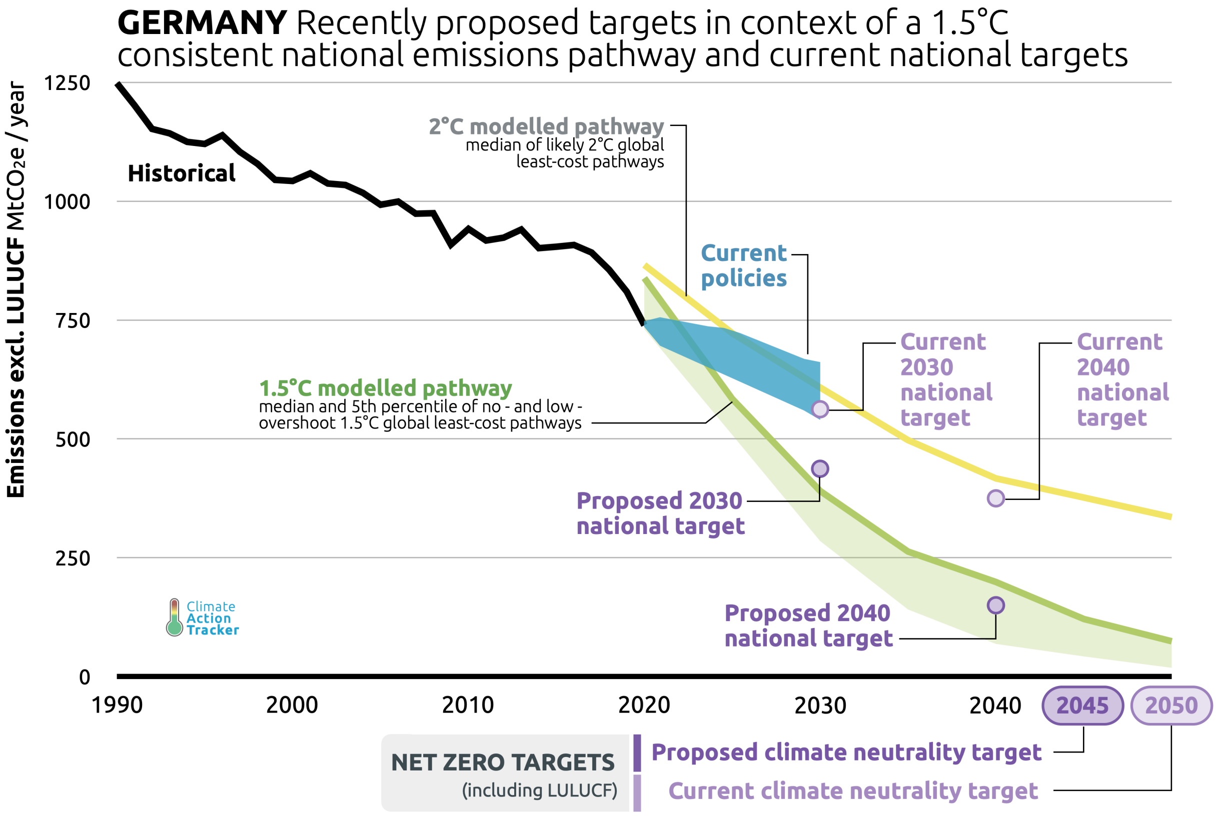

Figure 1.1: Emission pathways for Germany. Source: Climate Action Tracker (2021a)

Moreover, current warming projections show that our global efforts to reduce greenhouse gas emissions are also insufficient (Climate Action Tracker, 2021c). Figure 1.2 presents the global greenhouse gas emissions paths and their associated temperature increase by 2100. We see that the current policies would lead to a temperature increase of about 3°C. Even the existing pledges and targets are not compatible with the 1.5°C target. Therefore, we have to decrease our emissions drastically in the next ten years if we want to achieve this target. With the current increasing temperature pace, we would reach the target in March 2034 (Copernicus Climate Change Service, 2021).

The difference between the target and the current path is one reason for studying the political economy of climate change. From a normative perspective, we saw that there is evidence that the 1.5°C is optimal, but the question remains as to why we are not on track to meet it and what needs to be done to keep pace. Chapter 2 presents one mechanism, namely the substitution between private migration and public mitigation, that may partially explain the difference.

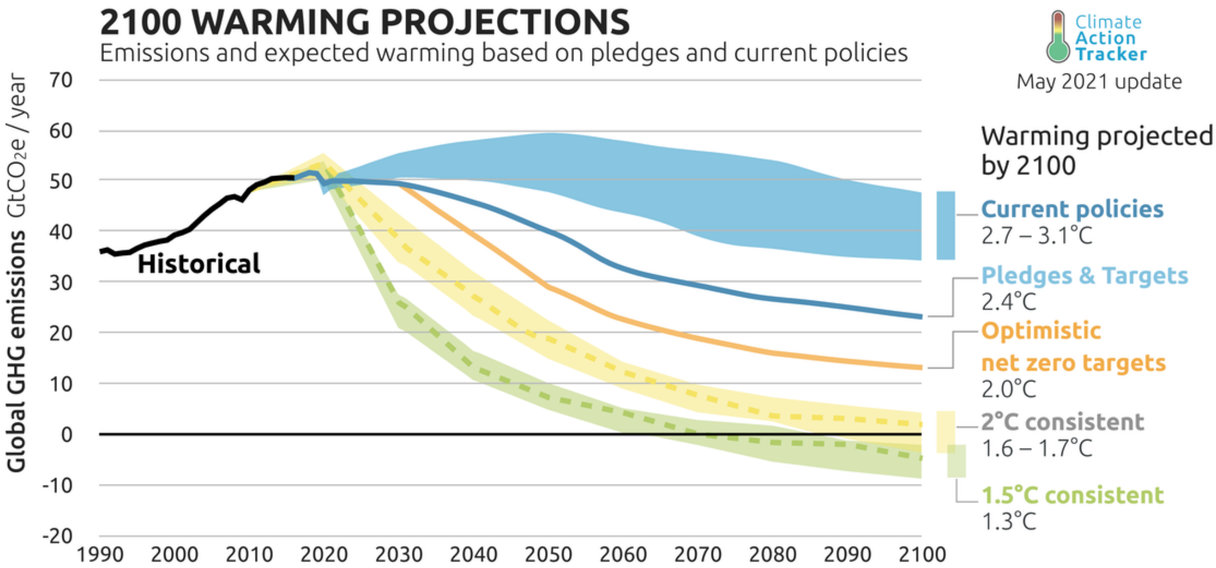

Figure 1.2: Warming projections. Source: Climate Action Tracker (2021c)

1.2 Climate change and the public

As this introduction is being written, the debate on how to combat climate change in Germany is intensifying due to the upcoming parliamentary election. Climate change is an important campaign topic and is in the election program of every party. The Green Party is considered the most competent on this issue (Foschungsgruppe Wahlen e.V., 2019). But opposition to their proposed stricter climate protection measures is growing stronger. For example, they want to raise the carbon price from 55 to 60 euros per ton of CO_2, which would increase the price of gasoline by 16 cents. Together with a proposed speed limit on highways, a heated discussion flared up, and the Greens' poll ratings started to drop (SPIEGEL, 2021). When it comes to car mobility, the public seems to react very sensitively. And this is not only restricted to Germany. Three years earlier, the so-called "Yellow Vests" protested heavily against abolishing the existing tax advantage for diesel fuel in France. There were even violent riots, and President Macron had to make some concessions (Grossman, 2019). We can find an example with even more severe consequences in the election of President Trump in the United States in 2016. During his campaign, he had promised a withdrawal from the Paris Agreement, which most certainly secured him many votes from climate change skeptics and deniers. As president, he then kept that promise (Tollefson, 2017).

At the same time, there are more and more movements calling for stricter action against climate change. Probably the most prominent at the moment is “Fridays For Future”. This student movement, led by Greta Thunberg, began in 2018 by not going to school every Friday to protest for more climate action. According to them, their largest demonstration took place on September 27, 2019, with over 3.7 million people participating in over 2000 cities and 151 countries (Fridays for Future, 2021). One of their arguments is that governments around the world are not doing enough to ensure that global warming does not exceed 1.5°C compared to pre-industrial levels by the end of the century.

While these are only a fraction of all examples of the interaction between public interest, science, and politics, we still get a first glance at the importance of the public influence on climate protection measures. Especially in free countries, no government can enforce strict climate change measures, even if these measures should be highly efficient, without broad public support. Hence, analyzing the political economy of climate change helps us understand how specific laws and measures are introduced while others cannot pass legislation. Furthermore, it may help us to design future measures that are publicly accepted and still efficient. In Chapter 3, an example of a law that could pass legislation, the German Climate Package, is analyzed. However, the public acceptance and legislation of specific laws are only a part of the whole political process. Before that comes the public perception of climate change. If someone is not worried about the consequences of climate change or does not acknowledge anthropogenic climate change, he will not support climate protection measures. Thus, to increase our understanding of the political economy of climate change, we need to understand climate change worries. In Chapter 4, we, therefore, investigate how robust such worries are to daily weather changes.

1.3 Outline and summary

In this section, the relationship between each chapter is presented, and then each chapter is summarized.

1.3.1 Outline

Each chapter covers different parts of the political economy of climate change. In Chapter 2, we study the influence of migration on mitigation from a political economy perspective. We find a problematic mechanism that may lead to a socially inefficient mitigation level and a trapped population. Chapter 3 investigates the political economy of the German Climate Package and the commuting allowance. In contrast to Chapter 2, in Chapter 3, we identify a mechanism that allows the government to implement a higher mitigation level in the form of a carbon tax in the transport sector. Finally, in Chapter 4, we study the influence of weather on climate change concerns. One may ask how this is related to the political economy of climate change. However, we argue that climate change concerns can be seen as a proxy for the support of protection measures. If someone is very concerned about the consequences of climate change, it is more likely that he will support stricter climate protection laws. Compared to Chapters 2 and 3, where we use a partial equilibrium model within a political economy framework, in Chapter 4, we use German survey data to examine this question empirically. The following sections provide a summary of each chapter.

1.3.2 The influence of migration on mitigation

Chapter 2 presents the first essay, "The Influence of Migration on Mitigation - A Political Economy Approach." Migration is becoming an increasingly important issue for climate scientists because it has various political and economic consequences. However, for most governments of developed countries, climate change-induced migration was not an important issue. For the European Union, this view began to change with the migration crisis in 2015. The situation drew public attention to the whole migration context, and people began to look for possible causes. And one of these possible causes that naturally come to mind is climate change. An article that strengthened the idea of climate change as a cause for this crisis and therefore got much attention was published by Kelley et al. (2015). The authors found evidence that a preceding drought between 2007 and 2010, which can be attributed to anthropogenic climate change, consequently played an important role in the Syrian Civil War. While this specific result is challenged by Selby et al. (2017), Abel et al. (2019) find evidence for this link between climate change-driven disasters, violent conflicts, and migration.

In Chapter 2, the focus lies on the relationship between climate change and migration that goes in the other direction, namely the influence of migration on the shape of climate change mitigation. To demonstrate this relationship, we use a political economy model in which people living in a flood-prone coastal region have a choice to move away and/or invest in climate change mitigation. The decision to move away is private, while the level of mitigation is determined by majority voting and comes before the migration decision. Individuals have low or high incomes in the model and live close to the coast or far away from it. One finding is that the migration option decreases the preferred level of mitigation both in the social planner's solution and in the political equilibrium. This result is in line with the literature which finds that private adaptation can substitute public mitigation. However, another result is that migration may create a trap for low-income individuals, which may have important consequences for countries like China or Bangladesh, where coastal zones are densely populated.

This chapter contributes to three strands of literature: the interaction between mitigation and adaptation, the political economy of environmental regulations, and the economics of climate change-driven migration.

First, to study the interaction between mitigation and adaptation, many researchers use the earlier mentioned integrated assessment models (Agrawala et al., 2011; Bosello et al., 2010; de Bruin and Dellink, 2011; de Bruin et al., 2009; Tol, 2007). With these models, the researchers can analyze the optimal path of adaptation and mitigation. However, this is not the only way to study the interaction. There are also other approaches, like using game theory (Buob and Stephan, 2011), an endogenous risk model (Kane and Shogren, 2000), or even experiments with public good games (Hasson et al., 2010). This chapter contributes to this strand by modeling and analyzing the interaction within a political economy framework. We do not only acknowledge the difference in the investment type, as adaption is in most cases private, while mitigation is a public investment choice, but also show the political consequences of this difference.

Second, the chapter also contributes to the political economy of environmental regulations. This strand started by looking at the influence of lobbies that want direct regulations as market barrier (Buchanan and Tullock, 1975). In more recent articles, a competitive economy setting is used, where each lobby tries to influence the government with campaign contributions to their benefit (Aidt, 1998; Damania, 1999; Fredriksson, 1997). Habla and Roeder (2013, 2017) and Ono (2005) use overlapping generations model to study the political economy of environmental taxes. Our contribution to this strand of literature is to incorporate migration as a private adaptation measure into a political economy model where climate change mitigation is determined by majority voting. To the best of our knowledge, this is the first attempt to combine a politically determined mitigation level with a private adaption measure.

The third and last strand that Chapter 2 contributes to is about the economics of climate change-driven migration. There are many empirical articles that study the influence of natural disasters on internal and international migration (Beine and Parsons, 2015; Cattaneo and Peri, 2016; Coniglio and Pesce, 2015; Drabo and Mbaye, 2015; Gray and Mueller, 2012; Marchiori et al., 2012). One of the few theoretical contributions is made by Mason (2017) who uses a dynamic model. We contribute to this strand by modeling migration explicitly as a protection measure. Our model also shows the possibility of trapped populations, which is in line with Foresight (2011).

1.3.3 The German climate package and the commuting allowance

Chapter 3 covers the second essay "The Political Economy of the German Climate Package and the Commuting Allowance". In Germany, several subsidies in the transport sector are, at least from a purely environmental perspective, problematic (Umweltbundesamt, 2016). For example, diesel has a lower energy tax rate than gasoline despite having a higher carbon share per liter and a higher emission of nitrogen oxides during combustion. To compensate for this advantage, the vehicle tax for cars with a diesel engine is higher. However, the vehicle tax is independent of the mileage, and thus diesel cars are especially attractive for those who drive the most. Another example that is mentioned by the Umweltbundesamt (2016) is the commuting tax allowance. In Germany, one-way travel between home and work is tax-deductible. Until 2021, the rate was 30 cents per kilometer for everyone, but now it is 30 cents for a distance below 21 km and 35 cents for a distance above or equal to 21km. This increase was introduced to compensate long-distance commuters for higher fuel prices due to the new carbon tax in the transport sector that was introduced with the Climate Package. Tax revenues from the new carbon tax are used to fund the increase in the commuting allowance. In this chapter, we want to show how this linkage between commuting allowance and carbon tax can be a political equilibrium even though it benefits only a minority.

We use a political economy framework where individuals have different incomes and either do not commute to work or commute a short or long distance by car. A fuel tax[4] is introduced to correct a negative externality that comes with commuting. The tax rate is determined by majority voting in a second voting stage. In the first stage, individuals decide whether to use the revenues from the fuel tax to introduce lump-sum transfers or increase an existing commuting allowance. We show that a political equilibrium exists where the fuel tax revenues are completely used to increase the commuting allowance despite being only beneficial to the long-distance commuters. This result is possible because the group that does not commute uses the higher commuting allowance to induce the long-distance commuters to vote for a higher fuel tax.

The chapter contributes to two strands of literature. The first one is the political economy of commuting subsidies. Important contributions in this area are made by Borck and Wrede (2005, 2008), who use a monocentric city model to explain the emergence of commuting subsidies. We contribute to this strand by finding a new cause for the existence of commuting subsidies. In our model, the commuting subsidy may be introduced to gain the long-distance commuters' support for higher carbon taxes.

The second strand is one that is already mentioned in the previous section, namely the political economy of environmental regulations, and more specific the political economy of environmental taxes. Again, Aidt (1998), Damania (1999), and Fredriksson (1997) and their analysis of lobby influence have to be mentioned here. Cremer et al. (2004a,b, 2008) study the political economy of environmental taxes where a heterogeneity in labor and capital income is the main driving force in their political economy model. Our contribution to this strand is to show how the redistribution of tax revenues to a minority can be used to increase the tax rate in the political equilibrium.

1.3.4 Weather effects on climate change concerns

In Chapter 4, the last essay, "The Influence of Weather on Climate Change Concerns - Evidence from Germany", is presented. As mentioned earlier, the public debate is getting increasingly heated. But before someone supports any law that targets climate change, he has to believe in anthropogenic climate change, and even if he believes in it, he must be worried about the consequences. Therefore, acknowledging man-made climate change

[4]In our model, we consider commuting as sole energy good and therefore use the term fuel tax instead of carbon tax.

and worrying about it are necessary conditions to support climate laws.

To study the influence of weather on climate change concerns, we use the German Socio-Economic Panel (SOEP) and merge it with daily weather data from the German Meteorological Office. To control for unobserved individual heterogeneity, we employ an individual fixed effects model. Moreover, we include all relevant weather variables instead of just temperature since using only one variable could lead to an omitted variable bias. We can reject the hypothesis that weather has no effect on climate change concerns at the 5% significance level and find significant positive effects for precipitation and negative effects for temperature and humidity. However, while being statistically significant, from an economic and political perspective, the effects are rather small.

This chapter contributes mainly to the literature on weather effects on climate change concerns. Bergquist and Warshaw (2019), Brooks et al. (2014), Egan and Mullin (2012), Hamilton and Stampone (2013), Joireman et al. (2010), Potoski et al. (2015), and Zaval et al. (2014) investigate whether temperature influences climate change concerns or beliefs. Demski et al. (2017), Frondel et al. (2017), Konisky et al. (2016), and Palm et al. (2017) use experienced weather extremes like storms, floods or heatwaves as independent variable.[5] Compared to those studies, we have the advantage of using a large representative survey with repeated observations. Thus, we can employ panel techniques to eliminate unobserved time-constant individual heterogeneity.

[5] Notice that the concepts of believing and worrying are often used similarly. This is not entirely precise since someone could believe in anthropogenic climate change but not worry about it. The reason for doing so is that most studies in the U.S. cover climate change beliefs, while studies from other countries rather use climate change worries. In our study, we use climate change worries as the main dependent variable.

Chapter 2

The Influence of Migration on Mitigation - A Political Economy Approach

2.1 Introduction

14.7 million people had to leave their homes in 2015 due to weather-related hazards. Among these were 8.3 million migrants who had to relocate because of floods (Bilak et al., 2016). While those numbers were already high, they will be probably even higher due to climate change and in particular, to rising sea levels. In its forecast, the Intergovernmental Panel on Climate Change (IPCC) has projected that the global mean sea level will rise between 0.26 and 0.98 meters by 2081 - 2100 compared to 1986 - 2005.[1] Another problem for coastal zones is land subsidence, which amplifies the effects of a rising sea level. Large delta cities are especially affected by this as they extract a lot of groundwater, which leads to decreasing groundwater levels and therefore to land subsidence. For example, Tokyo's mean cumulative subsidence was 4.250 m between 1900-2013 (see Erkens et al., 2015). If all the factors such as rising sea levels, land subsidence, and growing coastal cities are taken together, it is reasonable to expect rising migration numbers in the future. To get an idea of how many people could be affected, Strauss et al. (2015) look into the very long run effects of rising sea levels. They use the final sea level rise that could occur under different warming scenarios and investigate how many people would be affected if this sea level rise were to happen today. Under a four degree Celsius warming scenario, they find that 470 to 760 million people of today's population would be affected. Furthermore,

[1] Here, 0.26 m is the lower bound of the 95% confidence interval for the low emission scenario while 0.98 m is the upper bound of the 95% confidence interval for the high emission scenario (see Church et al., 2013).

developing countries will particularly suffer. For example, with a one-meter sea level rise around 5% of Vietnam's land area would be inundated. Almost 11% of the population live in this area and around 10% of Vietnam's GDP is obtained there (see Dasgupta et al., 2009).[2]

Despite the facts mentioned above, migration has been neglected in environmental policy analysis. At first, only mitigation, which mostly consists of emission reduction, was considered as a possible instrument to fight climate change. There were several reasons why adaptive measures, such as building dikes, were not the first choice. One reason was that for some decision-makers, adaptation would look like surrendering to the climate change (see Parry et al., 1998). This view has been changing since the 1980s (see Schipper, 2006). Migration, however, was not accepted as a possible adaptation measure because only the negative consequences were acknowledged. Recently, scientists have been arguing that this point of view could be a mistake; see, e.g. Black et al. (2011). The Foresight (2011) Report studies the effects of environmental changes on migration and concludes that policy makers have to examine the positive and negative aspects of migration. Preventing migration could worsen the situation because people could get trapped in risk zones.

This chapter will not discuss whether climate change-driven migration is positive or negative but will study the influence that the mere option to migrate could have on the political outcome regarding climate change mitigation. The argument goes as follows. People consider moving away in order to reduce their expected damage from climate change. If they keep this migration option in mind, it changes the preferred level for protective measures for every individual. They do not want this much protection any more or at least not as much as without a relocation option.

To analyze the effect, we use a political economy model and compare the outcome from this model with a utilitarian social planner's solution. The focus lies on a coastal region where individuals face a flood risk, that lowers their utility through a damage function. We assume that the damage decreases with the distance to the sea and that it is proportional to income. The inhabitants differ in their income and their location. In the first stage, individuals vote on the mitigation level which will be decided by the median voter and has an effect on the flood probability. This mitigation effort is financed through proportional income taxation. Furthermore, individuals have the option to move away

[2]For a general overview of which countries could be affected the most, see Table 2.A.1 in the Appendix.

which is associated with variable and fixed relocation costs. Individuals are rational and maximize their utility at each stage.

Regarding mitigation, we find that the option to move away decreases the median voter's mitigation level. The reason for this lies in the different marginal benefit of mitigation if individuals acknowledge their moving option. Furthermore, we find that the median voter's preferred mitigation level without migration is lower than the social planner's mitigation level without migration if the majority of individuals live far enough from the coast. This is the case because the social planner maximizes the weighted sum of all utility functions. Hence, he considers the average location, which is closer than the median. Inequalities in income levels, on the other hand, do not matter since both expected damage and taxes are income proportional.

With migration, the general comparison is not clear because differences in income levels lead to different preferred locations to where individuals want to migrate. These preferred locations determine the expected damage and therefore the marginal benefit of mitigation. Conditional on the population distribution, it is possible that some groups have a higher marginal benefit of mitigation and others a lower one compared to the median voter. It then depends on which group has a stronger effect on the sum of all utilities if the social planner's solution is less than, equal to, or greater than the median voter's solution. However, if we assume that a majority lives so far away from the coast that they face no flood risk, we get a political outcome with no mitigation at all. We show that this cannot be a socially efficient solution. Another result of this model is the formation of poverty traps. Especially, high fixed costs can create a situation where low-income individuals close to the coast do not move away while high-income individuals do. Combined with a political situation where the trapped population is a minority and the mitigation level is lower than in the social optimum, a dangerous poverty trap could be created.

