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Land Transport Systems under Climate Change: A Macroeconomic Assessment of Adaptation Measures for the Case of Austria

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In the light of climate change, transport systems become increasingly stressed by extreme weather and gradual climatic changes, resulting in direct costs which arise in the affected sector as well as indirect costs due to economic spill-over effects. To attenuate these costs, sector specific adaptation measures are needed, raising the question of the net-benefits of adaptation at a macroeconomic level. However, despite their importance such assessments of impacts and adaptation at the macro-level are scarce and coarse in their implementation. This paper contributes to fill this research gap by analyzing specific adaptation measures for the land transport sectors. To reveal both direct and indirect effects of impacts and adaptation a computable general equilibrium model is deployed. Results confirm the importance of a macroeconomic framework since the indirect effects are found to be larger than the direct ones due to strong economic interlinkages with the transport system. Adaptation measures are able to reduce climate change induced GDP and welfare losses as well as unemployment; even though adaptation does not always seem economically reasonable at the business level.

Keywords: Climate change; transport; impacts; adaptation; computable general equilibrium;

JEL codes: C68, Q51, Q54, Q58, R42

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1. Introduction

Developed economies are characterized by a high degree of division of labor and therefore rely on working transport infrastructures and services to maintain production processes. Especially land transport services are key requirements in many economic sectors, in particular when just-in-time production is in vogue and also private households rely heavily on transport. The contribution of the land transport sector to national GDP ranges between 3 and 7% in the EU27 (EUROSTAT, 2014), reflecting its relative weight. The increasing dependency on transport services have led to substantial emissions of CO_2 (23% of global emissions are attributed to transport [Sims et al., 2014]), causing climate change. In turn the realization of climate change has manifold impacts on the transport system; in particular infrastructures which are especially affected by extreme weather events such as flooding, but also storm surges and sea level rise (Koetse and Rietveld, 2009; Nemry and Demirel, 2012). Knowing that, the question of macroeconomic effects – capturing direct and indirect consequences – of damaged and disrupted transport systems needs to be addressed in order to develop and put in place sound climate policies and adaptation strategies.

Yet, despite their importance, comprehensive quantitative studies on climate change impacts and adaptation in the transport system are scarce. Most of the published literature focuses either on qualitative predictions (Arent et al., 2014) or on the sectoral costs of certain subsystems like impacts on pavements, safety, disruption of services (Chinowsky and Arndt, 2012; Chinowsky et al., 2010; Larsen et al., 2008) or on regionally small scales like cities (Hunt and Watkiss, 2011). Also in large economic climate change impact studies for Europe the transport system is not included, like in Ciscar et al. (2011) and Aaheim et al. (2012). In some other studies like in Ciscar et al. (2014), Watkiss (2011) or Bednar-Friedl et al. (2015) impacts on the transport sector are taken into account, however still at a very coarse level; More precisely climate change impacts are introduced solely as additional obliged consumption and a decreases in the general capital stock. However, those two approaches are problematic as obliged consumption means that households are carrying the costs of climate change, even though actual costs arise in the production sectors of the economy and may not be passed onto consumers that easily (households may find substitutes). The second approach is also questionable since the reduction of the general capital stock is rather inaccurate since those sectors which are capital intensive suffer the most, even if impacts may occur elsewhere. In the underlying analysis we overcome these problems in impact modeling by altering the specific technologies of the different transport sectors to ensure that impacts (and the resulting costs and price increases) arise in the right place.

Regarding the macroeconomic consequences of adaptation literature is also tenuous. Aaheim et al. (2012, 2011) for example include adaptation, but only to a very limited extent. More precisely the authors include solely price driven changes in demand – also called *autonomous* adaptation – but neglect any structural changes (institutional and/or infrastructural). Another caveat of this approach is the inability to decompose the effects between impacts and autonomous adaptation as both happens at the same time within the same endogenous optimization procedure. Due to this lack of clarity autonomous adaptations is sometimes attributed to the impacts of climate change or to the so called 'costs of inaction' (see e.g. Steininger et al., 2015). In contrast, *planned* adaptation actively changes structures in order to reduce climate change impacts by either institutional changes (soft measures such as changing laws, incentives or life styles) or by building new and adapting existing infrastructure (hard measures like improving resilience by retrofitting, building safety fences or dams). Only few assessments of planned adaptation have been carried out yet on a macroeconomic level. There are some studies on sea-level rise (Darwin and Tol, 2001; Deke et al., 2001) which model planned adaptation as forced investment and therefore as a reduction in the (productive) capital stock, ignoring the stimulating effect to the economy via construction activities. Bosello et al. (2007), also investigating sea-level rise, overcome this shortcoming by explicitly modeling investment and the respective demand stimuli. However, regarding planned adaptation for transport systems studies like these are not available (at least to the best knowledge of the author).

In this paper we thus fill this research gap by carrying out a macroeconomic assessment of climate change impacts and explicit sector specific adaptation measures in the land transport sectors. Therefore we use a computable general equilibrium (CGE) model with a high resolution of the transport system. The analysis is carried out for the case of Austria; a country lying in Europe's

Alpine Region confronted with relatively strong average temperature increases and severe flood events in the recent decades. Until 2050 Austria expects further warming and an intensification of extreme precipitation events (Gobiet et al., 2014; Hofstätter and Mattula, 2010; Kromp-Kolb et al., 2014). As this holds for many other regions the results and revealed mechanisms are also transferrable to other countries with similar economic structures.

The analysis is carried out in three steps. First, we elaborate the current average annual weather induced damage costs in the road and rail transport sectors. This provides insights into sectoral vulnerability and the database for the second step: obtaining the macroeconomic costs of possible future climate change impacts until 2050, including the indirect costs. To do so we deploy a CGE model for the case of Austria. Thereby we are able to show by how much additional climate change induced damage costs are amplified within the economic system due to interconnectedness between sectors. In the third and final step, we add sector specific adaptation measures, inducing new costs but also reducing damages. As we face high uncertainties regarding the damage reduction potential of adaptation we additionally carry out a sensitivity analysis to find the threshold of necessary damage reduction by which a net benefit from adaptation at a macroeconomic and societal level is generated.

Methodologically the underlying paper contributes to the literature of macroeconomic climate change impact assessments (e.g. Aaheim et al., 2012; Berrittella et al., 2006; Bigano et al., 2008; Bosello et al., 2012; Ciscar et al., 2014) but extends the state of the art analysis by (i) modeling the transport system at a high sectoral resolution (the land transport system is distinguished by eight sectors) allowing to assign impact functions to activities within the transport system and by (ii) integrating non-market driven (planned as opposed to autonomous) sectoral adaptation measures, which in turn trigger further macroeconomic and societal effects.

The main findings are the following. First, when looking at current weather induced damage costs in Austria we see that the absolute damages are much higher in the road transport sector than in the rail sector, however, when putting the numbers into perspective with regard to network length, the rail sector is affected much stronger than the road sector. Second, in a scenario with climate change the damage costs emerging in the road and rail transport sectors (i.e. direct impacts) are amplified by a factor >2 within the economic system due to sectoral interconnectedness (see also Hallegatte et al., 2007 on the importance of that mechanism). Third, when adaptation measures come into play, adaptation does not always show a clear net-benefit at the sectoral level, however, at a macroeconomic and societal perspective adaptation clearly pays off; despite the additional sectoral costs of adaptation. More precisely, GDP and welfare losses are reduced by 55% and 34% respectively and unemployment declines by 0.04% points due to adaptation. Finally, we ask the question by how much the direct impacts need to be reduced by adaptation in order to achieve a net benefit of adaptation on a macroeconomic scale. Regarding GDP, this threshold lies at 4% and at 12% for welfare. Hence if direct damage costs can be reduced by more than 4% (12%) by adaptation measures, then adaptation pays off from a macroeconomic (societal) perspective.

The remainder of the paper is structured as follows. In section 2 current weather induced damage costs, future climate change impacts as well as possible adaptation options are monetized for Austria's road and rail sector. Section 3 describes the methodology. It comprises a non-technical description of the CGE model, including the sectoral aggregation and production structures, as well as an explanation of how climate change impacts, different adaptation measures and damage reduction is modeled within the CGE framework. Section 4 provides the main results of the study which are firstly described at the sectoral and then at the macroeconomic perspective, including a sensitivity analysis regarding damage reduction potentials of adaptation measures.

