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Gabriel Bachner, Birgit Bednar-Friedl and Nina Knittel

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Department of Economics
Department of Public Economics
University of Graz

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Gabriel Bachner[1], Birgit Bednar-Friedl [1,2,*], Nina Knittel[1]

[1)] Wegener Center for Climate and Global Change, University of Graz, Brandhofgasse 5, 8010 Graz, Austria
[2)] Institute of Economics, University of Graz, Universitätsstraße 15, 8010 Graz, Austria
[*)] Corresponding author. Email: birgit.friedl@uni-graz.at

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Abstract:

Public adaptation to climate change affects government budgets directly on the expenditure side, but budgets are also indirectly affected via a change in the tax base and a diversion of government consumption. While these indirect effects have been analyzed intensively for mitigation policies, a similarly detailed model-based analysis for adaptation policy is still missing. The present paper addresses this gap for the case of Austria in 2050 by (i) developing an adaptation expenditure pathway starting from current adaptation-relevant expenditures on programs and measures; (ii) analyzing the macroeconomic consequences thereof in a computable general equilibrium model; and (iii) assessing both direct and indirect effects on government revenues and expenditures. We find that public adaptation can lead to substantial positive macroeconomic effects on gross domestic product, welfare, and employment and that this effect is robust with respect to different assumptions on the effectiveness of adaptation measures. Despite the additional direct public expenses for adaptation, the overall government revenues, and therefore the budget balance, increase (relative to a climate change impact scenario without adaptation). These higher revenues trace back to reduced tax losses from less severe climate change impacts as well as higher labor tax revenues since soft and green adaptation measures stimulate employment. On the expenditure side, less expenditures on disaster relief and unemployment benefits enable increasing government consumption in other areas like health and education.

Keywords: climate change, public adaptation, indirect effects, public budgets, computable general equilibrium

JEL codes: Q54, H61, C68

1. Introduction

In the last decade, national strategies for adaptation to climate change as well as implementation plans have been developed and implemented to various degrees in numerous countries (Lesnikowski et al. 2015). It is a widely held conjecture that, unlike mitigation, adaptation is a private good and that therefore private actors should be the ones who carry out adaptation actively (Tol 2005), whereas the role of the public sector is limited to providing the right incentives for private adaptation (Jones et al. 2013) and to correct for market failure (Osberghaus et al. 2010). However, the state is the owner of public infrastructure, acts as service provider e.g. by means of early warning systems, or plays a significant role as information broker e.g. to coordinate preparedness for and response to extreme weather conditions (Eakin and Patt 2011). This view is also supported when taking a closer look at national adaptations strategies and plans, according to which a considerable share of adaptation is initiated by legislation, as well as financed and implemented by the public sector (Urwin and Jordan 2008; Biesbroek et al. 2010; McDonald 2011; Mees et al. 2012). Given that adaptation involves therefore significant expenditures also for the public sector, this paper takes a closer look at the direct and indirect consequences of public adaptation for federal budgets.

The public household is affected by climate change impacts and public adaptation through various channels (Bräuer et al. 2009; Bachner and Bednar-Friedl 2018). The impacts of climate change lead to *direct costs* for the public household in the form of e.g. higher expenditures for disaster relief payments to private households or reconstruction of damaged public infrastructure. Adaptation leads to direct costs in the form of additional public expenditures, but it also reduces some of the direct impact costs (benefit of adaptation). In addition, *indirect effects* arise on public budgets because of changes in tax revenues (cf. Lis and Nickel 2010; Schinko et al. 2016).

Public adaptation is usually strongly integrated in the government's general practices to "climate proof" investment decisions and to mainstream adaptation into other policy fields (Bierbaum et al. 2013).[1] The economic literature on adaptation has so far mostly ignored this complexity and modeled adaptation in a very stylized way, e.g. in the form of generic adaptation capital that is built up to increase the adaptive capacity of an economy to identify an optimal adaptation level (de Bruin et al. 2009; Agrawala et al. 2011a, b; Bosello et al. 2013). For practical decision making on public adaptation, however, these generalized insights from integrated assessment models have been of insufficient granularity as they do not allow for an assessment of the effects and usefulness of specific adaptation measures. The present paper intends to fill this gap by developing a detailed expenditure pathway for public adaptation until 2050 and assesses the economy-wide and budgetary effects of its implementatino. As a starting point we use a screening of public adaptation expenditures in the current federal budget for Austria (similar to a study by Gilmore and St.Clair 2018 for the US).

As shown in numerous economic climate change impact assessments, climate change impacts lead to significant losses in a broad range of economic sectors and for overall economic performance (Ciscar et al. 2011, 2012; Bosello et al. 2012; Bosello and De Cian 2014; OECD 2015; Steininger et al. 2015; Dellink et al. 2017). Moreover, cross-sectoral and macroeconomic effects can be a multitude of these impacts within the sector due to indirect effects (Hallegatte et al. 2007). As argued above, also adaptation does not only lead to direct effects in the form of expenditures on measures, programs and investments, but also exerts indirect effects on public budgets: due to sectoral spillover and macroeconomic feedback effects, the tax base can be affected and thereby it alters the budget balance and the fiscal position of a country.

[1] In many national adaptation strategies, the number of measures identified and proposed is quite large because adaptation affects many sectors. In the case of Austria, the national adaptation strategy covers 14 different impact fields and consists of 132 measures in total (BMLFUW 2012).

Yet, while the fiscal implications of mitigation have been investigated in several papers (for a review, see Siegmeier et al. 2018), there is relatively little known about the implications of public adaptation for government budgets. We argue that there is an essential difference between mitigation and adaptation, needing a separate analysis for the effects of public adaptation on government budgets. While many mitigation policies such as carbon taxes have the potential to generate revenues, the direct effects of adaptation arise mostly on the expenditure side. Mitigation therefore allows to cut distortionary taxes or to increase expenditures e.g. on carbon free technologies, but the contrary holds for adaptation: public expenditures have to be cut, or other taxes have to be raised in order to ensure sustainable government finances.

Despite the underrepresentation of the topic of fiscal implications of public adaptation in the academic literature, some papers provide useful starting points for our analysis. Regarding the direct consequences of climate change impacts for public budgets, some papers describe the consequences of climate change adaptation for government budgets in a qualitative way and provide empirical estimates for these changes in expenditures (Bräuer et al. 2009; Osberghaus and Reif 2010; World Bank 2010; Jones et al. 2013; Gilmore and St.Clair 2018). Complementary to this literature, econometric approaches have been applied to historical data to estimate the effects of climate variability and extreme weather events on public finances (Lis and Nickel 2010; Ouattara and Strobl 2013; Melecky and Raddatz 2015; Leppänen et al. 2015). These papers are limited to the direct effects on public expenditures and do not address the indirect impacts via changing government revenues due to sectorial and macroeconomic effects of climate change. The indirect effects to public budgets have however been analyzed for climate change impacts, but not for public adaptation, in a computable general equilibrium framework (Bachner and Bednar-Friedl 2018). Moreover, most of the previous studies are limited to an assessment of past impacts but do not investigate future impacts of climate change (with the exception of Leppänen et al. 2015; Bachner and Bednar-Friedl 2018).