This chapter contributes to three strands of literature. The first strand is about the interaction between adaptation and mitigation. The IPCC devoted a whole chapter to this topic (see Klein et al., 2007). From a macroeconomic perspective, Tol (2007) studies how the impacts of a rising sea level can be influenced through adaptation and mitigation. He uses an integrated assessment model (IAM)[3] for this reason and concludes that the

[3]These models are typically standard growth models which are extended with a greenhouse gas emission function, a temperature function, and a damage function. A critical review has been done by Pindyck (2013).

benefits of adaptation regarding sea level rise exceed the costs many times over. Agrawala et al. (2011), de Bruin et al. (2009), de Bruin and Dellink (2011) and Bosello et al. (2010) also use IAMs to study the interactions between the two instruments. Kane and Shogren (2000) analyze the link between adaptation and mitigation within an endogenous risk model. The authors show that there can be interior solutions as well, i.e. a mix between adaptation and mitigation, as corner solutions, where there is either only adaptation or mitigation. Buob and Stephan (2011) explore the strategic interaction between the two instruments in a non-cooperative game. Bréchet et al. (2016) look into both cooperative and non-cooperative strategies on a macroeconomics level. Ingham et al. (2007) and Zemel (2015) incorporate uncertainty effects into their analyses. Hasson et al. (2010) use a public good experiment to study the link between adaptation and mitigation. In our model, we analyze the interaction between migration, which is an adaptation instrument and mitigation. Compared to the other contributions in this area, we model migration and therefore adaptation as a private choice, where different levels of adaptation are chosen by different individuals. As far as we know, this is the first attempt to create such a model.

The second strand is about the political economy of environmental protection and climate change. A good amount of literature on the economics of climate change concentrates on environmental regulation, and a lot of research has been done to find efficient regulation instruments from a normative perspective. However, in reality, we see that these instruments, like Pigouvian taxation, are often not implemented or at least not the way they were supposed to (see Oates and Portney, 2003). An early contribution to this strand of literature is Buchanan and Tullock (1975). They argue that firms prefer rather direct regulation than environmental taxation because these regulations can be seen as barriers to entry. Fredriksson (1997), Aidt (1998) and Damania (1999) also investigate the influence of lobby groups on the shape of environmental regulation. Fredriksson and Svensson (2003) study the effects of political stability and corruption on environmental policies. Habla and Roeder (2013, 2017) and Ono (2005) analyze the political economy of mitigation by means of an overlapping generations model. A model which looks at the political economy of adaptation instead of mitigation is provided by Anbarci et al. (2005). They investigate how a country's income inequality and its per capita level of income can affect the number of fatalities during an earthquake. Our contribution to this strand of literature is to look into migration as a possible factor that can alter the political outcome. Since migration numbers are expected to rise, the effect of migration on the political economy of climate change should not be neglected.

The third strand looks into the economics of climate change-driven migration. Most articles are empirical studies that try to identify a causal link between extreme weather anomalies and migration. Cattaneo and Peri (2016) use data from 115 countries between the years 1960 and 2000 to study the effect of increasing temperatures on internal and international migration. For middle-income countries, they find that higher temperatures lead to more migration within a country and more emigration to other countries. For poor countries, on the other hand, they show a negative influence on both migration types. Drabo and Mbaye (2015), Coniglio and Pesce (2015), Beine and Parsons (2015), Marchiori et al. (2012), and Gray and Mueller (2012) show direct and indirect effects from different natural disasters on internal and international migration in different regions. While most of the literature finds some evidence on climate change-induced migration, Chen et al. (2017) find negative effects of floods on migration in Bangladesh, which means that the probability of migration decreases after a flood. One explanation for this result is a possible entrapment situation where people can not afford to move away. The literature mentioned so far studies the link between climate change and migration. Mason (2017), however, uses a dynamic model to investigate the effect of migration on the greenhouse gas emission path. He finds that migration works like an additional ecotax, providing an incentive for more mitigation. This chapter contributes to this strand of literature by modeling migration within a country where we distinguish between high- and low-income individuals and consider an entrapment situation.

This chapter is structured as follows. Section 2.2 explains the model environment. In Section 2.3, we derive the social optimum, and in Section 2.4 we study the political process. In Section 2.5, changes to the model environment are being discussed. Section 2.6 concludes the chapter.

2.2 The model

Consider a coastal region where individuals with different income y_i and different initial locations $\hat{x}_j$ are exposed to a flood risk. $\hat{x}_j$ is the distance between the sea and the location where they live at the beginning. For better tractability, we assume that individuals live only at two locations at the beginning, namely far (f) and close (c) to the sea, and belong to two income types. Thus, they have a low income y_l or a high income y_h and as initial locations, $\hat{x}_j = \hat{x}_f$ or $\hat{x}_j = \hat{x}_c$. The population mass is normalized to one and the fractions of every type are shown in the following table, where $\theta_l + \theta_h = 1$, and $\lambda_c + \lambda_f = 1$. Furthermore, we assume a right skewed income distribution which implies that the median income y_m is lower than the average income $\bar{y}$. For our two income types, this means that $\theta_h < 0.5$, and $\theta_l > 0.5$.

		Distance		
		close $\hat{x}_c$	far $\hat{x}_f$	Σ
Income	high y_h	$\theta_h \lambda_c$	$\theta_h \lambda_f$	$\theta_h < 0.5$
	low y_l	$\theta_l \lambda_c$	$\theta_l \lambda_f$	$\theta_l > 0.5$
	Σ	λ_c	λ_f	1

Table 2.1: Distribution for the four types of individuals

The probability of a flood is represented by π and is assumed to be independent of the location. This is the probability of occurrence. The damage that is done by the flood is represented by $\alpha(\hat{x}_j)$. It is assumed that the damage is higher the closer the location is to the sea $(\alpha(\hat{x}_c) > \alpha(\hat{x}_f))$. Individual ij's expected damage is given by $L_{ij} = \alpha(\hat{x}_j)\pi y_i$ so that we have an income proportional loss. In the case with just four types, the loss ranking is $L_{ic} > L_{if}$ and $L_{hj} > L_{lj}$.

To protect themselves from the flood, the inhabitants of the coastal region have two options. The first one is climate change mitigation. The mitigation level is represented by M. One can think of afforestation or investing in new green technology that reduces greenhouse gas emissions as types of mitigation. This effort is associated with costs $C_M(M)$ and is financed by a linear income tax τ.[4] It is assumed that this measure can slow down rising sea levels, which leads to a lower flood probability π compared to a situation with no mitigation, and we suppose a diminishing effect. We can formalize this as

$$\frac{\partial \pi(M)}{\partial M} < 0 \text{ and } \frac{\partial^2 \pi(M)}{\partial M^2} > 0. \tag{2.1}$$

It is a political choice, so the median voter will decide about the level that is finally introduced.

[4] We assume convex costs; hence $\partial C_M(M)/\partial M > 0,$ and $\partial^2 C_M(M)/\partial M^2 > 0$.

The second option for protection is migration. People can move away to reduce their expected flood damage. This is associated with total relocation costs $T(x) = t(x - \hat{x}_j)^2 + F$, where t is a variable cost parameter, F are fixed costs, and x is the new location of choice. If individuals decide not to move, fixed costs F do not have to be paid, and $T(x = x_j) = 0$. Furthermore, it is assumed that the positive effect of moving away diminishes until it becomes zero at the location x_{max}. We can formalize this protection measure as

$$\frac{\partial \alpha(x)}{\partial x} < 0, \ \frac{\partial^2 \alpha(x)}{\partial x^2} > 0 \text{ and } \alpha(x_{max}) = 0. \tag{2.2}$$

The reason why we use a damage function with two components is that adaptation and mitigation reduce the expected damage differently. The Intergovernmental Panel on Climate Change (IPCC) (2014) defines mitigation as "*[a] human intervention to reduce the sources or enhance the sinks of greenhouse gases (...)*" while adaptation is defined as "*[t]he process of adjustment to actual or expected climate and its effects.*" This means that mitigation lowers the probability that the damage will occur while adaptation lowers the damage but will not change the probability.

The expected utility function for each individual is

$$U_{ij} = (1 - \tau)y_i - t(x - \hat{x}_j)^2 - F - \alpha(x)\pi(M)y_i, \tag{2.3}$$

where the first term is an individual's net income.

The decision process is as follows. First, there is a vote on the optimal mitigation level, and the median voter decides what amount of mitigation is implemented. Then, the location choice is carried out. Since individuals anticipate their optimal location choice in the voting stage, we have to use backwards induction to determine every individual's optimal choice.

2.2.1 Relocation choice

In order to obtain the indirect utility functions, we need to determine individual ij's optimal location choice. Individuals take the mitigation level as given and consider moving away to a safer location that is farther away from the coast. Since moving away is not only associated with variable costs but also fixed costs, individuals have to decide at first if choosing any $\triangle x_j = x - \hat{x}_j > 0$ is better than choosing $\triangle x_j = 0$. This is the extensive margin. On the intensive margin, they maximize their utility function in order to get the optimal location decision x_{ij}.

2.2.1.1 Intensive margin

We begin with analyzing the intensive margin of the relocation choice. The following utility function is maximized with respect to x:

$$\max_{x \in [\hat{x}_j, x_{max}]} U_{ij} = (1-\tau)y_i - t(x - \hat{x}_j)^2 - F - \alpha(x)\pi(M)y_i. \tag{2.4}$$

The first-order condition is given by

$$-\frac{\partial \alpha(x)}{\partial x}\pi(M)y_i = 2t(x - \hat{x}_j). \tag{2.5}$$

The left-hand side (LHS) of Equation (2.5) represents the marginal benefit, which is the damage reduction from moving one unit farther away. The right-hand side (RHS) shows the additional costs of moving one unit farther away from the original location. Let x_{ij} be the optimal location for individual ij.[5]

To analyze the effect of mitigation on the location decision, we can use the implicit function theorem, which gives us

$$\frac{\partial x_{ij}}{\partial M} = \frac{1}{SOC_{x_{ij}}} \frac{\partial \alpha(x_{ij})}{\partial x_{ij}} \frac{\partial \pi(M)}{\partial M} y_i < 0. \tag{2.6}$$

The denominator is negative since it is the second-order condition regarding the optimal location. Because the damage decreases in the distance to the sea and the flood probability is smaller with a higher mitigation level, the numerator must be greater than zero. Hence, individual ij's optimal location decreases with more mitigation. The effect of relocation costs on the migration decision is given by

$$\frac{\partial x_{ij}}{\partial t} = \frac{2(x_{ij} - \hat{x}_j)}{SOC_{x_{ij}}} < 0, \tag{2.7}$$

which implies that higher relocation costs reduce the migration distance. We summarize

[5]The second-order condition holds. See Appendix 2.A.2.

both findings in the following lemma.

Lemma 2.1 (Influence of mitigation and relocation costs on the location choice)

i) A higher mitigation level M leads to a optimal choice of x_{ij}, which is closer to the sea.

ii) Higher relocation costs have a negative effect on x_{ij}.

2.2.1.2 Preference ranking

In the following, we will examine the location choices of our four individual types. This is important for the mitigation stage where the median voter needs to be determined. Taking the derivatives of x_{ij} and the moving distance $\triangle x_{ij} = x_{ij} - \hat{x}_j$ with respect to y_i yields

$$\frac{\partial x_{ij}}{\partial y_i} = \frac{\partial \triangle x_{ij}}{\partial y_i} = \frac{1}{SOC_{x_{ij}}} \frac{\partial \alpha(x_{ij})}{\partial x_{ij}} \pi(M) > 0. \tag{2.8}$$

We see that income has a positive influence on migration, which means that a high-income individual will move farther away than a low-income type. Intuitively, it can be explained by looking at Equation (2.5). Since income is part of the marginal benefit but not of the the marginal costs, someone with a higher income has a higher marginal benefit but the same marginal costs.

Now, regarding the comparison between the two original location types, we take the derivatives of x_{ij} and $\triangle x_{ij}$ with respect to $\hat{x}_j$ and get

$$\frac{\partial x_{ij}}{\partial \hat{x}_j} = \frac{-2t}{SOC_{x_{ij}}} \in (0,1), \tag{2.9}$$

$$\frac{\partial \triangle x_{ij}}{\partial \hat{x}_j} = \frac{-2t}{SOC_{x_{ij}}} - 1 < 0. \tag{2.10}$$

Equation (2.9) has also a positive sign, which means that, for a given income, the optimal location increases with the original distance to the sea.[6]

In Equation (2.10), we see that the distance that someone is moving away is decreasing with the original distance to the sea. The reason for this is that the individual that lives

[6] It lies between zero and one because $SOC_{x_{ij}} = -\partial^2 \alpha(x_{ij})/\partial x_{ij}^2 \pi(M) y_i - 2t < -2t < 0$.

closer to the coast has a higher benefit of moving away than the one that lives farther away. Finally, the following comparisons can be made:

$$\triangle x_h > \triangle x_l \text{ and } \triangle x_c > \triangle x_f \tag{2.11}$$

$$x_h > x_l \text{ and } x_c < x_f. \tag{2.12}$$

With the information from (2.11) and (2.12), we can then establish two possible rankings:

$$x_{lc} < x_{hc} < x_{lf} < x_{hf} \tag{2.13}$$

$$x_{lc} < x_{lf} \leq x_{hc} < x_{hf} \tag{2.14}$$

We have two rankings because the comparison between x_{lf} and x_{hc} is not clear. It is possible that the high-income group that originally lives close to the coast moves farther away than the low-income group that already lives far away from the coast. This situation becomes more likely the greater the difference in income is $(y_h - y_l)$ and the closer both types originally live together $(\hat{x}_f - \hat{x}_c)$. We consider both situations.

2.2.1.3 Extensive margin

In this section, we analyze the extensive margin where individuals decide if moving to their preferred location is better than not moving at all. They compare their utility where $x = x_{ij}$ with the utility where $x = \hat{x}_j$. If $U_{ij}(x_{ij}) \geq U_{ij}(\hat{x}_j)$ their optimal location is x_{ij}. Otherwise, they stay at their original location $\hat{x}_j$. Note that without fixed costs, it is always beneficial to move. This can be easily verified by inserting $x = \hat{x}_j$ into the first-order condition (Equation (2.5)).

We compute the critical value for the fixed costs where someone is indifferent between moving and staying, using the following equation:

$$\widetilde{F}_{ij}(M, t, y_i, \hat{x}_j) = \pi(M) y_i (\alpha(\hat{x}_j) - \alpha(x_{ij})) - t(x_{ij} - \hat{x}_j)^2 = 0. \tag{2.15}$$

Since the critical level depends on $\hat{x}_j$ and y_i, every individual has his own critical fixed costs value which is therefore subscripted by ij. Whenever fixed costs F are above $\widetilde{F}_{ij}$, it is not optimal to move away.

In the following, we will examine some comparative statics that are especially relevant for the poverty trap discussion. The influence of the variable relocation costs t on the critical level of fixed costs are given by

$$\frac{\partial \widetilde{F}_{ij}}{\partial t} = -(x_{ij} - \hat{x}_j)^2 < 0. \tag{2.16}$$

Not surprisingly, higher relocation costs lead to lower critical fixed costs, which implies that ceteris paribus, fewer people will move away. The effect of mitigation on the critical value is given by

$$\frac{\partial \widetilde{F}_{ij}}{\partial M} = \frac{\partial \pi(M)}{\partial M} y_i(\alpha(\hat{x}_j) - \alpha(x_{ij})) < 0. \tag{2.17}$$

We see decreasing critical fixed costs with higher mitigation levels. The explanation for this result is that a higher mitigation level reduces the benefit of moving. The following two equations show the effect of the heterogeneity variables on $\widetilde{F}_{ij}$:

$$\frac{\partial \widetilde{F}_{ij}}{\partial \hat{x}_j} = \pi(M) y_i \frac{\partial \alpha(\hat{x}_j)}{\partial \hat{x}_j} + 2t(x_{ij} - \hat{x}_j) < 0, \tag{2.18}$$

$$\frac{\partial \widetilde{F}_{ij}}{\partial y_i} = \pi(M)(\alpha(\hat{x}_j) - \alpha(x_{ij})) > 0. \tag{2.19}$$

We see a negative effect for $\hat{x}_j$[7] and a positive one for y_i.

In order to get clear preference rankings at the mitigation stage, we assume that $F = 0$ so that $\widetilde{F}_{ij} > F = 0$. Hence, moving is always the better choice. When we discuss the poverty trap problem, we relax this assumption. In the following section, we derive the economic equilibrium before we proceed to the social planner's solution and the political equilibrium.

2.2.2 Economic equilibrium

An economic equilibrium is characterized by a balanced public budget. The government collects income taxes and invests its funds into mitigation. Hence, the government's

[7] The sign is negative because $\partial\alpha(\hat{x}_j)/\partial\hat{x}_j < \partial\alpha(x_{ij})/\partial x_{ij}$, and therefore Equation (2.18) is less than the first-order condition (Equation (2.5)).

budget constraint is

$$\sum_i \theta_i y_i \tau = C_M(M) \Rightarrow \ \tau(M) = \frac{C_M(M)}{\sum_i \theta_i y_i} = \frac{C_M(M)}{\bar{y}}.$$

One can see immediately that more mitigation leads to a higher tax rate, so that

$$\frac{\partial \tau(M)}{\partial M} = \frac{\frac{\partial C_M(M)}{\partial M}}{\bar{y}} > 0. \tag{2.20}$$

By substituting (2.20) and the optimal location choice x_{ij} into (2.3), we obtain individual ij's indirect utility function

$$V_{ij}(M) = (1 - \tau(M))y_i - t(x_{ij} - \hat{x}_j)^2 - F - \alpha(x_{ij})\pi(M)y_i, \tag{2.21}$$

where an individual takes into account that the mitigation level M has an impact on his tax rate and on his relocation choice.

2.3 Social optimum

In this section, we determine the social optimum. This gives us a benchmark that can be compared to the outcome in the political equilibrium. The utilitarian social planner maximizes the sum of all individuals' utilities W with respect to mitigation.

$$\max_M \ W(M) = \sum_i \sum_j \theta_i \lambda_j V_{ij}(M). \tag{2.22}$$

With the help of the envelope theorem, the first-order condition with respect to the mitigation level M is given by

$$\frac{\partial W}{\partial M} = -\frac{\partial \tau(M)}{\partial M}\bar{y} - \frac{\partial \pi(M)}{\partial M} \sum_i \sum_j \left[\theta_i \lambda_j \alpha(x_{ij}) y_i\right] = 0, \tag{2.23}$$

where $\bar{y}$ is the average income of the four types. From (2.23), it follows that the social planner chooses the optimal amount M_S where the marginal costs of mitigation equals the sum of all individuals' marginal benefits.[8] Now, let us consider a situation where we

[8] We assume that the second-order condition holds. See Appendix 2.A.2.

have infinitely high relocation costs so that $x_{ij} = \hat{x}_j$. Then, we can rewrite (2.23) and have

$$-\frac{\partial \tau(M)}{\partial M} = \frac{\partial \pi(M)}{\partial M}\bar{\alpha}, \tag{2.24}$$

where $\bar{\alpha} = \lambda_c \alpha(\hat{x}_c) + \lambda_f \alpha(\hat{x}_f)$. This implies that the socially optimal mitigation level without migration depends only on the average damage.

The effect of relocation costs on the socially optimal mitigation amount M_S is given by

$$\frac{\partial M_S}{\partial t} = \frac{1}{SOC_{M_S}} \frac{\partial \pi(M_S)}{\partial M_S} \sum_i \sum_j \left[\theta_i \lambda_j \frac{\partial \alpha(x_{ij})}{\partial x_{ij}} \frac{\partial x_{ij}}{\partial t} y_i \right] > 0. \tag{2.25}$$

The positive sign implies that higher relocation costs lead to higher mitigation levels. We summarize this result in the following lemma.

Lemma 2.2 (Influence of relocation costs on socially optimal mitigation)

Relocation costs have a positive effect on the socially optimal mitigation level, and therefore the level is lower with migration.

2.4 Analyzing the political process

In this section, we analyze the political process. First, we determine the optimal mitigation choice for every individual and then create a ranking to identify the median voter's solution. Finally, we compare the outcome in the political equilibrium with the social planner's solution and look at the poverty trap problem that can arise in the political equilibrium.

2.4.1 Individual ij's preferred mitigation level

The individual ij can anticipate his optimal location choice x_{ij}. Hence, he maximizes his indirect utility function V_{ij} with respect to M:

$$\max_M \; V_{ij}(M) = \big(1 - \tau(M)\big) y_i - \alpha(x_{ij})\pi(M) y_i - t(x_{ij} - \hat{x}_j)^2 - F. \tag{2.26}$$

Using the Envelope theorem, we obtain the following first-order condition:

$$\frac{\partial \tau(M)}{\partial M} y_i = -\alpha(x_{ij}) \frac{\partial \pi(M)}{\partial M} y_i. \tag{2.27}$$

An optimal mitigation choice M_{ij} for individual ij can be determined implicitly.[9] The LHS of Equation (2.27) can be interpreted as the marginal costs of having a higher mitigation level and the RHS as the marginal benefit, which is the expected damage reduction of having one additional mitigation unit.

Relocation costs change the optimal mitigation choice through the anticipated location:

$$\frac{\partial M_{ij}}{\partial t} = \frac{1}{SOC_{M_{ij}}} \frac{\partial \alpha(x_{ij})}{\partial x_{ij}} \frac{\partial x_{ij}}{\partial t} \frac{\partial \pi(M_{ij})}{\partial M_{ij}} y_i > 0. \tag{2.28}$$

With higher relocation costs, individuals will stay closer to their original location. This will increase the marginal benefit of mitigation and hence result in more mitigation, leading to the following lemma:

Lemma 2.3 (Influence of relocation costs on an individual's mitigation level)

Relocation costs have a positive effect on the preferred mitigation level of an individual, and therefore his mitigation level is higher without migration.

2.4.2 Identifying the median voter

To identify the median voter, we need to look at each type's preference for mitigation. The derivative of M_{ij} with respect to $\hat{x}_j$ is

$$\frac{\partial M_{ij}}{\partial \hat{x}_j} = \frac{1}{SOC_{M_{ij}}} \frac{\partial \alpha(x_{ij})}{\partial x_{ij}} \frac{\partial x_{ij}}{\partial \hat{x}_j} \frac{\partial \pi(M_{ij})}{\partial M_{ij}} y_i < 0. \tag{2.29}$$

The negative sign in Equation (2.29) implies that someone who lives near the coast wants a higher mitigation level than someone who lives far away. Now, regarding income, we

[9] We assume that the second-order condition with respect to M holds. See Appendix 2.A.2.

can compute the following derivative:

$$\frac{\partial M_{ij}}{\partial y_i} = \frac{-1}{SOC_{M_{ij}}}\Bigg[\underbrace{-\frac{\partial \tau(M_{ij})}{\partial M_{ij}} - \alpha(x_{ij})\frac{\partial \pi(M_{ij})}{\partial M_{ij}}}_{=0} - \frac{\partial \alpha(x_{ij})}{\partial x_{ij}}\frac{\partial x_{ij}}{\partial y_i}\frac{\partial \pi(M_{ij})}{\partial M_{ij}}y_i\Bigg] < 0. \qquad (2.30)$$

Note, that the first two terms in braces must be zero since they correspond to the first-order condition regarding the preferred mitigation level M_{ij}. The third term represents the indirect effect of income on the marginal benefit of mitigation. It is negative because a higher income leads to a location that is farther away from the coast, which results in a lower expected damage. Overall, Equation (2.30) is negative, implying a decreasing preferred mitigation level with an increasing income. Without migration, the effect would be equal to zero as the last term would disappear.

Now, from Equations (2.29) and (2.30), we create the following two possible rankings for the four groups.

$$M_{lc} > M_{hc} > M_{lf} > M_{hf} \qquad (2.31)$$

$$M_{lc} > M_{lf} \geq M_{hc} > M_{hf} \qquad (2.32)$$

These rankings have almost the same order as the location rankings, only that now, the lc-type has the highest value and the hf-type the lowest one. This result is not surprising if we look at Equations (2.29) and (2.30). The effects of the original location $\hat{x}_j$ and income y_i on the preferred mitigation M_{ij} work only through the location effect. We can also see this by looking at the first-order condition. The only difference for our four types in Equation (2.27) can arise through different location choices x_{ij}. Therefore, the ranking order must be the same but with different signs since a closer location leads to a higher marginal benefit from mitigation and thus to a higher preferred mitigation level.

