Burden Sharing in a Greenhouse: Egalitarianism and Sovereignty Reconciled

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Downloadable Appendix

(ftp://ftp.zew.de/pub/zew-docs/div/entitlements.pdf)

Appendix A: Algebraic Model Description

This appendix presents the algebraic equilibrium conditions of our intertemporal multi-region, multi-sector general equilibrium model designed to investigate the economic implications of alternative long-term emission entitlement schemes.

The following key assumptions apply for the "generic" model:

- Output and factor prices are fully flexible and markets are perfectly competitive.
- Labor force productivity increases at an exogenous growth rate (Harrod-neutral technological progress).
- In equilibrium, there is a period-by-period balance between exports from each region and global demand for those goods. The model adopts the Armington assumption for export and import markets of a non-energy macro good to differentiate between commodities produced for the domestic market, the export market and the import market. Fossil fuels are treated as perfect substitutes on international markets.
- In each region, a representative consumer (likewise the social planner) maximizes the present value of lifetime utility subject to (i) an intertemporal balance of payments constraint, (ii) the constraint that the output per period is either consumed (incl. intermediate demand and exports) or invested, and (iii) the equation of motion for the capital stock, i.e. capital stocks evolve through depreciation and new investment. This renders the optimal level of consumption and investment over time.
- The agents have an infinite horizon, and their expectations are forward looking and rational. To approximate an infinite horizon model with a finite horizon model we assume that the representative consumer purchases capital in the model's post-horizon period at a price which is consistent with steady-state equilibrium growth (terminal condition).

The model is formulated as a system of nonlinear inequalities using GAMS/MPSGE (Rutherford 1999) and solved using PATH (Dirkse and Ferris 1995). The inequalities correspond to the three classes of conditions associated with a general equilibrium: (i) exhaustion of product (zero-profit) conditions for constant-returns-to-scale producers, (ii) market clearance for all goods and factors, and (iii) income balance for the representative consumers in each region.

The fundamental unknowns of the system are three vectors: activity levels (production indices), non-negative prices, and consumer incomes. In equilibrium, each of these variables is linked to one inequality condition: an activity level to an exhaustion of product constraint, a commodity price to a market clearance condition, and a consumer income variable to an income definition equation. An equilibrium allocation determines production, prices and incomes.

In the following algebraic exposition, the notation Π^X is used to denote the zero-profit function of activity *X*. Formally, all production activities exhibit constant returns to scale, hence differentiating Π^X with respect to input and output prices provides compensated demand and supply coefficients, which appear subsequently in the market-clearance conditions. All prices are expressed as present values.

A.1 Exhaustion of Product Conditions

Macro Good Production

Aggregate output in region *r* describes the supply of the non-energy macro good to the domestic market and export market. A separable nested constant elasticity of substitution (CES) cost function is employed to specify the substitution possibilities between capital (*K*), labor (*L*) and an energy composite (*E*). At the top level, a constant elasticity describes the substitution possibilities between the energy aggregate and the aggregate of labor and capital. At the second level capital and labor trade off with a unitary elasticity of substitution. On the output side, production is split between goods produced for the domestic market and goods produced for the export market according to a constant elasticity of transformation. The (intra-period) zero-profit condition for the production of the macro good is:

$$\Pi_{rt}^{Y} = \left(\theta_r^X p_{rt}^{X^{1+\eta_r}} + (1-\theta_r^X) p_{rt}^{1+\eta_r}\right)^{\frac{1}{1+\eta_r}} - \left[\theta_r^{EY}\left(\frac{p_{rt}^{EY}}{\beta_{rt}}\right)^{1-\sigma_r^{KLE}} + (1-\theta_r^{EY})\left(w_{rt}^{\alpha_r} v_{rt}^{1-\alpha_r}\right)^{1-\sigma_r^{KLE}}\right]^{\frac{1}{1-\sigma_r^{KLE}}} = 0$$

where:

p_{rt}^X	output price of macro good produced in region *r* and period *t* for export market,
p_{rt}	output price of macro good produced in region *r* and period *t* for domestic market,
p_{rt}^{EY}	price of industrial energy aggregate for macro good production in region *r* and period *t*,
w_{rt}	wage rate in region *r* and period *t*,
v_{rt}	rental price of capital services in region *r* and period *t*,
θ_r^X	benchmark share of exports in macro good production of region *r*,
θ_r^{EY}	benchmark share of industrial energy aggregate in macro good production of region *r*,
α_r	benchmark share of labor in value-added of macro good production in region *r*,

