Research Papers
Issue RP0162
November 2012

CIP - Climate Impacts and Policy Division

Including adaptive capacity in the WITCH model

By **Enrica De Cian**
Fondazione ENI Enrico Mattei (FEEM),
Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC)
enrica.decian@cmcc.it

Licia Ferranna
Fondazione ENI Enrico Mattei (FEEM),
Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC)
825676@stud.unive.it

SUMMARY The present report describes the methodological approach and the technical procedure followed to enrich the AD-WITCH hard linked integrated assessment model with a finer description of adaptive capacity.

This report represents the Deliverable P58 developed within the framework of Work Package 6.2.10 of the GEMINA project, funded by the Italian Ministry of Education, University and Research and the Italian Ministry of Environment, Land and Sea.

Summary

1 INTRODUCTION

This report describes the development of a richer description of adaptive capacity in the AD-WITCH model. This is now endogenous being linked to per capita GDP through a relation parameterized following Yohe and Tol (2002). In addition a "trend" component is added accounting for the role of population size which is however exogenous. A second novelty is a partly endogenous treatment of economic growth based on Carraro, De Cian, Tavoni (2009). In the model, GDP is partly driven by the stock of human capital and knowledge.

2 THE IMPROVED AD-WITCH MODEL: ADAPTIVE CAPACITY

The modelling tool used in the present analysis is an improved version of the AD-WITCH model (Bosello et al. 2011, Agrawala et al. 2010, Agrawala et al. 2011) whose main features are summarised below[1].

AD-WITCH builds on the WITCH model (Bosetti et al. 2006, Bosetti et al. 2009), of which it shares the main characteristics. It is an intertemporal, optimal growth model in which forward-looking agents choose the path of investments to maximise a social welfare function subject to a budget constraint. A reduced-form global circulation model links emissions from industrial activities to temperature increase. On its turn temperature increase translates in GDP losses via a reduced-form climate change damage function. The model can be solved in two alternative game theoretical settings. In the non-cooperative one, the twelve model regions[2] behave strategically with respect to all major economic decision variables – including adaptation and emission abatement levels. This yields a Nash equilibrium, which does not internalise the environmental externality. The cooperative setting describes a first-best world, in which all externalities are internalised, because a benevolent social planner maximises a global welfare function[3].

In AD-WITCH, adaptation response is modelled as a set of control variables chosen optimally together with all the other controls, namely investments in physical capital, R&D, and energy technologies. The large number of adaptive responses that exist has been aggregated into four macro categories: generic and specific adaptive capacity-building, anticipatory and reactive adaptation.

Generic adaptive capacity building captures the link between the status of the development of a region and the final impact of climate change on its economic system (Parry 2009). Specific adaptive capacity building accounts for all investments dedicated to facilitate adaptation activities

---

[1] The interested reader is addressed directly to Bosello et al. (2011) for further detail.

[2] Western Europe (WEU), Latin and Central America (LACA),

[3] AD-WITCH, as well as the WITCH model, features technology externalities due to the presence of Learning-By-Researching and Learning-By-Doing effects. The cooperative scenario internalises all externalities. For more insights on the treatment of technical change in the WITCH model see Bosetti et al. (2009).

(e.g. improvement of meteorological services, of early warning systems, the development of climate modelling and impact assessment etc.). Anticipatory adaptation gathers all the measures where a stock of defensive capital must already be operational when the damage materialises (e.g. dike building). By contrast, reactive adaptation gathers all actions that are put in place when the climatic impact effectively materialises (e.g. use of air conditioning) to accommodate the damages not avoided by anticipatory adaptation or mitigation.