Without migration, only the difference in the original location and therefore in the expected damage would drive the preference ranking:

$$M_{lc} = M_{hc} > M_{lf} = M_{hf}. \qquad (2.33)$$

Now, we can determine the median voter. It depends on which of the two possible rankings will be realized. If the first one (Equation (2.31)) is true, we have three possible candidates for the median voter, the lc-type, the hc-type, and the lf-type. The type that has a low income and lives close to the coast will be the median voter in this case if $\lambda_c\theta_l > 0.5$, implying that he solely constitutes the majority. In the other case, where $\lambda_c > 0.5$ but $\lambda_c\theta_l \leq 0.5$, the median voter is someone that lives close to the coast and has a high income. In the situation where less than half of the population lives close to the coast ($\lambda_c < 0.5$), the median voter is the lf-type. If Equation (2.32) is the realized ranking, the median voter must always be someone who has a low income. If $\lambda_c\theta_l > 0.5$, he is someone who lives close to the coast, otherwise the median voter is the lf-type. This is the case because we assume a right skewed income distribution. We summarize these findings in the following proposition.[10]

Proposition 2.1 (The median voter over the mitigation level)

i) Whenever the hc-type stays closer to the coast than the lf-type ($x_{hc} < x_{lf}$), the median voter's solution for mitigation is

$$M_m = \begin{cases} M_{lc} & \text{if } \lambda_c\theta_l > 0.5, \\ M_{hc} & \text{if } \lambda_c > 0.5 \wedge \lambda_c\theta_l \leq 0.5, \\ M_{lf} & \text{if } \lambda_c \leq 0.5. \end{cases} \tag{2.34}$$

ii) If the hc-type moves as far as or farther away than the lf-type ($x_{hc} \geq x_{lf}$), the median voter's solution is

$$M_m = \begin{cases} M_{lc} & \text{if } \lambda_c\theta_l > 0.5, \\ M_{lf} & \text{if } \lambda_c\theta_l \leq 0.5. \end{cases} \tag{2.35}$$

2.4.3 Comparison to a situation without migration and to the social optimum

We compare the median voter's solution to the solution with no migration. Relocation costs are supposed to be infinitely high to determine the optimal mitigation level without

[10] Technically, at thresholds, there are no median voters since the median values lie between two neighboring mitigation levels. For instance, if $\theta_l\lambda_c = 0.5$ in Equation (2.34), then every value between $[M_{hc}, M_{lc}]$ is possible for the solution in the political equilibrium. To keep the analysis clear, we assume that the lower value will be chosen at the thresholds.

migration. This would be the case if, for instance, migration is prohibited by the government. From Section 2.4.1, we know that higher relocation costs lead to higher mitigation levels (Equation (2.28)). Therefore, the median voter's mitigation level with migration is lower compared to the situation without a relocation option.

Regarding the comparison between the social planner's and median voter's solution, we evaluate the socially optimal first-order condition (Equation (2.23)) at the median voter's preferred mitigation level:

$$\left.\frac{\partial W}{\partial M}\right|_{M=M_m} = \underbrace{\frac{\partial \pi(M_m)}{\partial M_m}}_{<0} \left[\alpha(x_m)\bar{y} - \sum_i \sum_j [\theta_i \lambda_j \alpha(x_{ij}) y_i]\right] \gtreqless 0. \tag{2.36}$$

The sign of Equation (2.36) depends on the difference in brackets. Hence,

$$M_m \lesseqgtr M_S \Leftrightarrow \alpha(x_m)\bar{y} \lesseqgtr \sum_i \sum_j [\theta_i \lambda_j \alpha(x_{ij}) y_i]. \tag{2.37}$$

Even if we consider specific values for λ_c, and therefore different scenarios for the median voter, the sign stays undetermined in most cases. We know that the median voter's mitigation level is higher than in the social optimum only if he is someone who lives close to the coast and has a low income (lc-type) (see Appendix 2.A.3).

However, we can look at the situation without migration. Evaluating the socially optimal first-order condition without migration (Equation (2.24)) at the median voter's solution without migration yields

$$M_m \lesseqgtr M_S \Leftrightarrow \alpha(\hat{x}_m) \lesseqgtr \lambda_c \alpha(\hat{x}_c) + \lambda_f \alpha(\hat{x}_f) = \bar{\alpha}. \tag{2.38}$$

Note that the comparison does not depend on income anymore because without migration, income drops out in the social planner's first-order condition. If the majority lives not at the coast ($\lambda_c \leq 0.5$), the median voter is always an lf-type (see Proposition 2.1). From Equation (2.38), it then follows that his mitigation level will be lower than the socially optimal level without migration. The reason for this lies in the unequal location distribution. The average location $\bar{x}$ is closer to the sea than the median location x_m. Since the social planner maximizes the sum of utilities, the socially optimal mitigation level is higher than the median voter's solution. The opposite is true for $\lambda_c > 0.5$. The following proposition summarizes these results.

Proposition 2.2 (General comparison between social optimum and political equilibrium)

i) With migration, the median voter's mitigation level M_m is higher than in the social optimum M_S if the median voter is someone that lives close to the coast and has a low income (lc-type). Otherwise, it is not clear if the median voter's level is higher than, equal to, or less than in the social optimum.

ii) Without migration, the median voter's mitigation level M_m is lower than in the social optimum M_S if the majority is not living close to the coast ($\lambda_c \leq 0.5$), and it is higher in the opposite case ($\lambda_c > 0.5$).

Using the results from above, we want to look into a more specific example. Consider a country where we have a minority living at the coast so that the median voter will be an lf-type (e.g. China, where 11% of the population live in low elevation coastal zones; see Table 2.A.1). Furthermore, we assume that the f-type individuals live so far away from the coast ($\hat{x}_f = x_{max}$) that their expected damage from flooding is zero ($\alpha(\hat{x}_f) = 0$). In this case, the f-type individuals neither relocate nor need any mitigation, as they have no benefits of these options. Therefore, we have no mitigation in the political equilibrium, and we can show that the median voter's mitigation level is lower than in the social planner's solution (see Appendix 2.A.3). Note that within our framework, migration has a positive effect on individuals' utilities and on social welfare since it is modeled as an adaptation measure that reduces the expected damage. Preventing relocation creates a Pareto inferior situation as the median voter's mitigation level is unchanged while the expected damage of the close coast individuals is then higher. This argument is in line with Foresight (2011) who state that decision-makers should not prevent migration because it would force people to stay in vulnerable regions. We summarize the results from this scenario in the following proposition.

Proposition 2.3 (Socially inefficient mitigation level)
If the f-type individuals live so far away from the coast ($\hat{x}_f = x_{max}$) that they do not face a flood risk, and if they constitute the majority ($\lambda_f > 0.5$), the mitigation level in the political equilibrium is socially inefficiently low.

Since in nine of ten countries with the greatest coastal population the coastal population does not hold a majority, the scenario described above is not unrealistic. (see Table 2.A.1). In particular, this applies to Asian countries such as China, India, Bangladesh, and Vietnam where millions of individuals live in coastal areas. In this subsection, we still assume that there are no fixed costs, and therefore both high and low-income individuals that live close to coast relocate. In the next subsection, however, we want to relax this assumption in order to analyze the effects of fixed costs on the political equilibrium. In particular, we consider a situation where the lc-type does not move away due to high fixed costs.

2.4.4 Poverty trap

Poverty traps are characterized by self-enforcing mechanisms that prevent individuals, regions, or countries from escaping their poverty. Several of such mechanisms are being discussed in the literature (see Azariadis and Stachurski, 2005; Kraay and McKenzie, 2014). One of them is the so-called geographic poverty trap, that is defined by Jalan and Ravallion (2002) as one household's inability to increase its wealth in one region while an otherwise identical household is able to increase its wealth in a different region. Another explanation for potential poverty traps come from environmental factors where climate change impacts are a possible factor for future poverty traps (see Olsson et al., 2014).

In our model, we look into possible geographic poverty traps that are caused by environmental factors directly and indirectly through migration. While rich individuals move away to safer locations, poor individuals may financially not be able to do so. This could indirectly create a geographic trap since it leaves the region with low regional capital. Moreover, the region then faces what Black et al. (2011) call "the double set of risk" as individuals are unable to move away and are vulnerable to environmental risks due to their low capital. According to Cattaneo and Peri (2016), such poverty traps can arise especially in low-income countries.

In order to analyze the formation of poverty traps, we illustrate at first the extensive margin (Section 2.2.1.3) in Figure 2.1. We see the relationship between the critical fixed costs $\widetilde{F}_{ij}$ and income y_i. The critical value $\widetilde{F}_{ij}$ is increasing (see Equation (2.19)) and convex[11] in income y_i. Critical fixed costs for close-coast individuals $\widetilde{F}_{ic}$ are always higher

[11] The second partial derivative is positive (see Appendix 2.A.4).

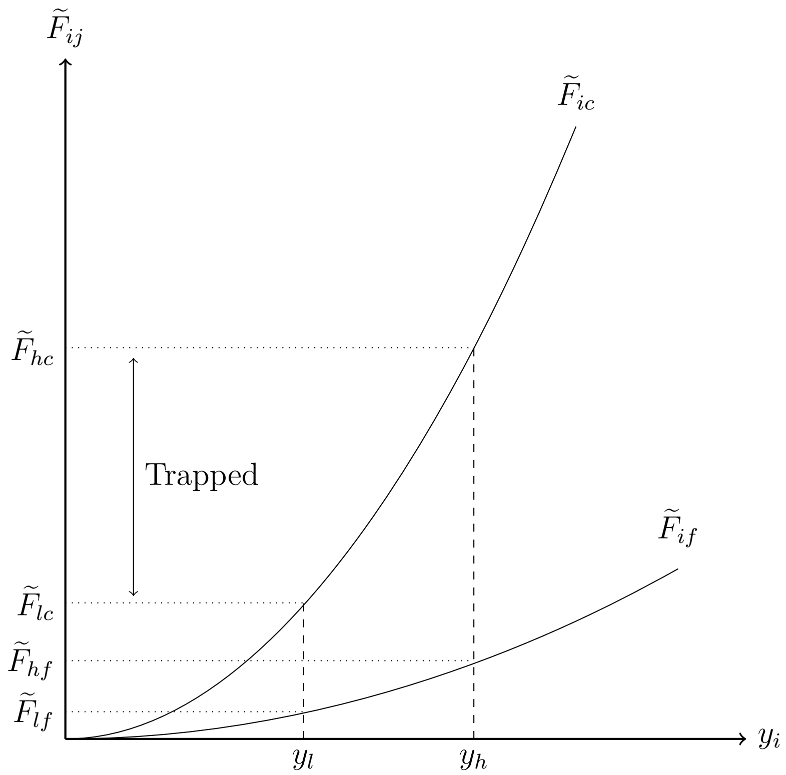

Figure 2.1: Relationship between the critical fixed costs $\widetilde{F}_{ij}$ and income y_i.

than for individuals who live in the hinterlands (see Equation (2.18)). This implies that it is more likely that a c-type will move even when high fixed costs are in place. Furthermore, the slope of $\widetilde{F}_{ic}$ is steeper than the slope of $\widetilde{F}_{if}$.[12] The vertical dashed lines are possible income levels for the high and low-income type. From the intersections between these income levels and the fixed costs lines, we can read the critical fixed costs level for every individual $\widetilde{F}_{ij}$.

As long as someone's critical fixed costs value $\widetilde{F}_{ij}$ lies above fixed costs F, his optimal choice is to move away. The range where a trap can arise is given by $(\widetilde{F}_{lc}, \widetilde{F}_{hc}]$. Whenever fixed costs are in this interval, we get the situation that the high-income type who lives close to the coast moves away while the low-income type does not. Note, that this situation can occur in the political equilibrium as well as in the social optimum. The chosen mitigation level will be decisive if this trap is dangerous for the lc-type.

Since $\widetilde{F}_{ij}$ depends on the mitigation level M, the range $(\widetilde{F}_{lc}, \widetilde{F}_{hc}]$ will also depend on it. From Equation (2.17), we know that the relationship between $\widetilde{F}_{ij}$ and M is negative. This means that a lower mitigation level makes it more likely that individuals will move away. However, the possible trap interval becomes larger with a lower M (see Appendix 2.A.4). Besides mitigation, income inequality has an effect on the trap range. As can be easily verified in Figure 2.1, a higher income inequality creates a larger interval, making a relocation trap more likely.

Similar to the last subsection, we consider a situation where the lf-type is the median voter, and his original location is so far away that his expected damage is zero. Again, this results in a mitigation level that is zero in the political equilibrium. In addition, we assume that fixed costs are now positive and satisfy the condition $\widetilde{F}_{hc} > F > \widetilde{F}_{lc}\ \forall M$. We can then show that the median voter's mitigation level is lower than in the social optimum, resulting in a poverty trap for the lc-type (see Appendix 2.A.5). We summarize the findings in the following proposition.

[12] The cross partial derivative is negative (see Appendix 2.A.4).

Proposition 2.4 (Poverty trap)

If $F \in (\widetilde{F}_{lc}, \widetilde{F}_{hc}]$, only the low-income type that originally lives close to the coast stays at the coast (lc-type). Moreover, if the median voter is someone who lives so far away from the coast that he faces no flood risk ($\hat{x}_f = x_{max}$), and if the possible mitigation levels and fixed costs satisfy the condition $\widetilde{F}_{hc} > F > \widetilde{F}_{lc}$ $\forall M$, the mitigation level in the political equilibrium will be inefficiently low, which could result in a poverty trap for the lc-type.

2.5 Extensions

In the following, we make some changes to the model and compare the results with the base model. In the first subsection, we introduce an additional adaptation stage that is modeled as a dike. The idea is that having a dike could decrease both mitigation and migration. Hence, we analyze the interactions between the location choice, mitigation, and this new adaptation measure. In the second subsection, we consider individuals that differ in age instead of income and therefore extend the model to two periods. This is important as young and old individuals evaluate their options differently due to different time horizons, and this could impact the outcome in the political equilibrium (e.g. see Habla and Roeder, 2013).

2.5.1 Additional adaptation stage

So far, migration was the only adaptation measure. Now, we include the additional adaptation stage modeled as a dike (D). Since migration is a private adaption measure and dike building is a public one, this extension could give us some insight into the interaction between publicly and privately financed adaptation measures. The timing in the following setup is such that individuals decide at first about building a dike and then about the mitigation level. Since this is a discrete choice, D will be either one or zero. We assume that having a dike reduces the damage for a given location and that this damage reduction decreases with the distance to the sea:

$$\alpha(x, D = 1) < \alpha(x, D = 0) \text{ and } \frac{\partial \alpha(x, D = 0)}{\partial x} < \frac{\partial \alpha(x, D = 1)}{\partial x}. \tag{2.39}$$

The migration decision is affected by the decision to build a dike. Now, we have two optimal location choices: One for the case where no dike is built ($x_{ij}(D=0)$), and one for the case with a dike ($x_{ij}(D=1)$). The corresponding first-order condition is given by[13]

$$-\frac{\partial\alpha(x,D)}{\partial x}\pi(M)y_i - 2t(x-\hat{x}_j) = 0. \tag{2.40}$$

It is easy to see that having a dike only affects the derivative of α with respect to x, and since we assumed that the derivative with a dike is greater than without one, the marginal benefit of moving is smaller with a dike while the marginal costs stay unchanged. Therefore, the optimal location must be closer to the sea with a dike:

$$x_{ij}(D=1) < x_{ij}(D=0). \tag{2.41}$$

Before we can analyze the effect of having a dike on the mitigation stage, we have to think about financing the dike. We assume that it is financed by the same linear income tax τ as mitigation and that there are no interactions between mitigation and the dike in the cost function. Therefore, we get the following indirect utility function:

$$V_{ij}(M,D) = (1-\tau(M,D))y_i - t(x_{ij}(D)-\hat{x}_j)^2 - F - \alpha(x_{ij}(D),D)\pi(M)y_i. \tag{2.42}$$

Similar to the migration stage, every individual has two optimal mitigation levels: $M_{ij}(D=1)$ and $M_{ij}(D=0)$. We have the following first-order condition:[14]

$$\frac{\partial V_{ij}}{\partial M} = -\frac{\partial\tau}{\partial M}y_i - \alpha(x_{ij}(D),D)\frac{\partial\pi}{\partial M}y_i. \tag{2.43}$$

We see that having a dike changes the marginal benefit of mitigation since D will only appear in the damage function $\alpha(x_{ij}(D),D)$.[15]

We can also see that we have two effects. The first effect comes from the assumption that a dike decreases the damage. Hence, for a given location, the marginal benefit of mitigation

[13]Note that technically there are two first-order conditions since D is a discrete variable.

[14]The second-order condition is given in the Appendix 2.A.6.

[15]Since we assumed that there are no cost interactions between a dike and mitigation, having a dike does not affect the marginal costs of mitigation.

is lower with a dike. The second effect works through the location choice $x_{ij}(D)$. As mentioned above, individuals are staying closer to the sea with a dike. This, however, leads to higher damage α and therefore to a higher marginal benefit of mitigation. Overall, the effect of the dike on mitigation depends on which of the two effects is greater:

$$\alpha(x_{ij}(D=1), D=1) \lesseqqgtr \alpha(x_{ij}(D=0), D=0) \tag{2.44}$$

$$\Rightarrow M_{ij}(D=1) \lesseqqgtr M_{ij}(D=0). \tag{2.45}$$

The effect of migration on mitigation with a dike is also negative, but we cannot say which effect is stronger due to the ambiguous sign in Equation (2.44).

In the following, we want to analyze the adaptation stage itself. An individual is in favor of the dike whenever the utility difference between having a dike and not having one is greater than zero:

$$\triangle V_{ij}(D) = V_{ij}(D=1) - V_{ij}(D=0) > 0. \tag{2.46}$$

Every individual anticipates the median voter's solution for mitigation on the subsequent stage. Therefore, the indirect utility function is

$$\begin{aligned} V_{ij}(D) = {} & (1-\tau(M_m(D), D))\, y_i - \alpha(x_{ij}(D), D)\pi(M_m(D))y_i \\ & - t(x_{ij}(D) - \hat{x}_j)^2 - F. \end{aligned} \tag{2.47}$$

The dike decision influences the indirect utility function through all stages, and there are several effects that work in the opposite direction. Without making more assumptions about the form of the damage function, it is not possible to determine when the dike is built.

2.5.2 Heterogeneity in age instead of income, the delayed effect of mitigation

In this section, we consider individuals that differ in age instead of income. We use a two period setting where young individuals (Y) live in both periods while the old ones (O) only live in the first period. Mitigation reduces the probability in the second period, whereas the costs occur only in the present. In the first period, we have an exogenous damage probability $\pi_0 = \pi(M = 0)$. The discount factor is denoted by $\delta \in (0,1)$. The utility functions for both types of individuals are

$$U_j^O = (1-\tau)y - t(x-\hat{x}_j)^2 - F - \alpha(x)\pi^0 y, \tag{2.48}$$
$$U_j^Y = (1-\tau)y - t(x-\hat{x}_j)^2 - F - \alpha(x)\pi^0 y + \delta[y - \alpha(x)\pi(M)y]. \tag{2.49}$$

Differentiating both functions with respect to x yields the following first-order conditions:

$$\frac{\partial U_j^O}{\partial x} = -2t(x-\hat{x}_j) - \frac{\partial \alpha(x)}{\partial x_j}\pi_0 y = 0, \tag{2.50}$$
$$\frac{\partial U_j^Y}{\partial x} = -2t(x-\hat{x}_j) - \frac{\partial \alpha(x)}{\partial x_j}(\pi_0 + \delta\pi(M))y = 0. \tag{2.51}$$

Let x_j^O and x_j^Y denote the optimal location choices for our young and old individuals.[16] Compared to the location choices from the base model, x_j^O must be equal or greater than x_{ij}, while x_j^Y is always greater than x_{ij} for given income levels.

In the economic equilibrium, we get the indirect utility functions by substituting x_j^O, x_j^Y and the government's budget constraint[17] into (2.48) and (2.49):

$$\begin{aligned} V_j^Y(M) =& (1-\tau(M))y - t(x_j^Y - \hat{x}_j)^2 - F - \alpha(x_j^Y)\pi^0 y \\ &+ \delta[y - \alpha(x_j^Y)\pi(M)y], \end{aligned} \tag{2.52}$$
$$V_j^O(M) = (1-\tau(M))y - t(x_j^O - \hat{x}_j)^2 - F - \alpha(x_j^O)\pi^0 y. \tag{2.53}$$

Differentiating both indirect utility functions with respect to M gives us

$$\frac{\partial V_j^O}{\partial M} = -\frac{\partial \tau(M)}{\partial M} y < 0, \tag{2.54}$$
$$\frac{\partial V_j^Y}{\partial M} = -\frac{\partial \tau(M)}{\partial M} y - \delta\alpha(x_j^Y)\frac{\partial \pi(M)}{\partial M} y = 0. \tag{2.55}$$

Not surprisingly, the old individuals do not want mitigation at all ($M_j^O = 0$) as they get no benefit from it. Young individuals want a mitigation level that is lower than in the

[16]The second-order condition holds. See Appendix 2.A.6.

[17]The government's budget constraint is the same as in the base model because of our assumption that the mitigation costs occur only in the first period.

base model ($M_j^Y < M_{ij}$).[18] There are two reasons for this result. The first one is that the marginal benefit is being discounted while the marginal costs are not. The second reason works through the location choice. Since young individuals move farther away compared to individuals in the base model, the marginal benefit of mitigation is even lower. Hence, a stronger relocation incentive is one reason for a lower mitigation level and therefore we can state that the effect of migration in this extension is stronger compared to the base model.

2.6 Conclusion

This chapter studies how the political equilibrium of mitigation changes if we include a relocation option. We show that the median voter's mitigation level is lower if he anticipates moving away than in the case where he does not have the option. This also applies to the socially optimal mitigation level, which is lower with the migration option. The general comparison between the socially optimal mitigation level and the median voter's level with migration is not clear as different relocation options due to different income levels change the marginal benefits of mitigation. However, if we assume that a majority lives very far away from the coast, where they do not face a flood risk, we show that it is socially inefficient to have no mitigation in the political equilibrium. This scenario is especially relevant for many Asian countries such as China, India, Bangladesh, and Vietnam, where millions of individuals live in low elevation coastal zones but are still a minority. Without migration, the median voter's mitigation level is inefficiently low if the majority lives far away from the coast. Note that in this model, it can be both privately and socially optimal to relocate and therefore put less effort into climate change mitigation.

A further result from the model is that the interaction between relocation and mitigation could give us an explanation of how poverty traps emerge. Consider a situation where a minority lives at the coast and at the same time fixed relocation costs are too high for low-income individuals. In this case, the high-income type would move to the hinterlands, and since only the minority lives at the coast, the median voter would not vote for enough protection measures compared to the socially optimal mitigation level.

[18] We assume that the second-order condition holds. See Appendix 2.A.6.

We also look into two extended model specifications. In the first one, we add an additional adaptation method, namely building a dike. We show that the interaction between mitigation and the dike is not clear. The second extension adds heterogeneity in age and a delayed benefit from mitigation. Here, we see that mitigation is even lower since old individuals do not want mitigation at all and young individuals want a lower mitigation level compared to the base model.

2.A Appendix

2.A.1 Population in LECZ

Ranked by total population in LECZ			*Ranked by share of population in LECZ*		
Country	Population	Share	Country	Population	Share
China	143,880	11	Bahamas	267	88
India	63,188	6	Suriname	318	76
Bangladesh	62,524	46	Netherlands	11,717	74
Vietnam	43,051	55	Vietnam	43,051	55
Indonesia	41,610	20	Guyana	415	55
Japan	30,477	24	Bangladesh	62,524	46
Egypt	25,655	38	Djibouti	289	41
USA	22,859	8	Belize	91	40
Thailand	16,478	26	Egypt	25,695	38
Philippines	13,329	18	The Gambia	494	38

Source: McGranahan et al. (2007)
Notes: Population numbers are given in thousands. Countries with a population less than 100,000 are excluded.

