From Coping with Natural Disasters in the Past to a Model of Future Optimal Adaptation

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Abstract

The aim of this paper is to gain insights from studying adaptation to natural disasters in the past in order to analyze optimal adaptation in Switzerland in the future. Most adaptation measures already undertaken in Switzerland are so-called reactive measures. They may be effective, but not necessarily efficient. We propose that future climate change asks for proactive measures to combat market damages in an efficient way. We come up with modeling adaptation as a cumulative stock in a computable general equilibrium (CGE) model called ADAPT-CH. We find that with an investment of up to 0.9% of the GDP, a little more than 58% of the exogenously given climate damages in Switzerland can be prevented until 2060.

Keywords: Adaptation, Climate Change, Dynamic CGE Model, Switzerland, Natural Disasters

JEL-Classification: C91, C68, D58, D91, E21

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1 Introduction

Mitigation and adaptation are the most important tools to deal with the negative impacts of global climate change. Since the benefit of mitigation is a public good, there is a need for international cooperation to abate carbon dioxide (CO_2) emissions in an efficient way. But finding a far-reaching international agreement on mitigation strategies is hard and obviously requires a lot of negotiations. The failure of the Copenhagen climate conference 2009 to find a successor of the Kyoto Protocol has made this clear once more. Nevertheless, many countries already face the impacts of global climate change and they are looking for ways to cope with the situation unilaterally. Since adaptation is a private good, it is an efficient instrument for unilateral policy decisions. Mendelsohn (2000) analyzed a number of studies dealing with adaptation from different angles and stated that unilateral adaptation is indeed a very powerful tool to decrease damages from climate change. According to Mendelsohn (2000), adaptation has the potential to prevent up to 80% of climate damages.

Tol and Fankhauser (1998) claimed after looking into the literature on *integrated assessment models* (IAMs) that most models do not consider adaptation as a decision variable. A recent study from Patt, van Vuuren, Berkhout, Aaheim, Hof, Isaac, and Mechler (2010) confirms this fact. This is where we fill in the gap, using adaptation as a decision variable in this chapter.

In our analysis, we focus on adaptation in Switzerland. Switzerland is a small economy with greenhouse gas (GHG) emissions that account to less than 0.2% of the global total. Although Switzerland is willing to support international negotiations on mitigation targets, its influence on global climate change reduction is thus quite limited. This is why we focus on adaptation in this work, leaving mitigation aside.

In detail, the aim of this part is to analyze the level of optimal adaptation for Switzerland with respect to cumulative adaptation that is subject to the building up of a capital stock of adaptation. An example for cumulative adaptation are infrastructural adaptation measures. So far, studies on adaptation in Switzerland either focused on regions (Elsaesser and Buerki 2002), sectors (Behringer, Buerki, and Fuhrer 2000) or were set up as policy guidelines (North, Kljun, and Kasseri 2007). Most of the work on adaptation in Switzerland analyzes the effect of climate change on tourism in the alpine region (Matasci and Crabrera-Altamirano 2009, Weber 2007) or on the agricultural sector (Finger 2009). Our approach is a more integral one. We define an optimal solution for all of Switzerland, focussing on cumulative adaptation.

To develop an idea on how to model cumulative adaptation in Switzerland adequately, we start our analysis by looking into the past, trying to learn from adaptation measures already undertaken, especially infrastructural flood protection measures. In section 2, we look at past natural disasters in Switzerland and illustrate events from the 13th century on in several disaster maps. Additionally, we analyze adaptation measures done in the past. After looking into the theory of adaptation in section 3, we conclude that most infrastructural adaptation measures in Switzerland are *reactive* and not *proactive* (see Smit, Burton, Klein, and Street 1999). Burton (1996) states that proactive adaptation is more efficient than reactive adaptation. Since we want to analyze the efficient level of future adaptation for Switzerland, we thus focus on proactive adaptation in the modeling part of this chapter.

Analyzing the past is just one aspect in setting up a model of optimal adaptation. Future climate data has to be considered, too. In section 4, we look at the latest climate change predictions for Switzerland by using the newest data from the ENSEMBLE project.[1] Considering the development of precipitation and temperature in Switzerland, efficient proactive adaptation becomes even more important.

In section 5, a *computable general equilibrium* (CGE) model is introduced, called ADAPT-CH. The model analyzes the efficient investment in proactive, cumulative adaptation measures in Switzerland numerically, using the ENSEMBLE climate data from section 4 as climate data input. The basic idea is that adaptation is an investment good like capital. Once an adaptation stock is accumulated, it is effective for the whole time horizon of the model. This approach was first introduced by Bosello (2004) in an multi-region IAM. But in contrast to the work of Bosello (2004), the ADAPT-CH model is a one-region model and it is not set up as an IAM. We concentrate on Switzerland and on adaptation only, ignoring mitigation due to the economic characteristics of Switzerland and the inertia of the climate system. Section 6 shows the results computed with the ADAPT-CH model.

Section 7 then concludes, discussing also the implications given by our focus on solely cumulative adaptation.

Overall, this chapter contributes to up to date research, bringing up several new approaches. First, adaptation is defined as a decision variable in a CGE model. Second, adaptation in Switzerland is analyzed from a national perspective, not focussing on single regions or sectors. Third, this national analysis takes into account the lessons learned in the past and uses this knowledge to set up guidelines

[1]The ENSEMBLE project is supported by the European Commission's 6th Framework Programme as a 5 year Integrated Project from 2004-2009 under the Thematic Sub-Priority Global Change and Ecosystems.

for future cumulative adaptation.

2 Disaster Maps and Flood Protection

We start our analysis by looking into the past. By illustrating natural disasters graphically, we show where disasters have happened, if adaptation measures were taken against these disasters and if adaptation was effective. We will focus our analysis on flood protection, being one possibility for cumulative, infrastructural adaptation. The understanding if adaptation was effective will help us to define future adaptation measures that may not only be effective but also efficient. This is done in a CGE model of optimal adaptation in section 5. Let us now focus on past disasters first.

In our graphical analysis, we distinguish between floods, mass movements, storms and avalanche events. Data on natural events caused by thunderstorms (floods and mass movements) were available from the 13th century on (Roethlisberger 1991, Roethlisberger 1998), data about avalanches from the 15th century on (Institut für Schnee- und Lawinenforschung Schweiz (SLF) 2007) and data on storms were only available for the 20th and 21st century (Die Nationale Plattform Naturgefahren (PLANAT) n.d., Interkantonaler Rueckversicherungsverband (IRV) n.d., IPCC Data Distribution Centre (IPPC-DCC) n.d., Jud n.d.).

Roethlisberger (1991) and Roethlisberger (1998) classified data on thunderstorms into different categories depending on the damage caused. He distinguished between light to middle, heavy, very heavy and catastrophic damages. In his publications he focused on heavy to catastrophic events. These events caused at least a damage of 2 million Swiss Francs at a 1990 price level.

Data on avalanches (see Institut für Schnee- und Lawinenforschung Schweiz (SLF) 2007) contained about 12'200 records. It would be too confusing to illustrate all of these events. We therefore extract avalanche events that caused five deaths or more. We illustrate the resulting approximately 50 events in our disaster maps.

The left hand side of figure 1 shows the natural disasters that took place from the 13th to the 16th century. We can only illustrate a few events. There were not more data available, probably because of the bad documentation on events in general at this time. Still, locations that are exhibited to floods become clear, such as the Schaechen-, the Reuss- and the Urseren - valley in the Canton Uri (central Switzerland) and the Rhine - valley in the Canton of St. Gallen.

The right hand side of figure 1 displays natural disasters that took place in the 17th and 18th century. Events cluster around a few locations. The already mentioned exhibited locations were again struck by floods, as well as the region

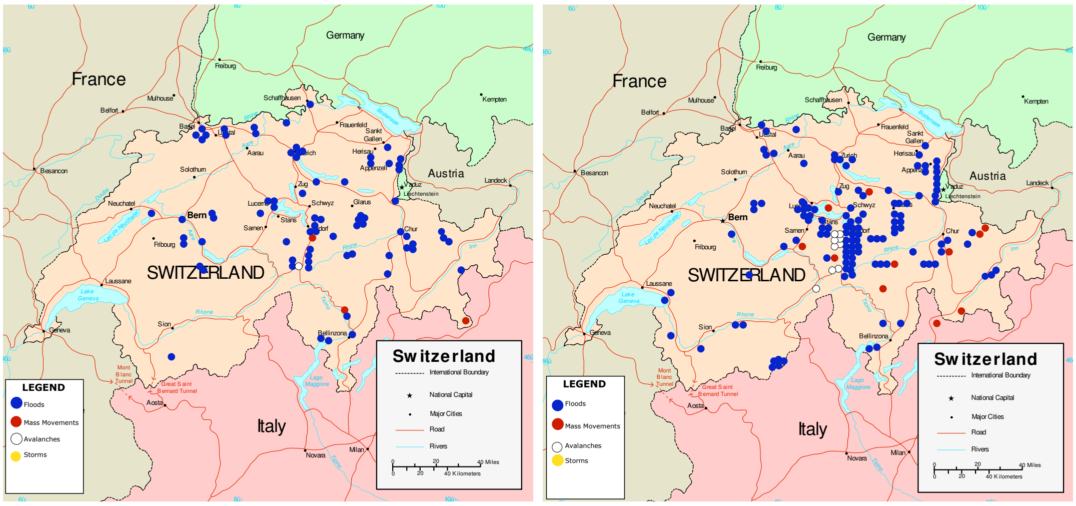

Figure 1: Natural disasters 13th to 16th century (map on the left) and natural disasters 17th to 18th century (map on the right).

around the city of Lucerne and the east coast of the Vierwaldstaettersee. In the Canton Valais, the Mattmark lake broke out several times. The Canton Uri was hit by some avalanches.