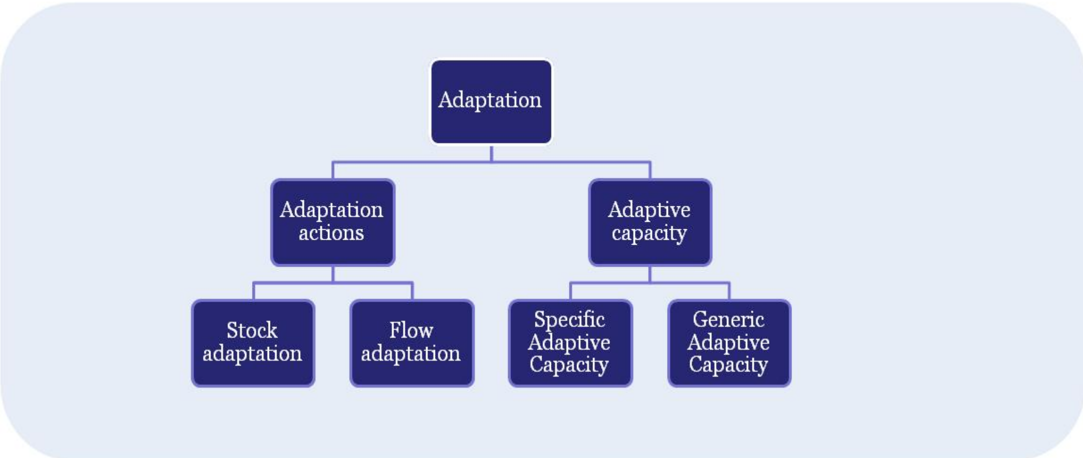


Figure 1. The adaptation tree in AD-WITCH.

In the original framework developed for AD-WITCH (Bosello et al. 2010, 2011) the choice between different adaptation types is organized by a nested sequence of CES functions. In a first node it is possible to choose between investment in adaptation actions and/or building adaptive capacity. Within adaptation actions, meanwhile, it is possible to choose between stock/proactive and flow/reactive adaptation. These are considered to be substitutes. Adaptive capacity is then composed of generic and specific adaptive capacity, also considered to be substitutes. Both generic and specific adaptive capacities improve the effectiveness of adaptation.

A first novelty of the present analysis is the specification of generic capacity. It is treated as endogenous and its parameterization follows Yohe and Tol (2002), even though some sensitivity has been done on the basis of Alberini et al. (2006).

Yohe and Tol (2002) estimate an equation where the dependent variable is the natural logarithm of people affected (normalized with population size in 1995) by natural disaster in the period 1990-2000. Alberini et al. (2006) estimate an equation where the dependent variable is country l's deaths in extreme weather events per million people in year t, panel of data from over 100 countries covering the years 1990-2003. Two specifications are considered. The first uses an adaptive capacity index (constructed by Alberini herself and based on experts' judgments). The second uses POLITY2 in place of the index. Such a variable proxies adaptive capacity capturing institutions, political processes, the government's willingness to provide assistance in case of natural disasters and social capital, even though imperfectly. Used estimates are reported in Table 1.

Table 1: Estimates of the relationship between generic adaptive capacity and its drivers.

	Yohe and Tol (2002) (Central Case)	*Alberini et al. (2006) (Cap Index)*	*Alberini et al. (2006) (POLITY2)*
GDP per capita (a)	**-1.02**	**-0.08847**	**-0.10339**
Population density (b)	**0.24**	**0.000379**	**0.000727**

Generic capacity building is linked to per-capita GDP by a factor of (roughly) one while the exponent associated to population density is 0.24. Hence, generic capacity has been modelled as follows:

$$GCAP_{n,t} = [\, Y_{n,t}/L_{n,t} \,]^{1.02} * [\, L_{n,t} \,/WPOP_t \,]^{(-0.24)} \qquad (1)$$

where $Y_{n,t}$ is country's n GDP; $L_{n,t}$ represents regional population and $WPOP_t$ is global population.

On its turn, specific adaptive capacity building is investment driven, thus it accumulates over time according to:

$$SCAP_{n,t} = (1-\delta) * \, SCAP_{n,t-1} + \, I\_SCAP_{n,t} \qquad (2)$$

where $I\_SCAP_{n,t}$ represents new investments in specific capacity while the stock depreciates at a rate δ.

A second novelty is a partly endogenous treatment of economic growth based on Carraro, De Cian, Tavoni (2009). In the model, GDP is partly driven by the stock of human capital and knowledge. Regions can decide to invest also in these sectors to stimulate economic growth. Since generic capacity is linked to per capita GDP, the stock of human capital and the stock of knowledge ultimately affect the adaptive capacity (see Figure 2).