2. Data: Current damages, future impacts and adaptation

2.1. Current damage costs

In Austria weather induced damage costs to road infrastructure are collected at the provincial level, leading to inconsistencies across databases. Either there are differences regarding the categorization of damages (flood, mudflow, debris flow, landslide, rockfall, etc.) or differences in the registration procedure itself; meaning that in some provinces only those damages which exceed a certain threshold are registered and in some other provinces all damages are registered. Besides, in some provinces no data are available at all.

Therefore we draw on results from Doll and Sieber (2010) who provide data for certain European regions (including the Alpine region, consisting of Switzerland, Austria and Slovenia) and also some data at country level (including Austria). Damage costs are subsumed into the four impact categories *Flood and Rain*, *Ice and Snow*, *Storm* as well as *Heat* and are given for the time period of 2000-2010. Each of these categories has a direct impact on infrastructure, operation and/or users triggering sectoral damage costs. From this database current costs for Austria's road transport sector are extracted, either by taking over directly the given costs for Austria, or by scaling down the costs in the Alpine Region using Austria's share of road network length in the Alpine Region (53%; based on European Union, 2012). The resulting average annual damage costs in the road sector are given in Table 1. In total the costs in the road transport sector sum up to 47 M € per year. The lion's share of costs is attributable to damages to infrastructure assets which sum up to 39 M € per year (82% of total annual costs). Most of these damages are triggered by *Flood and Rain* events (24 M €). The second largest cost component is damages to vehicles with annual damages of 5 M € (10% of total costs).

Table 1: Current average annual weather induced damage costs in the road transport sector in Austria. (Source: Doll and Sieber, 2010; European Union, 2012 and own calculations)

	in M €		in % of total	
Infrastructure	**Assets**	**Operation**	**Assets**	**Operation**
Flood and Rain	23.90	0.19	51%	0%
Ice and Snow	8.46	0.01	18%	0%
Storm	3.73	0.02	8%	0%
Heat	2.11	0.62	5%	1%
Sum	**38.20**	**0.84**	**82%**	**2%**
Vehicles	**Assets**	**Operation**	**Assets**	**Operation**
Flood and Rain	4.76	0.97	10%	2%
Ice and Snow	0.00	0.01	0%	0%
Storm	0.00	0.06	0%	0%
Heat	0.02	0.00	0%	0%
Sum	**4.78**	**1.04**	**10%**	**2%**
Users	**Safety**	**Time**	**Safety**	**Time**
Flood and Rain	0.18	1.18	0%	3%
Ice and Snow	0.39	0.00	1%	0%
Storm	0.00	0.11	0%	0%
Heat	0.00	0.01	0%	0%
Sum	**0.56**	**1.30**	**1%**	**3%**

The current average annual weather induced costs in the rail sector are 18 M € and summarized in Table 2. Again we draw on Doll and Sieber (2010) using the following numbers: Passenger and freight detouring lead to costs of 13,000 € and 6,000 € respectively, costs for time losses in passenger transport lead to 7,000 € and costs for time losses in freight transport lead to 15,000 € (all costs are per day and damage event). In addition to these numbers further information is necessary to calculate annual costs. In accordance with sector experts we assume damages to infrastructure of 280,000 € and vehicles of 15,000 € (on average per damage event) as well as 45 damage events per year. In addition we assume that for each damage event one section is interrupted. Regarding the distribution across impact categories about 95% of all infrastructure damages are triggered by *Flood and Rain*. Vehicles damages are triggered mainly by *Flood and Rain* (70%) as well as *Storm* (20%).

Table 2: Current average annual weather induced damage costs in the rail transport sector in Austria. (Source: Doll and Sieber, 2010 and own calculations)

Cost category	M €	%
Infrastructure damages	16.11	88%
Passenger detouring	0.56	3%
Freight detouring	0.26	1%
Damages to vehicles	0.67	4%
User time losses	0.77	4%
sum	18.38	100%

Comparing infrastructure damage costs between the road and rail transport sectors the costs are two to three times larger in the road sector. However, when put into perspective by network length (124,000 km road network and 5,000 km rail network; European Union, 2012 and ÖBB, 2014 respectively) we see that damages are about 300 €/km in the road transport sector and 3,300 €/km in the rail sector. Thus, damage events concerning infrastructure are eleven times costlier in the rail sector than in the road sector.[1]

2.2. Climate change impacts

According to Kromp-Kolb et al. (2014) climate change in Austria is characterized by an increase in average temperature of nearly +2°C since 1880 (in contrast to +0.85°C on a global scale) and further temperature increase is expected (+1.4°C until 2050 relative to current temperatures). Regarding extreme precipitation events the Alpine region (including Austria) expects an intensification; especially in the winter season (Frei et al., 2006; Gobiet et al., 2014; Hofstätter and Mattula, 2010).

Regarding future economic losses Jongman et al. (2014 p.1) state that "observed extreme flood losses could more than double in frequency by 2050 under future climate change and socio-economic development". Also Aaheim et al. (2012) assume that the frequency of natural hazards doubles. This assumption should reflect an increase in temperature of +3.5°C, which in turn is well in line with the expected temperature increase in Austria (+2°C since 1880 and further +1.4% until 2050; Kromp-

[1] One explanation for this difference is the value of the regarded infrastructure. Dulac (2013) gives construction costs per lane-km and track-km for roads and rail respectively which are 4-5 times higher for rails. Furthermore, since many of the damaged roads lie in remote areas of Austria where often only gravel roads are in place, the average value of roads being affected is even smaller, explaining another part of the cost gap.

Kolb et al., 2014). Taking these studies as a yardstick and given that the major impact category for Austria's transport infrastructures is *Flood and Rain* (including mudflows and landslides), we assume a doubling of current weather induced impact costs in Austria's land transport sectors due to climate change until 2050.

2.3. Climate change adaptation

Regarding adaptation, we consider seven technical and planned adaptation measures which are implemented in the road and rail transport sectors to reduce climate change impacts (see Table 3). Starting with the road transport sectors, the first measure is the enlargement of drainage system capacities alongside roads by +20% (*DRA-rd*), with total investment costs of 130 M € (based on Altvater et al., 2012) and annual costs of 4 M € (assuming 30 years until full depreciation). Second, vegetation management next to roads is intensified by 20% (*VEG-rd*); leading to annual personnel costs of 14 M € plus 7 M € material costs (ACA, 2013). Third, early warning systems are improved by installation of additional hydrological stations (*HYD-rd*). Total investment costs for this measure are about 1 € M, leading to 0.1 € M annual depreciation, and running costs for maintenance are 0.2 M €. Finally, the frequency of visual road inspection is doubled. Due to this measure severe damages due to frost and heat are prevented, as damages can be detected and repaired earlier (*VIS-rd*), costing about 1 M € per year (ACA, 2013).

For the rail sectors less information can be gathered from the literature. Therefore we apply the first two measures from the road sectors equivalently to the rail sectors: First, drainage system capacities are enlarged by +20%; leading to annual costs of 0.2 M € (*DRA-rl*). Second, vegetation management is intensified by 20%, resulting in annual personnel costs of 0.7 M € and 0.4 M € material costs.

Table 3: Adaptation measures for the road and rail transport sectors with total investment volume and annualized adaptation costs at the sector levels.