Figure 2 on the left hand side illustrates natural disasters that took place in the 19th century. There are more events compared with previous centuries. It is probable that the quality of the documentation on events improved and therefore more data are available. There are still many flooding events in the Schaechen-, Reuss (UR)- and Urseren - valley, as well as in the Rhine - valley (SG). There are many flooding events in the Rhone - valley, in the Ticino - valley and in the Cantons of Nidwalden and Obwalden. Some flooding events cluster around the city of Basel and in the Toess- valley in the Canton of Zurich. Clusters of mass movements occurred in the western part of the Canton Ticino (Vallemaggia area), as well as in the Cantons Schwyz and Graubuenden.

Natural disasters that took place in the 20th century are divided into six separate maps. Showing all events in one map would be to confusing. From 1900 to 1969, events are shown in time intervals of 18 to 26 years, taking important historical events as criteria to split up the events to the different maps. From 1970 on, one map shows the events of one decade.

Figure 2 on the right hand side illustrates the events that took place from 1900 to 1918. There are few events, mostly in the Canton Ticino (floods and mass movements). Flooding events in the Canton Uri and in the Rhine - valley in the Canton St. Gallen have decreased remarkably. This could be the result of the Reuss and Rhine corrections done in the 19th century. Figure 5 shows the measures undertaken against floods from the 16th to 20th century. Measures

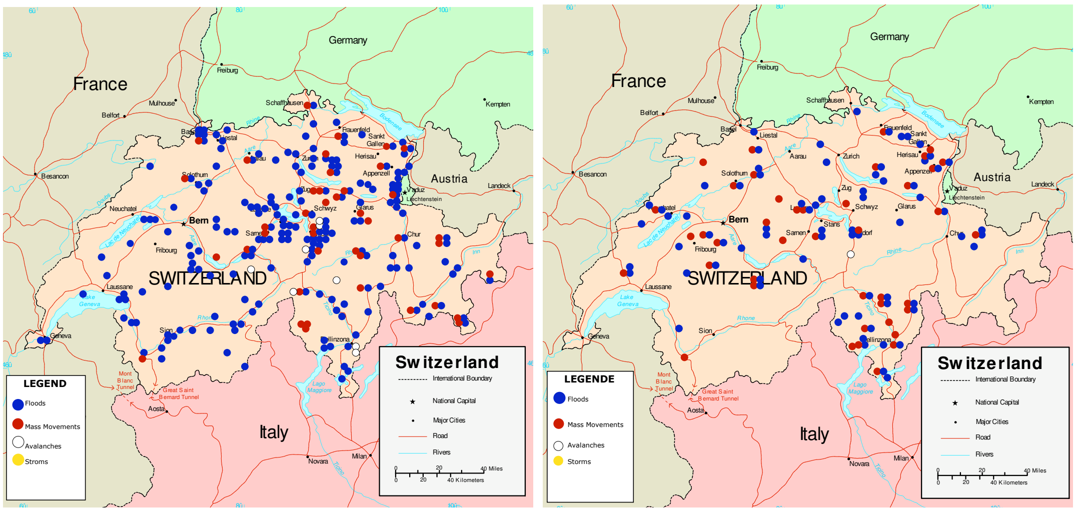

Figure 2: Natural disasters 19th century (map on the left) and natural disasters 1900 - 1918 (map on the right).

against floods have also been undertaken in the Rhone-valley, in the Seeland region, in the region between Walensee and Zuerichsee, in the Aare and Emme - valley and in the Canton Graubuenden part of the Rhine - valley. In all these locations, floods have decreased in the period from 1900 to 1918 compared with previous years.

Figure 3 on the left hand side displays natural disasters that happened from 1919 to 1945. Events are evenly distributed across (the german part of) Switzerland. Although measures against floods had been undertaken in the Canton Uri, several events occurred in this time period. There are several mass movements and avalanches in this region as well. In our typology, mass movements can be related to thunderstorms and can therefore occur simultaneously to floods. Debris flows are part of this category as well. Several flooding and mass movement events happened in the Teoss - valley (Canton Zuerich) and in the Cantons Glarus and Graubuenden. The western part of Switzerland is practically free of events.

Figure 3 on the right hand side shows natural disasters that happened from 1946 to 1969. There are few flooding events, distributed across the Cantons Berne, Valais, Ticino, Graubuenden, Lucerne and Zuerich. Central Switzerland, in previous years heavily exposed to floods, shows nearly no events in this period. In contrast to prior time spans, more locations were struck by avalanches, mostly in the southern part of Switzerland.

Figure 4 on the left hand side illustrates the natural disasters that took place from 1970 to 1979. There were quite some events, especially floods in the Cantons Bern and Lucerne (Emmental and Entlebuch) as well as floods and mass movements in the Canton Ticino (Maggia- valley and the region of the Onsernone-

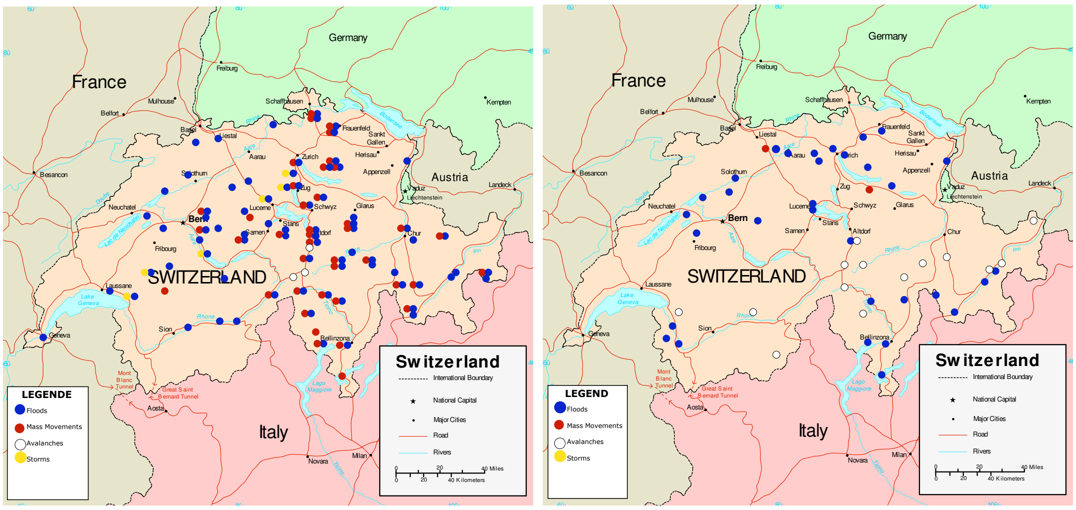

Figure 3: Natural disasters 1919 - 1945 (map on the left) and natural disasters 1946 - 1969 (map on the right).

valley, Blenio - valley). In the rest of Switzerland there were only few events.

Figure 4 on the right hand side displays natural disasters from 1980 to 1989. Several flooding and mass movement events occurred mostly in the western part of Switzerland (Berner Oberland, Emmental and Val de Travers) and in the Cantons Lucerne and Ticino (Blenio- and Calanca - valley, Locarno and Bellinzona region). Avalanche events occurred in the Cantons Graubuenden and Valais.

The publications of Roethlisberger (1991) and Roethlisberger (1998) list damages up to 1991. Using other data sources for more recent data would not allow us to guarantee the comparability of data. We therefore pass on illustrating data from 1990 on and move over to the protection measures against floods undertaken in Switzerland.

2.1 Protection Measures against Floods in Switzerland

The disaster maps shown in the previous section have displayed the vulnerable points of Switzerland. It is obvious that certain regions suffer much more from natural disasters. Especially floods threaten the same regions over and over again. Of course, people have not idly waited for the next flood to come but have struggled to protect themselves from floods.

Figure 5 shows the protection measures against floods taken in the 16th to the 20th century (Swiss Federal Office for the Environment n.d., Vischer 2003). The most prominent measures were the corrections of the Reuss and the Engelberger Aa, the Zuger Seeabsenkung, the corrections of the Kander, the Linth, the Rhine, the Rhone and the stretches of water in the Jura region. Several other lakes were corrected as well.