Since the quantification of climate change adaptation induced effects on public budgets is therefore still underdeveloped, the objectives of this paper are summarized as follows. First, we develop a public expenditure pathway until 2050 by starting from a screening of the current federal budget in Austria. We develop the pathway by drawing on suggestions from the literature (e.g. on the timing of measures to ensure flexible adjustment over time) and on consultation with stakeholders. Second, we assess the consequences of this adaptation pathway for the federal budget by using a computable general equilibrium (CGE) model. According to Fisher-Vanden et al. (2013), CGE models are, due to their sectorial detail and their differentiation by different economic agents, particularly well suited to assess different types of adaptation activities. In addition, the CGE model in use is rich in detail on government revenues and expenditures and is therefore able to capture both, the direct and the indirect effects of climate change impacts and public adaptation on government budgets. The analysis is carried out for the case of Austria.

The remainder of the paper is structured as follows. Section 2 describes how climate change impacts and public adaptation affect government budgets, by first describing the general mechanisms and then describing the current and potential future expenditures on public adaptation in three impact fields in Austria. Section 3 describes the methodology and the data used to assess the direct and indirect effects of adaptation to the government budget. Section 4 describes the key results, and section 5 concludes.

2. Climate change impacts, public adaptation, and the government budget

2.1. Conceptual model

Both climate change and adaptation affect federal government budgets on the expenditure and revenue side. Figure 1 illustrates the effects of climate change impacts on different government expenditure categories. In the baseline case (or business as usual without climate change), government expenditures consist of four major items: (i) relief payments for damages caused by extreme weather events and climatic changes (e.g. in the form of a national disaster fund), (ii) other non-climate related government consumption (provision of public services like education, health system, etc.), (iii) social security payments for unemployed, and (iv) other transfers to households. The first two items are both attributed to general "government consumption".

With climate change, both the composition and the level of government expenditures change. As a direct effect of climate change on government expenditures, relief payments to households increase due to higher damages caused by extreme events. But also several indirect effects emerge. First, depending on the sectorial and macroeconomic impact of climate change, tax revenues change: as most macroeconomic climate change impact studies find a negative impact of climate change on economic activity, it is plausible to assume that there is a tax revenue loss. Therefore, total government revenues decline (see the gray shaded area in the second column of Figure 1) and unemployment benefits increase because of an increase in unemployment (another consequence which is related to lower economic activity). In order to ensure that government expenditures remain within its now smaller total so that the public deficit does not increase, two adjustments are possible: transfers to households or other, non-climate related government consumption need to decline. It is again plausible for many countries to assume that the level of government consumption is fixed by multi-annual budgeting rules. As a consequence, the total level of government consumption remains constant but is restructured towards more disaster relief payments and less other government consumption (non-climate related); leaving transfers to be reduced.

With adaptation, again direct and indirect effects emerge on government expenditures. The direct effect is caused by public adaptation expenditures. We assume in Figure 1, that public adaptation is part of the multi-annual budgeting (planned adaptation) and that therefore adaptation comes on top of government consumption. The indirect effects arise again via macroeconomic feedback effects. Because of (effective) adaptation, climate change impacts are reduced and economic activity increases, and therefore the tax base and total government revenues increase (compared to the climate change impact case). Note that tax revenues are still smaller than in the baseline case because it is plausible to assume that adaptation can reduce some of the impacts but not all of them (residual damages emerge). Government consumption is restructured because disaster relief payments are smaller with adaptation and therefore other government consumption can be expanded again (however, not reaching the baseline level). Due to a potential increase of employment, which can be caused by both higher economic activity and a comparatively high labor intensity of government consumption, unemployment benefits decline (again only relative to the case with climate change). Depending on the size of the of tax revenue loss and the effect on unemployment with adaptation, other transfers can then be either increased (as shown in Figure 1) or have to be cut to keep the balance between revenue and expenditure.

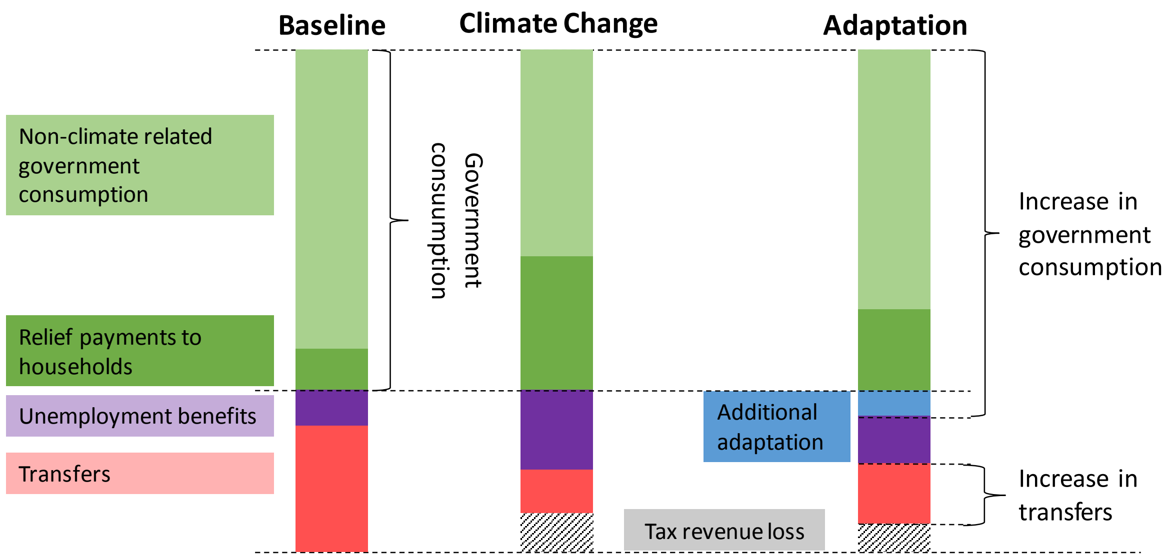

Figure 1: Effects of climate change impacts and adaptation on government expenditures

For the government revenue side, we distinguish five categories: factor taxes on labor and capital; output taxes; value added taxes; and other taxes (most notably export and import taxes). Both climate change and adaptation exert an indirect effect on tax revenues, by changing the tax base (sectorial output, employment, capital use etc.). As argued above, it is reasonable that climate change impacts reduce economic activity and increase unemployment, reducing revenues from labor, output and value added taxes. Likewise, (effective) adaptation might reduce these macroeconomic impacts to a certain degree, and therefore total tax revenues should be higher (i.e. less severe tax revenue losses).

Finally, it is important to consider government budgeting rules. Many countries have committed themselves to avoid excessive deficits and to pursue fiscal sustainability. For instance, the European Stability and Growth pact (European Union 2008, Art. 121 and 126) requires that all member states keep the government deficit below 3% of GDP and the government debt should not exceed 60% of GDP. Pereira and Pereira (2014) investigate how a tax on CO_2 affects economic performance and government budgets under different budgetary rules (fixed government consumption; fixed government investment; fixed government consumption and investment). They find that the CO_2 tax increases government revenues and that therefore not only government consumption but also government debt increase compared to a rule of fixed government consumption. Bachner and Bednar-Friedl (2018) investigate the influence of climate change impacts on government budgets under different fiscal rules. They find that both a cut in transfers and an increase in capital taxes are more effective in fiscal consolidation (i.e. keeping the deficit constant) compared to an increase in labor or output taxes or in foreign lending. In our analysis in Section 3 and illustrated in Figure 1, we therefore assume that (i) government consumption is fixed in the climate change impact scenario, and that (ii) transfers to households are adjusted to ensure that government revenues are balanced with government expenditures.