Qualitative description of adaptation measures and first order damage reduction	Technical description of modeling	Total investment volume [M €]	Annualized adaptation costs [M €]
Road			
DRA-rd: Enlargement of drainage systems (+20% capacity); First order damage reduction: Reduces infrastructure damages due to flooding.	Higher sectoral depreciation (capital input) and more investment towards the construction sector	129.17	4.31
VEG-rd: Additional vegetation management to enhance water runoff (+20% increase in expenditure); First order damage reduction: Reduces infrastructure damages due to flooding.	More sectoral labor demand and a shift in running costs to machinery (material costs)	-	20.88
HYD-rd: Additional hydrological stations for early warning systems; First order damage reduction: Reduces vehicles and user damages due to flooding.	Higher sectoral depreciation (capital input) and a shift in running costs to machinery (material costs)	1.23	0.28
VIS-rd: Increase in visual inspection of roads (doubling of frequency); First order damage reduction: Reduces infrastructure damages due to frost and heat.	More sectoral labor demand	-	1.38
Sum road			**26.84**
Rail			
DRA-rl: *E*nlargement of drainage systems (+20% capacity); First order damage reduction: Reduces infrastructure damages due to flooding.	Higher sectoral depreciation (capital input) and more investment towards the construction sector	6.53	0.22
VEG-rl: Additional vegetation management (+20% increase in expenditure); First order damage reduction: Reduces infrastructure damages due to flooding.	More sectoral labor demand and a shift in running costs to machinery (material costs)	-	1.06
Sum rail			**1.27**
General			
TAP: Increase annual expenditures for torrent and avalanche protection (e.g. fences, dams etc…) by 50%; First order damage reduction: Reduces infrastructure damages due to flooding, storm and snow & ice	Higher sectoral depreciation (capital input) and more investment towards the construction sector	22.90	22.90
Sum all			**51.02**

As a final and more general measure which protects road and rail transport systems (besides other non-transport infrastructure) the transport related expenditures of the Austrian torrent and avalanche protection agency are expanded by +50% (*TAP*); leading to additional annual costs of 23 M €.[2] Total annual adaptation costs at the sector levels add up to 51 M € (thereof 27 M € in the road transport sector, 1.3 M € in the rail transport sector and 23 M € as a general measure (*TAP*)).

3. Methodology

3.1. The computable general equilibrium model

Modern economies are characterized by a high degree of division of labor and therefore interconnectedness across agents. Hence, when designing climate change adaptation policies the sector specific costs may be misleading as "knock-on" or "indirect" effects which arise due to connections within the economic system are not captured. For example, a certain climate change adaptation measure in the rail transport sector may cause costs in that sector, but as these costs reduce interruptions and time losses in the rest of the economy, there may be a benefit from a societal perspective. Consequently a comprehensive approach is needed to assess the macroeconomic and societal costs of climate change adaptation as well as impacts.

We apply a CGE model for the case of Austria, which is able to capture the indirect effects of exogenous shocks like climate change impacts and/or planned adaptation measures. In general CGE models are based on national input output tables (extended by national accounting data) to comprise connections among producers and consumers. These agents optimize their behavior subject to technological and budgetary constraints until a state of economic equilibrium is reached. This equilibrium then can be disturbed or "shocked" by e.g. climate change impacts, leading to endogenous changes of relative prices as well as demand and supply quantities until a new state of equilibrium is reached. In the context of climate change impacts, this means that agents react to climate change

[2] Data from the Austrian Torrent and Avalanche Protection Agency ("Wildbach und Lawinenverbauung") are used to calculate the absolute costs of this measure.

induced price effects. This corresponds to *autonomous* adaptation to climate change, which stands in contrast to *planned* adaptation.

By transferring climate change impacts and planned adaptation measures into a CGE modeling framework, we are thus able reveal the macroeconomic and societal costs and benefits (including the indirect effects).

Austria's economy is modeled as a static, small open economy CGE model with 2008 as base year (based on Bachner et al., 2015). In total there are 46 domestic production sectors (see Appendix A). Figure 1 gives the conceptual overview of the applied CGE model and shows flows of goods and services as well as production factors (monetary flows run in the respective opposite directions). The representative private household (*privHH*) is endowed with the production factors labour (*L*) and capital (*K*) and obtains transfers from the government (*GOV*). The production factors are used in domestic production (*X*) together with intermediate inputs to produce goods and services which are either used domestically or exported (*EX*). According to Armington (1969) goods and services produced in different world regions are not perfectly substitutable, thus every region treats its imports (*IM*) and goods from domestic production (*D*) differently. Therefore the so called "Armington aggregate" (*G*) bundles goods and services coming from domestic production and other world regions, which can be substituted with sector specific elasticities. Goods and services from *G* are then either used as intermediate input for production or are consumed by private households (*privHH*) and the government (*GOV*). The government collects taxes which are levied on *L* and *K* (input taxes) as well as taxes on production and consumption (output taxes).

By definition all flows within a correctly calibrated model lead to the benchmark equilibrium, depicting the current status of the economy in terms of annual flows. When this benchmark equilibrium is shocked the model adjusts relative prices and demand and supply quantities such that a new equilibrium emerges, where all flows are balanced again. By comparing system variables prior and after a shock it is possible to capture macroeconomic and societal effects.

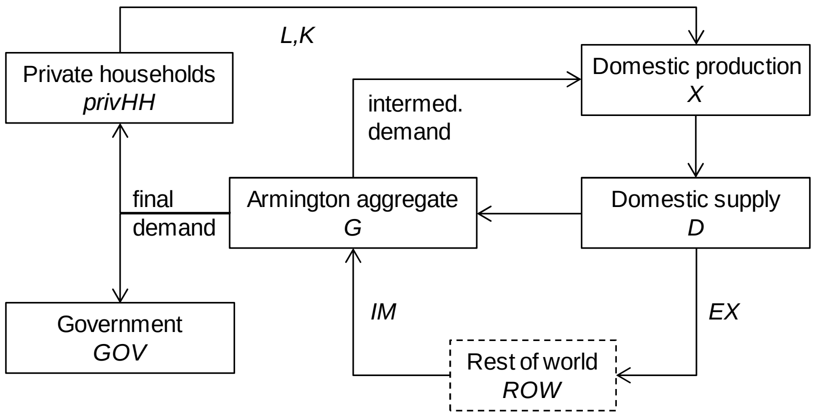

Figure 1: Diagrammatic overview of the CGE model (source: Bachner et al., 2015)

The original model is enhanced with a special focus on the transport system. The land transport sector is disaggregated[3] into three sectors providing transport infrastructure (*STROAD* for road, *STRAIL* for rail and *STREST* for the rest of transport infrastructure providers) and the operating land transport service sectors which are separated into two rail transport service sectors (*FRRAIL* for freight and *PSRAIL* for passenger transport), one sector for short range public transport (*SHTR*), one sector for road freight transport services (*FRROAD*) and one sector which is providing the rest of land transport services (*REST*, e.g. taxi operation, long range buses, transport via pipelines etc.). Motorized individual transport is extracted from household consumption and modeled as an extra production sector (*MIT*) which is demanded by *privHH* solely.

Domestic production *X* of sector *i* is characterized by a nested constant elasticity of substitution (CES) function (see Figure 2; lowercases represent elasticities of substitution). On the top level of production of commodity *i*, a capital-labour-energy composite ((*KL*)*E*) can be substituted for an intermediate material-transport composite (*MATR*) with the sector specific elasticity of substitution *top*. On the second level of the nesting structure there are two branches: First, (*KL*)*E* is produced by a capital-labour composite (*KL*) and an energy composite *E* (consisting of sector inputs from *COKE*, *ELEC* and *REXT*) which can be substituted for each other with a sector specific elasticity *kle*. On the second branch, *MATR* is produced using a material and services composite (*MA*) which subsumes inputs from

[3] The disaggregation of the land transport sectors (NACE code H49 [Land transport] and H52_53 [Warehousing and support activities for transportation]) is based on EUROSTAT (2014) as well as on data from annual reports of transport companies in Austria.

all sectors except the energy sectors and the transport sectors (G_i-G_k; including imports). These intermediate inputs can be substituted against each other with the sector specific elasticity *int*. Next to material inputs also transport serves as input in the production process of every sector; represented by composite *TRAN*. It is divided into land transport (*LT*, which trades off between *FRRAIL* and *FRROAD*), water transport (*WT*), air transport (*AT*) as well as other transport (*REST*). Elasticities of substitution are based on Okagawa and Ban (2008). Regarding the elasticities between *MA* and *TRAN* we assume *matr* = 0.1, between different transport modes we assume *tr* = 0 (fixed proportions of transport modes used) and *trl* 0.9 (reflecting the possibility of substitution between rail and road but to a limited extent).

This general production structure applies for all economic sectors *i* except for the five transport service sectors *FRRAIL*, *PSRAIL*, *SHTR*, *FRROAD* and *REST*, which additionally demand inputs from transport infrastructure providers (Figure 3). Passenger transport services (*PSRAIL*, *SHTR* and *MIT*) are not included in the production process of X_i, as those services are demanded solely by *privHH*.