Table 2.2: Ranking of countries with the largest population counts and shares in the Low Elevation Coastal Zone (LECZ)

2.A.2 Second-order conditions for the base model

The second-order conditions for the optimal location choices and the preferred mitigation levels in the base model are given by

$$\mathrm{SOC}_{x_{ij}} \equiv \frac{\partial^2 U_{ij}}{\partial x^2} = -2t - \frac{\partial^2 \alpha(x)}{\partial x^2}\pi(M) y_i < 0 \tag{2.56}$$

$$\mathrm{SOC}_{M_{ij}} \equiv \frac{\partial^2 V_{ij}}{\partial M^2} = -\underbrace{\frac{\partial^2 \tau(M)}{\partial M^2} y_i}_{<0} - \underbrace{\frac{\partial \alpha(x_{ij})}{\partial x_{ij}}}_{>0} \underbrace{\frac{\partial x_{ij}}{\partial M}}_{<0} \underbrace{\frac{\partial \pi(M)}{\partial M} y_i}_{<0} \underbrace{-\alpha(x_{ij}) \frac{\partial^2 \pi(M)}{\partial M^2} y_i}_{<0} \lesseqgtr 0. \tag{2.57}$$

The sign of $\text{SOC}_{M_{ij}}$ is ambiguous. Hence we assume that

$$\frac{\partial^2 \tau(M)}{\partial M^2} + \alpha(x_{ij})\frac{\partial^2 \pi(M)}{\partial M^2} > -\frac{\partial \alpha(x_{ij})}{\partial x_{ij}}\frac{\partial x_{ij}}{\partial M}\frac{\partial \pi(M)}{\partial M},$$
$$\text{so that } \frac{\partial^2 V_{ij}}{\partial M^2} < 0$$

The second-order condition for the socially optimal mitigation level is given by

$$\begin{aligned}\text{SOC}_{M_S} \equiv \frac{\partial^2 W}{\partial M^2} = & \underbrace{-\frac{\partial^2 \tau(M)}{\partial M^2}\bar{y}}_{<0} \underbrace{-\frac{\partial^2 \pi(M)}{\partial M^2}\sum_i\sum_j [\theta_i \lambda_j \alpha(x_{ij}) y_i]}_{<0} \\ & \underbrace{-\frac{\partial \pi(M)}{\partial M}}_{>0}\sum_i\sum_j \left[\underbrace{\theta_i \lambda_j y_i \frac{\partial \alpha(x_{ij})}{\partial x_{ij}}}_{<0}\underbrace{\frac{\partial x_{ij}}{\partial M}}_{<0}\right] \lesseqgtr 0. \qquad (2.58)\end{aligned}$$

The sign of the second-order condition with respect to mitigation is ambiguous. Hence, we assume that

$$\begin{aligned}&\frac{\partial^2 \tau(M)}{\partial M^2}\bar{y} + \frac{\partial^2 \pi(M)}{\partial M^2}\sum_i\sum_j [\theta_i \lambda_j \alpha(x_{ij}) y_i] > \\ &-\frac{\partial \pi(M)}{\partial M}\sum_i\sum_j \left[\theta_i \lambda_j y_i \frac{\partial \alpha(x_{ij})}{\partial x_{ij}}\frac{\partial x_{ij}}{\partial M}\right], \qquad (2.59)\\ &\text{so that } \frac{\partial^2 W}{\partial M^2} < 0.\end{aligned}$$

2.A.3 Comparison between the socially optimum and the median voter's solution

We can rewrite Equation (2.37) in the following way:

$$\theta_l y_l \alpha(x_m) + \theta_h y_h \alpha(x_m) \lesseqgtr \theta_l y_l [\underbrace{\lambda_c \alpha(x_{lc}) + \lambda_f \alpha(x_{lf})}_{\lesseqgtr \alpha(x_m)}] + \theta_h y_h [\underbrace{\lambda_c \alpha(x_{hc}) + \lambda_f \alpha(x_{hf})}_{\lesseqgtr \alpha(x_m)}]. \quad (2.60)$$

Equations (2.13) and (2.14) from Section 2.2.1.2 imply that

$$\alpha(x_{lc}) > \alpha(x_{hc}) > \alpha(x_{lf}) > \alpha(x_{hf}), \tag{2.61}$$

$$\alpha(x_{lc}) > \alpha(x_{lf}) \geq \alpha(x_{hc}) > \alpha(x_{hf}). \tag{2.62}$$

As stated in Proposition 2.1, there are three possible candidates for the median voter, namely *lc*-, *hc*-, and *lf*-type. If the median voter is a *lc*-type, i.e. if $\lambda_c \theta_l > 0.5$, one can see immediately that the first sum in square brackets of the RHS in Equation (2.60) is less or equal to $\alpha(x_{lc})$ while the second sum in square brackets is always less than $\alpha(x_{lc})$. Therefore, the LHS of Equation (2.60) is greater than the RHS, implying that the median voter's mitigation level is socially inefficient high. However, if the median voter is a *hc*-type, the sign is not clear. The terms in the first square brackets are less than, equal to or greater than $\alpha(x_{hc})$ while the terms in the second square brackets are less than or equal than $\alpha(x_{hc})$. Note that this holds regardless of which of the two rankings (2.61) or (2.62) is realized. With a *lf*-type as the median voter, we get only an unambiguous sign if we assume that the *f*-type's original location is so far away from the coast that $\alpha(\hat{x}_f) = 0$. Here, the terms in the first square brackets are greater than or equal to $\alpha(x_{lf})$, and the terms in the second square brackets are greater than $\alpha(x_{lf})$. Without these assumptions, the terms in the first brackets are less than or equal to $\alpha(x_{lf})$ while now the terms in the second square brackets are undetermined.

2.A.4 (Cross) partial derivatives of critical fixed costs with respect to income, mitigation, and original location.

The second partial derivative of $\widetilde{F}_{ij}$ with respect to y_i is given by

$$\frac{\partial^2 \widetilde{F}_{ij}}{\partial y_i^2} = -\pi(M) \frac{\partial \alpha(x_{ij})}{\partial x_{ij}} \frac{\partial x_{ij}}{\partial y_i} > 0. \tag{2.63}$$

The cross partial derivative of $\widetilde{F}_{ij}$ with respect to $\hat{x}_j$ is given by

$$\frac{\partial^2 \widetilde{F}_{ij}}{\partial y \partial \hat{x}} = \pi(M) \left(\frac{\partial \alpha(x_{ij})}{\partial \hat{x}_j} - \frac{\partial \alpha(x_{ij})}{\partial x_{ij}} \frac{\partial x_{ij}}{\partial \hat{x}_j} \right) < 0. \tag{2.64}$$

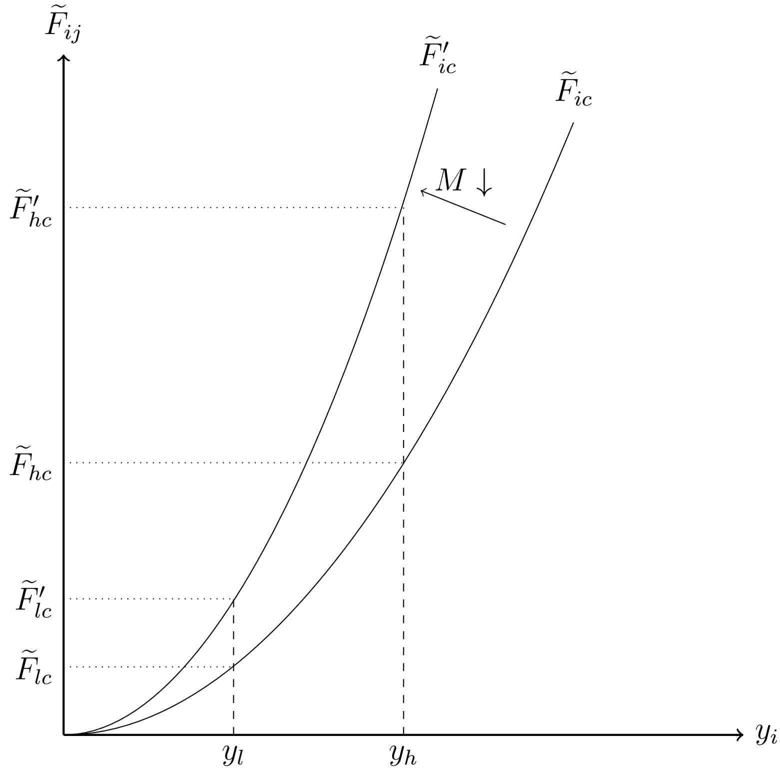

Figure 2.2: Influence of mitigation M on the critical fixed costs $\widetilde{F}_{ij}$.

The expression in parentheses is negative because $\partial x_{ij}/\partial \hat{x}_j \in (0,1)$ (see Equation (2.9)), and $\partial\alpha/\partial\hat{x}_j < \partial\alpha/\partial x_{ij}$.

The cross partial derivative of $\widetilde{F}_{ij}$ with respect to M is given by

$$\frac{\partial^2 \widetilde{F}_{ij}}{\partial y \partial M} = \frac{\pi(M)}{\partial M}\left(\alpha(\hat{x}_j) - \alpha(x_{ij})\right) - \pi(M)\frac{\partial \alpha(x_{ij})}{\partial x_{ij}}\frac{\partial x_{ij}}{\partial M} < 0. \tag{2.65}$$

Therefore, the slope in Figure 2.1 is getting steeper with a lower level of mitigation. Since F_{ij} is convex, a lower mitigation level then creates a larger fixed costs range for a given income difference. The following figure illustrates this.

2.A.5 Comparison between the social optimum and the median voter's solution with a poverty trap

If the conditions $\alpha(\hat{x}_f) = 0$ and $\widetilde{F}_{hc} > F > \widetilde{F}_{lc}$ $\forall M$ are satisfied, we have the following location ranking:

$$x_{lc} = \hat{x}_c < x_{hc} < x_{lf} = x_{hf} = \hat{x}_f. \tag{2.66}$$

Whenever a minority lives close to the coast, the comparison between the social planner's solution and median voter's solution yields

$$\theta_l y_l \alpha(x_m) + \theta_h y_h \alpha(x_m) < \theta_l y_l [\underbrace{\lambda_c \alpha(\hat{x}_c) + \lambda_f \alpha(\hat{x}_f)}_{=\bar{\alpha} > \alpha(x_m) = 0}] + \theta_h y_h [\underbrace{\lambda_c \alpha(x_{hc}) + \lambda_f \alpha(\hat{x}_f)}_{> \alpha(x_m)}], \tag{2.67}$$

and therefore the median voter's mitigation level M_m is lower than the social planner's mitigation level M_S.

2.A.6 Second-order conditions for the extended models

The second-order conditions for the optimal location choices and for the preferred mitigation levels for both old and young individuals in Section 2.5.2 are given by

$$\mathrm{SOC}_{x_j^O} \equiv \frac{\partial^2 V_j^O}{\partial x^2} = -2t - \frac{\partial^2 \alpha(x)}{\partial x^2} \pi_0 y < 0 \tag{2.68}$$

$$\mathrm{SOC}_{x_j^Y} \equiv \frac{\partial^2 V_j^Y}{\partial x^2} = -2t - \frac{\partial^2 \alpha(x)}{\partial x^2} (\pi_0 + \delta \pi(M)) y < 0 \tag{2.69}$$

$$\mathrm{SOC}_{M_j^Y} \equiv \frac{\partial^2 V_j^Y}{\partial M^2} = \underbrace{-\frac{\partial^2 \tau(M)}{\partial M^2} y}_{<0} \underbrace{-\delta \frac{\partial \alpha(x_j^Y)}{\partial x_j^Y}}_{>0} \underbrace{\frac{\partial x_j^Y}{\partial M}}_{<0} \underbrace{\frac{\partial \pi(M)}{\partial M} y}_{<0} \underbrace{-\delta \alpha(x_j^Y) \frac{\partial^2 \pi(M)}{\partial M^2} y}_{<0} \lesseqgtr 0. \tag{2.70}$$

The sign of the last equation is ambiguous. Hence, we assume that

$$\frac{\partial^2\tau(M)}{\partial M^2} + \alpha(x_j^Y)\frac{\partial^2\pi(M)}{\partial M^2} > -\frac{\partial\alpha(x_j^Y)}{\partial x_j^Y}\frac{\partial x_j^Y}{\partial M}\frac{\partial\pi(M)}{\partial M}, \tag{2.71}$$

so that $\dfrac{\partial^2 {V_j^Y}^2}{\partial M} < 0.$

Chapter 3

The Political Economy of the German Climate Package and the Commuting Allowance

3.1 Introduction

According to the German Environment Agency, the traffic sector in Germany emitted about 164 million tons of CO_2 into the atmosphere in 2019, which amounts to 20 percent of Germany's total CO_2 emissions. By far the largest share comes from road traffic with almost 160 tons of CO_2. Despite several efforts in the past, this number did not decrease (+0.3% compared to 1990) (Umweltbundesamt, 2021).

As it is necessary to lower the emissions in every sector, the German Federal Government addresses the problem in its Climate Package by introducing a CO_2 pricing for the transport sector. In 2021, one ton of CO_2 will cost 25 euros increasing the price for gasoline to about 7 euro cents and the price for diesel about 8 euro cents. The price for CO_2 will gradually increase up to 55 euros per ton in 2025, leading to a price increase of 15 euro cents for gasoline and 17 euro cents for diesel. At the same time, there will be a temporary increase in the commuting allowance to compensate those who have to commute to work. Between 2021 and 2023, the commuting allowance will increase from 30 to 35 euro cents per kilometer, and between 2024 and 2026, the allowance will be 38 euro cents per kilometer. Afterward, it will decrease to 30 euro cents per kilometer again. Moreover, this increase only applies from the 21st km one-way distance.[1]

It has to be mentioned that the commuting allowance in general and its increase is heavily debated. For a short review of different arguments, see e.g. Hirte and Tscharaktschiew (2013). In this chapter, we do not want to discuss the commuting allowance itself but explain its increase within the German Climate Package. We use a political economy model with two stages where we have three distinct groups that differ in the distance to their workplace and income. We assume that the groups with the longest and intermediate distance have to commute at least some part by car, and those who live very close to their workplace or work remotely do not use the car. Individuals cannot change their distance, and only the group with the largest one is entitled to get a higher commuting allowance. However, individuals can choose to commute more fuel-efficient, e.g., by using carpooling or more efficient cars. This lowers the costs of commuting but comes with a disutility since it is more uncomfortable and time-consuming in most cases. Moreover, commuting creates a negative externality and to correct it, a fuel tax[2] is introduced. The fuel tax revenues can be used for a lump-sum transfer or to increase the commuting allowance. Both the fuel tax rate and the redistribution scheme are political decisions.

In the first stage, individuals vote over the redistribution scheme of the fuel tax revenues while they decide about the fuel tax rate in the second stage. We find that the group with the longest commuting distance may prefer a higher fuel tax than the group with the intermediate distance, making him the median voter since those who do not commute at all want the highest fuel tax. This preference is only possible if the tax revenue is redistributed through higher commuting tax allowances. The lower the price elasticity for fuel and the smaller the share of the long-distance commuters, the more likely this situation gets. We show that the long-distance type always wants the tax revenue to be redistributed through higher commuting allowances in the first stage. In contrast, the short-distance type prefers that all revenues are redistributed via lump-sum transfers. The group that does not commute is then the decisive voter. While it is clear that they have a financial incentive to vote for redistribution via lump-sum transfers, a second incentive

[1] One may ask why the threshold is 21 km. The official reasoning is to compensate only those with very long commuting distances. However, the commuting tax allowance is hardly beneficial for those below this threshold since there is a general tax allowance for work-related expenses of 1000 euros.

[2] In our model, we consider commuting as sole energy good and therefore use the term fuel tax instead of carbon tax.

comes from their environmental awareness of the negative externality. They anticipate that a increased commuting allowance may induce the long-distance type to vote for a higher fuel tax than the short-distance commuter. Spoken differently, it means that the group that does not commute by car uses the commuting allowance as a mechanism to buy the long-distance commuters' support for a higher fuel tax at the expense of those who commute a short distance.

This chapter contributes to two strands of literature. The first strand is about the political economy of commuting subsidies. The main contribution in this strand of literature is made by Borck and Wrede (2005). The authors use a monocentric city model to study the political support for a commuting subsidy. In their model, two income groups have different incentives to vote for a commuting subsidy, depending on whether they live in the city center or the suburbs and whether the landownership is endogenous or exogenous. In Borck and Wrede (2008), they extend their model to two different commuting choices. Our contribution to this strand of literature is to show a different mechanism that leads to a positive commuting subsidy. In our model, a commuting tax allowance is used by the non-commuting group to get the long-distance commuters' support for a higher fuel tax. Another contribution that is related to this area is made by Barbaro and Suedekum (2009). In contrast to our chapter, they investigate why tax exceptions like the commuting allowance in Germany are not abolished if it only benefits a minority.

The second strand that this chapter contributes to is about the political economy of environmental taxes. Early contributions in this strand of literature are made by Aidt (1998), Damania (1999), and Fredriksson (1997). They look into the influence that lobby groups have on the environmental tax rate in the political equilibrium. The link between environmental taxes and the redistribution of its revenues is investigated by Cremer et al. (2004a,b, 2008). The authors study the political support for environmental taxes when individuals are heterogeneous in terms of their capital endowment and labor wages and when the revenues are used to reduce tax rates for capital gains and labor income. They vary their model with respect to the voting order and the political competition model. One paper that builds on those contributions and is closely related to ours is Habla and Roeder (2013). The authors study the political economy of the German ecotax reform, where the tax revenue is used to reduce pension contributions. Similar to our model, this use of tax revenues is a way to enforce a higher ecotax. However, the double dividend hypothesis cannot be applied in our model since a redistribution through higher commuting tax allowances does not reduce inefficiencies in other areas.

This chapter is structured as follows. In Section 3.2, the model setting is explained. Then, Section 3.3 shows the socially optimal choice, and in Section 3.4, the political process is studied in detail. Finally Section 3.5 discusses different assumptions in the model, while Section 3.6 concludes the paper.

3.2 The model

Consider an economy with individuals that differ in their one-way commuting distances x_j and income y_i. We distinguish between three commuting types ($j \in \{n, s, l\}$). The n-type lives very close to his workplace or works remotely. He does not use a car for his daily commuting. The largest share of this type lives in urban areas (Bundesministerium für Verkehr und digitale Infrastruktur (BMVI), 2018). The type-s individual lives farther away from his workplace and uses a car for his commuting but the distance is below the threshold to be entitled to the commuting tax allowance. In contrast, the type-l individual commutes the longest way and is the only one entitled to the commuting tax allowance. The shares of these types are represented by λ_j, and the size of the population is normalized to one. Income y_i is distributed continuously according to the cumulative distribution function $F(y)$.

The individuals gain their utility through consumption of a commodity good c and through commuting x_j. The price for the commodity good is normalized to one, and the commuting costs depend on the fuel price p_f, which is taxed by θ, and the amount of fuel used. The choice over the commuting distance and hence the labor supply decision is assumed to be inelastic. However, individuals can choose the effort e to commute more fuel-efficient. One example is driving slower. Using carpooling or park and ride are also possible ways to increase the fuel efficiency.[3] The higher the effort, the lower the costs for commuting, but the price for this effort is a lower commuting utility as it can be more time consuming and uncomfortable:

$$\frac{\partial u(e, x_j)}{\partial e} < 0, \frac{\partial^2 u(e, x_j)}{\partial e^2} \leq 0$$

[3]Note that the assumption of inelastic commuting distance does not mean that the distance by car must also be inelastic, as the use of carpools or park and ride also reduces the per capita distance.

For the fuel efficiency, we assume a function $\psi(e)$ with $\psi'(e) < 0$ and $\psi''(e) > 0$ that gives us the amount of fuel that is needed to commute one kilometer when effort e is chosen.

Through the consumption of fossil fuels, commuting produces CO_2 emissions which impact individuals' utilities negatively by $\gamma_j h(D)$, where $h'(D) > 0$, $h''(D) = 0$, γ_j represents a climate change awareness parameter, and D is the aggregate fuel consumption. We assume that those who live very close to their workplace (n-type) have the highest awareness since they live mostly in urban areas while those who commute by car have the same awareness:

$$\gamma_n > \gamma_s = \gamma_l$$

This assumption can be justified by looking at the green voters' spatial distribution. According to Brenke and Kritikos (2017), larger cities have the greatest share of green voters.

3.2.1 Consumption choice

Individuals with income y_i and commuting distance x_j maximize the following utility function:

$$U_{ij} = c + u(e, x_j) - \gamma_j h(D) \tag{3.1}$$

Their budget constraint is

$$y_i - t(y_i)(y_i - Ax_j) + T \geq 2(p_f + \theta)x_j\psi(e) + c. \tag{3.2}$$

The left-hand side is the net income, where $t(y_i)$ is the personal income tax rate and A is the commuting subsidy which comes in the form of a tax allowance that decreases the taxable income. T is a lump-sum transfer. The right-hand side of Equation (3.2) represents the price for the commodity good c and for commuting where the price for commuting has to be paid twice for going to and from the workplace.

Plugging Equation (3.2) into Equation (3.1) gives us the following maximization problem:

$$\max_{e} U_{ij}(e) = y_i - t(y_i)(y_i - Ax_j) + T - 2(p_f + \theta)x_j\psi(e) + u(e, x_j) - \gamma_j h(D) \tag{3.3}$$

The corresponding first-order condition is

$$\frac{\partial U_{ij}(e)}{\partial e} = -2(p_f + \theta)\psi'(e)x_j + \frac{\partial u(e, x_j)}{\partial e} = 0, \tag{3.4}$$

where we get an implicitly determined optimal efficiency effort $e_j(\theta, x_j)$.[4] Using the implicit function theorem, the following comparative statics can be computed:

$$\frac{\partial e(\theta, x_j)}{\partial \theta} = -\frac{1}{SOC_{e_j}}[-2\psi'(e)x_j] > 0 \tag{3.5}$$

$$\frac{\partial e(\theta, x_j)}{\partial x_j} = -\frac{1}{SOC_{e_j}}\left[-2(p_f + \theta)\psi'(e) + \frac{\partial^2 u(e, x_j)}{\partial e \partial x_j}\right] \lesseqgtr 0 \tag{3.6}$$

Higher fuel taxes lead to higher efficiency as they increase the marginal benefit of driving more efficiently. However, the effect of a longer commuting distance is not clear. The reason for this lies in the cross partial derivative of utility with respect to distance and efficiency effort. While it costs more to drive a longer distance, the disutility of driving more efficiently could increase with a higher distance. Regardless of the derivative's sign, we assume that the long-distance type always has higher commuting expenses than the short-distance type.

Notice that the chosen efficiency effort does not depend on an individual's income. Instead, the income effect is completely absorbed by the consumption of the commodity good. This result leads to a regressive fuel tax which is empirically verified (Bach et al., 2018). In Section 3.5, we discuss this result in more detail.

3.2.2 Economic equilibrium

An economic equilibrium is characterized by a balanced public budget. Fuel is taxed by θ, where the share $\alpha \in \{0; 1\}$ of the tax revenue is used to finance an increase in the commuting tax allowance A, which is paid only one-way, and the share $(1 - \alpha)$ is redistributed as a lump-sum transfer T.[5]

The aggregated demand for fuel in this economy is solely determined by the fuel con-

[4] The second-order condition for a global maximum is satisfied (see Appendix 3.A).