2.2. Current and future public adaptation at the federal level in Austria

The Austrian national adaptation strategy aims to reduce the negative impacts of global climate change on the environment, society and economy and to identify opportunities arising from climate change. The corresponding action plan (BMLFUW 2012) comprises 132 measures in 14 impact fields: Agriculture, Forestry, Water, Tourism, Electricity, Buildings, Protection from Natural Hazards, Catastrophe Management, Health, Ecosystems and Biodiversity, Transport, Spatial Planning, Manufacturing and Trade, Cities and Urban Green. The public sector is involved in almost all impact fields of the adaptation strategy, either by initiating, financing or by implementing the measures (Knittel and Bednar-Friedl 2016).

In the following analysis we focus on the impact fields with the highest federal budgetary importance and with potentially strong impacts for the Austrian economy (Bednar-Friedl et al. 2017): Agriculture, Forestry and Catastrophe Management (including Protection from Natural Hazards). Agriculture is connected to the public domain, since it is heavily subsidized and thus adaptation in this sector is indirectly funded by public resources. Forestry is of high relevance, since this impact field's contribution to the overall economic damages is relatively high (-0.8% GDP loss in 2050 by climate change impacts in the forestry sector, Bachner et al., 2015b). In addition, the government owns a large share of the protective forests in Austria and is thus responsible for the maintenance of its protective effect. The impact field Catastrophe Management is closely connected to the public domain, since the main vehicle in post-disaster risk management in Austria – the disaster fund – is fully financed out of tax revenue (Schinko et al. 2016). In addition, we include Research and Development as a supplementary and publicly financed activity to foster adaptation.

To identify current federal expenditures on public adaptation within the three impact fields, we screened the federal budget in the base year for adaptation relevant expenditure items and categorized each adaptation expenditure category as either a gray, green or a soft measure (see Appendix A.2 for methodological details). "Soft" measures comprise information measures such as early warning systems, "gray" measures comprise structural protection, as for example flood protection dams; and "green" measures are ecosystem measures, natural flood retention areas or forest management. In addition, we include a separate category "Research and Development".

The result of the screening is shown in the first time slice (2016) in Figure 2. Currently, the largest public adaptation relevant expenditures items are gray measures in the impact field Catastrophe Management (CATM, € 471 million p.a.) and green measures in the impact field Agriculture (AGRI, € 257 million p.a.).

Soft measures as well as research and development (R&D) play only a minor part in the current adaptation expenditures. In total, current annual adaptation relevant expenditures sum up to € 908 million (15% of total expenditures of the screened budgetary subdivisions).

Starting from the adaptation relevant public expenditures in the year 2016, we develop an indicative adaptation pathway until mid-century (2050). This pathway combines expert judgment on the additional resources needed for single adaptation measures and on limits to further increases of certain adaptation measures (such as gray adaptation measures), international recommendations on the useful timing and phasing of gray, green, and soft measures (Watkiss et al. 2014). For the development of the reference ("Baseline") expenditure path the growth rate that is assumed in the mid-term budget forecast for the Federal State of Austria (BMF 2015) is used (assuming the same shares as in 2016). Methodological details can be found in Appendix A.2.

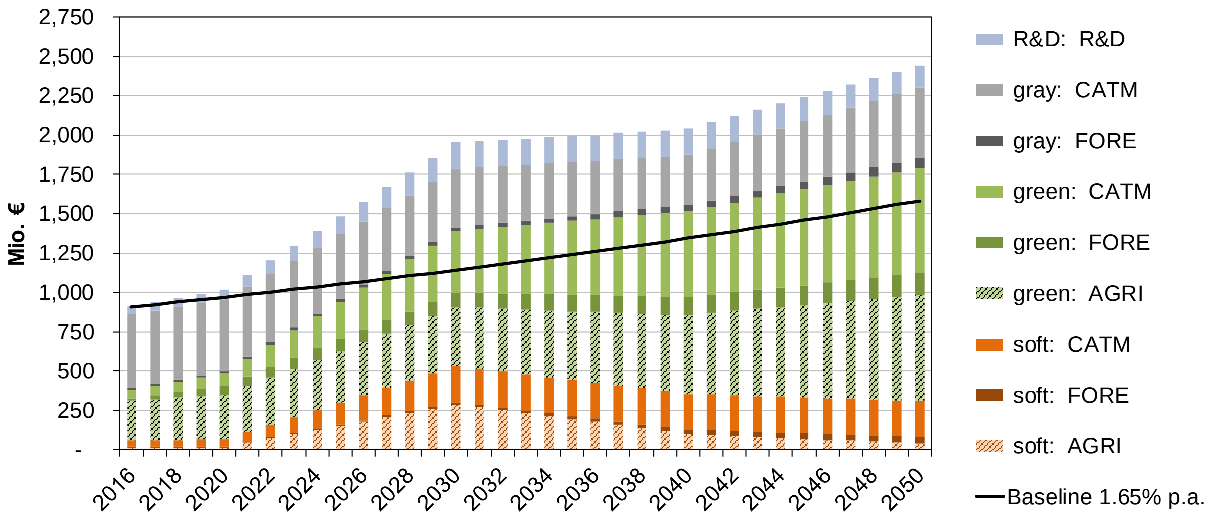

Figure 2: Indicative adaptation pathway until 2050 (R&D: Research and Development; CATM: Catastrophe Management; FORE: Forestry, AGRI: Agriculture).

Figure 2 illustrates this indicative pathway in terms of expenditures, separated by type of measure (gray, green or soft) and the impact field in which adaptation is carried out (funded). Expenditures on gray measures, such as flood protection, dominate in the period up to 2020. However, since in Austria the ongoing investment cycle in the refurbishment of the water and wastewater network is to be completed by 2020, the indicative scenario foresees a slight decline in this category in period 2020 to 2040, with a resurgence of investment from 2040 onwards. In the current budget, expenditures on soft measures, such as information provision and early warning systems, are small compared to other categories. Thus, we assume a relatively strong increase in this category in period 2020 to 2030 to increase adaptive capacity in the respective impact fields. Since the budgetary and structural limits of gray measures are expected to be reached by 2030, expenditures on gray measures are assumed to decline from 2030 onward, whereas expenditures on green measures, such as the expansion of retention areas, measures for rural development (Austrian Agri-Environmental Programme “ÖPUL”), or forest management are assumed to increase by 2030. Expenditures on Research and Development contribute to all impact fields and we assume here that they increase up to 2030 and stay constant afterwards. In total, expenditures of this indicative scenario rise by 3% per year over the period 2016-2050. In comparison, other public expenditures in this indicative pathway grow at the average economic growth rate of 1.65% (“Baseline” in Figure 2).