Regarding final demand of *privHH*, the aggregate demand function (composite *W*) is depicted in Figure 4. On the top level the composite *NEE* combines non-energy goods (*NE*) with energy consumption (*E*, consisting of *COKE*, *ELEC* and *REXT*). Similar to the production structure of domestic production the *NE* composite is produced using commodities G_i to G_k but with a different elasticity of substitution (*nene*). The composite *NEE* can be traded off with an elasticity of substitution of *s* with a transport composite (*TRA*). *TRA* consists of *MIT* as well as public transport (*PBTR*) which in turn subsumes inputs from the transport sectors *AT*, *WT* as well as *LT*. The latter trades off services across *SHTR*, *PSRAIL* and *REST*.[4]

[4] The elasticities of substitution regarding different transport modes are based on Abrell et al. (2010) as well as Paltsev et al. (2005, 2004) with *s* = 0.5 and *u* = 0.2. Elasticities *tr* and *ltr* are assumed to be 0.1, reflecting rather rigid preferences regarding the choice of transport modes of households.

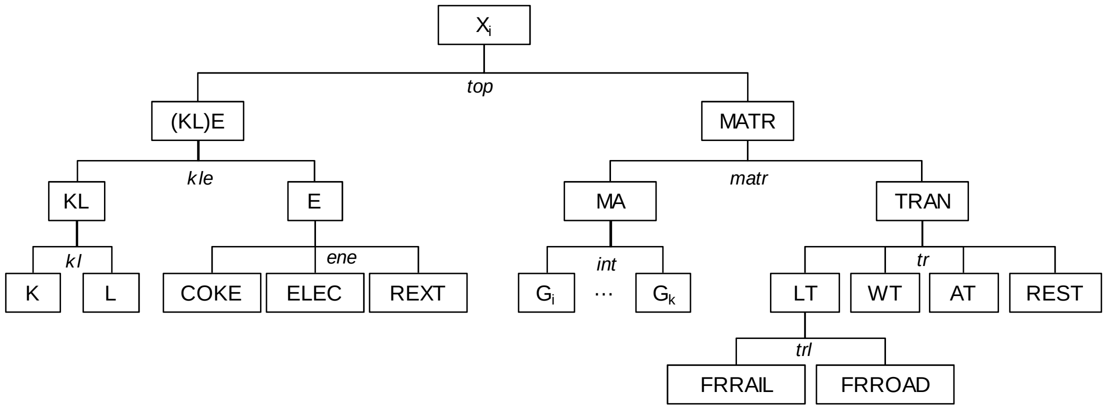

Figure 2: Nested constant elasticity of substitution production structure for domestic production.

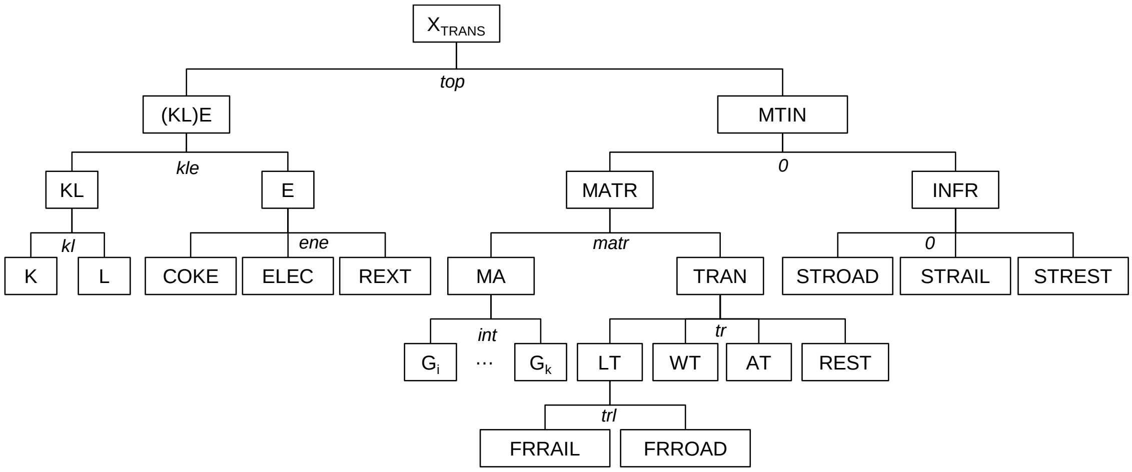

Figure 3: Nested constant elasticity of substitution production structure for the transport service sectors.

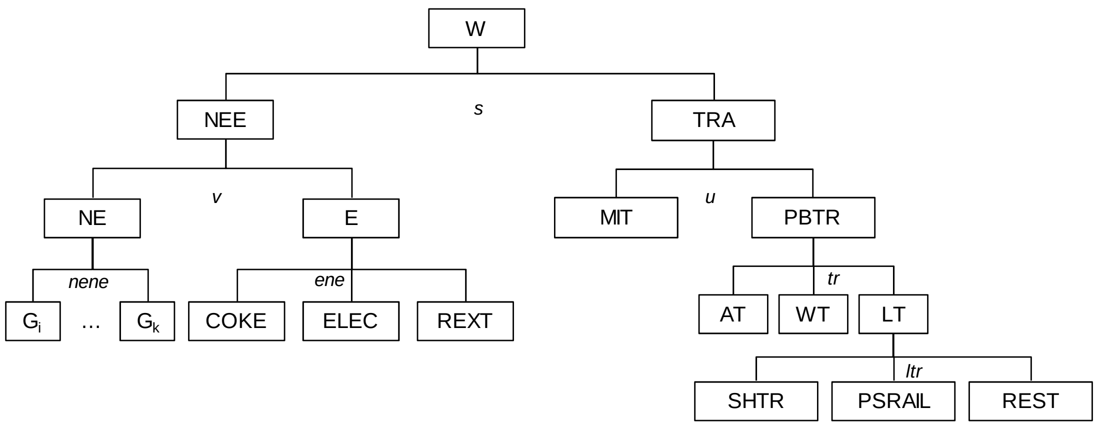

Figure 4: Nested constant elasticity of substitution demand function of private households.

3.2. Modeling climate change impacts

The current weather induced costs to the transport sectors are already calibrated within the benchmark equilibrium of the CGE model. Consequently shocking the model with the current weather induced costs from Table 1 and Table 2 means a doubling of current damages and therefore represents the underlying climate change impact scenario we want to explore. Hence, we actually analyze the climate change impacts of 2050 in today's economy; a commonly chosen approach (see e.g. Ciscar et al., 2011 or Halsnæs et al., 2007) with the advantage not having to make any assumptions about the future development of the economy as well as discounting.[5] Note that this approach only yields the *additional* costs of a changing climate, which would have to be added to the (unknown) macroeconomic and societal costs which arise already today to get the total costs. Hence, all results are given in million (M) $€_{2008}$ and scales would be much higher if a baseline scenario (including growth etc.) had been applied.

Climate change impacts – expressed as economic damage costs in euros – are transferred into the CGE model to reveal the macroeconomic and societal costs of climate change impacts in terms of GDP and welfare (including indirect feedback effects within the economy). This is carried out according to the description in Table 4 and Table 5. The given "direct impacts" (or sectoral costs) are used as input data in the CGE model. Damages to infrastructure are modeled as higher average annual depreciation in infrastructure providing sectors (i.e. higher demand for capital input). The corresponding necessary higher investment expenditures flow into the construction sector.[6] This means that we alter the production cost structures (i.e. technologies) of the respective transport sectors in terms of lower productivity which translates into higher prices which ripple through the whole economy. Other impacts are captured as changes in running costs of economic sectors or households' consumption using shifting parameters across the production or consumption function, respectively.

[5] In contrast, other studies such as Steininger et al. (2015) construct a baseline scenario for a future economic development, including assumptions regarding annual growth, future demand and production patterns, climate policy etc.

[6] 20% of damaged infrastructure is assumed to be already fully depreciated. Therefore the true costs in terms of additional capital costs are only 80%.