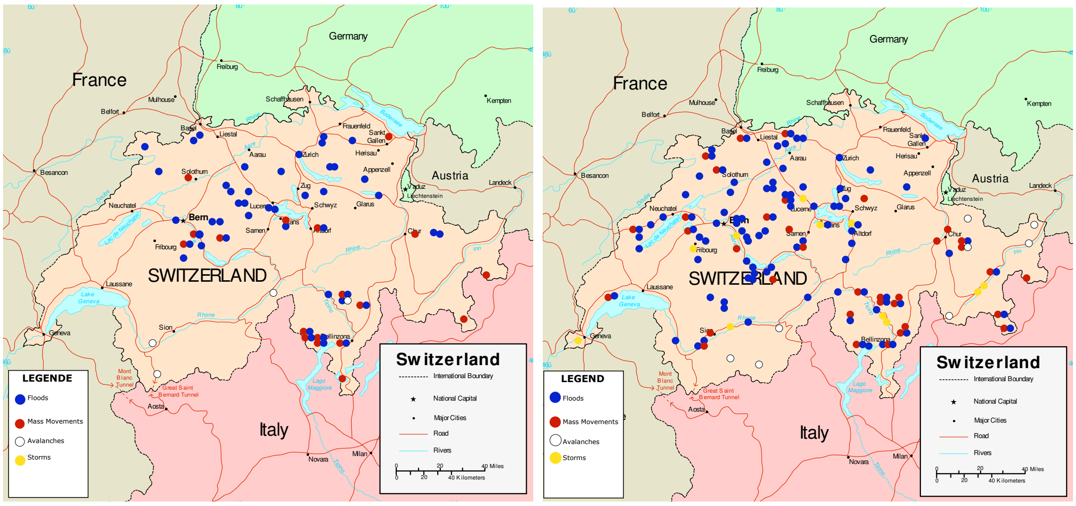

Figure 4: Natural disasters 1970 - 1979 (map on the left) and natural disasters 1980 - 1989 (map on the right).

According to our graphical analysis, these measures seem to have been effective to some extent. As can be seen in the disaster maps, floods have threatened e.g. the Reuss valley in the Canton Uri, the Rhine valley in the Canton St. Gallen and the regions along the Vierwaldstaettersee for centuries. The corrections of lakes and rivers that started in the 16th century were able to lessen, but not always avoid the floods in these regions.

We can therefore state that flood protection as an example for cumulative adaptation was more or less effective. But adaptation not only has to be effective, it also has to be cost efficient to be optimal. It is our goal to define an optimal adaptation strategy to prevent Switzerland from future damages caused by climate change, especially damages caused by floods. We thus want to know, which criteria adaptation has to meet in order to be optimal.

We limit our analysis to cumulative adaptation, such as infrastructural adaptation measures, and define our optimum accordingly. By focussing on cumulative adaptation, not all damages caused by climate change can be prevented. Damages that ask for immediate, short term reaction, such as instantaneous adaptation can not be prevented. Instantaneous adaptation measures, e.g. the change in crop types in the agricultural sector are not being taken into account in our model. In order to fully adapt to climate change though, also instantaneous adaptation measures would have to be taken into account and would have to be facilitated by the government. Nevertheless, our analysis focusses on flood protection measures. We therefore limit our analysis to cumulative adaptation, keeping the model as simple as possible in order to be able to fully understand the resulting effects. Further, the principle of cumulative adaptation best reflects the notion of antic-

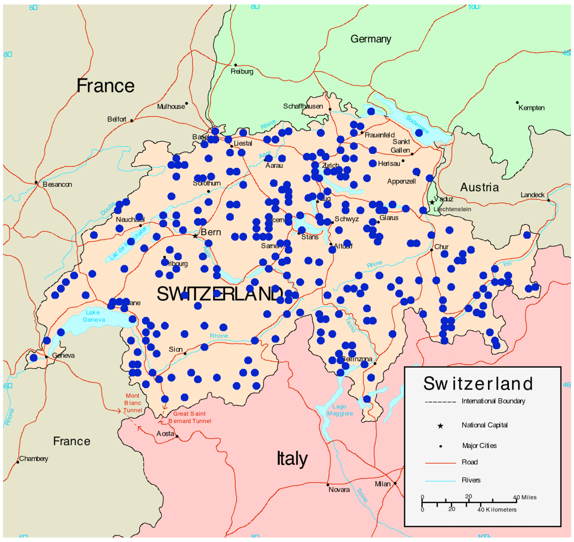

Figure 5: Flood protection measures.

ipatory, proactive adaptation that is a cornerstone for an efficient solution (see Burton 1996).

Before we calculate our model of optimal cumulative adaptation, we look at the definitions of adaptation. These definitions will help us to better understand the many facets of adaptation and they will help us to define the optimal cumulative adaptation needed in Switzerland.

3 Definition and Effect of Adaptation

According to the IPCC Third Assessment Report, adaptation is defined as the "adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. This term refers to changes in processes, practices, or structures to moderate or offset potential damages or to take advantage of opportunities associated with changes in climate. It involves adjustment to reduce the vulnerability of communities, regions, or activities to climatic change and variability" (Smit, Pilifosova, Burton, Challenger, Huq, Klein, and Yohe 2001, p.882).

So far we have studied the effects of floods and resulting flood protection measures. According to the IPCC definition, flood protection measures are changes in structures that moderate or offset the damages from floods. The following list of proposed flood protection measures introduced by Die Nationale Plattform Naturgefahren (PLANAT) (n.d.) shows that theses measures mostly contain infrastructural and architectural solutions. The proposed measures are the following:

1. Maintenance of existing prevention buildings.

2. Infrastructural measures in order to decrease the damage potential. This means that jeopardized areas should not be overbuilt and more space should be left free to rivers and lakes.

3. If the above mentioned measures are not sufficient, there need to be more active measures taken. A possibility is for example the construction of retention buildings and the redirection or discharge of flood peaks.

The realization of these measures may not always be easy, though. In Switzerland, the federal state is mainly responsible for legislation in respect to adaptation. The Cantons on the other hand are only partly operative organs and mainly responsible for financing and subsidization of measures. Finally, the enforcing organs are the communities. They are responsible for the realization of hazard maps and the implementation of edificial, infrastructural and organizational measures. Therefore, efficient adaptation in Switzerland has to take organizational obstacles and take e.g. the time needed to go all through the different levels into account.

In our model ADAPT-CH, we would like to define cost efficient adaptation in Switzerland with respect to cumulative adaptation, especially with respect to flood protection measures. In this context, we need to understand the different characteristics and forms of adaptation. Adaptation, e.g. can be autonomous or planned, it can be a short or a long term investment or it can be anticipatory or reactive (Smit, Burton, Klein, and Street 1999). Further, countries or regions may have different potentials for adaptation that depend on the vulnerability of the system to climate change and its adaptive capacity. Therefore, in order to determine possible and efficient adaptation measures, the underlying potential for adaptation of the system, region or country has to be assessed. It is commonly agreed that the potential for adaptation and the concept of vulnerability to climate change are related.

Vulnerability to climate change is a function of the sensitivity to changes in climate and the ability to adapt to such changes (Tol, Fankhauser, and Smith 1998).

Adaptive capacity in turn is the “potential or ability of a system, region, or community to adapt to the effects or impacts of climate change. Enhancement of adaptive capacity represents a practical means of coping with changes and uncertainties in climate, including variability and extremes. This way, enhancement of adaptive capacity reduces vulnerabilities and promotes sustainable development” (Smit, Pilifosova, Burton, Challenger, Huq, Klein, and Yohe 2001, p.882). The main factors of influence on the adaptive capacity of communities and regions are economic wealth, technology, information and skills, infrastructure, institutions and equity.

From this definition it follows that the potential for adaptation is bigger in developed in contrast to developing countries. Switzerland should therefore be in a good position to combat the effects of climate change by means of adaptation. Nevertheless, due to the high density of population and the consequential dense settlements in Switzerland, there is not much potential for people to move out endangered areas. Rivers and lakes may have been corrected. Severe floods that overflow dikes or canals may still cause damage.

In our graphical analysis of past flood events and flood protection measures we have seen that, as far as we can tell, adaptation was quite effective. Nevertheless, adaptation should also be efficient. An important point to meet this criteria may be the timing of adaptation. Burton (1996) mentions that anticipatory adaptation is more effective and less costly than retrofitting. In the past centuries, adaptation was taken after damages had already occurred. In our model on optimal cumulative adaptation we must therefore focus on anticipatory adaptation in order to make investments in adaptation cost-efficient.

The idea of anticipatory adaptation can very well be reflected in the concept of *cumulative adaptation* that we use in our model. The prominent feature of the concept is that adaptation is seen as an investment good, resulting in the establishment of an adaptation stock. That way, the effect of adaptation lasts over the entire period of concern. This approach was first discussed by Bosello (2004). In contrast, adaptation can also be immediate, short term, or instantaneous. *Instantaneous adaptation* refers to measures that have to be adjusted and thought over every period. These measures are active over only one period of time (De Bruin, Dellink, and Tol 2009). A good example for instantaneous adaptation can be found in the agricultural sector. Due to climate change, crop types have to be adjusted on a regular basis. The effect of the adjustment only lasts a very limited time until the next adjustment in crop types has to be made.

Apart from the time dimension of adaptation, we also have to study the structure of adaptation costs. According to Tol, Fankhauser, and Smith (1998), the existing literature though, only rarely reports adaptation costs (as opposed to net costs of damages). The cost-effectiveness of adaptation measures is not assessed very often either.

Fankhauser (1998) is among the few who have analyzed the costs of adaptation more thoroughly. He suggests the principle of *imposed costs* of climate change. The imposed costs are calculated from subtracting the total costs in a reference scenario without climate change and baseline adaptation from the total minimum climate change costs in a climate change scenario with extended adaptation. Adaptations costs, climate change damage costs, ordinary climate damage costs and other relevant costs in the reference and the climate change scenario add up to the total costs considered. It may be hard to differentiate between a baseline and a climate change scenario and even harder to distinguish between different adaptation costs of the scenarios. Interesting though, is the split of the costs into single elements mentioned above.