3. Method

3.1. The Computable General Equilibrium Model

To analyze the economy-wide and budgetary effects of climate change impacts and adaptation, including the indirect effects, we use a single-country, comparative static computable general equilibrium (CGE) model of Austria (Bachner et al. 2015b; Steininger et al. 2016b; Bachner and Bednar-Friedl 2018). In general, CGE models are based on balanced input output tables, which ensures that all economic sectors and agents are interlinked and that there is no excess supply or demand. Thus, the economy is described as a closed system of monetary flows, which is balanced, or in a state of equilibrium, in which all markets are cleared simultaneously (“general equilibrium”). Within this framework producers, or sectors, maximize profits (or minimize production costs) by choosing the optimal combination of factor and intermediate inputs according to specified production functions, while consumers maximize their utility out of the consumption of goods and services according to a specified consumption function. Whenever the initial equilibrium is disturbed, relative prices change such that a new equilibrium emerges in which all markets are cleared again. Since this type of model features interconnectedness across all economic sectors and agents and in addition long-term endogenous price responses it is well suited to assess the economy-wide implications of climate change impacts and adaptation.

The model covers 40 economic sectors using intermediate inputs as well as two production factors, labor and capital, to create output according to nested constant elasticity of substitution (CES) production functions. There is one representative private household, which is endowed with labor and capital. The respective factor income is spent for consumption (modeled as a nested CES function). In addition to the private household, there is a public household, which provides public services, financed by the following taxes: sales taxes on output, tax on capital gains, labor tax, value added tax and export tax. All tax rates are fixed, thus determining flexible government income, which in turn gives the total amount of available public budget to be spent. Regarding the labor market, the model includes classical unemployment. International trade is depicted via the Armington (1969) assumption, i.e. domestic goods/services are imperfectly substitutable for goods/services coming from abroad. The foreign balance is fixed at the share of the benchmark year (2008). For more details on the model and the algebraic formulation see Bachner (2017).

3.2. Modelling of climate change impacts

Climate change *impacts* are identified and implemented in ten climate change impact fields. For each of these fields, several "impact chains" – describing stepwise the effects of changes of physical climate parameters to economic materialization – are quantified in a range of (bio)physical models. These impact chains are then implemented into the macroeconomic CGE model by (i) changes in production cost structures (e.g. a different production process in Agriculture), (ii) changes in productivity (e.g. yield changes in Agriculture and Forestry), (iii) changes in investments (e.g. reconstruction of infrastructure after flood events), and (iv) changes in public expenditures (e.g. more post-disaster relief payments undertaken by the government in Catastrophe Management). Table 1 summarizes the impacts which are implemented for those impact fields that we are focusing on in the present analysis of adaptation (Agriculture, Forestry, and Catastrophe Management). For the remaining impact fields, see Appendix A.1.

Table 1: Coverage of impact chains, (bio-)physical impact models and implementation of impacts in the CGE model

Impact field	Impact chains	(Bio)physical impact model used for quantifying impact
Agriculture	Crop productivity of main crops (grain maize, winter wheat, winter rape, soybean, temporary grassland) and grassland due to changes in temperature and precipitation	Regression analysis (Mitter et al. 2015b) based on simulations with the biophysical process model EPIC (Izaurralde et al. 2006) and the farm optimization model PASMA (Schmid 2004)
Forestry	Biomass productivity in commercial production forests due to changed precipitation and temperature, bark beetle disturbances on productivity of commercial forests and protection functionality of protection forests	Estimation of productivity changes with forestry revenue model PICUS 3G (Schörghuber et al. 2010) and of damages from spruce bark beetles with FISCEN scenario model (Seidl et al. 2009, 2011); impact of bark beetle disturbances on protection functionality based on expert guess (Lexer et al. 2015)
Catastrophe Management	Building damages due to riverine floods	Simulation of riverine flooding damages in a hybrid convolution approach (Hochrainer-Stigler et al. 2014) (which builds on results of the LISFLOOD model, the ClimateCost project (Feyen and Watkiss 2011; Rojas et al. 2013) and on the AdamCost project (Kundzewicz et al. 2010; Lugeri et al. 2010)

3.3. Modelling of public adaptation: Costs and avoided damages

Adaptation costs are divided into two components: On the one hand, adaptation changes the structure and level of *sectoral operating costs* and government *consumption* (e.g. contracting to spatial planning bureaus, maintenance costs for public infrastructure, labor costs) and on the other hand, it affects *investments*. Changes in sectoral operating costs are modelled as shifts within the production cost structures with holding unit costs constant (but having a different composition of costs). Changes in government consumption patterns and levels are modelled as additional consumption, financed via cuts in transfers to the private household (and hence reduced private consumption). Accumulation effects of annual investment changes are accounted for, resulting in a changed capital stock in 2050 with associated changed annual capital costs (depreciation).[2] Changes in investment are financed via changed savings and thus corresponding changes in consumption.

Table 2 shows how the indicative adaptation pathway (Figure 2) eventually translates into annual changes of sectorial costs as well as changes in government consumption (annualized for 2050, relative to a climate change impact scenario without adaptation). In the sector Agriculture, we see a shift towards more labor and machinery input (mainly because of more green measures). In the sector Forestry, adaptation leads to a shift in expenditure towards more machinery, capital and labor as well as construction. In the Water sector (as part of the impact field Catastrophe Management), we see a shift to more expenditure for labor and capital, but a reduction in expenditures for construction (since necessary investments in water infrastructure decline slightly). The government spends more on labor intensive R&D as well as on civil engineering and planning. Regarding aggregate investment there are two opposing effects: On the one hand, investment costs for additional water infrastructure decline and on the other hand, investments for

[2] Note that the deployed CGE model is not dynamic but comparative-static. The development of the capital stock is therefore no explicit part of the model but accounted for when developing the adaptation pathway.

green measures in Forestry increase. For details on the calculations of Table 2 please see Appendix A.2.

Table 2: Translation of the adaptation path into annual cost vectors for modelled sectors and agents in 2050 (in million €)

	Agriculture	Forestry	Water	Government consumption	Aggregate investment
Labor	+25	+69	+48		
Capital (incl. land)		+126	+32		
Research and development				+60	
Civil engineering and planning				+165	
Machinery	+213	+102			
Construction (Investment)		+39	-45		-6
Total	+239	+336	+93	+226	-6

Finally, the benefit or effectiveness of adaptation are avoided damages. While the evidence on the effectiveness tends to be much better for gray adaptation (Bierbaum et al. 2013), there exist several estimates also for soft and green adaptation particularly in the context of flood protection (Kuik et al. 2016). Following Mitter et al. (2015) and Schönhart et al. (2016), we assume that agricultural crops yields in Austria can be increased by 10% via adaptation of management practices. Regarding the Forestry impact field, damage reduction potentials were estimated by experts. Here, damages can be reduced by 30-40%, depending on the type of impacts and adaptation measure (Kolström et al. 2011; Lexer 2017). For the impact field catastrophe management (flood protection) we use benefit-cost ratios from a meta-analysis of flood protection measures, which analyzed more than 80 projects within the period of 1991-2015 (Kuik et al. 2016). According to this meta-analysis, the effectiveness of the adaptation measures covered by the indicative adaptation pathway differs considerably by type of measure: soft measures are more effective for every euro spent than gray and green measures. To account for uncertainty we also apply upper and lower bounds concerning the effectiveness of adaptation measures. For details please see Appendix A.3.

3.4. Specification of scenarios

In our model assessment, we distinguish between three types of scenarios: the Baseline scenario, the Impact scenario (climate change without adaptation), and the Adaptation scenario.