[5] We assume that the revenues can be only redistributed completely either through lump-sum transfers or through commuting allowances. However, in order to keep the notation simple, we treat α as a continuous variable.

sumption that emerges from commuting:

$$D(\theta) = \lambda_l 2x_l \psi(e_l(\theta)) + \lambda_s 2x_s \psi(e_s(\theta)) \tag{3.7}$$

The higher the fuel tax, the lower the aggregated demand:

$$\frac{\partial D(\theta)}{\partial \theta} = D' = \lambda_l 2x_l \psi'(e_l(\theta)) \frac{\partial e_l(\theta)}{\partial \theta} + \lambda_s 2x_s \psi'(e_s(\theta)) \frac{\partial e_s(\theta)}{\partial \theta} < 0 \tag{3.8}$$

The income tax rate t is a function of an individual's income y_i and it is politically not open to debate. The corresponding revenues cannot be redistributed as they are already used for other expenditures R:

$$\int t(y_i) y_i dF(y) = R \tag{3.9}$$

Now, the share α of the fuel tax revenue is used for the commuting tax allowance:

$$\alpha\theta D(\theta) = \lambda_l x_l A \int t(y_i) dF(y) \tag{3.10}$$

Only the l-types are entitled to a tax allowance, while both commuting types have to pay for the fuel taxes. We can rearrange Equation (3.10) and get the commuting tax allowance as a function of the fuel tax rate and the redistribution share:

$$A(\theta, \alpha) = \frac{\alpha\theta D(\theta)}{\lambda_l x_l \int t(y_i) dF(y)} = \frac{\alpha\theta D(\theta)}{\lambda_l x_l \bar{t}} \tag{3.11}$$

As the fuel tax rate is politically determined, it is important to know how the commuting tax allowance changes with an increasing or decreasing fuel tax rate. Hence, we compute the following derivative:

$$\frac{\partial A(\theta, \alpha)}{\partial \theta} = \frac{\alpha(\theta D'(\theta) + D(\theta))}{\lambda_l x_l \bar{t}} \tag{3.12}$$

The sign of this derivative is determined by the expression

$$\theta D'(\theta) + D(\theta) = D(\theta)(\epsilon_\theta + 1), \tag{3.13}$$

where $\epsilon_\theta = D'(\theta)\frac{\theta}{D(\theta)}$. Equation (3.13) is positive whenever the elasticity is greater than -1, which implies an inelastic reaction. According to Brons et al. (2008), the mean price elasticity for gasoline is -0.34 in the short run and -0.84 in the long run. Hence, an increase in the fuel tax rate increases the commuting tax allowance.

The share $1-\alpha$ of the fuel tax revenue is used for lump-sum transfers:

$$T(\theta, \alpha) = (1-\alpha)\theta D(\theta) \tag{3.14}$$

In contrast to the commuting tax allowance, everyone is entitled to these transfers.

Since commuting tax allowance and lump-sum transfer use the same tax revenue, a higher fuel tax for a given α also implies a higher lump-sum transfer:

$$\frac{\partial T(\theta, \alpha)}{\partial \theta} = (1-\alpha)D(\theta)(\epsilon_\theta + 1) > 0 \tag{3.15}$$

Inserting the commuting tax allowance (Equation (3.11)), the lump-sum transfer (Equation (3.14)), and the optimal efficiency efforts into the utility function gives us the indirect utility functions. Thus, for each commuting type, we get a different indirect utility function.

$$\begin{aligned} V_{il}(\theta, \alpha) &= y_i - t(y_i)(y_i - A(\theta, \alpha)x_l) + T(\theta, \alpha) - \gamma_l h(D(\theta)) \\ &\quad - 2(p_f + \theta)\psi(e_l(\theta))x_l + u(e_l(\theta), x_l) \end{aligned} \tag{3.16}$$

$$\begin{aligned} V_{is}(\theta, \alpha) &= (1 - t(y_i))y_i + T(\theta, \alpha) - \gamma_s h(D(\theta)) \\ &\quad - 2(p_f + \theta)\psi(e_s(\theta))x_s + u(e_s(\theta), x_s) \end{aligned} \tag{3.17}$$

$$V_{in}(\theta, \alpha) = (1 - t(y_i))y_i + T(\theta, \alpha) - \gamma_n h(D(\theta)) \tag{3.18}$$

The difference in the types is that they choose different fuel efficiency efforts and that only the long-distance commuter is entitled to the commuting tax allowance. Since the third type does not commute at all and therefore has no commuting expenses, his indirect utility function simplifies to Equation (3.18).

3.3 Social optimal choice

In this section, we analyze the social planner's optimal solution for the fuel tax and the redistribution scheme. Later, we compare this solution with the outcome in the political equilibrium. A utilitarian social planner maximizes the sum of the individuals' indirect utility functions with respect to the fuel tax rate θ and the redistribution share α:

$$\max_{\theta,\alpha} W(\theta,\alpha) = \int [\lambda_l V_{il} + \lambda_s V_{is} + (1-\lambda_l-\lambda_s)V_{in}]dF(y) \tag{3.19}$$

The first-order condition with respect to the fuel tax is given by:

$$-\bar{\gamma}h'(D)D' + \frac{\partial T}{\partial \theta} + \lambda_l \left(\frac{\partial A}{\partial \theta} x_l \bar{t}\right) - \sum_{j\neq n} \lambda_j 2\psi(e_j(\theta))x_j = 0 \tag{3.20}$$

The first three terms represent the marginal benefits of higher fuel taxes: emission reduction, higher lump-sum transfers and higher commuting tax allowances. The last term in Equation (3.20) captures the disadvantage of higher fuel taxes, namely higher commuting expenses.[6]

By inserting Equations (3.12) and (3.15) into the first-order condition (3.20), we get, after some further rearrangements, the following expression:

$$D'(\theta)(\theta - \bar{\gamma}h'(D)) = 0 \;\Leftrightarrow\; \theta = \bar{\gamma}h'(D) \tag{3.21}$$

We can see that a utilitarian social planner will choose a Pigouvian tax, as it equals the average marginal damage. A single individual does not consider that choosing the efficiency effort e, which determines the fuel consumption, affects the aggregated emissions E and therefore the utilities of others. The Pigouvian tax corrects this behavior which constitutes the standard problem of externalities.

The first-order condition with respect to the redistribution share α is given by:

$$\frac{\partial T}{\partial \alpha} + \lambda_l \frac{\partial A}{\partial \alpha} x_l \int t(y_i)dF(y) = 0 \tag{3.22}$$

Again, we can simplify this and get the following expression:

$$-D(\theta) + D(\theta) = 0 \tag{3.23}$$

This expression is independent of α which implies that every tax revenue allocation is optimal from a social perspective. While this result may seem surprising, it comes from

[6]The second-order condition for a global maximum is satisfied (see Appendix 3.A).

having both a utilitarian social planner and quasi-linear preferences. As a result, individuals have the same marginal utility of income, and while different redistribution schemes lead to different income distributions, the sum of utilities stays unchanged. We summarize this finding in the following proposition.

Proposition 3.1 (The social optimal choice)

i) The utilitarian social planner chooses a fuel tax rate that equals the average marginal damage, i.e. a pigouvian tax.

ii) Any redistribution of the fuel tax revenue is socially optimal.

3.4 Political equilibrium

In this section, we analyze the political equilibrium outcome. In the first stage, individuals decide how to redistribute the fuel tax revenues, and in the second stage they vote on the fuel tax rate. With this sequence, we follow Cremer et al. (2004a) with the difference that the refund rule in our model is also politically determined.[7] As we assume perfectly informed and rational individuals, we use backward induction to solve this problem.

3.4.1 Second stage: fuel tax

In this stage, every individual takes the redistribution scheme α as given and maximizes his indirect utility function with respect to the fuel tax θ. Since we have three distinct commuting groups with different indirect utility functions, we investigate their optimal choice separately.

[7] While this sequence of voting may be discussed, it seems to be accurate for the German Climate Package. During the negotiations for this package, the increase in the commuting allowance was decided early in the process. The tax rate, on the other hand, was determined later and even renegotiated in a second round from 10 euros per ton of CO_2 to 25 euros (Edenhofer et al., 2020).

3.4.1.1 Preferred fuel tax

Differentiating the indirect utility function (3.16) with respect to the fuel tax θ gives us the corresponding first-order condition for the long-distance commuters:

$$\frac{\partial V_{il}}{\partial \theta} = \frac{\partial A}{\partial \theta} t(y_i) x_l + \frac{\partial T}{\partial \theta} - \gamma_l h'(D(\theta)) D'(\theta) - 2\psi(e_l(\theta)) x_l = 0 \tag{3.24}$$

$$\Leftrightarrow D(\theta)(\epsilon + 1) \left[\alpha \frac{1}{\lambda_l} \frac{t(y_i)}{\bar{t}} + (1 - \alpha) \right] - \gamma_l h'(D(\theta)) D'(\theta) - 2\psi(e_l(\theta)) x_l = 0 \tag{3.25}$$

The first term represents the marginal benefit of a higher fuel tax from redistribution via lump-sum transfers and higher commuting allowances. The second term captures the marginal benefit of emission reduction, while the last term shows the marginal cost of a higher fuel tax due to higher commuting costs.

Equation (3.24) determines implicitly the fuel tax rate that is preferred by the long-distance commuter. We denote this variable as $\theta_{il}(\alpha)$. In order to have single-peaked preferences, we assume the second-order condition (SOC_θ) to be negative (see Appendix 3.A).

The short-distance commuter maximizes his indirect utility function (Equation (3.17)) and has the following first-order condition:

$$\frac{\partial V_{is}}{\partial \theta} = \frac{\partial T}{\partial \theta} - \gamma_s h'(D) D' - 2\psi(e_s(\theta)) x_s = 0 \tag{3.26}$$

$$\Leftrightarrow D(\theta)(\epsilon + 1)(1 - \alpha) - \gamma_s h'(D) D'(\theta) - 2\psi(e_s(\theta)) x_s = 0 \tag{3.27}$$

Again, we denote the fuel tax that solves this condition as $\theta_s(\alpha)$, and we assume the second-order condition to hold. If the revenue from higher fuel taxes is redistributed via higher commuting allowances ($\alpha = 1$), the s-type has a lower marginal benefit than the l-type. On the other hand, he has lower marginal costs than the long-distance type.

The type that is not commuting at all has the following first-order condition:

$$\frac{\partial V_{in}}{\partial \theta} = \frac{\partial T}{\partial \theta} - \gamma_s h'(D) D' > 0 \tag{3.28}$$

$$\Leftrightarrow \left[\theta D'(\theta) + D(\theta)\right](1 - \alpha) - \gamma_n h'(D) D'(\theta) > 0 \tag{3.29}$$

As he does not consume fuel, he has no marginal costs of higher fuel taxes. At the same time, even if the tax revenue should be completely redistributed through higher commuting allowances, he has a benefit of the emission reduction. Therefore, his first-order condition is always positive, implying that he wants the fuel tax to be as high as possible.

3.4.1.2 Identifying the median voter

In order to determine the median voter, we have to look at some comparative statics. Regarding the income y_i, we can compute the following derivatives:

$$\frac{\partial \theta_{il}}{\partial y_i} = -\frac{1}{SOC_{\theta_{il}}} \left[\theta D'(\theta) + D(\theta)\right] \left[\alpha \frac{1}{\lambda_l} \frac{t'}{\bar{t}}\right] \geq 0 \tag{3.30}$$

$$\frac{\partial \theta_s}{\partial y_i} = \frac{\partial \theta_n}{\partial y_i} = 0 \tag{3.31}$$

If $\alpha = 1$, the derivative for the l-type is positive. A higher income leads to a higher marginal income tax rate, and therefore the benefit of the commuting allowance increases. If $\alpha = 0$, the optimal fuel tax does not depend on income as the tax revenue is then redistributed completely via lump-sum transfers. The same is true for the s- and n-types as they are not entitled to commuting allowances.

In order to analyze the first stage, we also need to know how the preferred fuel tax depends on α. The following derivatives answer this question:

$$\frac{\partial \theta_{il}}{\partial \alpha} = -\frac{1}{SOC_{\theta_{il}}} \left[\theta D'(\theta) + D(\theta)\right] \left[\frac{1}{\lambda_l} \frac{t(y_i)}{\bar{t}} - 1\right] > 0 \tag{3.32}$$

$$\frac{\partial \theta_s}{\partial \alpha} = -\frac{-1}{SOC_{\theta_s}} \left[\theta D'(\theta) + D(\theta)\right] < 0 \tag{3.33}$$

$$\frac{\partial \theta_n}{\partial \alpha} = -\frac{-1}{SOC_{\theta_n}} \left[\theta D'(\theta) + D(\theta)\right] < 0 \tag{3.34}$$

Again, as the s- and n-types are not entitled to the commuting allowances' increase, they do not benefit if a larger share of the tax revenue is redistributed through commuting allowances. Instead, they get less from the tax revenue as lump-sum transfers. Hence, $\alpha = 1$ leads to a lower preferred fuel tax for these groups. For the l-type, it depends on the individual's income tax rate and on the population share of his group. We assume that this derivative is always positive, so that a higher commuting tax allowance is always better than a lump-sum transfer for the long-distance commuters.[8]

From the previous analysis, we know that the n-type cannot be the median voter since he wants the fuel tax rate to be as high as possible. Therefore, we need to compare the preferred fuel tax rates for the l- and s-type. We plug in the s-type's first-order condition into the l-type's first-order condition and get the following expression:

$$\left.\frac{\partial V_{il}}{\partial \theta}\right|_{\theta=\theta_s} = \alpha \frac{1}{\lambda_l}\frac{t(y_i)}{\bar{t}} D(1+\epsilon) - 2\Big(x_l \psi(e_l(\theta)) - x_s \psi(e_s(\theta))\Big) \gtreqless 0 \tag{3.35}$$

The first term represents the l-type's monetary benefit from the commuting tax allowance. The second term shows the difference in commuting expenditures. For example, suppose the tax revenues are completely redistributed via lump-sum transfers ($\alpha = 0$). In that case, Equation (3.35) is always negative, implying that the s-type's preferred fuel tax is higher, making him the median voter at this stage. This situation is illustrated in Figure 3.1.

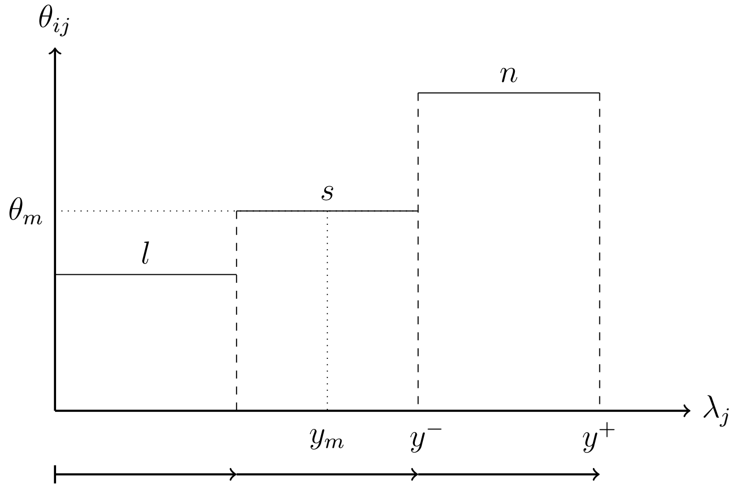

Figure 3.1: Preferred fuel taxes for $\alpha = 0$

However, if the fuel tax revenues are redistributed through higher commuting allowances, the monetary benefit from the higher commuting allowance may outweigh the difference in commuting expenditures. The sign of Equation (3.35) also depends on the l-type's

[8] Technically, we assume that $\frac{1}{\lambda_l}\frac{t(y_i)}{\bar{t}} > 1$. With the long-distance commuters not having more than 30% of the population share, this assumption implicates that an individual's income tax rate cannot be lower than 30% of the average tax rate within this group. As long-distance commuters have a higher income on average (Bundesministerium für Verkehr und digitale Infrastruktur (BMVI), 2018) and the German income tax rate is capped at 45%, this is not an unrealistic assumption.

income level and on the population share λ_l.

If α=1, we can define a critical income level $\hat{y}$ as the l-type's income level that leads to the same preferred fuel tax as the s-type's one. This critical income level is implicitely given by the following equation:

$$\frac{1}{\lambda_l}\frac{t(\hat{y})}{\bar{t}}D(1+\epsilon)-2\Big(x_l\psi(e_l(\theta))-x_s\psi(e_s(\theta))\Big)=0 \;\Leftrightarrow\; \theta_s=\theta_{il} \tag{3.36}$$

Whenever the l-type's income lies below $\hat{y}$, his preferred fuel tax rate is lower than the s-type's rate. Whether the l-type or the s-type is the median voter, therefore, depends on this critical income level and the l- and s-types' distribution. Whenever the number of s-type individuals plus the number of l-type individuals that have an income below $\hat{y}$ constitute more than 50% of the population, the median voter's solution is the s-type's preferred solution. However, if the number is below 50%, the l-type constitutes the median voter with the income of the median voter being determined by

$$\lambda_n+\lambda_l(1-F(y_m))=\frac{1}{2}\Leftrightarrow F(y_m)=1-\frac{0.5-\lambda_n}{\lambda_l}. \tag{3.37}$$

This situation is illustrated in Figure 3.2.

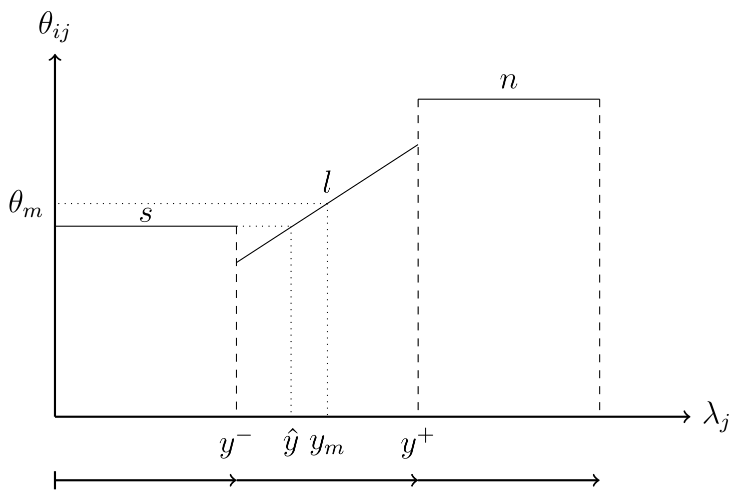

Figure 3.2: Preferred fuel taxes for $\alpha=1$

We summarize these results in the following Lemma:

Lemma 3.1 (The median voter over the fuel tax rate)

i) If the fuel tax revenues are redistributed via lump-sum transfers ($\alpha = 0$), the median voter will be a short-distance commuting type: $\theta_m = \theta_s$

ii) If the fuel tax revenues are redistributed through higher commuting allowances ($\alpha = 1$), it depends on the critical income $\hat{y}$ and the shares of l- and s-types in the population:

$$\theta_m = \begin{cases} \theta_s \text{ if } \lambda_s + \lambda_l F(\hat{y}) \geq 0.5 \\ \theta_{il} \text{ if } \lambda_n + \lambda_l(1 - F(\hat{y})) \geq 0.5 \end{cases}$$

The median voter's income for the second case is determined by $F(y_m) = 1 - \frac{0.5-\lambda_n}{\lambda_l}$.

In Germany, there are about 30% that commute below 5 km to work and another 30% that commute more than 20 km (Dauth and Haller, 2018). Together with the fact that especially the short-run elasticity for fuel is very low (Brons et al., 2008) and that long-distance commuters may drive more fuel efficient, it is likely that the l-type will be the median voter as both factors decrease the critical income $\hat{y}$.

3.4.1.3 Comparison to social optimum

In the last section, we saw that the median voter can be either a s- or l-type. Here, we want to compare both solutions to the social optimum. Evaluating the socially optimal first-order condition at the l-type's preferred fuel tax rate in the case where he is the median voter yields after some rearrangements:

$$\left.\frac{\partial W}{\partial \theta}\right|_{\theta=\theta_{il}} = \underbrace{\frac{\partial A}{\partial \theta} x_l t(y_m) \left(\lambda_l \frac{\bar{t}}{t(y_m)} - 1\right)}_{<0} + \underbrace{h'(D(\theta))D'(\theta)(\gamma_l - \bar{\gamma})}_{>0}$$
$$+ \underbrace{2\left(\psi(e_l(\theta))x_l - \sum_{j\neq n} \lambda_j \psi(e_j(\theta))x_j\right)}_{>0} \lesseqgtr 0 \qquad (3.38)$$

The first term in Equation (3.38) represents the difference in the ecotax rate that comes from the redistribution through higher commuting allowances within the long-distance commuters. It is negative because a l-type always prefers the redistribution via commuting allowances while he ignores that it does not benefit the other types. The negative sign means that this effect pushes the fuel tax rate over the social optimal level. The second term shows the awareness difference and is positive because the l-type has a below-average environmental awareness. The last term represents the difference in the commuting expenses and is also positive since the l-type has above-average commuting expenses.

If the s-type is the median voter, the comparison between his preferred rate and the social optimal rate is given by:

$$\left.\frac{\partial W}{\partial \theta}\right|_{\theta=\theta_s} = \underbrace{\frac{\partial A}{\partial \theta} x_l \lambda_l \bar{t}}_{>0} + \underbrace{h'(D(\theta))D'(\theta)(\gamma_s - \bar{\gamma})}_{>0}$$
$$+ \underbrace{2\left(\psi(e_s(\theta))x_s - \sum_{j \neq n} \lambda_j \psi(e_j(\theta))x_j\right)}_{\lesseqgtr 0} \lesseqgtr 0 \tag{3.39}$$

The first term comes from the l-type's commuting allowance. When the s-type constitutes the median voter, he ignores this effect while the social planner considers it. The second term again reflects the environmental awareness difference and is the same as for the l-type since $\gamma_l = \gamma_s$. The last term is the difference between the s-type's commuting expenses and the average commuting expenses. The sign is undetermined because the s-type has higher commuting expenses than the n-type but lower ones than the l-type. Therefore, we would need the exact distribution of the commuting expenses to say whether they are below- or above-average.

To sum up, for both median voter possibilities, the sign is undetermined because only one group wants a higher tax rate (n-type) than the median voter and the commuting type that is not the median voter prefers a lower tax rate. It then depends on the share of each group and the difference in their utilities whether the median voter's solution is socially inefficiently high or low.

3.4.2 First stage: preferred redistribution share

In this stage, individuals decide about their preferred redistribution mode α. Since we assume fully rational individuals, each group anticipates the identity of the median voter and his corresponding solution for the fuel tax rate.