Adaptation costs are the costs of implementing adaptation measures (e.g building a dam). Climate change damage costs are the extra damages occurring exclusively because of anthropogenic climate change. These two cost types constitute the main types of imposed costs according to Fankhauser (1998). "In addition adaptation decisions will often have cost implications that are not related to climate change. These too must be taken into account" (Fankhauser 1998, p.16). Not related to climate change are ordinary climate damage costs. These costs contain costs of adverse effects associated with the current climate. These costs would also occur in the absence of climate change. By increasing adaptation costs, climate change damage costs and ordinary climate damage costs will be reduced. Finally, other relevant costs are costs that can also be reduced by a higher input into adaptation. Fankhauser (1998) makes the example of hurricane shelters that are used as schools when no hurricanes are expected. Therefore, the extra expenditures for school buildings can be saved.

Thus, adaptation both leads to the reduction of costs (benefits from adaptation) that are directly related to climate change (climate change damage costs) and costs that have nothing to do with anthropogenic climate change (ordinary climate damage costs and other relevant costs).

Summarizing the relevant findings, our analysis on cost-efficient adaptation has to focus on anticipatory instead of reactive adaptation. These are the economic fundamentals for our adaptation model. In the next section, we will switch to the basics that underlie the natural sciences and look at the data that enter our numerical model.

4 ENSEMBLE Data for Switzerland

In order to analyze the future need for adaptation in Switzerland, the dimension of climate change is of interest, namely the development of precipitation and temperature. The ENSEMBLE project offers new regional data for temperature and precipitation. These data are used to calibrate the damage function of our ADAPT-CH model in section 5.1.

The ENSEMBLE data presented in this chapter are the mean values of five different Regional Climate Models (RCMs), driven by three different Global Climate Models (GCMs). The five RCMs have been developed by different institutions,

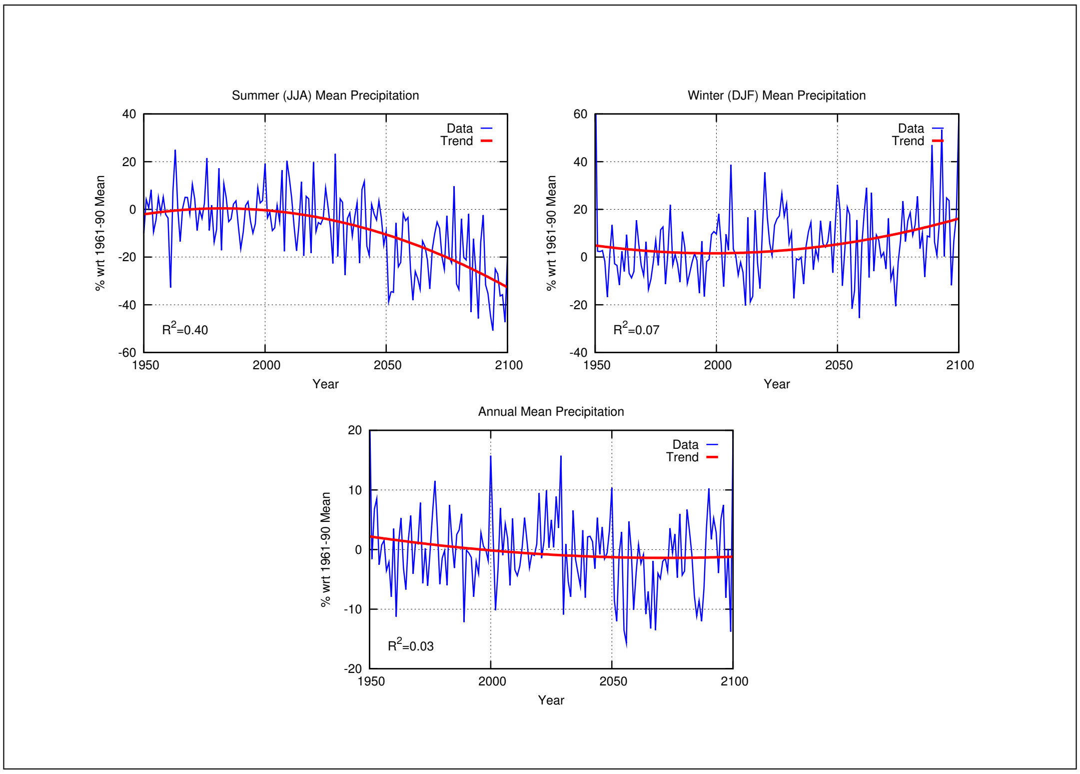

Figure 6: ENSEMBLE precipitation path for Switzerland for summer (JJA), winter (DJF) and annual mean. The precipitation change is stated in percent of the 1961-1990 mean. The trend line denotes the polynomial trend. The corresponding coefficients of determination R^2 are declared in each graph.

among others by the ETH Zuerich. The underlying emission scenario is the SRES (Special Report on Emissions Scenarios) A1B by the IPCC Working Group III (2000).[2]

Figure 6 shows the precipitation data for Switzerland from 1960 to 2100. All data are computed as precipitation anomalies with respect to the 1961-1990 mean in percent.

It can be seen in figure 6 that the summer gets drier in Switzerland in the near future. We can approximate this trend by a polynomial function of degree two, but the corresponding coefficient of determination R^2 is only 0.4. For winter and annual mean precipitation, there is even no significant trend in the data at all. That means that future precipitation is rather uncertain. Therefore, we do not include precipitation in the market damage function of the ADAPT-CH model. Another reason for not using precipitation data in our model is that there hardly is any literature about precipitation in damage functions. In the field of quantifying

[2]The A1B scenario assumes rapid economic growth, rapid introduction of new green technologies and convergence among world regions.

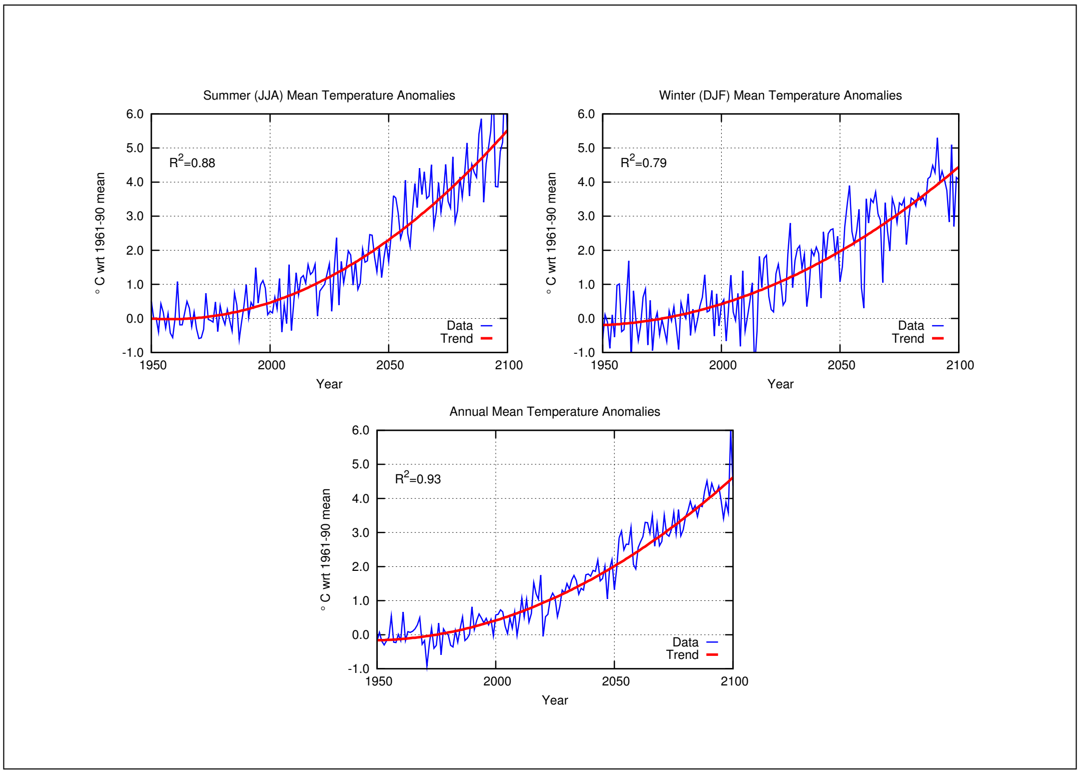

Figure 7: ENSEMBLE temperature path for Switzerland for summer(JJA), winter (DJF) and annual mean. The temperature change is stated in °C with respect to the 1961-1990 mean. The trend line denotes the polynomial trend. The corresponding coefficients of determination R^2 are declared in each graph.

damage functions there is still a lot to do. We need better functions that include precipitation and we need better predictions about future precipitation anomalies. For a country like Switzerland, drier winters could lead to high damages because of the lack of snow and the corresponding absence of tourists in the ski resorts.

Figure 7 illustrates the temperature data for the mean of the five RCMs for Switzerland. The temperature is measured as anomaly with respect to the 1961-1990 mean in °C.

Temperature data show an explicit trend for the future. There is a significant temperature increase in Switzerland in summer and in winter which can be approximated by a polynomial function of degree two. The corresponding coefficients of determination R^2 are high for summer and winter. For the ADAPT-CH model in section 5.1 we use the polynomial approximation for the annual mean temperature anomalies in Switzerland. The R^2 is very high and the data can easily be used to calibrate a market damage function for Switzerland of the type Hope (2006) or Nordhaus and Boyer (2000) are using.