The Baseline scenario describes the socio-economic development according to shared socio-economic pathway 2 (O'Neill et al. 2014). The implementation of this Baseline scenario entails assumptions about population and settlement developments (Hanika 2005, 2010), economic growth (1.65% p.a.; Schiman and Orischnig 2012), climate policy (via an exogenous CO_2 price of 41 €/t; IEA 2010), as well as the energy (IEA 2010) and agricultural sector (see König et al. 2015 for more details). Regarding the development of the budget deficit, we assume that the government budget deficit grows at the GDP growth rate so that the deficit-to-GDP ratio remains constant.[3]

The Impact scenario incorporates both socio-economic and climate change by 2050, implemented as average changes for the future 30-year climatic period 2036-2065 relative to the average of the base period 1981-2010. This is done for a "mid-range" climate scenario of a multi-model ensemble from the ENSEMBLES and the CMIP projects, downscaled to Austria (for details, see Formayer et al. 2015). The "mid-range" climate scenario represents the SRES A1B emissions scenario, which corresponds to the RCP6.0 scenario with a global mean temperature change of +2.5°C by the end of the century (Knutti and Sedláček 2013).[4] The localized climate scenario is generated from the Regional Circulation Model COSMO CLM

[3] This is an empirically well supported assumption for the structural deficit and is also in accordance with the Maastricht criteria.

[4] As shown in the Austrian Assessment Report 2014 (Austrian Panel on Climate Change 2014), the difference in climate signals between the different emission scenarios is very small until mid-century and only becomes more significant towards the end of the 21st century. The focus on the A1B scenario is therefore no serious limitation of the current approach.

(Meissner et al. 2009) forced with the Global Circulation Model ECHAM5. Climate change impacts are incorporate as described in Section 3.2. To keep expenditures on public service provision (i.e. government consumption in the CGE model) at the same level as in the Baseline scenario without climate change, we assume in the Impact scenario that transfers to private households are adjusted accordingly.

The Adaptation scenario builds on the Impact scenario but incorporates the direct costs and benefits of adaptation (i.e. avoided impact costs) as described in terms of methodology and data in section 0. For the effectiveness of adaptation, we use the mean effectiveness as the central simulation run, but also provide results for a bandwidth of effectiveness (as specified in Appendix A.3). Also in the Adaptation scenario, we assume that expenditures of public service provision are maintained at baseline level by adjusting transfers to households, but in addition allow for increased consumption for adaptation measures (as indicated in Figure 1).

4. Results

4.1. Economy-Wide Effects of Public Adaptation

By mid-century (2050) climate change induced annual Gross Domestic Product (GDP) losses in the Impact scenario are -0.15%, relative to the Baseline scenario for 2050 without climate change (see Appendix A.4 for the results of the Impact and the Adaptation scenario relative to the Baseline scenario). In the mean Adaptation scenario, these losses can be reduced by public adaptation to -0.06%; a net benefit of 0.09%-points of annual GDP arises therefore by adaptation (see the total GDP effect from adaptation in all three impact fields; indicated by the black diamonds in Figure 3). The reason for the positive GDP effect is twofold: First, there are positive effects from adaptation-specific productivity gains (impact field Agriculture) as well as positive employment effects. Without adaptation, unemployment would rise by +0.19%-points due to climate change impacts. This effect can be reduced by adaptation to +0.13%, thus by -0.06%-points, especially due to soft and green measures. Second, there are reductions of direct and indirect climate change impacts from the impact fields Forestry and Catastrophe Management.

The welfare loss[5] in the Impact scenario would be -0.48% (Steininger et al. 2016a), which in the Adaptation scenario can be reduced to -0.27%. Public adaptation reduces therefore the welfare loss by 0.2%-points but residual damages remain. Note that the size of the welfare effect is larger than the GDP effect in both scenarios, with and without adaptation. This is because "forced" consumption expenditures for the renewal of destroyed assets only restores the original state and thus do not contribute positively to welfare- in contrast to GDP, where forced consumption contributes positively.

Figure 3 furthermore shows how the effects from different impact fields contribute to the total effect of public adaptation on GDP, welfare, and unemployment. We find that the positive effect of adaptation on GDP arises from Agriculture (due to productivity gains) and Forestry (especially due to the reduction of damages to protective forests), whereas the GDP effect from adaptation in Catastrophe Management is marginal.[6] Substantial positive effects on welfare emerge from reduced damage costs in the impact field Catastrophe Management and the associated reduction in forced consumption. A positive contribution of adaptation to welfare also arises from Agriculture, due to productivity gains and thus a moderating effect on agricultural and food prices. In Forestry, we see positive welfare effects primarily caused by the reduced damage to protective forests and thus more public means available to increase transfers to households. We also see that unemployment is reduced by adaptation in all impact fields, which is driven by the focus on green and soft adaptation in the indicative adaptation pathway by mid-century; which also contributes

[5] Measured as Hicks'ian equivalent variation.

[6] This is due to a shift from a capital-intensive to a more labor-intensive structure, with the effects setting each other off regarding the GDP effect.

to the positive welfare effect. Regarding the uncertainty of effectiveness of adaptation, we see that the results are robust in terms of the direction of the effects.

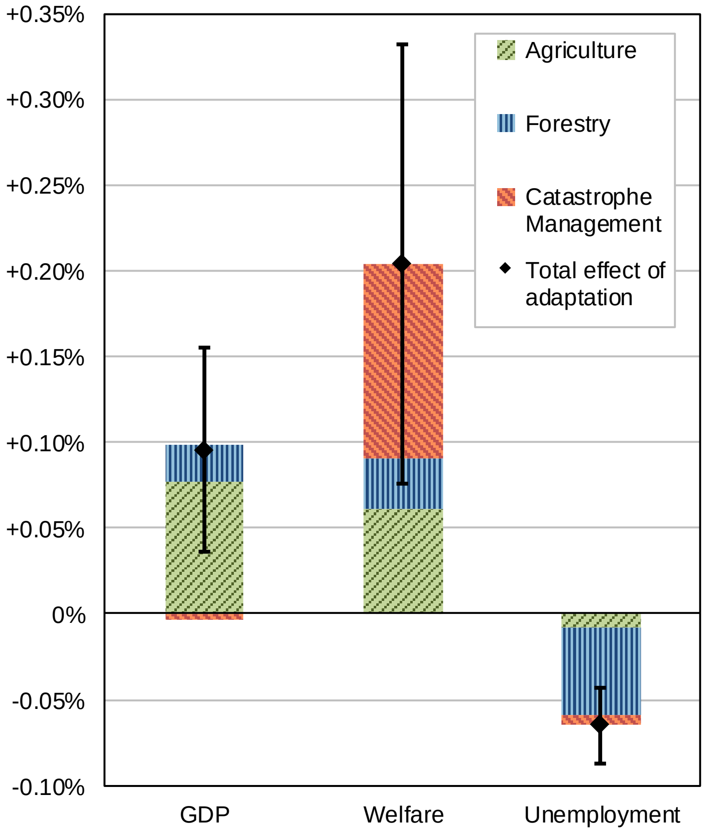

Figure 3: Effects of adaptation on gross domestic product (GDP), welfare and unemployment for 2050 (Adaptation scenario relative to Impact scenario), distinguished by impact field and in total. Error bars indicate different assumptions on effectiveness of adaptation measures to reduce climate change impacts (see the Appendix A.3 for details).