Regarding time and safety losses of private households due to traffic interruptions and accidents the welfare measure (equivalent variation) is adjusted *ex post*.[7]

3.1. Modeling climate change adaptation

The modeling of adaptation within the CGE model is characterized mostly by higher sectoral depreciation as a result of a larger capital stock as additional infrastructure is built up for protection (summarized in Table 3). Note that we handle impacts and adaptation differently concerning investments. As opposed to unanticipated impacts – modeled as shifts towards construction activity crowding out other investment activities – adaptation is regarded as a planned and anticipated activity and therefore total investments are expanded. This expansion of investments is carried out by the government and funded by tax increases which in turn reduce households' consumption.

In general every adaptation measure has a certain damage reduction potential (DRP) which works in three ways: First, damages or costs can be reduced directly by a measure (e.g. the enlargement of drainage systems reduces the damages by flooding to roads directly), representing "first order DRP". Second, there is a "second order DRP" of adaptation whenever it reduces damages or costs which are not directly related to the measure (e.g. less time or safety losses due to protected infrastructure). Third, as road and rail infrastructure often run close to each other, there are "co-benefits" across transportation sectors, meaning that the rail infrastructure benefits from protection measures for road infrastructure.[8] Table 4 and Table 5 show how this translates into damage cost reduction (i.e. reduced direct impacts) at the sector levels.

[7] Since the CGE model is not able to capture time and safety losses, the equivalent variation is adjusted after the model has been shocked and found a new equilibrium.
[8] Since roads and railways are often running parallel to each other there are possible co-benefits into both directions. However, as the road network is much larger than the rail network, the co-benefits in the road sector due to protected rail infrastructure is very small in relation to the whole road network length. To keep the model simple co-benefits are thus assumed only in one direction: From road to rail systems, but not vice versa.

Table 4: Climate change impacts and damage reduction by adaptation in the road transport sectors.

	Cost category	Technical description of modeling	Direct impact [M € p.a.]	Damage reduction [%]	Damage reduction [M € p.a.]
Infrastructure	Assets	Higher depreciation in infrastructure providing sectors due to damages to infrastructure;	38.20	64.7%	-24.73
	Operation	More public expenditures for traffic supporting services (e.g. traffic police, fire brigades, snow removal etc.)	0.84	16.7%	-0.14
Vehicles	Assets	More final demand for repair services and new vehicles;	4.78	44.0%	-2.11
	Operation	More expenditure by private households for running transport costs due to forced detours (motorized individual transport)	1.04	16.7%	-0.17
Users	Safety	Welfare losses (ex post adjustment)	0.56	41.6%	-0.23
	Time loss	Welfare losses (ex post adjustment)	1.30	25.3%	-0.33
Sum			46.73		-27.71

Due to the high uncertainty regarding DRP, we additionally carry out a sensitivity analysis. As there is no information by how much the damage costs can be reduced by each measure we start the analysis with 33% first order DRP, 17% second order DRP (the half of first order DRP) and 6% co-benefit DRP (one third of second order DRP). For the example of enlargement of drainage systems in the road sector this means that road infrastructure damages due to flooding are reduced by 33% (first order DRP), all other impacts due to flooding (e.g. time or safety losses) are reduced by 17% (second order) and flood-related infrastructure damages in the rail sector are reduced due to a co-benefit by 6%. This procedure was carried out for all of the seven adaptation measures, depending on their specific characteristics.

Table 5: Climate change impacts and damage reduction by adaptation in the rail transport sectors.

	Cost category	Technical description of modeling	Direct impact [M € p.a.]	Damage reduction [%]	Damage reduction [M € p.a.]
Infrastructure	Assets	Higher depreciation in infrastructure providing sectors due to damages to infrastructure;	16.11	73.0%	-11.76
Service	Detouring costs for passenger transport	Change in running costs in transport service providing sectors: more intermediate demand for other transport services (e.g. taxis, buses) and travel agencies	0.56	16.7%	-0.09
	Detouring costs for freight transport	Productivity loss in freight transport sector as capital and labor become less efficient (freight is detoured but not with other modes, implying efficiency losses)	0.26	16.7%	-0.04
Vehicles	Assets	Higher depreciation in infrastructure providing sectors due to damages to vehicles;	0.67	19.6%	-0.13
User	Passengers	Time losses for passengers due to detouring (by replacement bus service or by using private car instead of train) leading to welfare losses (ex post adjustment	0.17	16.7%	-0.03
	Freight	Time losses for firms due to freight detouring leading to a reduction in labor endowment	0.61	16.7%	-0.10
Sum			18.38		-12.16

4. Results

4.1. Sectoral breakdown of costs and benefits without feedback effects

Based on the chosen assumptions regarding damage reduction potentials (DRP) the annual costs[9] and benefits which emerge in the road and rail sectors are according to Table 6 (no macroeconomic feedback effects and indirect costs, yet). In the road transport sectors the costs after adaptation are nearly the same as the direct impact costs (46 and 47 M € respectively), meaning that there is no clear

[9] The costs arising for the *TAP* measure are not included in Table 6, as the attribution of protection to a certain transport sector is not possible. Besides, not only transport infrastructure is protected by this measure.

benefit from adaptation on the sectoral level. Regarding the rail sectors the costs after adaptation of 7.5 M € are much lower than the direct impact costs without adaptation of 18 M € (this is mainly due the fact of rather low adaptation costs attributed to the rail sector), hence a clear benefit from adaptation of 11 M € at the sectoral level emerges. Aggregating the road and rail sectors we see 65 M € costs without and 53 M € with adaptation, thus still a benefit from adaptation of 12 M €. Note that this breakdown depends strongly on the chosen assumptions for the DRP (see sensitivity analysis).

Table 6: Costs benefit breakdown of direct impacts and adaptation costs p.a. for the road and rail transport sectors (without economic indirect feedback effects).

	costs [M € p.a.]		
	road sectors	**rail sectors**	**road & rail**
Direct impact costs w/o adaptation	46.73	18.38	65.11
Impact reduction by adaptation	-27.71	-12.16	-39.87
Residual impact costs	19.01	6.22	25.24
Adaptation costs	+26.84	+1.27	+28.12
Costs after adaptation	45.86	7.50	53.35

4.2. Macroeconomic effects of climate change impacts

In the next step we plug in the direct impact costs for the road and rail sectors from Table 4 and Table 5 into the CGE model, which corresponds to a doubling of current damage costs, to find out the macroeconomic and societal costs of climate change impacts and by how much the direct impact costs are amplified within the economic system due to interconnectedness (no adaptation yet). We therefore use two measurements: change of GDP and change of welfare[10] relative to the benchmark equilibrium (base year 2008; see section 3.1**Error! Reference source not found.**) of the CGE model without any impacts. The red[11] bars in Figure 5 show the changes of GDP (left) and welfare (right) from impacts occurring in the road and rail sectors respectively in isolation and for a combined model run (all effects are given for the year 2008). In the combined case annual GDP is by -142 M € (-0.05%) lower than without impacts. Welfare loss adds up to -163 M € p.a. (-0.08%) and is thus even stronger than

[10] To measure welfare we use the Hicksian equivalent variation, which is based on goods and services which are consumed as final demand within the whole economy. The change in welfare in euros measures the lost consumption possibilities due to price changes, or equivalently the necessary payments to compensate for the welfare loss.

[11] For versions in grayscale: red = upward shaded; green = downward shaded; blue = horizontally shaded.

GDP loss.[12] The negative effects on GDP and welfare emerge by more than 95% from damaged infrastructure and the resulting higher depreciation and capital demands. When comparing the macroeconomic effect (-142 M € GDP loss) with the actual direct sectoral costs (-65 M €) we see that the direct effect is amplified by a factor of 2.2, meaning that the indirect effect is stronger than the direct effect. The large indirect effect is rooted in the strong interconnectedness of the transport sectors to the rest of the economy, where substitution possibilities across transport modes are very limited and thus production is affected strongly.

4.3. Macroeconomic effects of climate change adaptation

In the third and final step we add the previously described adaptation measures which on the one hand induce further costs but on the other hand reduce the damage costs of climate change according to the chosen assumptions of DRP (see section 3.1). The resulting changes in GDP and welfare with adaptation are given by the blue bars in Figure 5 (they can also be interpreted as residual macroeconomic or societal impact after adaptation). For GDP as well as for welfare, the losses are always smaller in the adaptation case (blue bars are always shorter than red bars). In the combined adaptation case GDP and welfare losses are by -63 and -109 M € lower compared to the benchmark equilibrium (-0.02% and -0.05% respectively), as opposed to the impact case with -142 and -163 M €.