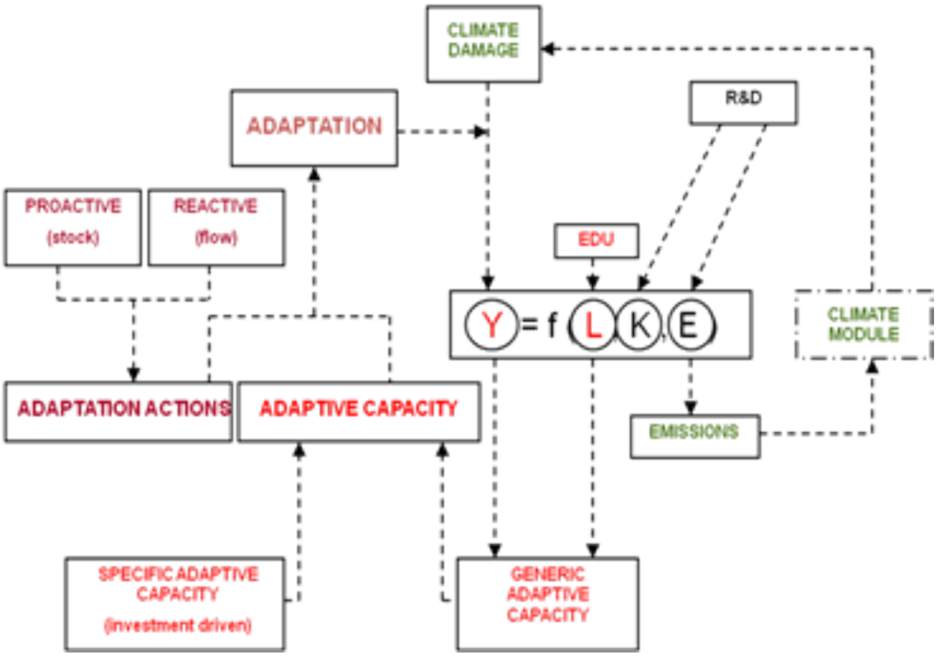


Figure 2 . General description of the model

As it can be seen in the figure, the output of the production process is a unique final good produced by means of three inputs: capital, labour and energy.

$$Y(t) = H(t)\{[AK(t)K(t)]^{\rho} + [AL(t)L(t)]^{\rho} + [AE(t)E(t)]^{\rho}\}^{1/\rho} \quad (3)$$

The coefficients (Ai with $i = K, L, E$) that pre-multiply the three inputs capital, labour and energy (K, L, E), describe the productivity of the singular production factor, whereas neutral technical change is described by H. In particular $\rho = (\sigma - 1)/\sigma$ where σ is the elasticity of substitution.

When technical change is endogenous, factor productivity at time t depends on factor productivities at time $t - s$, for all $s = 1, \dots, t$, and on its specific technological driver. Following Carraro and De Cian (2009), innovation ($R\&D$) better explains the dynamics of capital and energy productivities, while human capital (HK) is the main driver for labour productivity advancements. Hence, endogenous factor-augmenting technical progress may be expressed as follows:

$$AK\ (t) = AK_0\ R\&D^{\chi_K} \quad (4)$$

$$AE\ (t) = AE_0\ R\&D^{\chi_E} \quad (5)$$

$$AL\ (t) = AL_0\ HK^{\chi_L} \quad (6)$$

The equations (4), (5), (6) indicate that the evolution of the productivities of capital, energy and labour is related to their respective technology drivers according to the parameter χ_i with $i =$