4.2. Effects of Public Adaptation on Government Budgets

The government budget is affected on both the revenue and the expenditure side. We start the description of results with effects of public adaptation on the revenue side. In the Impact scenario, the government is confronted with annual tax revenue losses of -€ 497 million or -0.22% of total tax revenue. Especially losses in labor and production (sales) taxes are responsible for the decline in revenues. The effect of adaptation on the main tax revenue categories is shown in Figure 4 (a; Adaptation scenario compared to the Impact scenario). With adaptation, tax revenue losses are less severe for most of the main tax revenue categories, indicated by the total positive effect of adaptation (black diamonds in Figure 4, a). In particular, labor and production tax income is higher (due to higher economic activity and employment compared to the case without adaptation), however we see losses from value added tax revenue, since there is less forced consumption for restoring damaged assets and because the government needs to finance its adaptation expenditure (which is taxed at lower rates than private consumption) partly by cuts in private transfers. In total, revenue losses add up to only -€ 247 million p.a., or -0.11% after having implemented public adaptation.

Looking at the effects on the expenditure side, in the Impact scenario expenses for climate-related relief payments to households increase substantially (on average by +€ 547 million p.a., which is an increase of +180%) compared to the Baseline scenario without climate change. This increase in relief payments is financed by a reduction in non-climate related government consumption, which reflects ad-hoc payments via the national disaster fund out of the general budget. Rising unemployment (which is partly influenced by cuts in relatively labor-intensive government consumption) causes unemployment benefits to rise. Since we assume that the government must hold its public service provision constant[7], the burden arising from the revenue losses and the increase of unemployment benefits is financed by cuts in other transfers to households. To balance government consumption, transfers need to be cut by -€ 821 million in the Impact scenario (-0.8% of total transfers in 2050; excluding unemployment benefits).

[7] The idea behind this constraint is to make sure that public good and service provision such as health care, education or public infrastructure provision is not being reduced due to climate change impacts.

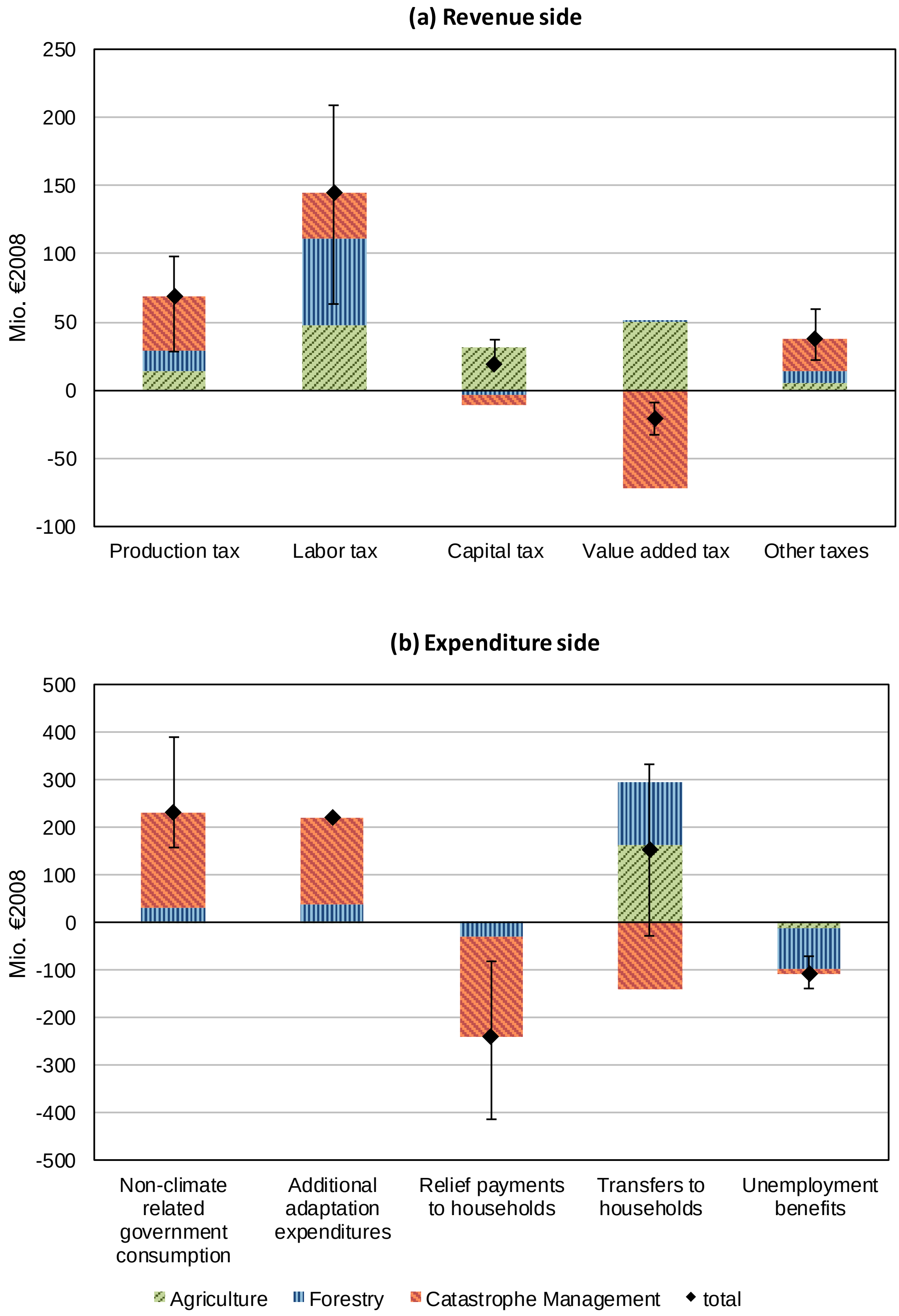

Figure 4: Decomposition of effects of public adaptation on tax revenue (a) and public expenditure (b) for the three adaptation fields for 2050 (Adaptation scenario relative to Impact scenario). Error bars indicate different assumptions on effectiveness of adaptation measures to reduce climate change impacts (see the Appendix A.3 for details).

Figure 4 (b) shows that in the Adaptation scenario relief payments to households can be reduced substantially, meaning that non-climate related government consumption can be increased compared to the Impact scenario. However, direct public adaptation expenditures amount to additional € 219 million. Moreover, due to higher tax revenues and less payments for unemployment benefits, transfers to households are higher in the mean Adaptation scenario than in the Impact scenario. Only when the effectiveness of adaptation is very low, transfers to households need to be reduced to ensure stability of government consumption (service provision).

Finally, Figure 4 decomposes the effects by the adaptation undertaken in each of the three impact fields. On the revenue side, we find that adaptation in all three impact fields generate more revenues from production and labor taxes, and that the relative contribution to higher labor taxes is particularly strong for public adaptation in Forestry, as forest management is comparatively labor intensive. Revenues from value added tax, however, decline from adaptation in Catastrophe Management. This is due to the slightly negative contribution of adaptation in Catastrophe Management (less forced consumption).