3.4.2.1 The long-distance commuter

Starting with the long-distance commuter, we have the following optimization problem:

$$\max_{\alpha} V_{il}(\theta_m(\alpha),\alpha) = y_i - t(y_i)(y_i - A(\theta_m(\alpha),\alpha)x_l) + T(\theta_m(\alpha),\alpha) - \gamma_l h(D(\theta_m(\alpha))) \\ - 2(p_f + \theta_m(\alpha))\psi(e_l(\theta_m(\alpha)))x_l + u(e_l(\theta_m(\alpha)), x_l) \tag{3.40}$$

The following derivative can be computed:

$$\frac{\partial V_{il}}{\partial \alpha} = \underbrace{t(y_i)\frac{\partial A}{\partial \alpha}x_l + \frac{\partial T}{\partial \alpha}}_{>0} + \underbrace{\frac{\partial \theta_m}{\partial \alpha}}_{<0 \text{ if } \theta_m=\theta_s} \Bigg[\underbrace{t(y_i)\frac{\partial A}{\partial \theta_m}x_l + \frac{\partial T}{\partial \theta_m} - \gamma_l h' \frac{\partial D}{\partial \theta_m} - 2\psi(e_l(\theta_m))x_l}_{\leq 0} \\ - \frac{\partial e_l}{\partial \theta_m}\underbrace{(2(p_f + \theta_m)\psi'(e_l(\theta_m))x_l - u'(e_l(\theta_m)))}_{=0} \Bigg] > 0 \tag{3.41}$$

The first two terms represent the direct effect of α on the income, while the term in square brackets shows the indirect effects that work through the fuel tax rate. The terms in square brackets are also the l-type's first-order condition regarding the fuel tax rate evaluated at the median voter's optimal tax rate. Note that the terms in parenthesis drop out due to the Envelope theorem. To determine the sign of the terms, we have to remember that the identity of the median voter also depends on the redistribution scheme. For $\alpha = 0$, we know that the s-type prefers a higher fuel tax than the l-type, making him the median voter. With an increasing α, up to the point where the median voter changes, the expression in the square brackets is negative since the median voter's fuel tax rate is too high from the l-type's perspective. Since $\frac{\partial \theta_s}{\partial \alpha}$ is also negative, this makes the whole term positive. Hence, $\alpha = 1$ is always the l-type's preferred choice.

3.4.2.2 The short-distance commuter

The short-distance commuter maximizes his indirect utility function with respect to α:

$$\max_{\alpha} V_{is}(\theta_m(\alpha),\alpha) = y_i + T(\theta_m(\alpha),\alpha) - \gamma_s h(D(\theta_m(\alpha))) \\ - 2(p_f + \theta_m(\alpha))\psi(e_s(\theta_m(\alpha)))x_s + u(e_s(\theta_m(\alpha)), x_s) \tag{3.42}$$

Remember that the difference to the l-type is that the s-type is not entitled to a commuting tax allowance. The derivative of V_{is} with respect to α is given by

$$\frac{\partial V_{is}}{\partial \alpha} = \underbrace{\frac{\partial T}{\partial \alpha}}_{<0} + \underbrace{\frac{\partial \theta_m}{\partial \alpha}}_{>0 \text{ if } \theta_m = \theta_{il}} \left[\underbrace{\frac{\partial T}{\partial \theta_m} - \gamma_s h' \frac{\partial D}{\partial \theta_m} - 2\psi(e_s(\theta_m))x_s}_{\leq 0} \right. \tag{3.43}$$

$$\left. - \frac{\partial e_s}{\partial \theta_m} \underbrace{\left(2(p_f + \theta_m)\psi'(e_s(\theta_m))x_s - u'(e_s(\theta_m))\right)}_{=0} \right] < 0. \tag{3.44}$$

Again, the first term represents the direct financial effect while the term in squared brackets represents the indirect effects that work through the fuel tax rate. Compared to the l-type, we have opposite signs. A greater α decreases the lump-sum redistribution of the tax revenues. For $\alpha = 0$, this is the only effect, as the indirect effects drop out because the s-type is the median voter with the terms in square brackets being his first-order condition regarding the fuel tax rate. With an increasing α, the s-type's preferred fuel tax rate decreases up to the point where it may be lower than the l-type's preferred tax rate. From this point, the terms in square brackets become negative since the median voter's fuel tax rate is then too high from the s-type's perspective. Therefore, the s-type's preferred redistribution mode is $\alpha = 0$.

3.4.2.3 The non-commuter

The type that does not commute at all maximizes his indirect utility function with respect to α:

$$\max_{\alpha} V_{in}(\theta_m(\alpha), \alpha) = y_i + T(\theta_m(\alpha), \alpha) - \gamma_n h(D(\theta_m(\alpha))) \tag{3.45}$$

We can compute the following derivative:

$$\frac{\partial V_{in}}{\partial \alpha} = \underbrace{\frac{\partial T}{\partial \alpha}}_{<0} + \underbrace{\frac{\partial \theta_m}{\partial \alpha}}_{\lesseqgtr 0} \left(\underbrace{\frac{\partial T}{\partial \theta_m} - \gamma_n h'(D) \frac{\partial D}{\partial \theta_m}}_{>0} \right) \lesseqgtr 0 \tag{3.46}$$

Since he is not entitled to a commuting tax allowance, the direct effect of α is negative. But in contrast to the s-type, the indirect effect can be positive. The n-type wants the fuel tax to be as high as possible. Therefore, the term in parentheses is always positive. Now, it depends on the median voter's identity in the second stage, which is also affected by the choice of α. Starting from $\alpha = 0$, the median voter is always the s-type, which leads to a negative indirect effect and an overall negative equation. In this case, the n-type wants all the revenues redistributed via lump-sum transfers. However, with an increasing α the l-type may become the median voter, leading to a positive indirect effect since a higher α then leads to a higher fuel tax. It is then possible that the indirect effect outweighs the direct effect where $\alpha = 1$ would be the optimal choice. This is the case whenever

$$V_{in}(\alpha = 1) > V_{in}(\alpha = 0) \Leftrightarrow \gamma_n[h(D(\theta_m(\alpha = 1))) - h(D(\theta_m(\alpha = 0)))] - T(\theta_s) > 0. \tag{3.47}$$

Since the l-type prefers redistribution through a higher commuting allowance and the s-type through lump-sum transfers, the non-commuting type is the decisive voter in this stage. It is possible that he will strategically vote for redistribution through increased commuting subsidy in order to increase the median voter's fuel tax rate.

3.4.3 The political equilibrium

In this section, we want to use the previous results to look into two possible political equilibria that emerge within this model. In the first one, the tax revenues are completely redistributed via lump-sum transfers, and the short-distance commuting type decides about the fuel tax rate. In the second one, the tax revenues are used to increase the commuting tax allowance, and the long-distance commuter wants a higher fuel tax rate than the s-type.

We summarize this result in the following proposition:

Proposition 3.2 (Political equilibria and social efficiency)
There are two possible equilibria

i) $\alpha_{eq} = 0, \theta_{eq} = \theta_s$ *where* $\frac{\partial V_{in}}{\partial \alpha} < 0$ *or* $V_{in}(\alpha = 0) > V_{in}(\alpha = 1)$

ii) $\alpha_{eq} = 1, \theta_{eq} = \theta_{il}$ *where* $\frac{\partial V_{in}}{\partial \alpha} > 0$ *or* $V_{in}(\alpha = 0) < V_{in}(\alpha = 1)$

In both cases, the redistribution scheme is socially efficient while the fuel tax rate can be higher or lower than in the social optimum.

The second political equilibrium is the more surprising one since the l-type has higher commuting expenses, and the n-type, who does not commute but decides about the redistribution share, votes for a positive commuting tax allowance. It is more likely to occur whenever the n-type's environmental awareness is high enough. We argue that most of this type live in urban areas. At the same time, urban areas and especially larger cities have a growing number of green voters (Brenke and Kritikos, 2017). Moreover, more than 40 municipalities have already declared a climate emergency (Umweltbundesamt, 2020). Both facts indicate a high climate change awareness and hence make the second equilibrium more likely. This equilibrium is also the one that could explain the design of the German Climate Package.

3.5 Discussion

In the following section, we discuss some of our simplifying assumptions.

3.5.1 Exogenous commuting distance choice

In our model, we assume that the commuting distance is exogenous, which means that the choice is completely inelastic. From an empirical point of view, most studies focus on the fuel demand price elasticity rather than on the commuting elasticity. We argue that our efficiency effort variable may also reflect the fuel demand elasticity because a higher efficiency effort implies a lower fuel demand. A study that instead examines the commuting elasticity is done by Giménez-Nadal and Molina (2019). They find that a one percent increase in the gasoline tax rate leads to a 0.07 percent decrease in commuting time. In addition, they find that the share of daily commuting time spent by car decreases by 0.35 percent, while commuting time spent by public transportation increases by 0.16 percent and other physical commuting time increases by 0.26 percent if the gasoline tax rate increases by one percent. By treating the commuting distance exogenously, we reflect this large difference in the elasticities in a simplistic way.

However, if individuals could reduce their commuting distance, they would choose an efficiency-distance pair to maximize their utility. Thus, they would respond to the introduction of a tax not only by increasing efficiency but also by reducing commuting distance. It would be more difficult to get an analytically tractable solution as the distribution of the commuting distance would then also depend on the fuel tax. E.g., it would be possible that high-income individuals whose commuting distance is close to but less than 21 km would strategically prefer a high fuel tax to become entitled to the commuting allowance depending on whether they would gain a monetary benefit from the commuting allowance relative to the higher commuting expenses.

3.5.2 Quasi-linear preferences

The assumption of quasi-linear preferences is the reason for the absence of income effects in the effort to drive more efficiently. As mentioned earlier, this is a simplified method of modeling regressive taxation. There is evidence that high-income households use more energy per capita for their mobility than low-income households (Held, 2019). Nevertheless, this effect could be due to the fact that among the long-distance commuters, there are more high-income than low-income households in Germany (Bach et al., 2018). When it comes to fuel efficiency, there is less evidence. E.g., Cox et al. (2012) find that richer households in Scotland use less efficient cars (in terms of emission per km). However, the data is from 2006. The recent diffusion of electric vehicles could lead to higher efficiency for high-income households, as low-income households cannot afford these expensive cars.

If we would use a different utility function, e.g., a CES utility function, income effects would be present. Therefore, we would have a lower efficiency effort for high-income individuals because the higher the income, the more they could afford to drive less efficiently. In the second stage, an income effect would lead to a lower preferred fuel tax for long- and short-distance commuters due to the lower efficiency. And since one of the two types represents the median voter, a lower fuel tax in political equilibrium would result. In the first stage, it would depend on the strength of the income effect for the long- and short-distance commuters whether a redistribution via commuting allowance would be more or less likely. However, it would not change the possibility of having an equilibrium where the l-type constitutes the median voter in the second stage and the fuel tax revenues are used to increase the commuting tax allowance.

3.5.3 Influence of the COVID-19 pandemic

While the legislation process of Germany's Climate Package was already finished before the COVID-19 pandemic started, it may be of interest, how this event could change the outcome of the political equilibrium in the future. The pandemic drastically increased the number of employees that work remotely from home, which implies an increasing share of those who do not commute in our model ($\lambda_n \uparrow$). Now, whenever the share should rise above 50%, their group would represent the median voter in both stages. In this case, a socially inefficiently high fuel tax would be chosen and the tax revenues would be redistributed via lump-sum transfers. However, if the share stays below 50%, it depends on whether the share of long-distance commuters increases or decreases.

Another effect that could arise from the pandemic is that those who commute to work are now more likely to prefer to use private cars rather than public transport. In our model, this could be reflected by a lower fuel demand elasticity, which in turn would make the equilibrium that comes with a commuting allowance increase more likely.

3.6 Conclusion

This chapter studies the political economy of the German Climate Package, where the revenues of an introduced carbon tax are redistributed by an increase in the commuting tax allowances. In our political economy model, individuals differ regarding their commuting distance and income and vote over a fuel tax rate and how to redistribute the tax revenues. We show a political equilibrium where an increase in the allowance is introduced to enforce a higher carbon tax despite benefiting only those who commute the longest distance.

In recent history, this is the second time the redistribution scheme is used to increase an environmental tax rate in the political equilibrium in Germany. In 2003, the German Government introduced an ecotax reform where the revenues were mostly used to lower the pension contribution rate. Hence, using tax revenues to buy support from special groups can be a successful strategy to increase or introduce environmental taxes. However, using this strategy can create other problems. While in the first reform in 2003, the redistribution scheme was efficient as it lowered distortionary pension contribution rates, this may not be the case for the recent Climate Package. The increase in the commuting allowance does not decrease inefficiencies in other areas, implying that the double dividend hypothesis cannot be applied.

3.A Appendix

The second-order condition for the optimal efficiency effort is given by:

$$SOC_{e_j} = \frac{\partial^2 U_{ij}}{\partial e^2} = -2(p_f + \theta)\psi''(e)x_j + \frac{\partial^2 u(e, x_j)}{\partial e^2} < 0 \tag{3.48}$$

The second-order condition for socially optimal fuel tax rate is given by

$$\frac{\partial^2 W}{\partial \theta^2} = D''(\underbrace{\theta - \bar{\gamma}h'(D)}_{=0}) + D' < 0 \tag{3.49}$$

The second-order conditions for the individuals' preferred fuel tax rate are

$$\begin{aligned} SOC_{\theta_{il}} = \frac{\partial^2 V_{il}}{\partial \theta^2} &= (\theta D'' + 2D')\left[\alpha \frac{1}{\lambda_l}\frac{t(y_i)}{\bar{t}} + (1-\alpha)\right] - \gamma_l h'(D)D'' \\ &- 2\psi'(e_l(\theta))\frac{\partial e_l(\theta)}{\partial \theta}x_l, \text{ and} \end{aligned} \tag{3.50}$$

$$\begin{aligned} SOC_{\theta_s} = \frac{\partial^2 V_{is}}{\partial \theta^2} &= (\theta D'' + 2D')(1-\alpha) - \gamma_s h'(D)D'' - 2\psi'(e_s(\theta))\frac{\partial e_s(\theta)}{\partial \theta}x_s, \\ &\text{where } D'' = \lambda_l 2x_l\left(\psi''\frac{\partial e_l}{\partial \theta} + \psi'\frac{\partial^2 e_l}{\partial \theta^2}\right) + \lambda_s 2x_s\left(\psi''\frac{\partial e_s}{\partial \theta} + \psi'\frac{\partial^2 e_s}{\partial \theta^2}\right). \end{aligned} \tag{3.51}$$

Chapter 4

The Influence of Weather on Climate Change Concerns - Evidence from Germany

4.1 Introduction

Climate change is perceived increasingly often as a major threat. According to the Pew Research Center (2019), in 13 of 26 countries, people see it even as a top threat for their country. While there are psychological barriers that prevent individual engagement against climate change (e.g., see Gifford, 2011), there is evidence that the concerns about the impacts of climate change are a strong predictor for the acceptance of climate change mitigation and adaption programs (Poortinga et al., 2012; Tjernström and Tietenberg, 2008). If someone is not concerned about the consequences of climate change or even does not believe in it, he certainly will not take or support action against it. It is therefore essential to know what is driving these concerns and beliefs. van der Linden (2017) gives an overview of the determinants for climate change risk perception from different studies. Among demographic variables, he finds that gender, race, and political values affect the concerns while no clear pattern exists for age, education, and income. Furthermore, he finds that knowledge about climate change increases the concerns and that emotions have a strong effect. Another determinant of climate change concerns that van der Linden (2017) mentions is a personal experience with local weather changes and extreme weather events.

There are several reasons to study the influence of weather on climate change concerns. One is that climate change will not only lead to higher average temperatures but will most likely increase the frequency of extreme weather events (Coumou and Rahmstorf, 2012).

The question that then arises is if the experienced changes in weather patterns and extreme weather events could create a deeper concern and lead to a higher pressure on politicians to act. However, as a policy implication from their findings, Owen et al. (2012) point out that if the concerns only increase when the weather is getting more extreme, it is probably already too late for mitigation measures. Another motivation for studying weather effects is to investigate what heuristics people use to update their climate change concerns. If they are more likely to use simple information such as weather rather than scientific results to update their concerns, this could teach us a lesson for communicating climate change. Finally, weather effects are interesting from a methodological point of view because they influence the concerns and other variables - at least in the short term - exogenously, while other estimated determinants may be biased by reversed causality. Nevertheless, there are issues that could also bias the estimated weather effects. In particular, the selection of weather variables, which is a trade-off between multicollinearity and an omitted variable bias, and possible unobserved individual heterogeneity have to be mentioned.

The number of studies that look into the effect of weather on climate change concerns is growing fast. Most studies use air temperature as the only weather variable. For example, Hamilton and Stampone (2013) use a telephone-based survey in the U.S. to learn if people believe in anthropogenic climate change. They combine their survey data with temperature data and find that there is a higher probability of believing in anthropogenic climate change on unseasonable hot days. Zaval et al. (2014) confirm this finding and find that the underlying mechanism in the individuals' decision process is an attribution substitution where complex information is substituted by available but less relevant information like temperature. Other studies that look into the effect of temperature are Bergquist and Warshaw (2019), Brooks et al. (2014), Egan and Mullin (2012), Joireman et al. (2010), Kim et al. (2021), and Potoski et al. (2015). Demski et al. (2017) and Palm et al. (2017) use experienced weather extremes like heatwaves, floods, or storms as weather variables. Owen et al. (2012) find that recently experienced heat waves and droughts increase the probability of supporting environmental protection laws. Both Konisky et al. (2016) and Frondel et al. (2017) show that the experience of extreme weather events also increases climate change concerns.[1]

In this chapter, we study the influence of daily weather on climate change concerns in

[1]Note that this is only a fraction of all studies that link weather and climate change concerns or beliefs. For a more complete list, see Howe et al. (2019).

Germany. We use data from the German Socio-Economic Panel (SOEP) and combine it with daily weather data from the German Meteorological Office. The advantage of using the SOEP is that it provides repeated observations over a maximum of ten waves. Therefore, we can employ an individual fixed effects model to account for unobserved heterogeneity. Except for Kim et al. (2021), this is the only attempt to do so using a large representative survey to identify weather effects in climate change concerns. Compared to Kim et al. (2021), we also include wind speed, humidity, sunshine duration, and atmospheric pressure as weather variables to prevent an omitted variables bias. We find small but robust effects for precipitation and humidity on climate change concerns but negative effects for temperature in contrast to other studies. Furthermore, we show that it is important to control for unobserved heterogeneity and to include different weather variables.

This chapter is structured as follows. Section 4.2 presents our data sources and methodological issues that come with the data. In Section 4.3, we discuss the empirical method, and Section 4.4 shows the results. Section 4.5 covers several robustness checks, and Section 4.6 discusses the results and concludes this chapter.

4.2 Data

This section presents our two data sources, namely the German Socio-Economic Panel (SOEP) and the German Meteorological Office (Deutscher Wetterdienst, DWD). Moreover, we explain the merging procedure and discuss some methodological problems.

4.2.1 Data sources

4.2.1.1 German Socio-Economic Panel

The German Socio-Economic Panel is a nationally representative annual household survey with about 30,000 individuals and 15,000 households that began in 1984. Its longitudinal setting allows us to use panel techniques, where we are able to control for unobserved heterogeneity. The SOEP contains not only standard demographic information such as age, gender, income, education, marital status, etc., but it also covers many topics about political orientation, well-being, and other more subjective measures (Goebel et al., 2019).

Our main variable of interest comes from the question "*How much are you concerned about the impacts of climate change?*", where three answers are possible: [1] "very concerned", [2] "somewhat concerned", and [3] "not concerned at all". For our regressions, we collapse the variable about climate change concerns into two categories. It takes the value one if an individual is very concerned and zero if the individual is somewhat concerned or not concerned at all. This strategy allows us to use a simple binary model with individual fixed effects.[2] For the first time, the question about climate change concerns was asked in the 2009 wave. Since the question was subsequently asked in every wave, we use a total of ten waves for our analysis.

At the spatial level, we use the so-called spatial planning regions ("Raumordnungsregionen"). This regional classification was created by Germany's "Federal Institute for Research on Building, Urban Affairs and Spatial Development" for large-scale spatial analyses, and they were created by capturing the stream of commuters between counties and cities. One region combines several NUTS-3 regions ("Landkreise, kreisfreie Städte"), and overall there are 96 regions. The advantage of using this level compared to more small-scaled ones such as counties is that we have a higher probability of finding the correct weather effect. For example, consider that someone lives in a rural county but works in a large city. Since we have no information about his workplace, he will be matched with the weather in his county. Whenever there is a systematic difference in the weather between the workplace and the individual's residence, this can lead to biased estimates of the weather effect. In particular, this will matter for temperature since the temperature in large cities is higher than in the surrounding rural areas.[3] Additionally, we exclude individuals who move to a different planning region to avoid the potential bias that would occur if more climate-concerned individuals moved away because of weather.

4.2.1.2 German Meteorological Office

For our weather variables, we use data from the German Meteorological Office. It is open data and available through an online platform, called "Climate Data Center" where many different variables with different temporal resolutions are available (Deutscher Wetterdi-

[2]The alternative would be to use an ordered logit model with fixed effects (see Baetschmann et al., 2020). However, the interpretation of these models is more complicated, and the estimation methods are relatively new (e.g., there is no built-in command for this estimation in Stata).

[3]This phenomena is called urban heat island or heat island effect (Oke, 1973).

enst, 2021). In this study, we focus on the main weather variables. These are precipitation, temperature, wind speed, relative humidity, sunshine, and atmospheric pressure. Precipitation measures the precipitation height in mm for one day, temperature shows the average temperature in °C for one day, wind speed is the average wind speed in m/s during a day, sunshine is measured in hours per day, and atmospheric shows the average atmospheric pressure in hPa per day. The number of stations varies for each variable. We use 2,142 stations for precipitation, 568 for temperature and relative humidity, 354 for wind speed, 374 for sunshine duration, and 271 for atmospheric pressure. We exclude stations that lie offshore or above 1000 m since no one is expected to live there.[4] The mean for the euclidean distance between the population-weighted centroid of the respective planning region (see next section) and each station is about 28km.

Variable	Unit	Number	Mean distance (in m)
Mean temperature	°C	568	27,981.50
Sunshine duration	hours	374	27,811.11
Rel. humidity	%	568	27,981.50
Avg. wind speed	m/s	354	27,590.12
Atmospheric pressure	hPa	271	26,090.34
Precipitation	mm	2,142	28,519.47

Table 4.1: Weather stations

In the next section, we describe how we aggregate the weather data and combine it with the household data.

4.2.2 Merging procedure

Since the respondent's residence and the exact day of the interview are known, we can assign him the weather of his planning region.

To illustrate the merging procedure, consider Figure 4.1. It shows the spatial planning region of Augsburg, which includes four counties and the city of Augsburg. The orange dot is the computed population-weighted centroid of this region, while the red dots are

[4] The highest municipality in Germany is Balderschwang in Bavaria with an elevation of 1044m.

Figure 4.1: Weather stations within spatial planning regions

weather stations for temperature.[5] The dashed lines indicate the distance between these weather stations and the population-weighted centroid, and the green and blue circles show a 50 km respectively 25 km radius around the centroid. The weather variable of a region j at time t is the inverse distance-weighted average of all stations n in this region,

$$W_{jt} = \frac{\sum_{s=1}^{n} \frac{1}{d_s} w_s}{\sum_{s=1}^{n} \frac{1}{d_s}}, \tag{4.1}$$

where s indicates the weather station, w_s is the value for the station s, and d_s is the distance between the population-weighted centroid and the station s. In Section 4.5, we

[5]In most cases, the population-weighted centroid and the geometric centroid are close to each other due to the construction of the spatial planning region as a commuting center. But in cases where the region's biggest city is not in its center or we have more than one big city, their location can differ.

also include different aggregation methods as robustness check.

To merge the two data sets, we also have to think about which time span to use for the weather variables. Since we do not know the exact time of the interview and want to make sure that the individuals were at least 24 hours exposed to the weather, we use the average of the interview day plus the day before. We also use a time span of four days (interview date plus three days before) and a week to investigate possible mid-term weather effects (e.g. long-lasting rain). We calculate the weather variable in the following way

$$W_{jt}^{T} = \frac{1}{T}\sum_{x=0}^{T} W_{j,t-x}, \tag{4.2}$$

$$Prec_{jt}^{T} = \sum_{x=0}^{T} Prec_{j,t-x}, \tag{4.3}$$

where $T = (1, 3, 7)$. For precipitation, it is more intuitive to use the sum instead of the average.