The green bars in Figure 5 show the difference between the impact scenario and the adaptation scenario and therefore give the net effect of adaptation in terms of GDP and welfare. In all cases a net benefit is generated by adaptation, with +78 M € of GDP and +54 M € welfare in the combined case. GDP losses are therefore reduced by 55% and welfare losses by 34%. These positive effects are triggered on the one hand by the reduction of damages and on the other hand via the labor market. Since some of the chosen adaptation measures are relatively labor intensive (specifically vegetation management) a reduction of unemployment of 0.04% points emerges, leading to more consumption and higher tax revenues.

[12] This is because motorized individual transport – which does not contribute directly to GDP – is affected negatively by higher prices for infrastructure charges and since it plays a large role in household’s consumption (15%) the effect on welfare is stronger than the one on GDP.

When impacts occur only in the road sectors, the sectoral cost benefit breakdown (see Table 6) has shown no clear benefit from adaptation, however we see a substantial net benefit on the macroeconomic and societal level (71% GDP and 49% welfare loss reduction). Regarding the rail sectors the loss reduction is somewhat smaller but still significant (44% GDP and 52% welfare loss reductions).

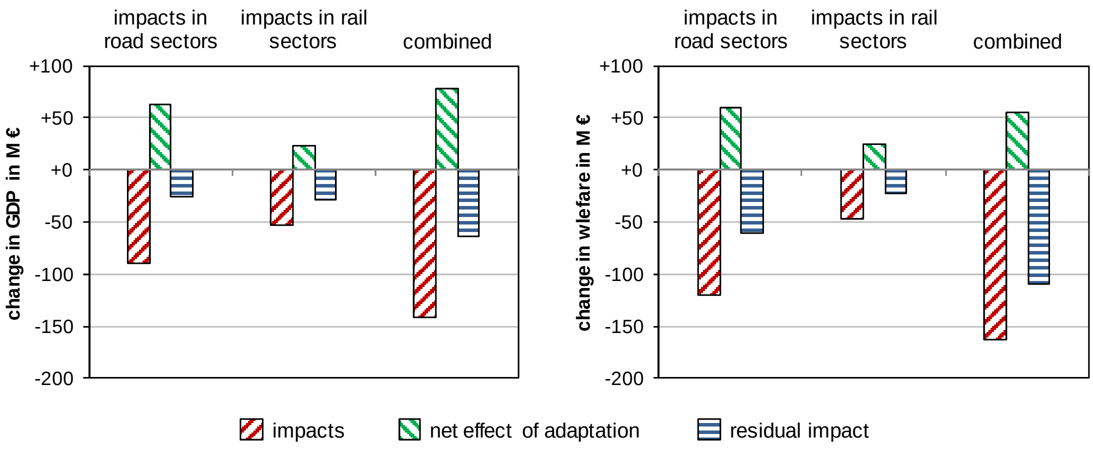

Figure 5: Changes of GDP and welfare without and with adaptation to climate change in the road and rail transport sectors in M € p.a. relative to the benchmark equilibrium (including indirect feedback effects).

How individual adaptation measures contribute to the net effect of adaptation per sector is given in Table 7.[13] In the road sector *VEG-rd* shows the strongest effect on GDP as well as on welfare (+25 M € and +31 M € respectively). Next to the effect of reduced impacts this measure contributed positively to GDP via the labor market. Since this measure is relative labor intensive employment increases, leading to more consumption (and therefore also higher welfare) and higher tax revenues (labor and value added). *HYD-rd* also shows a rather strong effect, especially on welfare (+26 M €), since not only infrastructures are protected by this adaptation measure but also time and safety losses are reduced. Regarding the rail sector the two adaptation measures show about the same effect, although *VEG-rl* is about 5 times costlier than *DRA-rl*. This can be explained again by a positive employment

[13] Note that the sum of effects of the individual adaptation measures does not match with the effect when all measures are active at the same time because the different adaptation measures are overlapping and sometimes compete against each other in terms of protection.

effect of *VEG-rl*, since it is labor relative intensive. Adaptation measure *TAP* reduces damages in the road and the rail sector; hence for the analysis of the isolated effect impacts are active in both sectors. GDP losses are reduced by 28 M €. The quite strong effect of this measure is because both road and rail infrastructures are protected (i.e. damages are reduced) and the construction sector is stimulated strongly. However, the effect of TAP on welfare is much smaller, since necessary investments are financed by tax increases and reducing households' consumption.

Table 7: GDP and welfare effect of adaptation measures in isolation.

	Net effect of adaptation [M € p.a.]	
	GDP	Welfare
DRA-rd	+5	+9
VEG-rd	+25	+31
HYD-rd	+19	+26
VIS-rd	+7	+14
all-rd	**+63**	**+59**
DRA-rl	+15	+17
VEG-rl	+14	+16
all-rl	**+23**	**+25**
TAP	+28	+9
all	**+78**	**+55**

The sectoral effects after macroeconomic feedbacks are given in Figure 6; measured in changes of output level relative to the benchmark equilibrium (in % and in M €). In the impact case (dark bars) all transport sectors' output is reduced by up to -1.6% in *STRAIL*, representing the relatively strong impact on rail infrastructure. As rail infrastructure serves as a key input in the rail freight (*FRRAIL*) and passenger (*PSRAIL*) transport sectors these are also affected relatively strong. The construction sector (*CONT*) is the only sector which is affected positively by climate change impacts as more demand is stimulated (+0.1%). In the adaptation case (light bars) the negative effect on the rail transport sectors can be reduced substantially (reflecting the clear benefit shown on the sectoral cost benefit breakdown in Table 6), whereas the effect in the other transport sectors is reduced only slightly. Note that the construction sector's benefit is reduced to some extent in the adaptation case but still remains positive. In all other sectors which are not shown in Figure 6 the net-benefit of adaptation is positive (between 0.01% and 0.05%-points of output quantity) with stronger effects in transport intensive sectors such as metals, machinery, wholesale and retail trade, wood, paper, chemicals (see Figure A 1 in Appendix C).

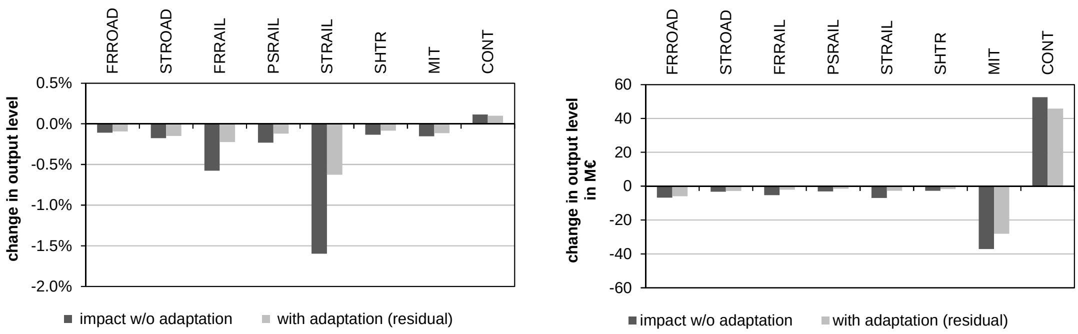

Figure 6: Sectoral effects of climate change impacts and adaptation in the transport sectors as well as the construction sector in % and in M € p.a. of output relative to the benchmark equilibrium. (FRROAD: freight road, STROAD: road infrastructure provision, FRRAIL: freight rail, PSRAIL: passenger rail, STRAIL: rail infrastructure provision, SHTR: short range public transport, MIT: motorized individual transport, CONT: construction)

4.4. Sensitivity analysis

As we face high uncertainties regarding damage reduction potential (DRP) we carry out a sensitivity analysis to find the threshold of DRP by which the residual impact becomes smaller than the impact without adaptation (i.e. achieving a net benefit of adaptation). Figure 7 shows the relation between GDP as well as welfare loss and the assumed DRP (combined case). The vertical solid line at a 33% first order DRP reflects the already described results. When reducing[14] the DRP we see that below 12% the net welfare benefit of adaptation vanishes, however the benefit measured in GDP is still positive. When reducing DRP below 4% also the net benefit in GDP becomes zero, hence at a DRP below 4% adaptation does not pay off any more on a macroeconomic level. The curvature of the loss functions in Figure 7 also shows that the marginal benefit of DRP declines. This is due to the multiplicative effect of the different adaptation measures' DRPs, meaning that once an adaptation measure reduces some damages (damage is multiplied by a factor < 1) the next measure's damage reduction in absolute terms gets smaller.