On the expenditure side, we find a significant reduction in relief payments to private households as a consequence of adaptation in Catastrophe Management in the form of structural flood protection. Adaptation expenditures increase particularly due to adaptation in Catastrophe Management and Forestry, because both sectors are recipients of subsidies for e.g. ensuring the function of protective forests. Interestingly, the effect of adaptation in Catastrophe Management to transfers would be negative when performed in isolation (since there is no large positive effect from these measures on employment and GDP), as expensive structural measures need to be financed by cuts in transfers. However, the overall positive contribution of adaptation in Forestry and Agriculture more than compensates for these transfer cuts.

5. Conclusions

In the first part of the paper, we show that public adaptation involves considerable costs for the federal budget in Austria, and that these costs are likely to rise in the future, both due to ongoing climate change but also due to re-investment cycles in public infrastructure. For requirements of solid government finances, these higher expenditures on adaptation require that other public expenditures are reduced accordingly, however, to which extent depends on how tax revenues and unemployment payments are affected by adaptation. To capture also these indirect effects of public adaptation, we use a computable general equilibrium model and investigate how public adaptation in three impact fields (Agriculture, Forestry, Catastrophe Management) affects GDP, welfare, and unemployment. The first key lesson learned is that public adaptation has a positive contribution to GDP, welfare, and reduces unemployment, but that also residual damages remain. This result is highly robust with regard to different assumptions on the effectiveness of adaptation measures to reduce climate change impacts.

When looking more closely at the government budget, we find that public adaptation has the potential to increase government revenues (in total and for all categories except valued added tax) because of higher economic activity as compared to a scenario with climate change impacts only. On the expenditure side, public adaptation leads to a partial redistribution of government expenditures towards adaptation but also to a reduced need for disaster relief payments. Moreover, reduced unemployment translates into less unemployment payments. The effect on transfers tends to be positive, but can be slightly negative when adaptation measures' effectiveness is assumed to be very low. Overall, therefore the second key lesson learned is that the positive *indirect* effects of public adaptation outweigh the *direct* public costs of adaptation, with a resulting increase in the overall government budget.

As this paper is the first to analyze not only the direct but also the indirect effects of public adaptation on government budgets, naturally several directions for future research can be identified. First, while we placed considerable effort on investigating uncertainties on the effectiveness of different types of adaptation measures, a better understanding of how the effectiveness of adaptation can change over time is definitely needed. A related aspect concerns physical limits and social or institutional barriers of adaptation that are also relevant for public adaptation, for instance when public authorities are not allowed to build up reserves to invest in adaptation in the future. Second, while we started out from the knowledge of experts within the respective ministries to develop an indicative and plausible adaptation pathway (in contrast to identifying e.g. the most cost-effective pathway within the model assessment), several alternative adaptation pathways could be developed and compared regarding their macroeconomic and budgetary consequences. Third, while the assumption of fixed government consumption might be a realistic assumption for many highly developed economies which committed themselves to fiscal stability, governments could be also tempted to deal with climate change adaptation by expanding their deficit and by foreign lending. Therefore, it would be interesting to investigate in more detail how different budgetary rules interact with public adaptation spending.

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Appendix

A.1: Modeling of impact chains in remaining impact fields

Supplementary to Table 1, where the modeling of (bio)physical impacts is described for the impact fields Agriculture, Forestry, and Catastrophe Management, Table A.1 provides the same information for the remaining impact fields that are included in the model. For further details we refer to (Bachner et al. 2015a; Steininger et al. 2015).

Table A.1: Coverage of impact chains, and (bio-)physical impact models used for the remaining impact fields

Impact field	Impact chains	(Bio)physical impact model
Electricity	Change in hydro, wind and solar electricity generation; Lower availability of cooling water for thermal and nuclear power plants, change in generation mix and/or reduction in system reliability	Simulations with dynamic electricity sector dispatch optimization model for electricity and heating HiREPS (Totschnig et al. 2013b, a; Kranzl et al. 2014, 2015)
Buildings: Heating and Cooling	Increased cooling energy demand in summer, decreased heating energy demand in winter	Simulations with dynamic bottom-up building stock, heating and cooling model for Austria Invert/EE-Lab ((Kranzl et al. 2015) based on (Müller et al. 2010; Kranzl et al. 2013, 2014; Müller 2015))
Tourism	Changes in winter and summer tourism demand	Regression analysis for overnight stays at NUTS3 level by season; costing based on regression and tourism satellite accounts (Köberl et al. 2015)
Water Supply and Sanitation	Water supply: Lower yield of springs and drying cracks in the soil; lower ground- and surface water recharge; turbidity of spring water; change of withdrawal.	Extrapolation of past trends from existing data and mark-up for climate change impacts (Neunteufel et al. 2015)

Impact field	Impact chains	(Bio)physical impact model
	Sanitation: Increase of waste water volume; increase of sewer flooding; sewer sedimentation during dry weather	
Transport	Road damages due to increase in floods, landslides and mudflows	Regression analysis on past damage events and costs (Bednar-Friedl et al. 2015)
Manufacturing and Trade	Productivity losses of workers due to heat and humidity	Statistical relationship between Wet Bulb Globe Temperature index and worker productivity (Urban and Steininger 2015 based on Kjellstrom et al. 2009)
Cities and Urban Green	Improved prevention against loss of climate comfort in urban environments by investments in and maintenance of parks	Extrapolation of past trends from existing data and mark-up for climate change impacts (Loibl et al. 2015 based on Gill et al. 2007)

A.2: Development of indicative adaptation pathway and calculation of annualized adaptation expenditures

The construction of the indicative adaptation pathway (as presented in Figure 2) and the corresponding changes in annual costs (as presented in Table 2) have been developed in a stepwise approach.

Step 1: Screening and analysis of current federal spending on adaptation

In step one the current adaptation relevant expenditures have been extracted from the federal budget by a detailed screening of the federal the budget and its subdivisions. In line with international standards by OECD DAC (2016) and the European Commission (2016), adaptation relevant expenditures include all expenditures that pursue climate change adaptation as a primary or a secondary goal. The federal government's budget plan and realization reports were screened at the level of subdivisions (SD). Subdivisions SD 41 (transport, innovation and technology), SD 42 (agriculture, forestry and water management) and SD 43 (environment) were identified to be relevant for adaptation in the three impact fields: Agriculture, Forestry and Catastrophe Management. Based on the subdivision's mission statement and the verbally announced targets of detailed budgets, those global and detailed budgets were identified that potentially include adaptation-relevant expenditures. Based on their budgetary importance, a number of global and detailed budgets were selected to be subjected to closer inspection, delivering adaptation relevant expenditures for each subdivision. In addition, interviews with representatives from administration have been carried out at various stages of the screening process, to ensure that the selected budgetary items are in fact adaptation relevant.

Step 2: Construction of adaptation pathway

In step two the expenditure pathway over time – until 2050 – has been constructed. As a starting point we used the adaptation relevant expenditures from step one and as a point of reference we assumed that without additional adaptation ("business-as-usual"), adaptation relevant expenditures would grow at the same rate as GDP in the baseline scenario (i.e. 1.65% p.a., Schiman and Orischnig 2012). We then constructed an indicative adaptation pathway, in which adaptation relevant expenditures grow more strongly than the rest of the economy to capture more ambitious and planned adaptation (compare Figure 2, in which the sum of adaptation relevant expenditures lies above the baseline 1.65% growth trajectory).