4.2.3 Summary statistics

Before getting to the regression strategy, it is helpful to take a look at some descriptive statistics, which are shown in Table 4.2. About 29% of the pooled sample are very concerned about the impacts of climate change, 54% are somewhat concerned, and 17% are not worried at all. Notice that the mean temperature over all observations is lower than the mean temperature in Germany over the last ten years. This is driven by the interview distribution in the SOEP. About 70% of the interviews are conducted from February to May. The exact weather and interview distribution for the pooled sample is shown in Figure 4.3 in the appendix of this chapter.

	Observ.	Mean	Std. Dev.	Min	Max
CC: very concerned	170608	0.29	0.45	0.00	1.00
CC: somewhat concerned	170608	0.54	0.50	0.00	1.00
CC: not concerned	170608	0.17	0.38	0.00	1.00
Temperature	170608	7.58	7.20	−17.96	29.87
Precipitation	170608	1.68	3.65	0.00	118.27
Wind	170608	3.49	1.69	0.55	21.15
Humidity	170608	76.16	11.69	29.81	100.00
Sunshine	170608	4.74	4.24	0.00	16.38
Pressure	170608	984.31	26.74	872.96	1041.87
Household size	170608	2.71	1.34	1.00	14.00
Age	170608	51.50	17.24	17.00	105.00
Age squared	170608	2949.33	1814.65	289.00	11025.00
Log. HH income	170608	7.87	0.58	0.00	12.21
Gender	170608	0.53	0.50	0.00	1.00
Doctor visits	170608	9.73	14.95	0.00	396.00
Legally handicapped	170608	0.13	0.34	0.00	1.00
Academic deg.	170608	0.24	0.43	0.00	1.00
Unemployed	170608	0.06	0.23	0.00	1.00
Employment status					
Full-time	170608	0.38	0.48	0.00	1.00
Part-time	170608	0.14	0.35	0.00	1.00
Vocational	170608	0.02	0.13	0.00	1.00
Marginal	170608	0.06	0.23	0.00	1.00
Not employed	170608	0.41	0.49	0.00	1.00
Sheltered workshop	170608	0.00	0.03	0.00	1.00
Marital status					
Married	170608	0.61	0.49	0.00	1.00
Separated	170608	0.02	0.15	0.00	1.00
Single	170608	0.20	0.40	0.00	1.00
Divorced	170608	0.09	0.29	0.00	1.00
Widowed	170608	0.07	0.25	0.00	1.00

Table 4.2: Summary statistics

In Figure 4.2, we see how climate change concerns change through the years. Surprisingly, there seems to be no clear time trend. However, the share of very concerned individuals in wave 2017 is noticeably higher than in the previous waves.

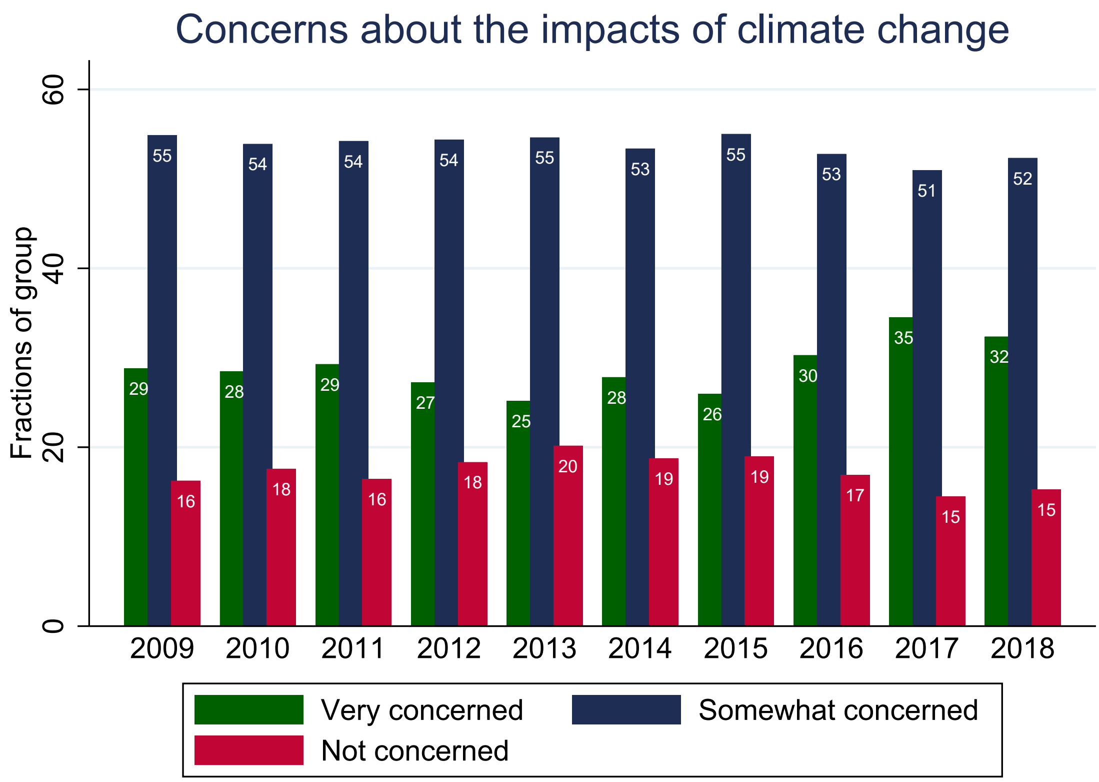

Figure 4.2: Climate change concerns in each wave

4.3 Empirical strategy

To study the link between weather and climate change concerns, we estimate the following linear probability model:

$$CC_{it} = W'_{it}\beta + X'_{it}\gamma + \alpha_i + \alpha_m + \alpha_t + \epsilon_{it} \tag{4.4}$$

CC_{it} is the main variable of interest that represents the climate change concerns. It takes the value one if individual i is very concerned about the impacts of climate change and zero if he is somewhat concerned or not concerned at all. W_{it} is a vector that contains the weather variables for individual i at the interview date t. As mentioned in Section

4.2, we use different time spans for all weather variables. For each time span, we run a separate regression. We also standardize our weather variables because each weather variable has a different unit. X_{it} is a vector with several control variables. It contains age, squared age, gender, the log of household income, household size, a dummy for an academic degree, marital status, employment status, the number of annual doctor visits, and a dummy for disability. β and γ are the corresponding coefficient vectors. α_i captures time-constant unobserved heterogeneity between individuals while α_m and α_t are month and year dummies. By including month fixed effects, we control for factors that occur every month for all individuals and correlate with our main variable and weather. We control for events that affect climate change concerns in the whole sample by including year fixed effects. To account for heteroscedastic error terms, we cluster our standard errors at the planning region level as the weather variable is aggregated at this level.

4.3.1 Unobserved heterogeneity

One of the main features of this study is to account for unobserved heterogeneity by including individual fixed effects. Especially since there is still an ongoing debate about the determinants of climate change concerns, it is not unreasonable to assume that there are many undetected factors correlated with climate change concerns and weather. An example is summer vacations. Households with a high climate change awareness may stay at home and are available for the survey interview, while less climate change aware households go on vacation. Since it is usually warmer and sunnier during summer vacation time, this response pattern could bias the estimation for temperature if we were to do a cross-sectional analysis.

To capture such unobserved factors, we estimate the model in Equation (4.4) by using the fixed effects estimator. The estimation relies only on the variation within individuals, which means that every time-constant variable is dropped. This way, we control for unobserved time-constant heterogeneity between individuals, but at the same time, we lose efficiency since we cannot use observable variation between individuals. An example of such variation would be an individual's birth year or, in most cases, gender (Wooldridge, 2010). Unfortunately, we cannot use the more efficient random effects specification since the null hypotheses that the unobserved heterogeneity is uncorrelated with the independent variables can be rejected after performing a Hausman test.

	Prec	Temp	W	H	S	Prs
Precipitation	1.00					
Temperature	0.10	1.00				
Wind	0.15	−0.10	1.00			
Humidity	0.29	−0.39	0.01	1.00		
Sunshine	−0.27	0.40	−0.21	−0.74	1.00	
Pressure	−0.14	0.04	0.02	−0.05	0.09	1.00

Table 4.3: Weather correlation matrix

4.3.2 Omitted variable bias

A problem that could arise by estimating Equation (4.4) is that standard errors could be inflated due to highly correlated weather variables. However, we cannot ignore these variables since it would lead to biased coefficients. When using weather variables, this is especially important since weather variables can have a high spatial and serial correlation (Auffhammer et al., 2013). Table 4.3 reports correlation coefficients for our weather variables on the day of the interview. All variables are significantly correlated, whereas the highest correlations coefficients are sunshine and humidity, sunshine and temperature, and temperature and humidity. E.g., if we would only include temperature, the effect of sunshine and humidity would be falsely assigned to the effect of temperature. Therefore, we must include all the weather variables, even if it is difficult to test if they have a solely significant impact. We also perform separate regressions for each weather variable to investigate the magnitude of this problem.

4.4 Results

4.4.1 Joint weather effects on climate change concerns

The results for our main specification are presented in Table 4.4. Every column shows results for our three different time spans. In Column (1), the average weather on the interview day plus the the day before was taken into account, in Column (2) the average weather on the interview date plus the weather of the last three days is used, and in Column (3) the average weather for the interview day plus the whole week before is used.

Overall, we can reject the null hypothesis that all weather variables jointly do not affect the concerns at the 5% significance level for the time spans $T = 1$ and $T = 3$. For $T = 7$, the p-value is slightly above the 10% mark. Furthermore, we find small but significant effects on climate change concerns for temperature, humidity, and precipitation. A one standard deviation increase in the precipitation with a time span $T = 3$ (8.86 mm, see Table 4.9) leads to a 0.26 percentage points higher probability for someone being very concerned about the impacts of climate change. The coefficient estimate is significant at a significance level of 5%. Regarding humidity, we find significant effects for all possible time spans. A one standard deviation decrease (increase) in the average humidity (about 10 perc. points) for $T = 3$ and $T = 7$ increases (decreases) the probability by about 0.5 percentage points to be very concerned about climate change. For $T = 1$, the coefficient estimate is somewhat smaller and less significant. In contrast to many earlier findings, we see negative significant effects for temperature. A one standard deviation decrease (increase) in the average temperature (about 7°C) for $T = 1$ and $T = 3$ leads to a 0.4 percentage points higher (lower) probability to be very concerned. In Section 4.6, we discuss these findings in more detail.

Besides our weather variables, we have to mention some interesting results for the control variables. Regarding the socio-economic variables, we find only significant effects for employment, gender, and marital status. A part-time employment increases the probability of being very concerned compared to a full-time employment while being in a sheltered workshop decreases it. Being separated decreases the probability of being very concerned about climate change impacts compared to being married. Notice that the coefficient for gender is very large. However, the reason for this is that we have only three observations changing their gender between waves. Therefore, the coefficient is hardly interpretable.

A likely explanation for the lack of more significant control variables is that there is not enough within variation in the sample. This is especially true for variables like education, occupation, and marital status. The age coefficient cannot be interpreted due to collinearity with the year dummies.

Dep. var.: CC: very concerned	(1)		(2)		(3)	
	$T = 1$		$T = 3$		$T = 7$	
Temperature	-0.0039^{**}	(0.0017)	-0.0042^{**}	(0.0019)	-0.0019	(0.0021)
Precipitation	0.0014	(0.0011)	0.0026^{**}	(0.0012)	0.0012	(0.0013)
Wind	0.0013	(0.0012)	0.0005	(0.0013)	0.0012	(0.0014)
Humidity	-0.0037^{*}	(0.0021)	-0.0053^{**}	(0.0022)	-0.0055^{**}	(0.0025)
Sunshine	0.0004	(0.0018)	-0.0023	(0.0020)	-0.0033	(0.0022)
Pressure	-0.0047	(0.0034)	-0.0031	(0.0037)	-0.0027	(0.0048)
Household size	-0.0032	(0.0026)	-0.0032	(0.0026)	-0.0032	(0.0026)
Age	-0.0015	(0.0181)	-0.0014	(0.0180)	-0.0015	(0.0180)
Age squared	0.0000	(0.0000)	0.0000	(0.0000)	0.0000	(0.0000)
Log. HH income	-0.0065	(0.0045)	-0.0064	(0.0045)	-0.0064	(0.0045)
Gender	0.3250^{*}	(0.1675)	0.3251^{*}	(0.1683)	0.3242^{*}	(0.1683)
Doctor visits	0.0000	(0.0001)	0.0000	(0.0001)	0.0000	(0.0001)
Legally handicapped	0.0050	(0.0058)	0.0050	(0.0058)	0.0050	(0.0058)
Academic deg.	-0.0116	(0.0154)	-0.0117	(0.0155)	-0.0117	(0.0155)
Unemployed	0.0039	(0.0062)	0.0039	(0.0062)	0.0038	(0.0062)
Employment status						
Full-time	ref.		ref.		ref.	
Part-time	0.0134^{**}	(0.0053)	0.0134^{**}	(0.0052)	0.0134^{**}	(0.0053)
Vocational	-0.0018	(0.0118)	-0.0017	(0.0118)	-0.0017	(0.0119)
Marginal	0.0107	(0.0075)	0.0107	(0.0075)	0.0108	(0.0075)
Not employed	0.0056	(0.0056)	0.0056	(0.0056)	0.0057	(0.0056)
Sheltered workshop	-0.0896^{*}	(0.0514)	-0.0900^{*}	(0.0514)	-0.0896^{*}	(0.0512)
Marital status						
Married	ref.		ref.		ref.	
Separated	-0.0228^{*}	(0.0130)	-0.0228^{*}	(0.0131)	-0.0228^{*}	(0.0130)
Single	-0.0011	(0.0105)	-0.0011	(0.0105)	-0.0012	(0.0105)
Divorced	0.0022	(0.0128)	0.0022	(0.0128)	0.0022	(0.0127)
Widowed	0.0009	(0.0130)	0.0011	(0.0129)	0.0011	(0.0130)
Month FE	✓		✓		✓	
Wave FE	✓		✓		✓	
Observations	170608		170608		170608	
R^2	0.008		0.008		0.008	
p-value (Weather)	0.0113		0.0244		0.1209	

Notes: Significance: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.
Standard errors (parentheses) are clustered at the planning regions' level.

Table 4.4: Weather effects on climate change concerns

4.4.2 Temperature categories and squared temperature

It is possible that the temperature effects on climate change concerns are non-linear, especially since previous findings suggest that both negative and positive extreme temperatures increase climate change concerns (Brooks et al., 2014). Therefore, we include squared temperature variables and categorized temperature variables with five bins into our regressions. Table 4.5 shows the results for those regressions.

The coefficient estimates for the temperature bins are shown in Columns (1) through (3). The lowest category has the greatest positive values, which become smaller for the subsequent three categories. For the highest temperature category, the coefficients become larger again, especially for $T = 3$ and $T = 7$, indicating that there indeed may exist non-linear effects. However, the difference between the coefficients and the reference category is not significantly different from zero. Column (4) through (6) show the coefficient estimates for the squared temperature. While the signs indicate a u-shaped relationship between temperature and climate change concerns, the quadratic coefficient term is not significantly different from zero.

In Section 4.6, we discuss these results and present some possible explanations.

Dep. var.: CC: very concerned						
	Temperature cat.			Squared temperature		
	(1)	(2)	(3)	(4)	(5)	(6)
	$T = 1$	$T = 3$	$T = 7$	$T = 1$	$T = 3$	$T = 7$
$x < -10°C$	0.0080	0.0073	0.0241			
	(0.0113)	(0.0135)	(0.0169)			
$-10°C \leq x < 0°C$	0.0025	0.0041	0.0004			
	(0.0034)	(0.0032)	(0.0031)			
$0°C \leq x < 10°C$	ref.	ref.	ref.			
$10°C \leq x < 20°C$	−0.0044	−0.0005	−0.0006			
	(0.0037)	(0.0038)	(0.0041)			
$20°C \leq x$	−0.0009	0.0076	0.0051			
	(0.0067)	(0.0064)	(0.0075)			
Precipitation	0.0013	0.0024*	0.0010	0.0014	0.0025*	0.0011
	(0.0011)	(0.0013)	(0.0013)	(0.0011)	(0.0013)	(0.0013)
Wind	0.0013	0.0006	0.0012	0.0015	0.0007	0.0014
	(0.0012)	(0.0013)	(0.0014)	(0.0012)	(0.0013)	(0.0014)
Humidity	−0.0035*	−0.0049**	−0.0052**	−0.0035	−0.0051**	−0.0051**
	(0.0021)	(0.0022)	(0.0024)	(0.0021)	(0.0022)	(0.0025)
Sunshine	0.0001	−0.0030	−0.0038*	0.0002	−0.0027	−0.0041*
	(0.0018)	(0.0020)	(0.0022)	(0.0018)	(0.0021)	(0.0022)
Pressure	−0.0041	−0.0025	−0.0029	−0.0048	−0.0033	−0.0031
	(0.0035)	(0.0037)	(0.0046)	(0.0034)	(0.0037)	(0.0047)
Temperature				−0.0032*	−0.0033	−0.0001
				(0.0018)	(0.0022)	(0.0023)
Squared temp.				0.0010	0.0012	0.0020
				(0.0011)	(0.0013)	(0.0013)
Controls	✓	✓	✓	✓	✓	✓
Month FE	✓	✓	✓	✓	✓	✓
Wave FE	✓	✓	✓	✓	✓	✓
Observations	170608	170608	170608	170608	170608	170608
R^2	0.008	0.008	0.008	0.008	0.008	0.008

Notes: Significance: $^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.
Standard errors (parentheses) are clustered at the planning regions' level.

Table 4.5: Weather effects on climate change concerns with temperature categories and squared temperature

4.4.3 Weather effects for each weather variable alone

To demonstrate the possible bias due to omitted weather variables, we run separate regressions for every single weather variable. The results from these regressions are shown in Table 4.6. Each row represents results from separate regressions. The most striking difference to Table 4.4 can be seen for $T = 3$. If solely taken into account, the average of the wind speed on the interview day plus the last three days has a significant positive effect on the probability of being very concerned about climate change impacts. Moreover, the coefficient estimate is almost five times larger than the estimate in Table 4.4, where all weather variables are being used. Without taking the other weather variables into account, one could be inclined to interpret this as a strong wind effect, while part of this effect could come from precipitation since both variables are correlated.

Dep. var.: CC: very concerned			
	(1)	(2)	(3)
	$T = 1$	$T = 3$	$T = 7$
Temperature	−0.0021	−0.0030*	−0.0009
	(0.0016)	(0.0018)	(0.0020)
Precipitation	0.0008	0.0019*	0.0010
	(0.0011)	(0.0011)	(0.0012)
Wind	0.0023**	0.0024**	0.0029**
	(0.0010)	(0.0012)	(0.0012)
Humidity	−0.0027**	−0.0017	−0.0020
	(0.0014)	(0.0016)	(0.0019)
Sunshine	0.0011	−0.0007	−0.0010
	(0.0012)	(0.0014)	(0.0017)
Pressure	−0.0039	−0.0045	−0.0051
	(0.0028)	(0.0032)	(0.0042)
Controls	✓	✓	✓
Month FE	✓	✓	✓
Wave FE	✓	✓	✓
Observations	170608	170608	170608

Notes: Significance: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. Standard errors (parentheses) are clustered at the planning regions' level.

Table 4.6: Weather effects on climate change concerns with just one independent weather variable

4.4.4 Heterogeneity in terms of age, gender, and education

According to Hornsey et al. (2016), gender, age and education have small but significant effects on climate change beliefs. Hence, it is not unreasonable to assume that the weather effects may also depend on these demographic variables. To detect if there are such effects present, we include interaction terms in our regressions. Specifically, interaction terms between all the weather variables and dummy variables for age, gender, and academic education are created. Alternatively, we could split the sample. However, the coefficient estimates would rely on much smaller samples, making it more difficult to detect the small significant effects that we have in the full sample. Moreover, it is impossible to tell whether the differences in coefficients between the samples are significant with a sample split. Since it is problematic to interpret age as a continuous variable in a fixed effects model, we use a dummy variable for being under 30 years old.

Table 4.7 shows the estimation results for the time span $T = 1$. Results for $T = 3$ and $T = 7$ are shown in Tables 4.12 and 4.13 in the appendix of this chapter. For $T = 1$ and $T = 3$, we find only one significant interaction term: the interaction between having an academic degree and sunshine duration. Having an academic degree makes someone 0.68 ($T = 1$) respectively 0.95 ($T = 3$) percentage points more likely to be very concerned about climate change than someone without an academic degree when sunshine duration increases by one standard deviation. Adding the base effect and interaction effect, we can say that a one standard deviation increase in sunshine duration increases the probability of being very concerned by 0.55 ($T = 1$) respectively 0.49 ($T = 3$) percentage points if someone has an academic degree. One possible explanation for this result could be that most people view sunshine duration as unproblematic in relation to climate change and do not recognize unseasonable patterns. Compared to the other weather variables, positive outliers may not be perceived directly or even perceived as pleasant, with individuals with higher education appearing to be more unbiased in their perceptions.

Dep. var.: CC: very concerned						
	(1)		(2)		(3)	
	Female		Age < 30		Academic	
Temperature	−0.0057***	(0.0020)	−0.0036*	(0.0018)	−0.0030	(0.0020)
Precipitation	0.0012	(0.0017)	0.0020	(0.0012)	0.0018	(0.0013)
Wind	0.0004	(0.0016)	0.0015	(0.0013)	0.0014	(0.0015)
Humidity	−0.0023	(0.0028)	−0.0039*	(0.0023)	−0.0048*	(0.0025)
Sunshine	0.0010	(0.0025)	0.0007	(0.0019)	−0.0013	(0.0021)
Pressure	−0.0068	(0.0043)	−0.0050	(0.0036)	−0.0028	(0.0040)
Female	0.3240*	(0.1663)				
Female × Temperature	0.0035	(0.0025)				
Female × Precipitation	0.0005	(0.0024)				
Female × Wind	0.0019	(0.0022)				
Female × Humidity	−0.0026	(0.0037)				
Female × Sunshine	−0.0011	(0.0031)				
Female × Pressure	0.0040	(0.0048)				
Age < 30			−0.0083	(0.0091)		
Age < 30 × Temperature			−0.0029	(0.0035)		
Age < 30 × Precipitation			−0.0045	(0.0035)		
Age < 30 × Wind			−0.0021	(0.0037)		
Age < 30 × Humidity			0.0016	(0.0054)		
Age < 30 × Sunshine			−0.0031	(0.0053)		
Age < 30 × Pressure			0.0033	(0.0062)		
Academic deg.					−0.0119	(0.0155)
Academic deg. × Temperature					−0.0033	(0.0034)
Academic deg. × Precipitation					−0.0015	(0.0022)
Academic deg. × Wind					−0.0004	(0.0026)
Academic deg. × Humidity					0.0045	(0.0039)
Academic deg. × Sunshine					0.0068*	(0.0036)
Academic deg. × Pressure					−0.0076	(0.0065)
Controls	✓		✓		✓	
Month FE	✓		✓		✓	
Wave FE	✓		✓		✓	
Observations	170608		170608		170608	
R^2	0.008		0.008		0.008	

Notes: Significance: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.
Standard errors (parentheses) are clustered at the planning regions' level.

Table 4.7: Weather effects on climate change concerns with interaction terms for $T = 1$

4.4.5 Weather effects on other worries and life satisfaction

Besides different interactions, another question that arises is if weather only affects the climate change worries or works through other concerns. Especially environmental concerns are of importance to investigate if weather specifically affects climate change concerns or environmental concerns in general. Moreover, one could ask if the concerns come from worries about personal financial impacts.

It is also reasonable to examine the weather effects on life satisfaction since there is a growing amount of literature that investigates this matter, e.g., Barrington-Leigh and Behzadnejad (2017), Connolly (2013), and Feddersen et al. (2016). Therefore, the weather effect may work through life satisfaction, which in turn affects climate change concerns.