K; L; E , which are the factor elasticities with respect to endogenous technology drivers. Once the endogenous dynamics of the factor productivities have been formalised, it is possible to investigate whether the technology drivers, i.e. human capital and innovation expressed as the stock of R&D, are energy-saving or energy-using. When a stabilisation policy is implemented, the behaviour of the technology drivers with respect to the use of the energy input will be determinant for the allocation of resources towards either R&D investments or education. The parameters linking factor productivity with endogenous technological drivers have been estimated by Carraro and De Cian (2009) using the Feasible Generalised Least Square Estimator. The estimation results indicate that all the three elasticities are positive and statistically significant; hence, factor productivities come as the result of an endogenous process. In particular, the central value of the elasticity of capital productivity with respect to generic knowledge has been estimated to be equal to 0.28 (χ_K), while the same parameter regarding the contribution of human capital to labour productivity and the effect of total R&D for energy productivity are, respectively, 0.17 (χ_L) and 0.59 (χ_E). Using these estimates it turns out that human capital is energy using, while knowledge is energy-saving (Carraro et al. 2009).

3 INCORPORATING ADAPTATION AS A POLICY VARIABLE IN THE AD-WITCH MODEL

This last section introduces a more detailed representation of the adaptation modelling framework used in AD-WITCH.

In the model, the damages that will be experienced in absence of adaptation, i.e. gross damages (GD), are exponentially linked to temperature changes (T):

$$GD_{j,t} = \alpha_{0,j} T_t + \alpha_{1,j} T_t^{\alpha_{2,j}} \tag{7}$$

where the subscript *j* represents the region and the subscript *t* the time period.

When adaptation is undertaken, the level of damage is reduced, leaving to a residual damage (RD). Residual damages are directly linked to gross damages and inversely to the achieved level of adaptation (ADAPT) according to the following function:

$$RD_{j,t} = \frac{GD_{j,t}}{1 + ADAPT_{j,t}} \tag{8}$$

According to the functional form, residual damages approaches zero when total adaptation reaches infinity, while residual damages are equal to gross damages in the case in which no adaptation is undertaken. In such a way, the fraction by which the gross damages can be reduced is limited to the interval of 0 to 1. Moreover, adaptation shows a decreasing marginal damage reduction: the more adaptation is used the less effective additional adaptation will be.

The net damage (ND) is the damage in the presence of adaptation, and it is given by the sum of adaptation costs and residual damage. Expenditure in adaptation are made by the whole of flow adaptation actions (FAD), stock adaptation (SAD), and in specific adaptive capacity (SAC).

Flow adaptation entails simultaneous costs and benefits. Stock adaptation instead is created with investments in adaptation (IA). Hence, the law of motion for adaptation stock is:

$$SAD_{j,t+1} = (1-\delta)SAD_{j,t} + IA_{j,t} \tag{9}$$

where δ is the capital depreciation rate (10% in AD-WITCH). The build-up for specific adaptive capacity is also based on the accumulation investments in specific adaptive capacity (IAC), which depreciates at a 3% rate.[4] Adaptation costs are thus given by:

$$\mathrm{AC} = \mathrm{FAD} + \mathrm{IA} + \mathrm{IAC} \tag{10}$$

Flow adaptation and investment in stock adaptation are aggregated together to adaptation actions (ACT) using a Constant Elasticity of Substitution (CES) function:

$$ACT_{j,t} = \beta_{1,j}(\beta_{2,j}FAD_{j,t}{}^{\rho} + (1-\beta_{2,j})SAD_{j,t}{}^{\rho})^{\frac{\beta_3}{\rho}} \tag{11}$$

Furthermore, adaptation actions are part of a bigger nest in which they are combined with adaptive capacity building. Adaptive capacity is also derived as a CES combination of specific (SAC) and generic (GAC) adaptive capacity:

$$AC_{j,t} = (\varphi_j SAC_{j,t}{}^{\gamma} + (1-\varphi_j)GAC_{j,t}{}^{\gamma})^{\frac{1}{\gamma}} \tag{12}$$

Finally, adaptation actions and adaptive capacity building are combined to form total adaptation, also with a CES function:

$$ADAPT_{j,t} = (\mu_j ACT_{j,t}{}^{\gamma} + (1-\mu_j)AC_{j,t}{}^{\gamma})^{\frac{1}{\rho}} \tag{13}$$

[4] Direct stock adaptation is comparable to building or adapting infrastructure so it is a capital-intensive activity which is assumed to depreciate at a rate close to that of physical capital. Specific adaptive capacity instead is assumed to depreciate at a lower rate because it has a knowledge component that is therefore closer to human capital, which depreciates at a lower rate.