As we have just seen, the ENSEMLES data predict an increase in temperature in winter and in summer, without a clear trend for winter precipitation. Even without accounting for precipitation in our model, the predicted temperature increase alone may lead to floods. In the future, the snow line will move up due to climate change and therefore precipitation will tend to fall in the form of rain instead of snow. In contrast to snow, rain will lead to an immediate increase of the levels of lakes and rivers, eventually causing floods.

5 A Model of Optimal Adaptation

Switzerland is a small economy with GHG emissions that account to less than 0.2% of global emissions. Hence, cutting back GHG emissions in Switzerland has almost no effect on global climate change. This does not imply, however, that Switzerland should not actively support international agreements on GHG abatement and burden sharing. It nevertheless makes clear that for Switzerland unilateral GHG mitigation has no impact on national market damages. In our ADAPT-CH model we account for this by assuming that global climate change is exogenously given. We consider adaptation to be the only option in order to domestically respond to climate change. This in particular makes sense, if we restrict ourselves to a mid-term analysis, where climate change and vulnerability are mainly driven by past emissions, due to the inertia of the climate system.

The ADAPT-CH model is a Ramsey type growth model that deals with adaptation as a decision variable. Basically, adaptation measures can be seen as an investment good. Once an investment in adaptation is made, the impact of this investment continues over the time horizon of the model. This is what we call cumulative adaptation. This approach was first discussed by Bosello (2004) and is contrary to the approach of De Bruin, Dellink, and Tol (2009) in the recent publication of the AD-DICE model. In the AD-DICE model of De Bruin, Dellink, and Tol (2009), adaptation acts instantaneously. In every period, the representative agent in the model decides how much to invest in adaptation and this investment is effective in the same period only.[3] The kind of adaptation we are interested in has quite different characteristics. We argued in section 2 and 3 that proactive, anticipatory adaptation is more efficient than reactive adaptation. Cumulative adaptation is thus an interesting approach, since it reflects best the characteristics of proactive adaptation. Building dams against floods, installing early warnings systems against natural hazards and investing into summer tourism because of the lack of snow in winter are adaptation measures that take the form of a long term

[3]Examples of instantaneous adaptation measures are changing crop types or changing the holiday destination (see De Bruin, Dellink, and Tol 2009).

investment and thus of a cumulative adaptation stock.[4] Although we take a similar formulation of adaptation as in the FEEM-RICE model of Bosello (2004) as a guideline, the ADAPT-CH model is quite different. First, the ADAPT-CH model is not an IAM model. We do not consider the option of mitigation and address only a mid-term time horizon of 50 years. Second, the ADAPT-CH model is not based on the damage representation of Nordhaus and Boyer (2000). We consider the damage representation of the PAGE2002 model (see Hope 2006). Third, the ADAPT-CH model is a one-region model, not a multi-region model like FEEM-RICE. But thanks to an *external closure rule*, we are able to analyze the impacts of unilateral adaptation on the trade balance.

5.1 The Characteristics of the ADAPT-CH Model

The ADAPT-CH model is a one-region CGE representation of a small open economy, closed with an external closure rule. The model is calibrated to the base year 2001 by using the input-output table of Nathani, Wickart, Oleschak, and van Nieuwkoop (2001).

It is important to recognize that there are several options for investing into future welfare. Here, investing into damage prevention through adaptation is one possibility, investing into future gross domestic product through the accumulation of a stock of physical capital the other. At any point in time t, a society therefore has to decide on how to split its scarce resources between consumption C_t, investing into the stock of adaptation A_t and building up the capital stock K_t.

The numerical model is a *non-linear programming* (NLP) model. In the NLP setting, the representative agent explicitly maximizes the discounted value of utility from consumption subject to a number of economic constraints.

The objective function in the ADAPT-CH model therefore is defined as:

$$\max \quad W = \sum_{t=1}^{T} \rho_t \log(C_t), \tag{1}$$

where W is welfare, ρ_t denotes the discount factor and C_t is the level of consumption in period t. Utility from consumption is defined as a logarithmic function. Therefore, utility is a concave function of consumption. Thus, the first derivative of the utility function is positive while the second derivative is negative.

The gross economic output Y_t in the ADAPT-CH model is given by a standard

[4] Bosello (2004) refers to his kind of adaptation as *planned adaptation*, which is comparable with our term of proactive adaptation. The opposite is *autonomous adaptation*, which is not covered by our model.

Cobb-Douglas function:

$$Y_t = \left(\frac{K_t}{K0}\right)^{\gamma} \cdot L_t^{1-\gamma}; \tag{2}$$

where L_t represents the exogenous labor supply, K_t the capital stock in period t, $K0$ the initial capital stock and γ the base year capital value share. The first derivative of the gross economic output with respect to capital as well as labor is positive, the second derivative is negative. Therefore, the gross economic output increases at a decreasing rate with capital as well as with the exogenous labor supply.

The representative agent can either invest in the productive physical capital stock K_t, or in the damage decreasing adaptation stock A_t, which is given by:

$$A_{t+1} = (1 - \delta_a) \cdot A_t + a_t, \tag{3}$$

where a_t is the investment in adaptation in t and δ_a the depreciation rate of the adaptation stock.

Consistently, the accumulation of capital can be written as:

$$K_{t+1} = (1 - \delta_k) \cdot K_t + I_t, \tag{4}$$

where I_t is the level of investments in t and δ_k the depreciation rate of the capital stock.

The adaptation measures undertaken reduce the level of exogenously given market damages. The Green GDP, or net economic output Q_t corresponds to the conventional GDP net of market damages of climate change. It can be written as:

$$Q_t = (1 - \phi(A_t) \cdot D_t) \cdot Y_t, \tag{5}$$

where $\phi(A_t)$ denotes the damage decreasing adaptation function depending on the stock of adaptation A_t and D_t the exogenously given damage function depending on the temperature increase T_t^{pre}. For calibration reasons, we split up the damage decreasing adaptation function and the function for market damages.

Green GDP increases at a decreasing rate with adaptation (in the temperature range considered). A temperature increase on the other hand decreases green GDP:

$$\frac{\partial Q_t}{\partial A_t} > 0,\ \frac{\partial^2 Q_t}{\partial A_t^2} < 0,\ \frac{\partial Q_t}{\partial T} < 0,\ \frac{\partial^2 Q_t}{\partial T^2} < 0,$$

The damage decreasing adaptation function $\phi(A_t)$ is given by the following function:

$$\phi(A_t) = e^{-\theta \cdot A_t}, \tag{6}$$

where θ is an efficiency parameter of adaptation.

The damage decreasing adaptation function $\phi(A_t)$ is always between zero and one and has the following marginal conditions:

$$\begin{aligned} \phi(0) &= 1, \\ \lim_{A_t -> \infty} \phi(A_t) &= 0 \end{aligned}$$

Furthermore, $\phi(A_t)$ must have decreasing marginal benefits of adaptation, since an investment in adaptation is more efficient if the adaptation stock is small. We use an exponential function for $\phi(A_t)$ to implement the wanted characteristics.

The bigger θ, the more efficient the investments in adaptation get. We assume that the adaptation stock in the base year 2001 is equal to zero, i.e.

$$A0 = 0 \tag{7}$$

This simply means that in the base year 2001, full exogenous damages occur in Switzerland. The same assumption is made in the model of Bosello (2004). Since the ADAPT-CH model reacts robustly to changes in the initial adaptation stock and the market damages in 2001 are still small, this is not a crucial assumption. Furthermore, it is difficult to determine past investments in adaptation measures, since the threat of climate change is kind of new to the society. As we argued in section 3, flood protection and other adaptation measures against natural hazards were most likely reactive and undertaken to gain and protect new land for houses or farmers and not to adapt against future climate damages.

The exogenously given damage function D_t is taken from the literature, but has to be chosen carefully. As Tol and Fankhauser (1998) point out, most damage functions used in IA models already include adaptation implicitly. Dickinson (2007) supports this theory and Patt, van Vuuren, Berkhout, Aaheim, Hof, Isaac, and Mechler (2010) emphasize that including adaptation implicitly in the damage function can cause a lot of problems. In particular, they point out that changes in the price of adaptation are not reflected in models that consider adaptation implicitly. Thus, considering adaptation implicitly reflects only a partial equilibrium approach. To analyze adaptation explicitly in the AD-DICE model, De Bruin, Dellink, and Tol (2009) take the DICE damage function from Nordhaus and Boyer (2000), but decompose adaptation from the original damage function.

We choose a different approach: In the ADAPT-CH model, we take the damage function that Hope (2006) considers in the PAGE2002 model. As Patt, van Vuuren, Berkhout, Aaheim, Hof, Isaac, and Mechler (2010) point out, the PAGE2002 model does not include implicit adaptation in the damage function. Hope (2006) takes into account adaptation with an additional scenario. This makes the damage representation in the PAGE2002 suitable for our purpose. Our contribution is thus to implement explicit adaptation in the damage representation of the PAGE2002 model.