[14] First order, second order DRP and co-benefits are reduced together at the same time in the following relations: first order DRP: -1%; second order DRP -0.5% (i.e. half of first order DRP), co-benefit -0.17% (i.e. one third of second order DRP)

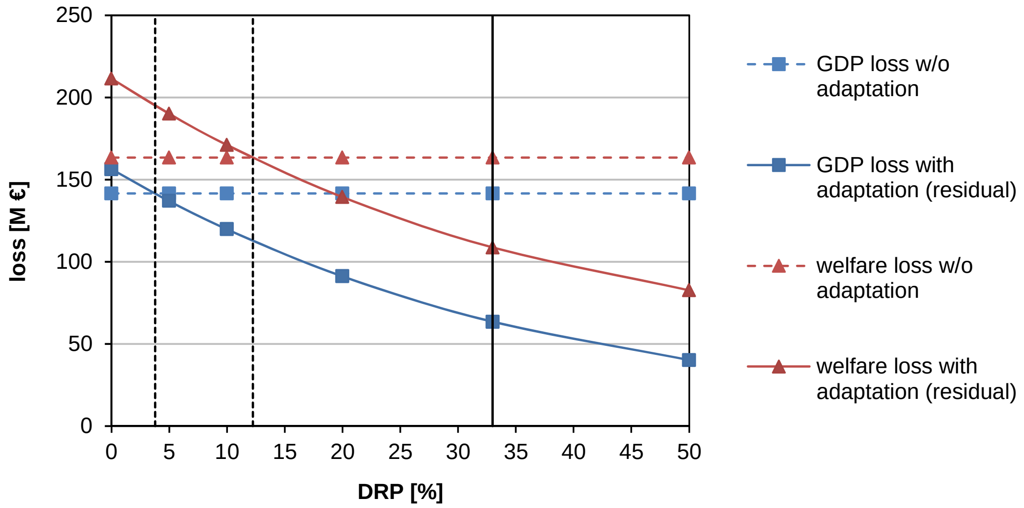

Figure 7: Relationship between damage reduction potential and annual GDP and welfare losses. Dashed vertical lines indicate thresholds for net benefit generation from adaptation measured in GDP and welfare.

5. Discussion and conclusions

Modern economies are characterized by strong intersectoral connections and thus rely strongly on working transport systems. However, these systems experience increasing stress and damages from extreme weather events due to climate change. These direct damage costs are then amplified by transmitting through the whole economy; leading to additional indirect costs, which need to be known in order to develop and implement sound policies to tackle climate change (either by mitigation or adaptation).

This paper therefore gives first estimates for the amplification factor of direct damage costs of climate change impacts in the land transport system for the case of Austria. By applying a computable general equilibrium (CGE) model with a very high resolution of the land transport sector, we find that direct damage costs more than double due to the strong dependence on the transport sectors (factor 2.2). This points out the general importance of comprehensive approaches when it comes to climate change impact assessments. Furthermore we can conclude that cost benefit analysis of adaptation measures at the sectoral level is too short-sighted. For the case of the road transport sector, we see that the cost benefit breakdown at the sectoral level does not show a clear benefit of adaptation, however substantial positive macroeconomic (GDP) and societal (welfare) effects are triggered, when planned adaptation is carried out and damage costs are reduced. Another conclusion to be drawn is that even at rather low damage reduction potentials of adaptation measures, net benefits of adaptation are possible. These positive effects of adaptation measures are particularly interesting as labor market effects are quite strong. This is due to the different natures of impacts and adaptation measures themselves. The former are more capital intensive, the latter involve a higher share of labor and hence unemployment is reduced by adaptation, leading to a stimulating effect which helps offsetting macroeconomic climate change impacts. Since adaptation stimulates positive effects throughout all economic sectors, the question arises whether they also should bear directly a part of the costs of adaptation, as for now the government is paying for adaptation measures and financing it by increased consumption taxes.

It must be emphasized that the results of the underlying paper are subject to substantial uncertainties regarding current and future damage costs since presently not enough information is available for more accurate estimates. For a first analysis current weather induced damage costs are simply doubled which is questionable. However, by doing this, estimates of macroeconomic costs of climate change impacts in the transport system are possible. Furthermore it is not known by how much adaptation measures are able to reduce direct damage costs; however this problem was addressed by a sensitivity analysis.

A critical point of the underlying analysis is that the chosen level of adaptation is not grounded on any optimality or efficiency criteria but on several quantifiable measure found in the literature. Since the marginal cost and marginal benefit curves of adaptation are not known a maximization of benefits by setting marginal costs equal marginal benefits is not possible. The construction of these curves requires further research which has to tackle several problems (e.g. the discrete nature of adaptation measures and their costs, the maximal level of possible implementation of adaptation measures, the damage reduction potentials of each measure etc.).

Another caveat of this study is that CGE models tend to be too flexible as substitution happens instantly after relative prices are changing and thus the estimated macroeconomic and societal damage costs may be underestimated. Moreover the applied CGE model is based on a yearly average of the nation's economy. Hence extreme events at local levels are captured only on average at the national level leading to further possible underestimations of the costs of impacts since local processes of transport disruption and further consequences along the production chain (upstream and downstream) cannot be considered in such an analysis. However, despite the mentioned shortcomings this approach allows us to reveal directions and mechanisms of indirect effects of climate change impacts on the transport system as well as macroeconomic effects of planned adaptation measures.

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Appendix

Appendix A: Economic sector aggregates

Table A 2 shows the economic sectors of the CGE model. The original NACE sectors V49 (Land Transport) and V52_53 (Warehousing and support activities for transportation) had been disaggregated to five transport service sectors and three transport supporting sectors (including infrastructure).

Table A 1: Economic sector aggregates with respective NACE and model code (Land transport sectors printed in bold).

NACE code	Sector description	model code
V01	Crop and animal production, hunting and related service activities	AGRI
V02	Forestry and logging	FORE
V86	Human health activities	HEAL
V87_88	Residential care activities; Social work activities without accommodation	RECA
V36	Water collection, treatment and supply	WATE
V37_39	Sewerage; Waste collection, treatment and disposal activities; materials recovery; Remediation activities and other waste management services	WAST
V35	Electricity, gas, steam and air conditioning supply	ELEC
V19	Manufacture of coke and refined petroleum products	COKE
V28_29	Manufacture of machinery and equipment n.e.c.; Manufacture of electrical equipment	MACH
V41_43	Construction of buildings; Civil engineering; Specialised construction activities	CONT
V68	Real estate activities	REAL
V71	Architectural and engineering activities; technical testing and analysis	ARCH
V45	Wholesale and retail trade and repair services of motor vehicles and motorcycles	MOTO
V49	**Freight transport rail**	**FRRAIL**
	Long range passenger transport rail	**PSRAIL**
	Short range public transport	**SHTR**
	Freight transport road	**FRROAD**
	Rest of Land transport and transport via pipelines	**REST**
V50	Water transport	WTRA
V51	Air transport	ATRA
V52_53	**Supporting activities for road transport; Road Infrastructure**	**STROAD**
	Supporting activities for rail transport; Road Infrastructure	**STRAIL**
	Warehousing and other support activities for transportation; Postal and courier activities	**STREST**
V10, V12	Manufacture of food products; Manufacture of tobacco products	FOOD
V11	Manufacture of beverages	BEVE