In absence of empirical estimates for the elasticities, the values have been chosen to reflect substitutability between the different adaptation types. The elasticity of substitution in AD-WITCH is 1.2, with an exponential parameter ρ equal to 0.2. This is due to the fact that the stock and flow adaptation actions are part of a bigger nest in the AD-WITCH model. Specific and generic adaptive capacities are assumed to be gross complements with an elasticity of substitution equal to 0.2. Adaptive capacity building and adaptation actions are instead assumed to be gross substitutes and have an elasticity of substitution of 1.2.

The model has been calibrated on the basis of Nordhaus and Boyer (2000), Agrawala and Fankhauser (2008) and UNFCCC (2007). The calibration point corresponds to an increase in temperature equal to 2.5°C, which is supposed to happen between 2060-2065 Protection levels, damage costs and adaptation costs calibrated and those reported by the literature are depicted in Figures 3, 4 and 5 respectively. Figure 6 reports the resulting adaptation cost/effectiveness curves for the AD-WITCH model regions.

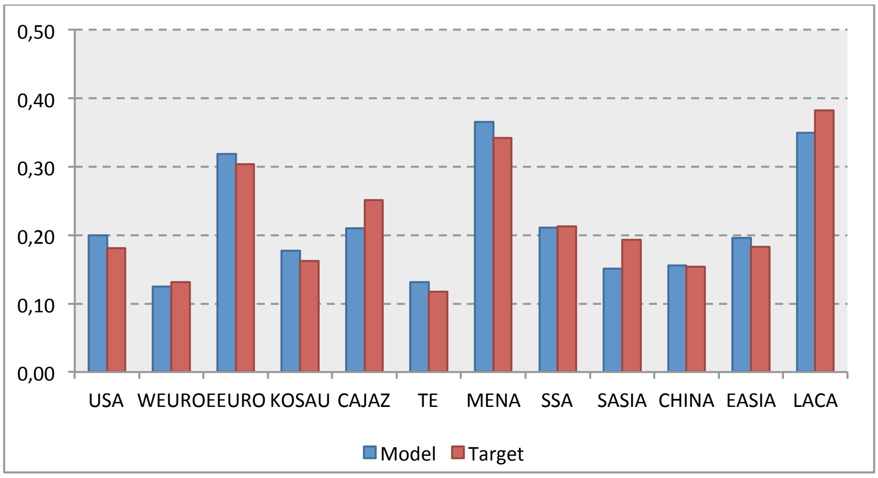


Figure 3: Protection Level for the reference case in the calibration point, when temperature increase 2.5°C above pre-industrial levels, which occurs between 2060 and 2065

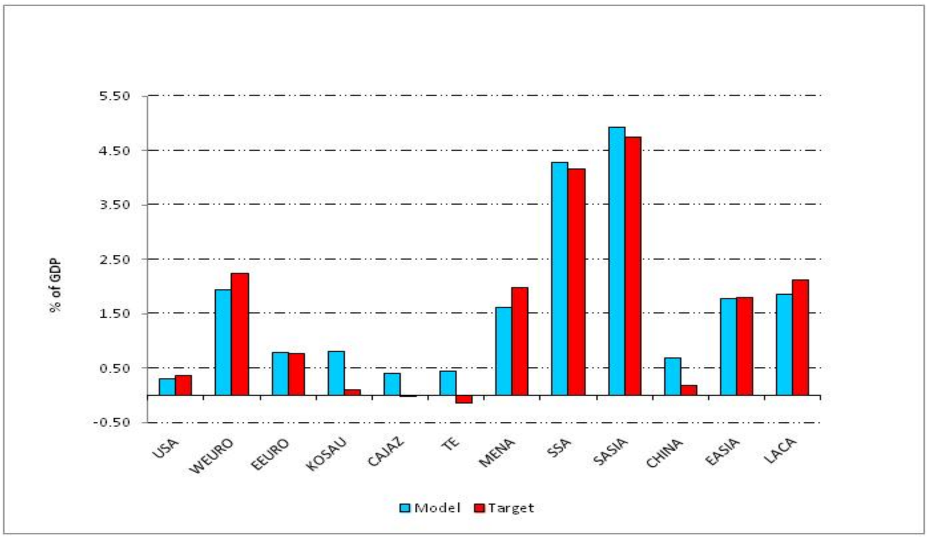


Figure 4: Protection Costs + residual damages for the reference case in the calibration point, when temperature increase 2.5°C above pre-industrial levels, which occurs between 2060 and 2065