The damage function of the PAGE2002 model factors in the possibility of a threshold level of temperature change, where the market damages explode.[5] It can be written as:

$$D_t = \left(\frac{T_t^{pre}}{2.5}\right)^V \cdot V + (T_t^{pre} - T_{dis}) \cdot P_{dis} \cdot V_{dis} \tag{8}$$

where T_t^{pre} denotes the temperature increase with respect to the preindustrial level and V the level of market damages with a temperature change of 2.5 °C. T_{dis} denotes the catastrophic threshold level, V_{dis} the GDP loss in case of the catastrophic increase of temperature and P_{dis} is a probability parameter.[6]

The exogenously given temperature increase T_t^{pre} with respect to the preindustrial level is given by:

$$T_t^{pre} = b_1 \cdot t + b_2 t^2 \cdot + b_3 + 0.4, \tag{9}$$

where b_1, b_2 and b_3 are the warming parameters that stem from section 4. The parameter 0.4 is necessary to compare the 1961-1990 temperature mean from section 4 with the preindustrial temperature level.

Figure 8 illustrates the combination of the exogenous market damages and the endogenous adaptation stock in the ADAPT-CH model. The graph in the top left corner of figure 8 shows the exogenous temperature increase in Switzerland according to the ENSEMBLE data in section 4 for the next 50 years. While for the ENSEMBLE data temperature change is computed with respect to the 1961-1990 mean, the PAGE2002 damage function is calibrated using the preindustrial temperature. The graph in the top right corner of figure 8 shows the market damage factor of the PAGE2002 damage function without any adaptation measures. The two graphs in the bottom left and right corner of figure 8 illustrate the effect of adaptation on the exogenous market damages, on the left hand side with a constant adaptation stock and a changing efficiency parameter θ and on the right

[5] Note that this threshold is never reached in the ADAPT-CH model.

[6] As suggested by Hof, den Elzen, and van Vuuren (2008), we choose the parameter as follows: $V = 1.76,\ T_{dis} = 5.0,\ V_{dis} = 11.66,\ P_{dis} = 10.33.$

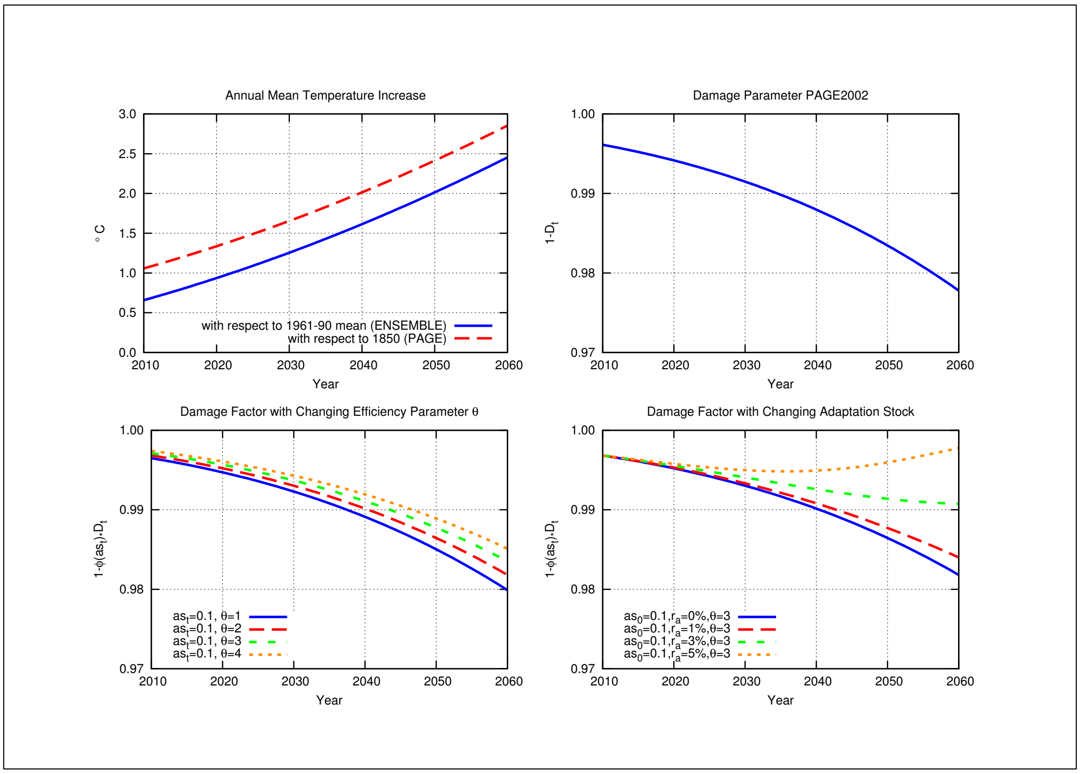

Figure 8: Overview of the temperature change in the ADAPT-CH model and the corresponding market damages with the PAGE2002 damage function.

hand side with a increasing adaptation stock of r_a percent per year and a constant efficiency parameter θ.

As mentioned above, the ADAPT-CH model is closed with an external closure rule. With this closure rule, trade with the rest of the world is simulated. We use the approach of Boadway and Treddenick (1978), but adapt the approach to a dynamic model. The level of imports m_t is given by the following equation:

$$m_t = m0 \left(\frac{pm_t}{exr}\right)^{\mu} \tag{10}$$

The parameter μ denotes the price elasticity of imports, $m0$ the base year import level, exr the exchange rate and pm_t the price level of imports. The price level of imports is exogenously given and depends on the equilibrium price path $pref_t$ and the damages in the rest of the world D_t. We can write pm_t as:

$$pm_t = \frac{pref_t}{1 - D_t} \tag{11}$$

The level of exports is given by:

$$x_t = x0 \left(\frac{px_t}{exr}\right)^{\eta} \tag{12}$$

where η denotes the price elasticity of exports, $x0$ the base year export level, exr the exchange rate and px_t the price level of exports. The price level of exports px_t is endogenous and depends on the level of damages in Switzerland and thus on the stock of adaptation. We can write px_t as:

$$px_t = \frac{pref_t}{1 - e^{-\theta \cdot as_t} \cdot D_t} \tag{13}$$

The change in net imports is thus triggered by a relative change in the price level of imports pm_t and exports px_t, combined with the price elasticity of imports μ and exports η. Other than in the model of Boadway and Treddenick (1978), we do not consider a balanced payment condition. As Whalley and Yeung (1984) argue, a trade model should not include an endogenous exchange rate and the system of Boadway and Treddenick (1978) can be overidentified. Thus, we allow Switzerland to have a trade imbalance and we set the exchange rate exr equal to one.

This trade imbalance affects the national income constraint for the representative agent. The national income constraint is given as follows:

$$Q_t + (m_t - x_t) = C_t + I_t + a_t \tag{14}$$

The net output Q_t plus net imports $(m_t - x_t)$ can be consumed (C_t), invested in the physical capital stock (I_t) or invested in the damage decreasing adaptation stock (a_t).

Note that we consider an additional policy constraint in the ADAPT-CH model. The investment level in proactive adaptation measures is often undertaken by the public sector and thus is bounded to constraints. We address this problem by assuming that there are growth boundaries for investing in adaptation. Specifically, it is not possible to increase or decrease the investments in adaptation by more than 5% per year. The corresponding conditions can be written as:

$$a_{t+1} \leq (1 + agr) \cdot a(t) \tag{15}$$

and

$$a_{t+1} \geq (1 - agr) \cdot a(t) \tag{16}$$

where agr is the adaptation growth boundary of 5%

Further, to avoid end of time horizon effects, we implement two terminal constraints, one for investments in the capital stock and one for investments in the adaptation stock. The terminal constraint for investments in the capital stock is given as:

$$\frac{I(T)}{I(T-1)} = \frac{Y(T)}{Y(T-1)}. \tag{17}$$

Between the second last period $T-1$ and the last period T, the investments in the physical capital stock grow at the same rate as the output. For the adaptation stock, the terminal constraint looks just the same:

$$\frac{a(T)}{a(T-1)} = \frac{Y(T)}{Y(T-1)}. \tag{18}$$

As for investments in the physical capital stock, investments in adaptation grow at the same rate as the output between the second last period $T-1$ and the last period T.

6 Results of the ADAPT-CH Model

We consider two different scenarios in the model, the baseline scenario and the *optimal adaptation scenario*. The baseline scenario reflects a state without any adaptation in Switzerland. Thus, full exogenous market damages occur. To compute the baseline scenario, the ADAPT-CH model is calibrated for Switzerland for the base year 2001. Growth rate g, interest rate r and depreciation rate of capital δ_k are computed under the assumption that the Swiss economy is in a steady state in 2001. We then compare this baseline scenario with the *optimal adaptation scenario*, in which the society efficiently reduces exogenous market damages caused by e.g. floods through an optimal investment in cumulative adaptation measures. We assume that these specific damages can be prevented by cumulative adaptation measures such as flood protection measures.

The main results of the ADAPT-CH model are illustrated in figures 9 to 11. Figure 9 shows the adaptation strategy in the *optimal adaptation scenario* and the impacts on market damages. Figure 10 compares the main variables of the model to the results of the baseline scenario. Finally, figure 11 illustrates the impacts of optimal adaptation in Switzerland on trade.

The graphs in the top left and right corner of figure 9 show the level of optimal investments in adaptation in Switzerland and the corresponding stock of adaptation, respectively. Until 2060, up to 0.9% of the Swiss GDP should be invested in cumulative adaptation measures per year. The corresponding adaptation stock rises to around 9% of the GDP in the year 2060.

