Adaptation Can Help Mitigation:
An Integrated Approach to Post-2012 Climate Policy*

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Online Appendix

Introducing adaptation into the Witch model

The model considers four different adaptation strategies. Adaptive capacity consists of a generic and a specific component. Adaptation activities can be of anticipatory and reactive nature. In AD-WITCH, climate change damage net of the adaptation effect, $CCDA_{n,t}$, acts as negative total factor productivity and reduces the net output, $YN_{n,t}$, available for final consumption and investments:

$$YN_{n,t} = \frac{1}{1 + CCDA_{n,t}} \cdot YG_{n,t} \qquad \text{(A1)}$$

Adaptation reduces the damages according to the following relationship:

$$CCDA_{n,t} = f(ADAPT_{n,t}, CCD_{n,t}) = \frac{1}{1 + ADAPT_{n,t}} \cdot CCD'_{n,t} \qquad \text{(A2)}$$

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where $CCD_{n,t}$ represents climate change damage gross of adaptation:

$$CCD_{n,t} = \theta_{1n} \cdot T_t + \theta_{2n} T_t^{\gamma_n} \quad \text{(A3)}$$

The chosen functional form implies two properties. First, it is bounded between 0 and 1. Second, an infinite amount of resources allocated to adaptation can reduce the residual climate change damage to 0 at the maximum. Adaptation exhibits decreasing marginal productivity, thus additional resources to adaptation become less and less effective in reducing damage.

Total adaptation, $ADAPT_{n,t}$, is a CES combination of different adaptation forms. The choice of the CES specification is determined by its great flexibility in representing the different degrees of substitutability and complementarity among its components. By simply adjusting the CES exponents, alternative assumptions about the relationships between different adaptation strategies can easily be tested.

A first CES nest aggregate adaptive capacity-building (*TCAP*) and adaptation activities (*ACT*):

$$ADAPT_{n,t} = (\alpha_{1,n} TCAP_{n,t}^{\rho_{ADA}} + \alpha_{2,n} ACT_{n,t}^{\rho_{ADA}})^{1/\rho_{ADA}} \quad \text{(A4)}$$

Adaptive capacity-building (*TCAP*) is a CES combination of generic (*G_CAP*) and specific (*S_CAP*) adaptation capacity:

$$TCAP_{n,t} = (\alpha_{3,n} G\_CAP_{n,t}^{\rho_{cap}} + \alpha_{4,n} S\_CAP_{n,t}^{\rho_{tcap}})^{1/\rho_{tcap}} \quad \text{(A5)}$$

Generic capacity is meant to capture those determinants that are broadly related to the socio-economic and institutional development of a country. The underlining assumption is that the richer a region the more adaptable it is. Generic capacity is assumed to evolve exogenously with the growth rate of total factor productivity. The initial value is an indicator of local capacity based on human capital and knowledge stock. It is computed using data on education and R&D

expenditure by World Development Indicators, 2008.[1] As a consequence, initial general capacity is larger in developed regions, but growth rates are higher in developing ones.

G_CAP follows an exogenous trend mimicking the growth rate of total factor productivity. The initial value is an indicator of local capacity based on human capital and knowledge stock:

$$G\_CAP_{n,t} = G\_CAP_{n,0} * TFP(n,t) \quad \text{(A6)}$$

Specific capacity includes all forms of expenditure, investments, and institutions that could increase the adaptive capacity of a system and thus make adaptation activities more effective in reducing climate change damages. Specific adaptive capacity building is modelled as a stock that is built over time by investing in adaptation-specific investments, $IS\_CAP_{n,t}$:

$$S\_CAP_{n,t} = (1-\delta_{CAP}) \cdot S\_CAP_{n,t-1} + IS\_CAP_{n,t} \quad \text{(A7)}$$

The stock depreciates at a rate of $\delta_{CAP,}$ which has been set equal to 3 per cent per year. Investments in specific capacity have been set to be approximately 1 per cent of world expenditure on education and total R&D in the calibration year. There are serious data constraint problems in the calibration of this variable. The only activities for which some data is available are innovation in the agricultural sector and implementation of early warning systems. If only these two forms of specific capacity were considered, specific capacity would probably be heavily underestimated because many other items would be excluded. For this reason, we decided to calibrate investments in specific capacity as a share of total world expenditure on education and total R&D.[2] We set the share to an arbitrarily low value, about 1 per cent, which corresponds to US$ 164 billion in 2060. This global amount has then been distributed to the

[1] Available at http://data.worldbank.org/data-catalog/world-development-indicators.
[2] Data on R&D and education expenditure are from World Development Indicators, 2008.

different regions according to the normalised share of education expenditure over GDP. This criterion corrects the otherwise uneven distribution of R&D investments highly concentrated in developed countries. Total adaptive capacity increases the effectiveness of adaptation activities (eq. A4). Adaptation activities, proactive or reactive, are aggregated together in another CES nest according to:

$$ACT_{n,t} = \beta(\alpha_{6,n} PAD_{n,t}^{\rho_{ACT}} + \alpha_{5,n} RAD_{n,t}^{\rho_{ACT}})^{1/\rho_{ACT}} \quad \text{(A8)}$$

Reactive adaptation $RAD_{n,t}$ consists of an expenditure flow undertaken in each period. Proactive adaptation $PAD_{n,t}$ is modelled as a stock of capital. It accumulates over time with adaptation-specific investments, $IPAD_{n,t}$, according to a standard law of motion:

$$PAD_{n,t} = (1 - \delta_{PAD}) \cdot PAD_{n,t-1} + IPAD_{n,t} \quad \text{(A9)}$$

The stock depreciates at a rate δ_{PAD} that equals the depreciation rate of physical capital, 10 per cent per year. Expenditure in the three adaptation measures (generic capacity is an exogenous trend) is accounted in the national income identity:

$$YN_{n,t} = C_{n,t} + I_{n,t} + IR\&D_{n,t} + \sum_{J} I_{j_{n,t}} + IS\_CAP_{n,t} + RAD_{n,t} + IPAD_{n,t} \quad \text{(A10)}$$

In equation (A10) expenditure in reactive adaptation, proactive adaptation, and specific adaptive capacity compete with the alternative uses of income, consumption $C_{n,t}$, investment in physical capital $I_{n,t}$, investment in other forms of innovation $IR\&D_{n,t}$ and in energy technologies $I_{j_{n,t}}$.

Residual damage is defined as the difference between gross and net output. From equation (A1) we have:

$$RD_{n,t} = YG_{n,t} - YN_{n,t} = CCDA_{n,t} YN_{n,t} \quad \text{(A11)}$$

Using equations (A2) and (A3), residual damage can be defined as follows:

$$RD_{n,t} = YN_{n,t} \frac{1}{1 + ADAPT_{n,t}} (\theta_{1n} \cdot T_t + \theta_{2n} T_t^{\gamma_n}) \quad \text{(A12)}$$