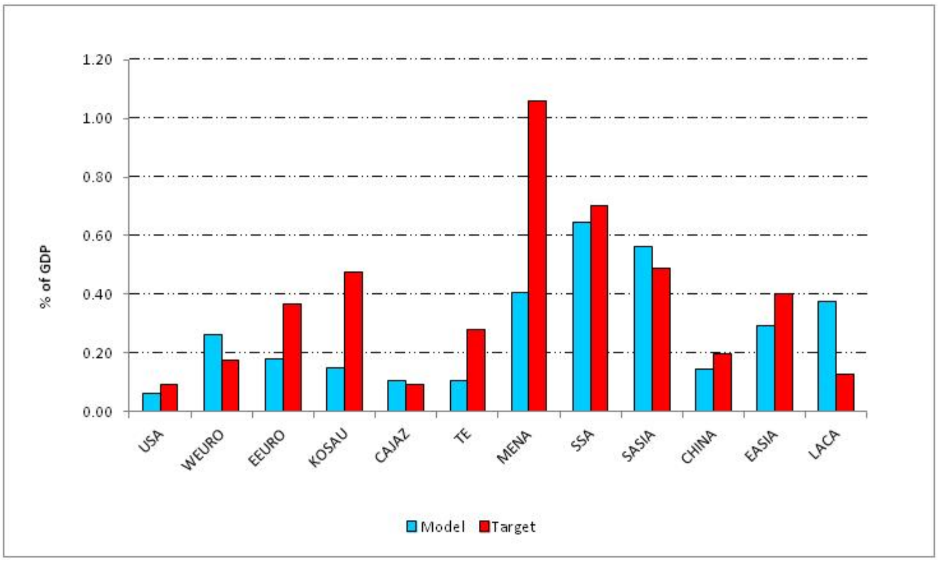


Figure 5: Protection Costs for the reference case in the calibration point, when temperature increase 2.5°C above pre-industrial levels, which occurs between 2060 and 2065