The graphs in the bottom left and right corner of figure 9 show the impact of the optimal adaptation strategy on the level of market damages by comparing the baseline scenario with the *optimal adaptation scenario*. While in the baseline

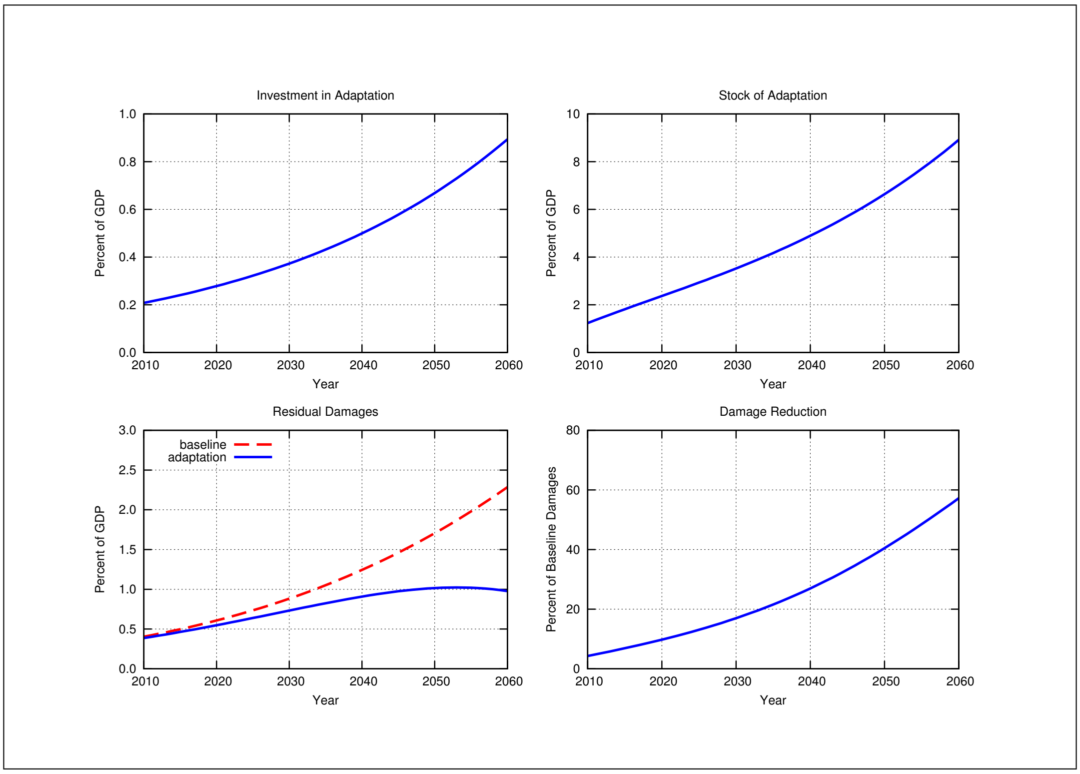

Figure 9: Optimal investments in adaptation measures in Switzerland and the corresponding impacts on market damages.

scenario market damages reach a level of around 2.4% of the GDP, with the optimal adaptation strategy this number declines to around 1%. This means that with an optimal strategy with respect to cumulative adaptation, up to 58% of the market damages considered are prevented until 2060. Note that all these numbers are comparable to the results of De Bruin, Dellink, and Tol (2009) and Bosello (2004).

In figure 10, the impacts of the optimal adaptation strategy on consumption, investments, production level and Green GDP are illustrated. This is done by normalizing the results of the baseline scenario to 100% and then comparing them to the results of the *optimal adaptation scenario*. As it is shown in the graph in the top left corner of figure 10, it is optimal to reduce consumption at the beginning of the time horizon in order to invest in adaptation measures. As a benefit from these investments, future consumption will be up to 0.7% higher than in the baseline scenario, which leads to an overall welfare improvement. At the same time, the investments in the physical capital stock are 1% higher in the *optimal adaptation scenario*, since the productivity of capital is improved. Or to phrase it differently, because the adaptation stock protects the productivity of capital, it is optimal to invest more in capital in the *optimal adaptation scenario* compared to the baseline scenario.

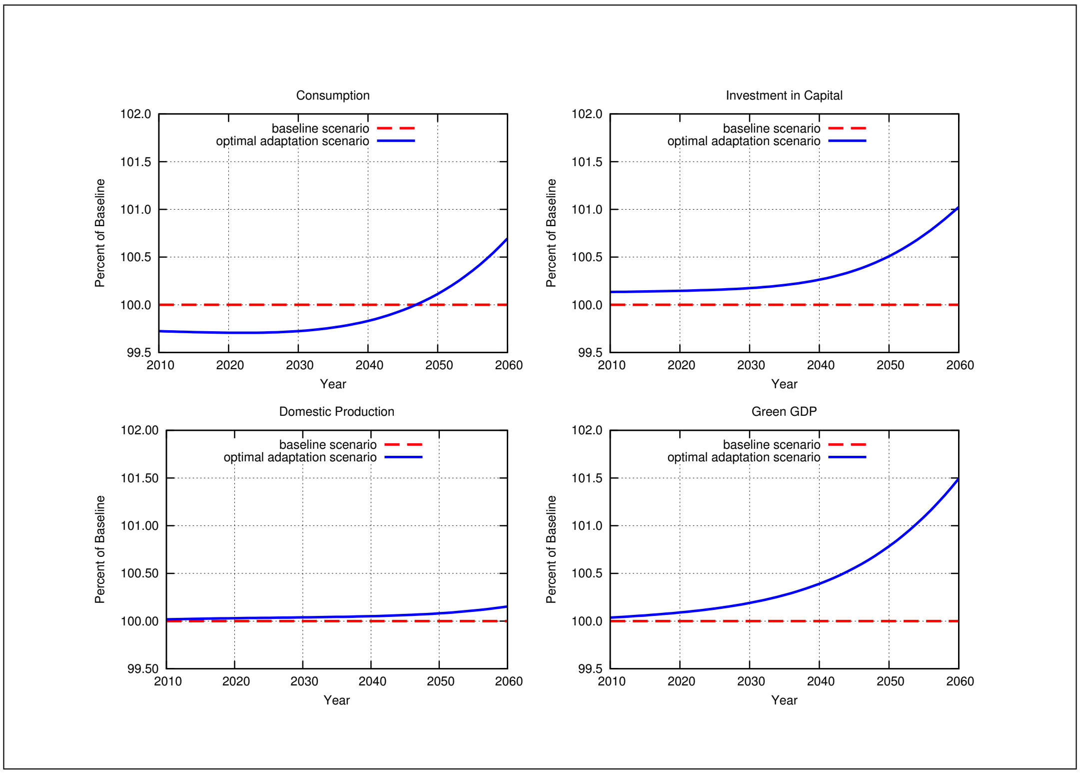

Figure 10: Effects of an optimal adaptation strategy on the main variables in the ADAPT-CH model.

The graph in the bottom left corner of figure 10 shows the level of domestic production in the *optimal adaptation scenario* compared to the baseline results. The higher capital stock in the *optimal adaptation scenario* leads to a 0.2% higher production level. This is not much, but combined with the damage reduction due to the optimal adaptation stock, the Green GDP is up to 1.5% higher in the *optimal adaptation scenario* until 2060.

The optimal adaptation strategy has major impacts on the trade balance. Since with adaptation the price level in Switzerland decreases compared to the rest of the world, exports from Switzerland get less expensive. Thanks to investments in adaptation, Switzerland can thus generate a trade surplus. This generates an additional incentive to invest in adaptation. Figure 11 illustrates these findings. The upper graph of figure 11 compares the baseline exports to the level of exports in the *optimal adaptation scenario* and the lower graph of figure 11 shows the corresponding net exports in percent of the GDP. Compared to the baseline scenario, exports are 0.7% higher in the *optimal adaptation scenario* and this leads to a trade surplus of 0.2% of GDP in 2060.

To test the robustness of the model, we consider a sensitivity analysis with the crucial parameters for adaptation, i.e. the depreciation rate of the adaptation stock δ_a and the efficiency parameter of adaptation θ. The graphs in the top