NACE code	Sector description	model code
V16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	WOOD
V17	Manufacture of paper and paper products	PAPE
V20	Manufacture of chemicals and chemical products	CHEM
V21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	PHAR
V22_23	Manufacture of rubber and plastic products; Manufacture of other non-metallic mineral products	PLAS
V24_25	Manufacture of basic metals; Manufacture of fabricated metal products, except machinery and equipment	META
V13_15, V18, V26_27, V30_33	Rest of manufacturing (Manufacture of textiles; Manufacture of wearing apparel; Manufacture of leather and related products; Printing and reproduction of recorded media; Manufacture of computer, electronic and optical products; Manufacture of electrical equipment; Manufacture of other transport equipment; Manufacture of furniture; Other manufacturing; Repair and installation of machinery and equipment)	RMAN
V46_47	Wholesale trade, except of motor vehicles and motorcycles; Retail trade, except of motor vehicles and motorcycles	TRAD
V64	Financial service activities, except insurance and pension funding	FINA
V65	Insurance, reinsurance and pension funding, except compulsory social security	INSU
V66	Activities auxiliary to financial services and insurance activities	AFIN
V84	Public administration and defence; compulsory social security	PUBL
V55_56	Accommodation; Food and beverage service activities	ACCO
V79	Travel agency, tour operator and other reservation service and related activities	TRAV
V90	Creative, arts and entertainment activities	ENTE
V91	Libraries, archives, museums and other cultural activities	CULT
V93	Sports activities and amusement and recreation activities	SPOR
V03, V05_09	Fishing and aquaculture; Mining of coal and lignite, Extraction of crude petroleum and natural gas, Mining of metal ores, Other mining and quarrying, Mining support service activities	REXT
V58	Publishing activities	RECR
V59_60	Motion picture, video and television programme production, sound recording and music publishing activities; Programming and broadcasting activities	
V92	Gambling and betting activities	
V69_70	Legal and accounting activities; Activities of head offices, management consultancy activities	SCIE
V72	Scientific research and development	
V73	Advertising and market research	
V74_75	Other professional, scientific and technical activities; Veterinary activities	
V61	Telecommunications	TELE
V62_63	Computer programming, consultancy and related activities; Information service activities	
V95	Repair of computers and personal and household goods	
V77	Rental and leasing activities	RSER
V78	Employment activities	
V80_82	Security and investigation activities; Services to buildings and landscape activities; Office administrative, office support and other business support activities	

NACE code	Sector description	model code
V85	Education	
V94	Activities of membership organisations	
V96	Other personal service activities	
V97_98	Activities of households as employers of domestic personnel; Undifferentiated goods- and services-producing activities of private households for own use	
V99	Activities of extraterritorial organisations and bodies	

Appendix B: Isolated effects of different impacts and adaptation measures

Table A 2 gives the effects on annual GDP and welfare of different impacts and adaptation options by sector in isolation. The first to columns show the absolute isolated effects relative to the benchmark equilibrium in M €. In both the road and the rail sector the damages to infrastructure assets are responsible for the lion's share of macroeconomic (GDP) and societal (welfare) costs. Regarding adaptation the net effect on GDP and welfare are given in the last two columns. In the road sector we see that *VEG-rd* (vegetation management) and *HYD-rd* (hydrological stations for early warning systems) contribute the strongest to the benefit of adaptation. In the rail sector the two measures *DRA-rl* (enlargement of drainage systems) and *VEG-rl* (vegetation management) are equally beneficial. Note, that the sum of effects of all individual adaptation measures in isolation is larger than the effect when all adaptation measures are simulated together in one model run. This is due to the multiplicative effect of the different adaptation measures' damage reduction potential.

Table A 2: GDP and welfare costs of climate change and adaptation in the road and rail sector by different impacts and adaptation measures in M€ p.a..

		change relative to benchmark equilibrium [M € p.a.]		net effect of adaptation [M € p.a.]	
		GDP	**welfare**	**GDP**	**welfare**
road	impacts:				
	infrastructure assets	-86	-112		
	infrastructure operation	+0	+0		
	vehicles	-3	-3		
	users	+0	-4		
	all impacts	**-89**	**-121**		
	all impacts + adaptation:				
	DRA-rd	-84	-111	+5	+9
	VEG-rd	-64	-90	+25	+31
	HYD-rd	-70	-94	+19	+26
	VIS-rd	-82	-106	+7	+14
	all impacts and adaptation	**-26**	**-61**	**63**	**59**
rail	impacts:				
	infrastructure assets	-49	-40		
	vehicles and service operation	-3	-3		
	users	+0	-4		
	all impacts	**-52**	**-47**		
	all impacts + adaptation:				
	DRA-rl	-37	-30	+15	+17
	VEG-rl	-38	-31	+14	+16
	all impacts and adaptation	**-29**	**-22**	**+23**	**+25**
road & rail	**all impacts**	**-142**	**-163**		
	all impacts and adaptation (incl. *TAP*)	**-63**	**-109**	**+78**	**+54**

Appendix C: Sectoral effects of climate change impacts and adaptation for all sectors except transport sectors

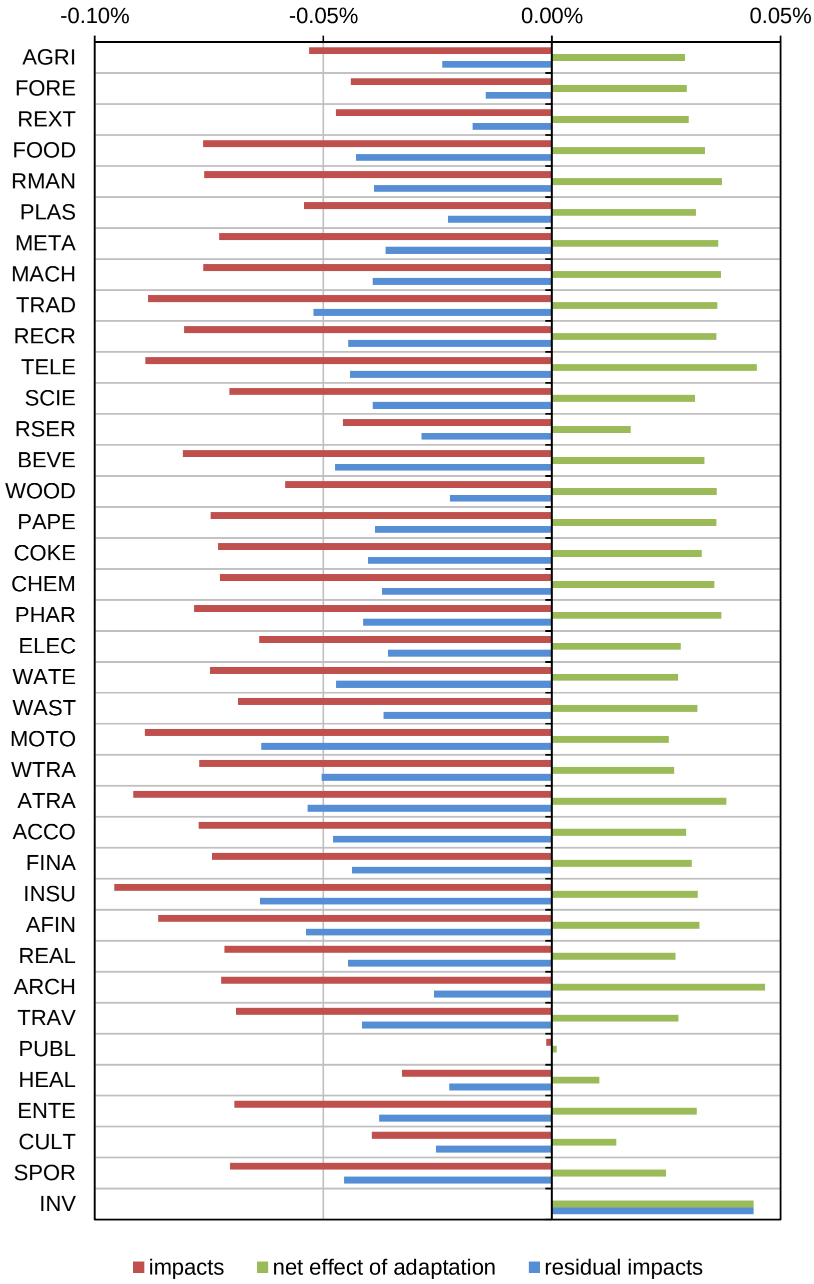

Figure A 1: Sectoral effects of climate change impacts and adaptation in % of output relative to the benchmark equilibrium (see Table A 1 for sector abbreviations)

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