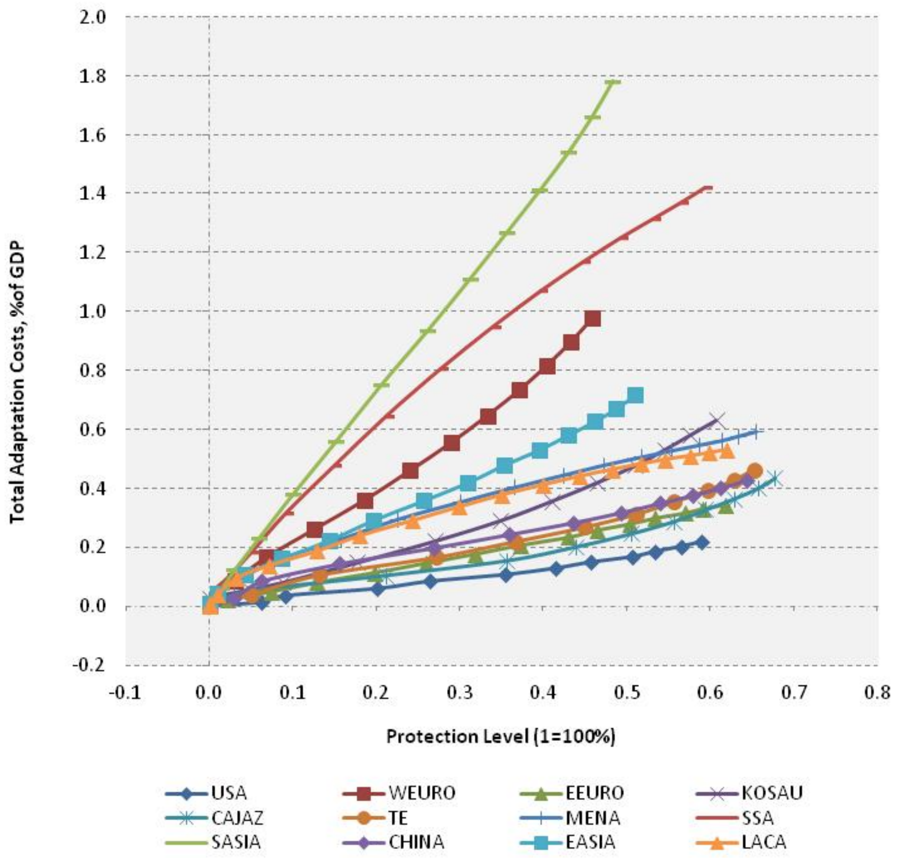
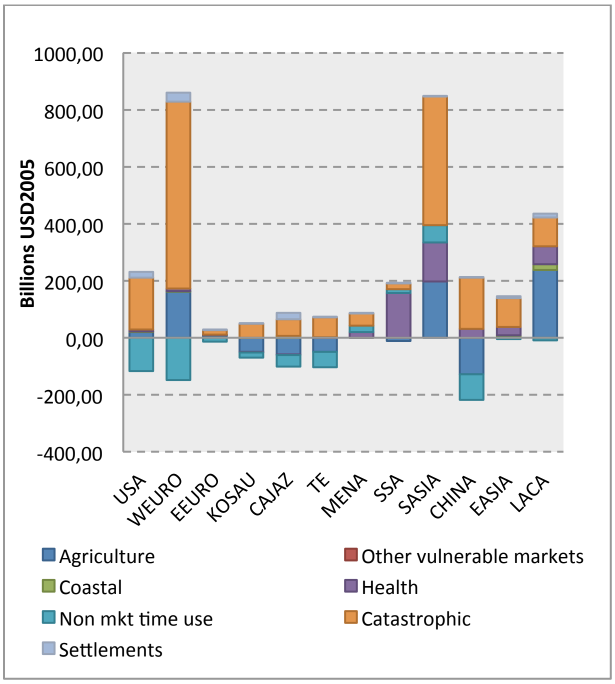


Figure 6: Adaptation cost/effectiveness curves for the AD-WITCH model regions

To conclude, damages differentiated for categories and for regions are represented in Figure 7.



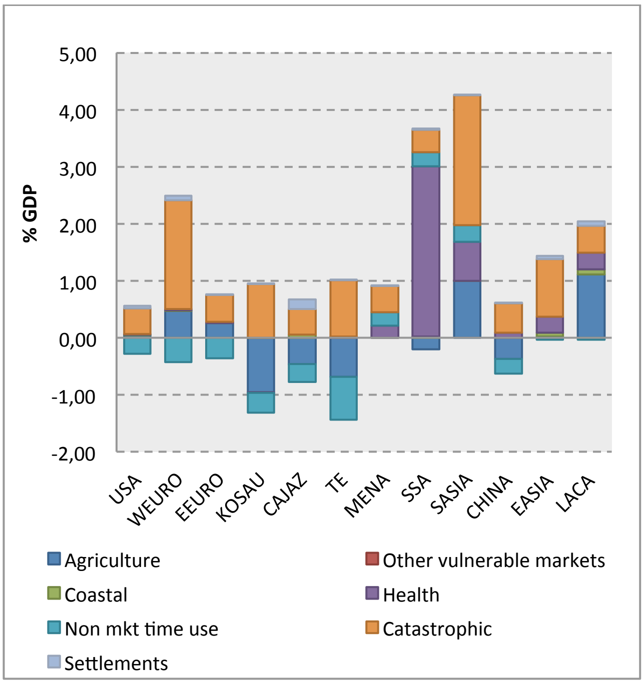


Figure 7: Damages at the calibration point: absolute values (left) and percentage of GDP (right).

The calibration process results in region-specific estimates for the parameters reported in Table 2.