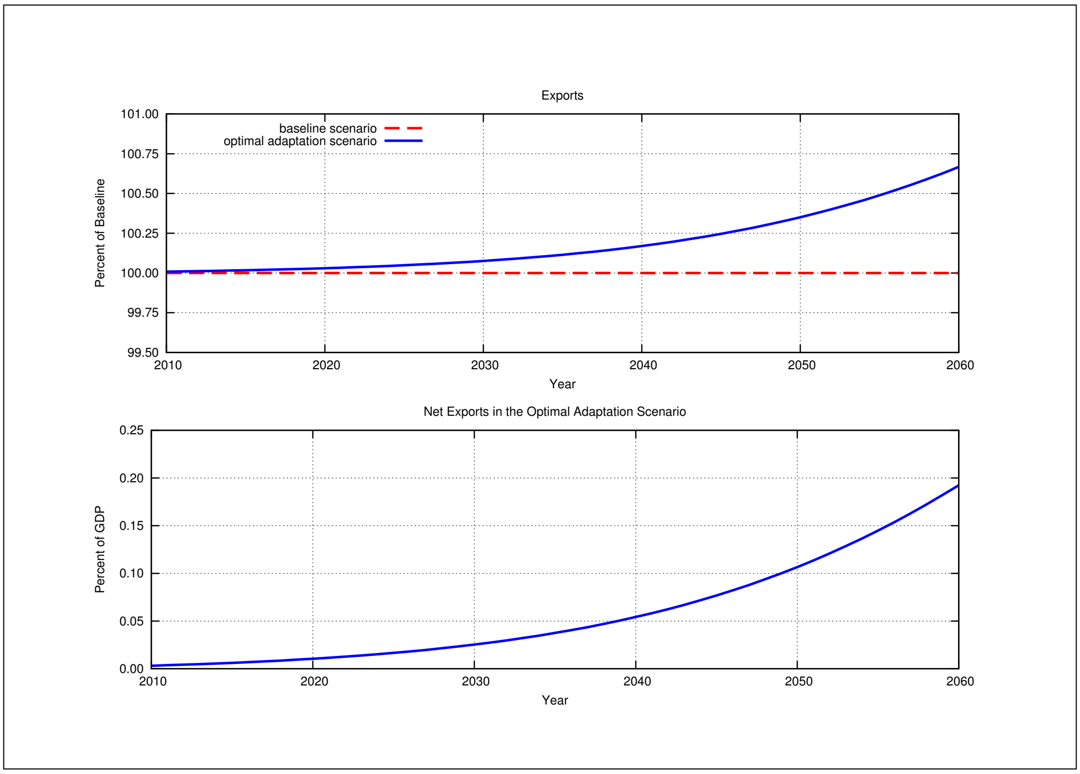

Figure 11: Effects of an optimal adaptation strategy on exports.

left and right corner of figure 12 illustrate the sensitivity analysis for the level of investments in adaptation and for the residual damages for changing δ_a, and the graphs in the bottom left and right corner for changing θ, respectively. The values calibrated in the ADAPT-CH model are illustrated as the solid line, the values for the sensitivity analysis are shown as a grey surface and the range is indicated in the graphs.

The results of the sensitivity analysis in figure 12 are as expected. The higher the depreciation rate δ_a of adaption, the less efficient the investments get. This is why the investments in adaptation are small for large depreciation rates. Accordingly, the higher the depreciation rate of adaptation, the higher the residual damages. The influence of the adaptation efficiency parameter θ is exactly vice versa: The higher the adaptation efficiency parameter, the more efficient the investments get. Thus, the higher θ, the higher the investments in adaptation. Accordingly, the higher θ, the lower the residual damages.

Note that the adaptation efficiency parameter θ, which is hard to estimate and crucial for the calibration of the model, reacts robustly to changes. In the range where the choice of θ produces an equilibrium investment path of adaptation, changes in the efficiency parameter do not alter the results drastically. This is important for the validity of the results.

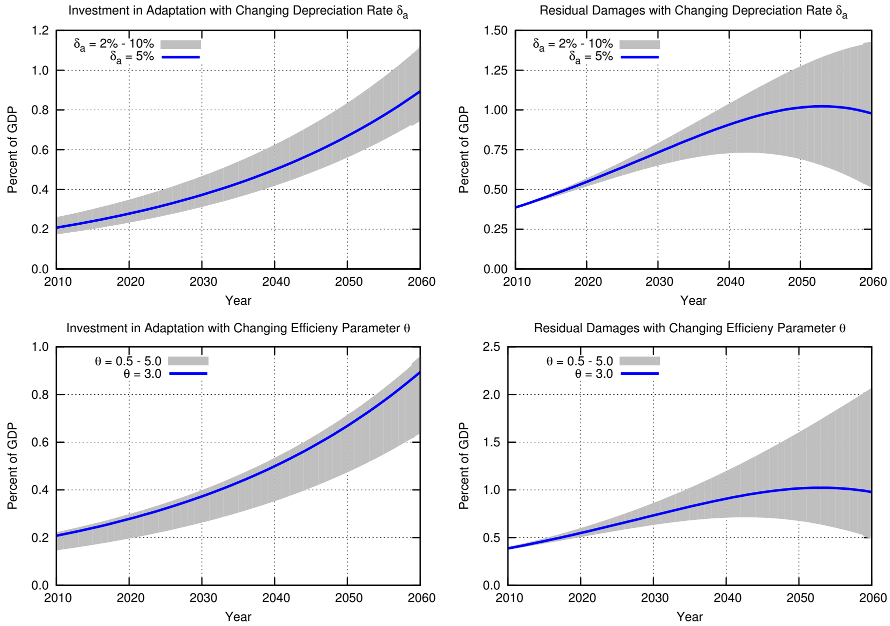

Figure 12: Results of the sensitivity analysis.

7 Conclusion

This part presents a completely new approach to address the issue of adaptation in Switzerland. So far, studies on adaptation in Switzerland have either focused on specific regions (Elsaesser and Buerki 2002) or specific sectors (Behringer, Buerki, and Fuhrer 2000). We choose a more integral approach by analyzing adaptation on a national level. To do so, we develop the ADAPT-CH model, a one-region CGE model with adaptation as a decision variable. As in the FEEM-RICE model of Bosello (2004), we model adaptation as investments in a cumulative stock. But we made a few changes compared to the existing literature on modelling adaptation as a decision variable. First, we do not consider the option of mitigation as in the FEEM-RICE model. We concentrate on adaptation only and address a mid-term time horizon of 50 years. Second, we do not take the damage representation of Nordhaus and Boyer (2000) as in the FEEM-RICE model of Bosello (2004) and in the AD-DICE model of De Bruin, Dellink, and Tol (2009). We consider the damage representation of the PAGE2002 model (see Hope 2006) and add adaptation as a decision variable.[7] Third, we analyze the impacts of adaptation on the trade balance by analyzing an external closure rule. And finally, we use the newest climate change projections for Switzerland in the ADAPT-CH model.

[7]Hope (2006) addresses adaptation with a special scenario, not with a endogenous variable.

To develop the idea of how adaptation should be modelled in a one-region CGE model for Switzerland, we started with a historical analysis of past natural disasters and of flood protection measures that were taken as a reaction to the disaster events. This has helped us to define a general approach in the ADAPT-CH model which takes into account anticipatory, cumulative adaptation.

The graphical analysis of past disaster events has shown us the most vulnerable places in Switzerland. Especially floods have threatened the same spots over and over again from the 13th century on. Flood protection measures in these vulnerable places that were taken from the 16th to the 20th century seem to have been effective, but taken ex post. Burton (1996) states that reactive adaptation is not as efficient as proactive, anticipatory adaptation. This is why we have focused on cumulative adaptation in the ADAPT-CH model, since this kind of adaptation reflects the idea of proactive measures best.[8]

To calibrate the ADAPT-CH model for Switzerland, we used the newest ENSEMBLE temperature prediction as climate data input.

It is important to note that this approach only takes into account market damages that can be prevented by cumulative adaptation measures. These damages caused by e.g. floods can be reduced or even prevented by infrastructural measures (e.g. dams) that underlie long-term anticipatory planning, and thus cumulative adaptation and the building up of an adaptation stock. Damages by climate change that can best be prevented by instantaneous adaptation, such as the change in crop types due to an increase in temperature, are not considered in our model. Neither are the respective adaptation measures. Investing only in cumulative adaptation, these damages can't be prevented. Our results only relate to the damages that can be prevented by cumulative adaptation and are therefore limited to some extent.

In our model we find that an annual investment of up to 0.9% of the GDP until 2060 can prevent us from a little over 58% of the damages considered.[9] We further find that unilateral adaptation can lead to a trade surplus. Investing in adaptation reduces the market damages and thus the production costs. This leads to a comparative advantage compared to the rest of the world and thus to a to trade surplus.

[8]This fact is also covered in the paper of Bosello (2004), with the difference that Bosello (2004) refers to proactive adaptation measures as *planned adaptation*.

[9]Note that these numbers are in line with the results of Bosello (2004) and De Bruin, Dellink, and Tol (2009).

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A Appendix

A.1 Parameters in the ADAPT-CH Model

Parameter	Description	Value
g	Growth rate labor supply	0.02
r	Interest rate	0.04
ρ	Discount rate	0.02
δ_k	Depreciation rate capital	0.05
δ_a	Depreciation rate adaptation stock	0.05
θ	Adaptation efficiency parameter	3.00
γ	Capital value share	
l_t	Labor supply	
agr	Adaptation growth boundary	0.05
η	Price elasticity exports	-0.50
μ	Price elasticity imports	-0.50
exr	Exchange rate	1.00
$pref_t$	Equilibrium price path	
a_1	Warming parameter ENSEMBLE data	0.0002021
a_2	Warming parameter ENSEMBLE data	0.0015632
a_3	Warming parameter ENSEMBLE data	-0.1636617
W	Market damages 2.5 °C temperature increase	1.76
T_{dis}	Catastrophic temperature increase	5.00
W_{dis}	GDP loss catastrophic temperature increase	11.66
P_{dis}	Probability of catastrophic temperature increase	10.33
D_t	Exogenous damage factor	
T_t^{pre}	Exogenous temperature increase	

Table 1: List of the parameters in the ADAPT-CH model.

A.2 Decision Variables in the ADAPT-CH Model

Variable	Description
k_t	Capital stock
i_t	Investments in the capital stock
A_t	Adaptation stock
a_t	Investments in the adaptation stock
c_t	Consumption level
q_t	Gross production
y_t	Green GDP
x_t	Exports
m_t	Imports
px_t	Price level of exports
pm_t	Price level of imports

Table 2: List of the decision variables in the ADAPT-CH model.