The pathway is meant to be indicative and is not arbitrarily defined. It is based on expert judgment, recommendations on the useful timing and phasing of gray, green, and soft measures (Watkiss et al. 2014), and on the mid-term budget forecast for the Federal State of Austria (BMF 2015). Also, we divided the pathway into policy-relevant periods in which the expenditures for different types of measures (gray, green and soft) grow at different rates. These periods are current-2020, 2021-2030, 2031-2040 and 2041-2050. In general, the pathway is constructed such that until 2030 expenditures for soft measures and R&D grow relatively strongly to build up adaptive capacity and the knowledge base. Expenditures for green measures increase more strongly than gray measures, since gray measures are to reach their limits for further implementation soon. Moreover, green measure are expected to be expensive since they involve the purchase of land in many cases (e.g. for flood retention areas). Expenditures for gray measures follow a slight up- and downward trend as they are tightly connected to the current and future investment cycle of the water infrastructure sector in Austria.

Step 3: Attribution to investment and operating costs

In order to implement the costs of adaptation correctly into the CGE model, the differentiation between investment costs and operating costs was necessary in a next step. All expenditures for gray measures were allocated fully (100%) to investment costs, whereas green measures for Catastrophe Management were allocated by 65% to investment costs (these include investments when e.g. retention areas are created). Then the accumulation of the "investment capital stock" until 2050 was calculated (according to the development of the pathway of step 2 and assuming a depreciation rate of 2%). Also for the climate change Impact scenario, the development of the capital stock was calculated to then compute the difference in the capital stock in 2050 for the Adaptation scenario. The difference in the capital stock in 2050 determined the change in the necessary additional annual capital input ("flow" or depreciation) in

2050 for the different sectors which perform adaptation measures (see row “capital” in Table 2). Also, the difference between the two scenarios’ adaptation capital stocks determined the in-year (2050) expenditure change for construction activities in those sectors that perform adaptation investments (see row “construction” in Table 2). Non-investment expenditures are considered operating costs and each adaptation implementing sector has additional expenditures for labor, land and machinery. The additional expenses for R&D and civil engineering and planning for soft measures are assumed to be fully covered by the government (see column “government consumption” in Table 2).

A.3: Modeling assumptions for impact cost reduction due to adaptation (benefit of adaptation)

In a final step, the benefits of adaptation measures were calculated. For the impact field Catastrophe Management we used benefit-cost-ratios (BCR) from the literature (Kuik et al. 2016), specified separately for gray, green and soft, and applied them to the costs of adaptation, that were derived from the constructed pathway in 2050. Note that we did not assume the full costs of the indicative pathway translating into direct benefits, since the costs as presented in the pathway are adaptation *relevant*, but not pure adaptation costs in the narrow sense. We thus only applied the BCRs from the literature to 25% of flood related long run capital expenditures, 25% of flood related green measure expenditures, 10% of urban water management expenditures and 10% of R&D, which lead to an overall BCR for flood prevention measures of 3.4 (see Table A.2 for details and upper and lower bounds).

For the impact field Agriculture we applied numbers from the literature (Mitter et al. 2015a; Schönhart et al. 2016), stating that by changing management practices and a warmer climate the productivity of the agricultural crop production can be increased by +10% (an increase of +4.4% to overall agricultural production). To account for the costs of changing management we subtracted the sum of adaptation costs from annual agricultural output (see Table A.2 for details and upper and lower bounds).

For the impact field Forestry we carried out expert interviews (Lexer 2017) and followed the literature (Kolström et al. 2011), stating that by educational measures against bark beetles, more intensive tending and thinning of forests, better infrastructure in forests, as well as genetics the climate change induced damages to forests can be reduced by 30-40% (see Table A.2 for details and upper and lower bounds).

Table A.2: Description, assumption and sources of damage reduction potentials of adaptation measures in the impact fields CATM (Catastrophe Management), AGRI (Agriculture) and FORE (Forestry).

Impact-field	Adaptation measure/ purpose	lower bound	Mean run	upper bound	Description of unit of measurement	Source
CATM	Soft flood protection measures	1.5	9.2	10.0	Benefit/Cost-ratio Lower bound: 10th percentile Upper bound: 90th percentile	(Kuik et al. 2016)
	Green flood protection measures	1.2	1.8	4.3		
	Gray flood protection measures	1.0	3.9	7.7		
AGRI	Change in agricultural crop management practices	5%	10%	15%	Yield increase potential in response to adaptation measures	(Mitter et al. 2015a; Schönhart et al. 2016)
FORE	Educational measures against bark beetles; more intensive tending of forests; better infrastructure in forests	20%	32%	45%	Damage reduction of damages to protective forest	(Kolström et al. 2011; Lexer 2017)
	Educational measures against bark beetles; more intensive tending of forests; better infrastructure in forests	35%	40%	45%	Damage reduction of damages to commercial timberland	
	Genetics: Better usage of autochthonous species to increase resilience of forests	0%	0.03%	0.03%	Reduction in timber growth loss	

A.4: Macroeconomic results for the Impact and Adaptation scenarios

Supplementary to section 4.1, where the macroeconomic results are expressed as deviations of the Adaptation scenario from the climate change Impact scenario, we provide here the results for the two scenarios separately. Note that both the impact scenario and the adaptation scenario include climate change impacts in all impact fields as described in Table 1 and Table A.1.

Table A.3 therefore gives the results for GDP, welfare, and unemployment in the "Impact" column for the Impact scenario relative to the Baseline scenario (i.e. with socio-economic change (SSP2) but without climate change), both for the year 2050. The "Adaptation" column provides the results for the Adaptation scenario with adaptation in Agriculture, Forestry, and Catastrophe Management, again relative to the Baseline scenario in 2050. When taking the difference between these two columns, we obtain the result of adaptation, which is shown in Figure 3 in the main text.

Table A.3: Macroeconomic results for the Climate Change Impact scenario and the Climate Change Impact with Adaptation scenario (with adaptation in Agriculture, Forestry, and Catastrophe Management), both relative to the reference scenario without climate change in 2050. Results are displayed by impact field and in total (net effect across all impact fields).

	GDP 2050		**Welfare 2050**		**Unemployment rate 2050**	
Impact field	**Impact**	**Adaptation***	**Impact**	**Adaptation***	**Impact**	**Adaptation***
Agriculture	+0.08%	+0.16%	+0.03%	+0.09%	+0.05%	+0.04%
Forestry	-0.08%	-0.05%	-0.10%	-0.07%	+0.06%	0.00%
Catastrophe Management	-0.01%	-0.01%	-0.24%	-0.13%	+0.02%	0.02%
Electricity	-0.08%	-0.08%	-0.09%	-0.09%	+0.04%	+0.04%
Buildings: Heating and cooling	+0.01%	+0.01%	+0.03%	+0.03%	-0.01%	-0.01%
Tourism	-0.06%	-0.06%	-0.07%	-0.07%	+0.04%	+0.04%
Remaining impact fields°	-0.02%	-0.02%	-0.03%	-0.03%	+0.01%	+0.01%
Total	**-0.15%**	**-0.06%**	**-0.48%**	**-0.27%**	**+0.20%**	**+3.63%**

° Remaining impact fields comprise: Water Supply and Sanitation, Transport infrastructure, Manufacturing and Trade, Cities and Urban Green.

* Adaptation only in the following impact fields: Agriculture, Forestry, Catastrophe Management.

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