In Tables 4.8, we look into this question by regressing environmental concerns, financial concerns, and life satisfaction on our weather variables. Columns (1) through (3) of Table 4.8 present the coefficient estimates for $T = 1$, $T = 3$ and $T = 7$ for environmental worries. We find only weak significant effects for humidity and barometric pressure. However, with 22.58%, the p-value for the joint significance test is quite high. In Columns (4) through (6), we see the regression results if we use financial worries as the dependent variable. Here, we cannot detect significant weather effects. Columns (7) through (9) show the coefficient estimates if we use life satisfaction as our variable of interest. Note that life satisfaction is measured on an 11-point scale. We do not find any weather effect that would be significantly different from zero. These results indicate that weather indeed affects climate change concerns directly and not through other domains of worries or life satisfaction.

Dep. var.:	Environmental concerns			Financial concerns			Life satisfaction		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$T = 1$	$T = 3$	$T = 7$	$T = 1$	$T = 3$	$T = 7$	$T = 1$	$T = 3$	$T = 7$
Temperature	−0.0010	−0.0000	0.0021	0.0003	−0.0001	−0.0003	−0.0095	−0.0112	−0.0127
	(0.0020)	(0.0019)	(0.0021)	(0.0016)	(0.0019)	(0.0024)	(0.0073)	(0.0073)	(0.0084)
Precipitation	0.0010	0.0015	0.0019	0.0004	0.0003	0.0000	−0.0057	−0.0021	−0.0070
	(0.0010)	(0.0011)	(0.0016)	(0.0010)	(0.0011)	(0.0012)	(0.0044)	(0.0043)	(0.0053)
Wind	0.0003	0.0002	−0.0005	−0.0016	−0.0019	−0.0014	0.0006	−0.0037	0.0019
	(0.0014)	(0.0017)	(0.0019)	(0.0011)	(0.0013)	(0.0013)	(0.0049)	(0.0041)	(0.0045)
Humidity	−0.0030*	−0.0031	−0.0040*	−0.0001	0.0004	0.0004	−0.0008	−0.0063	−0.0060
	(0.0017)	(0.0019)	(0.0023)	(0.0015)	(0.0015)	(0.0019)	(0.0057)	(0.0058)	(0.0073)
Sunshine	0.0004	−0.0006	−0.0005	−0.0021	−0.0020	−0.0031	−0.0008	−0.0095	−0.0051
	(0.0017)	(0.0018)	(0.0021)	(0.0016)	(0.0016)	(0.0022)	(0.0060)	(0.0065)	(0.0091)
Pressure	−0.0068*	−0.0047	−0.0039	0.0038	0.0033	0.0050	−0.0184	−0.0134	−0.0203
	(0.0039)	(0.0040)	(0.0046)	(0.0032)	(0.0039)	(0.0053)	(0.0129)	(0.0134)	(0.0155)
Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓
Month FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Wave FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Observations	170487	170487	170487	170487	170487	170487	167339	167339	167339
R^2	0.006	0.006	0.006	0.024	0.024	0.024	0.019	0.019	0.019
p-value	0.2292	0.4291	0.2175	0.4190	0.2879	0.3575	0.5209	0.3143	0.4634

Notes: Significance: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.
Standard errors (parentheses) are clustered at the planning regions' level.

Table 4.8: Weather effects on other domains of worries and life satisfaction

4.5 Robustness and sensitivity checks

In this section, different robustness and sensitivity analyses are presented.

4.5.1 Pooled OLS and logistic regressions

Columns (1) and (2) in Table 4.10 show the coefficient estimates if individual fixed effects are not included. The size of the precipitation coefficient is twice the size of the coefficient where individual fixed effects are included. Moreover, we get a different sign for the temperature coefficient. Both findings indicate that unobserved individual heterogeneity between individuals explains a large proportion of the variation in climate change concerns. This argument is strengthened if we look at the result from the F-Test, which is reported in Columns (3) and (4). The null hypothesis that the individual fixed effects have no joint effect can be strongly rejected. Another way to look at the importance of individual fixed effects is to do a simple OLS regression where we have a dummy for every individual as the only independent variable. It yields a R^2 of 0.55 and an adjusted R^2 of 0.41.[6] Since we have a binary dependent variable, it is also possible to use a logistic regression model with individual fixed effects. Results from this estimation are shown in Columns (5) and (6) of Table 4.10 as odds ratios. A value less than one indicates a negative effect, a value greater than one a positive effect. We see that the results with respect to sign and significance are similar to those that are estimated by the linear fixed effects model.

4.5.2 Different weather aggregation methods

In Table 4.11, the sensitivity of the results regarding the weather aggregation method is tested. Three alternative methods are shown, namely nearest neighbor (NN), station mean (SM), and squared inverse distance weighting (SQ). The NN method uses the station that is nearest to the population-weighted centroid. SM means that we have no distance weighting at all, and in the SQ method, we use the squared inverse distance to the population-weighted centroid as station weights. The first three columns show coefficient estimates for $T = 1$ and the second three for $T = 3$. The coefficient estimates from

[6] With this approach, we follow Feddersen et al., 2016. The R^2 values in the remainder of the chapter are within values without the variation that comes from the individual fixed effects.

the SM and the SQ method are similar to the results from the normal inverse distance weighting in Table 4.4. The NN method produces somewhat larger differences, and the precipitation coefficient generally reacts more sensitive to the aggregation method. However, all methods show the same signs and show a jointly significant effect of weather on climate change concerns.

4.6 Discussion and conclusion

This chapter studies the effect that weather has on climate change concerns. We find small but significant and robust weather effects on the probability of being very concerned about the impacts of climate change. A high amount of precipitation and low humidity increase the probability of reporting a deep concern. In contrast to many earlier findings, we find negative effects of temperature on the probability of being very concerned about climate change impacts.

There are some possible explanations for the negative temperature coefficient. The first one is that most studies focus on the United States and have therefore different climatic conditions and different weather expectations. Another explanation concerns the data. Almost 90% of the interviews in the SOEP are conducted between February and April. Hence, there are only a few observations with temperatures over 30°C or higher. Moreover, there are many negative outliers in our sample (see Figure 4.3). Therefore, it is possible that in a linear model, the negative effect outweighs the positive one. But even in the specification with temperature bins and squared temperature, we cannot detect a significant positive effect of higher temperatures. While the absence of a positive effect may be a puzzle, the existence of a negative effect is not necessarily surprising. Capstick and Pidgeon (2014) and Brooks et al. (2014) also find that negative temperatures increase climate change concerns.

The channels through which these effects work remain unclear. We find no evidence that these weather effects work through life satisfaction or other domains of worry. But it is not apparent if these effects work through the physical experience of weather or media coverage.

In general, the effects are quite small and are probably only detectable due to the large sample size. One explanation is that we estimate an average effect for the whole German population where many individuals simply may not be nor feel affected by daily weather changes. Therefore, it is unlikely that the experience of weather changes will create a higher political pressure. However, it is possible that those stronger affected groups, farmers for example, have more political influence. Unfortunately, the SOEP does not contain enough information about the current occupation to test this theory.

4.A Appendix

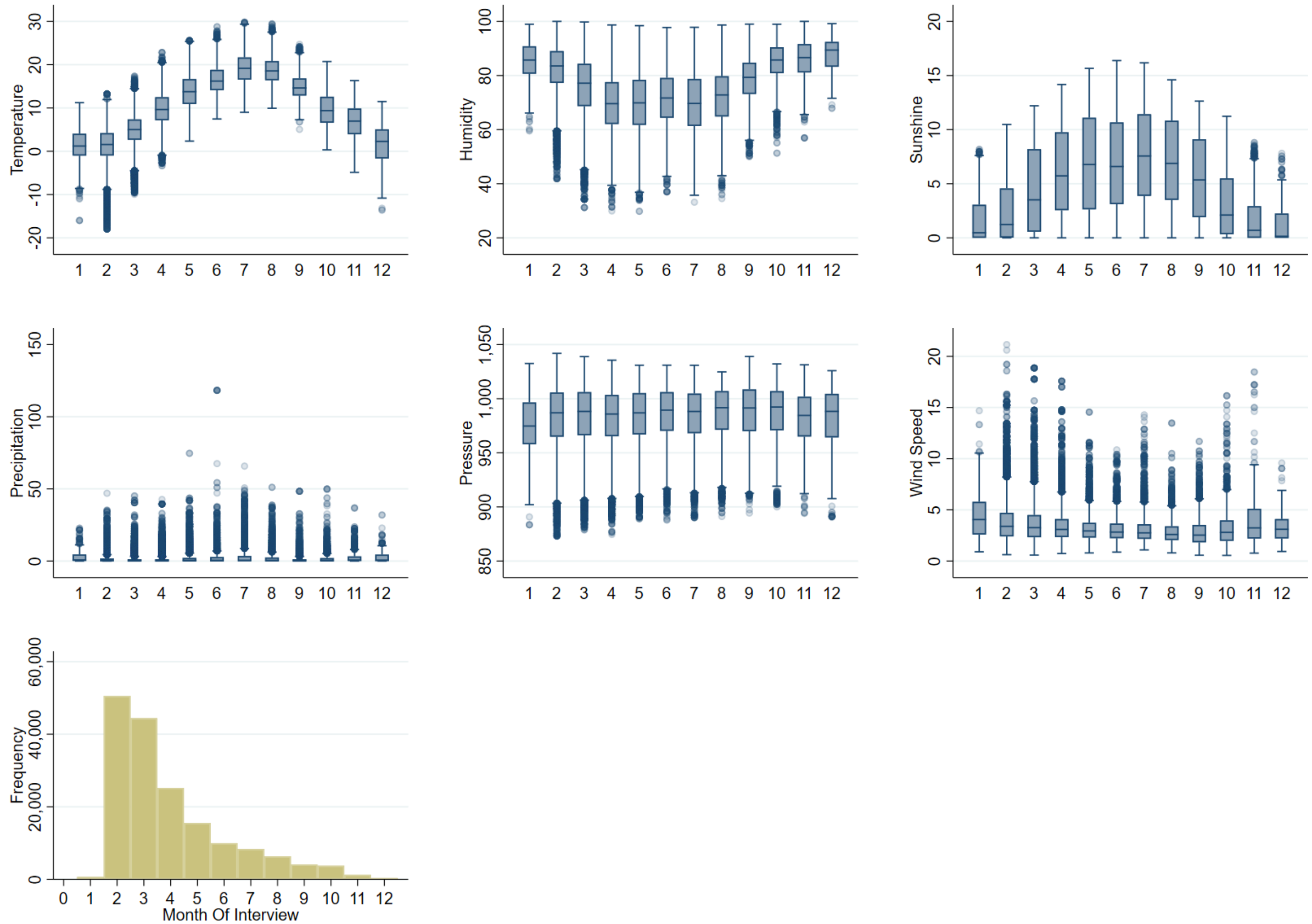

Figure 4.3: Weather and interview distribution over months

	Observ.	Mean	Std. dev.	Min	Max
$T = 1$					
Temperature	170608	7.55	7.13	−16.84	29.80
Precipitation	170608	3.38	5.77	0.00	131.35
Wind	170608	3.50	1.55	0.57	20.18
Humidity	170608	76.16	10.82	28.59	100.00
Sunshine	170608	4.73	3.70	0.00	16.15
Pressure	170608	984.25	26.61	874.14	1041.50
$T = 3$					
Temperature	170608	7.47	7.02	−16.22	29.17
Precipitation	170608	6.70	8.86	0.00	135.66
Wind	170608	3.51	1.39	0.88	18.64
Humidity	170608	76.21	9.78	31.29	99.21
Sunshine	170608	4.71	3.20	0.00	15.65
Pressure	170608	984.17	26.37	870.77	1040.92
$T = 7$					
Temperature	170608	7.29	6.88	−14.45	27.68
Precipitation	170608	13.24	13.56	0.00	170.12
Wind	170608	3.51	1.23	0.90	15.48
Humidity	170608	76.42	8.72	40.22	97.11
Sunshine	170608	4.65	2.76	0.00	14.74
Pressure	170608	984.15	26.07	872.95	1038.94

Table 4.9: Summary statistics for the weather variables

Dep. var.: CC: very concerned	Pooled OLS		Fixed effects		Logit fixed effects	
	(1)	(2)	(3)	(4)	(5)	(6)
	$T = 1$	$T = 3$	$T = 1$	$T = 3$	$T = 1$	$T = 3$
Temperature	0.0022	0.0014	-0.0039^{**}	-0.0042^{**}	0.9701^{*}	0.9660^{**}
	(0.0034)	(0.0033)	(0.0019)	(0.0020)	(0.0156)	(0.0165)
Precipitation	0.0032^{*}	0.0052^{**}	0.0014	0.0026^{**}	1.0116	1.0206^{**}
	(0.0019)	(0.0022)	(0.0012)	(0.0012)	(0.0097)	(0.0103)
Wind	0.0005	-0.0005	0.0014	0.0005	1.0115	1.0038
	(0.0036)	(0.0042)	(0.0013)	(0.0014)	(0.0107)	(0.0115)
Humidity	-0.0070	-0.0096^{*}	-0.0037^{**}	-0.0053^{**}	0.9686^{**}	0.9550^{***}
	(0.0044)	(0.0052)	(0.0018)	(0.0021)	(0.0148)	(0.0164)
Sunshine	-0.0033	-0.0058	0.0004	-0.0023	1.0011	0.9774
	(0.0038)	(0.0046)	(0.0018)	(0.0020)	(0.0147)	(0.0162)
Pressure	0.0030	0.0036	-0.0047	-0.0031	0.9642	0.9784
	(0.0052)	(0.0053)	(0.0033)	(0.0036)	(0.0262)	(0.0291)
Controls	✓	✓		✓	✓	✓
Month FE	✓	✓	✓	✓	✓	✓
Wave FE	✓	✓	✓	✓	✓	✓
Observations	170608	170608	170608	170608	87728	87728
R^2	0.014	0.014	0.008	0.008		
Pseudo R^2					0.016	0.016
F			4.3274	4.2556		

Notes: Significance: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.
Standard errors (parentheses) are clustered at the planning regions' level.

Table 4.10: Weather effects on climate change concerns with pooled OLS, individual fixed effects and logit fixed effects

Dep. var.: CC: very concerned						
		$T = 1$			$T = 3$	
	(1)	(2)	(3)	(4)	(5)	(6)
	NN	SM	SQ	NN	SM	SQ
Temperature	-0.0041^{**}	-0.0038^{**}	-0.0039^{**}	-0.0043^{**}	-0.0042^{**}	-0.0042^{**}
	(0.0017)	(0.0017)	(0.0017)	(0.0019)	(0.0019)	(0.0019)
Precipitation	0.0009	0.0016	0.0011	0.0020	0.0027^{**}	0.0023^{*}
	(0.0011)	(0.0011)	(0.0011)	(0.0012)	(0.0012)	(0.0012)
Wind	0.0018	0.0012	0.0015	0.0010	0.0004	0.0007
	(0.0012)	(0.0013)	(0.0011)	(0.0013)	(0.0015)	(0.0013)
Humidity	-0.0030	-0.0040^{*}	-0.0034	-0.0047^{**}	-0.0056^{**}	-0.0049^{**}
	(0.0021)	(0.0022)	(0.0021)	(0.0022)	(0.0023)	(0.0022)
Sunshine	0.0010	0.0001	0.0006	-0.0018	-0.0025	-0.0020
	(0.0017)	(0.0018)	(0.0017)	(0.0020)	(0.0021)	(0.0020)
Pressure	-0.0057^{*}	-0.0052	-0.0051	-0.0043	-0.0034	-0.0037
	(0.0032)	(0.0036)	(0.0033)	(0.0034)	(0.0038)	(0.0035)
Controls	✓	✓	✓	✓	✓	✓
Month FE	✓	✓	✓	✓	✓	✓
Wave FE	✓	✓	✓	✓	✓	✓
Observations	170608	170608	170608	170608	170608	170608
R^2	0.008	0.008	0.008	0.008	0.008	0.008
p-value	0.0029	0.0155	0.0084	0.0223	0.0156	0.0339

Notes: Significance: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.
Standard errors (parentheses) are clustered at the planning regions' level.

Table 4.11: Different weather aggregation methods

Dep. var.: CC: very concerned						
			$T=3$			
	(1)		(2)		(3)	
	Female		Age < 30		Academic	
Temperature	-0.0058^{***}	(0.0021)	-0.0039^{*}	(0.0020)	-0.0033	(0.0021)
Precipitation	0.0024	(0.0017)	0.0028^{**}	(0.0014)	0.0029^{**}	(0.0014)
Wind	-0.0008	(0.0016)	0.0008	(0.0015)	-0.0002	(0.0018)
Humidity	-0.0046	(0.0028)	-0.0052^{**}	(0.0024)	-0.0069^{**}	(0.0027)
Sunshine	-0.0027	(0.0026)	-0.0017	(0.0022)	-0.0046^{*}	(0.0025)
Pressure	-0.0064	(0.0045)	-0.0035	(0.0038)	-0.0007	(0.0042)
Female	0.3218^{*}	(0.1658)				
Female × Temperature	0.0029	(0.0026)				
Female × Precipitation	0.0004	(0.0028)				
Female × Wind	0.0026	(0.0024)				
Female × Humidity	-0.0014	(0.0039)				
Female × Sunshine	0.0008	(0.0033)				
Female × Pressure	0.0064	(0.0049)				
Age < 30			-0.0083	(0.0091)		
Age < 30 × Temperature			-0.0029	(0.0040)		
Age < 30 × Precipitation			-0.0019	(0.0040)		
Age < 30 × Wind			-0.0029	(0.0042)		
Age < 30 × Humidity			-0.0013	(0.0066)		
Age < 30 × Sunshine			-0.0059	(0.0055)		
Age < 30 × Pressure			0.0044	(0.0062)		
Academic deg.					-0.0121	(0.0155)
Academic deg. × Temperature					-0.0039	(0.0039)
Academic deg. × Precipitation					-0.0011	(0.0025)
Academic deg. × Wind					0.0026	(0.0031)
Academic deg. × Humidity					0.0065	(0.0051)
Academic deg. × Sunshine					0.0095^{**}	(0.0048)
Academic deg. × Pressure					-0.0097	(0.0071)
Controls	✓		✓		✓	
Month FE	✓		✓		✓	
Wave FE	✓		✓		✓	
Observations	170608		170608		170608	
R^2	0.008		0.008		0.008	

Notes: Significance: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.
Standard errors (parentheses) are clustered at the planning regions' level.

Table 4.12: Weather effects with interaction terms for $T = 3$

Dep. var.: CC: very concerned						
			$T = 7$			
	(1)		(2)		(3)	
	Female		Age < 30		Academic	
Temperature	−0.0033	(0.0023)	−0.0019	(0.0022)	−0.0005	(0.0025)
Precipitation	0.0012	(0.0016)	0.0012	(0.0015)	0.0013	(0.0014)
Wind	−0.0004	(0.0017)	0.0017	(0.0015)	0.0002	(0.0020)
Humidity	−0.0041	(0.0033)	−0.0055**	(0.0027)	−0.0068**	(0.0029)
Sunshine	−0.0031	(0.0033)	−0.0026	(0.0024)	−0.0054**	(0.0025)
Pressure	−0.0066	(0.0058)	−0.0033	(0.0049)	−0.0006	(0.0052)
Female	0.3223*	(0.1655)				
Female × Temperature	0.0026	(0.0029)				
Female × Precipitation	0.0000	(0.0025)				
Female × Wind	0.0029	(0.0026)				
Female × Humidity	−0.0026	(0.0044)				
Female × Sunshine	−0.0004	(0.0045)				
Female × Pressure	0.0073	(0.0061)				
Age < 30			−0.0080	(0.0091)		
Age < 30 × Temperature			−0.0001	(0.0048)		
Age < 30 × Precipitation			−0.0009	(0.0034)		
Age < 30 × Wind			−0.0063	(0.0042)		
Age < 30 × Humidity			0.0005	(0.0073)		
Age < 30 × Sunshine			−0.0066	(0.0057)		
Age < 30 × Pressure			0.0054	(0.0066)		
Academic deg.					−0.0121	(0.0155)
Academic deg. × Temperature					−0.0054	(0.0041)
Academic deg. × Precipitation					−0.0003	(0.0027)
Academic deg. × Wind					0.0033	(0.0038)
Academic deg. × Humidity					0.0051	(0.0059)
Academic deg. × Sunshine					0.0084	(0.0056)
Academic deg. × Pressure					−0.0087	(0.0079)
Controls	✓		✓		✓	
Month FE	✓		✓		✓	
Wave FE	✓		✓		✓	
Observations	170608		170608		170608	
R^2	0.008		0.008		0.008	

Notes: Significance: $^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.
Standard errors (parentheses) are clustered at the planning regions' level.

Table 4.13: Weather effects with interaction terms for $T = 7$

Chapter 5

Conclusion

This thesis includes three essays on the political economy of climate change. The political economy theory is a positive theory as it explains how certain political equilibria emerge. In contrast, the goal of a normative theory is to find optimal solutions for a given problem, e.g. the optimal investment path for climate change mitigation. There are already numerous normative studies concerning climate change, but still relatively few positive studies. As mentioned at the beginning of this thesis, the international community already agreed to limit global warming to 2°C and to do everything to keep it below 1.5°C. However, the current emission path is still not compatible with this goal. The primary motivation of this thesis is to understand this discrepancy by investigating different aspects of the political economy of climate change.

In Chapter 2, the influence of migration on climate change mitigation is analyzed from a political economy perspective. We focus on a coastal region where individuals are heterogeneous in income and location and where flood risk exists. To avoid the risk, inhabitants can move away and/or invest in climate change mitigation. One result is that the option to move away decreases the preferred level of mitigation. Moreover, we show that the political mitigation level may be socially inefficiently low and that under high relocation fixed costs, a poverty trap can emerge where poor individuals do not migrate.

Chapter 3 is about the political economy of the German Climate Package. In this political economy model, individuals differ regarding their incomes and their commuting distances. They either do not commute to work or commute a short or long distance by car. Commuting creates a negative externality, and to correct this, a politically determined fuel tax is introduced. The tax revenues can be used to either increase an existing commuting allowance or to introduce a lump-sum transfer. The decision on how to redistribute the revenues is also a political choice and comes before the decision about the fuel tax rate. We present a political equilibrium where the fuel tax revenues are completely used to increase the commuting allowance despite being only beneficial to the long-distance commuters. This result is possible because the group that does not commute uses the higher commuting allowance to induce the long-distance commuters to vote for a higher carbon tax.

In Chapter 4, we study the influence of weather on climate change concerns. We take the German Socio-Economic Panel (SOEP) and merge it with daily weather data from the German Meteorological Office. We control for unobserved individual heterogeneity by using an individual fixed effects model. Moreover, we include all relevant weather variables instead of just temperature since using only one variable could lead to an omitted variable bias. We can reject the hypothesis that weather has no effect on climate change concerns at the 5% significance level and find significant positive effects for precipitation and negative effects for temperature and humidity. However, while being statistically significant, from an economic and political perspective, the effects are rather small.

Each of the above chapters contributes to the political economy of climate change in a different way. Chapter 2 shows us a political economy mechanism that explains why there is too little investment in climate change mitigation. Chapter 3, on the other hand, presents a mechanism that can lead to higher investment in mitigation. Finally, Chapter 4 looks at how robust climate change concerns are to weather impacts. This question is also relevant to the political economy of climate change, as concerns about climate change are a necessary condition for supporting climate change concerns.

Nevertheless, this thesis can only examine a fraction of the political economy of climate change. Further research in this area is needed to identify and overcome potential policy barriers to the implementation of climate change mitigation measures as the window of opportunity to still achieve the 1.5 degree target is rapidly closing.

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