Table 2. Parameters of adaptation and damage functions (calibrated values)

	USA	WEURO	EEURO	KOSAU	CAJAZ	TE	MENA	SSA	SASIA	CHINA	EASIA	LACA
α_0	-0.0021	-0.0025	0.001	-0.007	-0.007	-0.008	0.002	0.0015	0.0004	-0.0045	0.001	-0.002
α_1	0.0014	0.0044	0.0014	0.0043	0.004	0.004	0.0035	0.0105	0.0105	0.003	0.0028	0.0105
α_2	2	2	1.8	2	2	2	1.6	1.6	1.8	2	2	1.1
μ_2	0.0001	0.01	0.0001	0.01	0.0001	0.2	0.3	0.315	0.3	0.15	0.25	0.3
φ_2	0.3	0.5	0.1	0.1	0.9	0.00001	0.00001	0.1	0.2	0.0001	0.1	0.2
β_1	5.7	0.85	50	22	18	42	24	14	2.1	3.8	8	7
β_2	0.5	0.5	0.6	0.6	0.5	0.5	0.6	0.6	0.6	0.4	0.4	0.4
β_3	1	1	1	1	1	1	1	1	1	1	1	1

4 REFERENCES

Agrawala, S. et al. (2010), *Plan or React? Analysis of Adaptation Costs and Benefits Using Integrated Assessment Models*, OECD Environment Working Papers, No. 23, OECD Publishing.

Agrawala. S, **Bosello, F**., Carraro, C. de Cian E. and E. Lanzi (2011), “Adapting to Climate Change: Costs, Benefits, and Modelling Approaches”, *International Review of Environmental and Resource Economics*, 2011, 5: 1–40

Agrawala, S. and S. Fankhauser, Eds. (2008). Economic Aspects of Adaptation to Climate Change: Costs, Benefits and Policy Instruments - Executive Summary. OECD, Paris, May 2008.

Alberini, A., Chiabai, A. and Muehlenbachs L. (2006). *Using expert judgment to assess adaptive capacity to climate change: Evidence from a conjoint choice survey*, Global Environmental Change 16, 123-144;

Bosello F., C. Carraro and E. De Cian (2010). Climate Policy and the Optimal Balance between Mitigation, Adaptation and Unavoided Damage, *Climate Change Economics*, vol. 1(02): pp. 71-92.

Bosello, F., Carraro, C. and E. De Cian (2011), " Adaptation Can Help Mitigation: An Integrated Approach to Post-2012 Climate Policy" FEEM Note di Lavoro 2011.069

Bosetti V., C. Carraro, M. Galeotti, E. Massetti and M. Tavoni (2006). “WITCH: A World Induced Technical Change Hybrid Model,” *The Energy Journal*. Special Issue on Hybrid Modeling of Energy-Environment Policies: Reconciling Bottom-up and Top-down: 13-38.

Bosetti V., E. De Cian, A. Sgobbi and M.Tavoni (2009). “*The 2008 WITCH Model: New Model Features and Baseline*”, FEEM Working Paper No. 085.2009.

Carraro, C., and E. De Cian (2009). *Factor Augmenting Technical Change: an Empirical Assessment.* Ca Foscari University of Venice 29.

Nordhaus W.D. and J. Boyer (2000). *Warming the World*. Economic Models of Global Warming, The MIT Press, Cambridge, MA.

Parry M. (2009) “Closing the loop between mitigation, impacts and adaptation,” Climatic Change: Vol. 96: pp 23–27

G. Yohe and Tol, R.S.H. (2002). *Indicators for social and economic coping capacity - moving toward a working definition of adaptive capacity*, Global Environmental Change 12, 25-40;

The Euro-Mediteranean Centre on Climate Change is a Ltd Company with its registered office and administration in Lecce and local units in Bologna, Venice, Capua, Sassari, Viterbo, Benevento and Milan. The society doesn't pursue profitable ends and aims to realize and manage the Centre, its promotion, and research coordination and different scientific and applied activities in the field of climate change study.

cmcc
Centro Euro-Mediterraneo sui Cambiamenti Climatici