η_r elasticity of transformation between production for the domestic market and production for the export market of region *r*,

σ_r^{KLE} elasticity of substitution between the energy aggregate and value-added in production for region *r,*

β_{rt} exogenous energy efficiency improvement index, which measures changes in technical efficiency for region *r* in period *t*,

and

Y_{rt} associated dual variable which indicates the activity level of macro good production in region *r* and period *t.*

Fossil Fuel Production

The production of fuels requires inputs of domestic supply (macro good) and a fuel-specific factor which can be thought of as a sector-specific resource.[1] The zero-profit condition has the form:

$$\prod_{rt,ff}^{F} = p_t^{ff} - \left[\theta_r^{ff} {q_{rt}^{ff}}^{1-\sigma_r^{ff}} + (1-\theta_r^{ff}) {p_{rt}^{A}}^{1-\sigma_r^{ff}} \right]^{\frac{1}{1-\sigma_r^{ff}}} = 0 \qquad ff \in \{COA, OIL, GAS\}$$

where:

p_t^{ff} world market price of fossil fuel *ff* in period *t,*

q_{rt}^{ff} price of fuel-specific resource for production of fossil fuel *ff* in region *r* and period *t,*

p_{rt}^{A} Armington price of macro good in region *r* and period *t,*

θ_r^{ff} benchmark share of fuel-specific resource for fossil fuel production in region *r,*

σ_r^{ff} elasticity of substitution between the fuel-specific resource and non-energy inputs in fossil fuel production of region *r,*

and

$F_{rt,ff}$ associated dual variable which indicates the activity level of fossil fuel production *ff* in region *r* and period *t*.

[1] A constant returns to scale production function with convex levelsets exhibits decreasing returns to scale in *remaining* factors when one or more inputs are in fixed supply. We exploit this result in representing a decreasing returns to scale function through a constant returns to scale activity which uses the fuel-specific factor.

The value of the elasticity of substitution σ_r^{ff} between non-energy inputs and the fuel-specific resource determines the price elasticity of fossil fuel supply ε_r^{ff} at the reference point, according to the relation:

$$\varepsilon_r^{ff} = \sigma_r^{ff} \frac{\theta_r^{ff}}{1-\theta_r^{ff}} .$$

Armington Production

Inputs of the macro good into energy production, investment demand and final consumption are a composite of a domestic and imported variety which trade off with a constant elasticity of substitution. The corresponding zero profit condition for the production of the Armington good is given by:

$$\prod_{rt}^{A} = p_{rt}^{A} - \left[\theta_r^A \, p_{rt}^{1-\sigma_r^A} + (1-\theta_r^A) \left[\left(\sum_s \theta_{sr}^M \, p_{st}^{X^{1-\sigma_r^M}} \right)^{\frac{1}{1-\sigma_r^M}} \right]^{1-\sigma_r^A} \right]^{\frac{1}{1-\sigma_r^A}} = 0$$

where:

θ_r^A benchmark share of domestic macro input into Armington production in region *r*,

θ_{sr}^M benchmark share of imports from region *s* (aliased with index *r*) in total macro good imports of region *r*,

σ_r^A Armington elasticity of substitution between domestic macro good and imported macro good aggregate for region *r*,

σ_r^M elasticity of substitution between macro good imports for region *r*,

and

A_{rt} associated dual variable which indicates the activity level of Armington production in region *r* and period *t*.

Production of the Industrial Energy Aggregate

Energy inputs to the macro production are a nested separable CES aggregation of oil, gas and coal. Gas and oil trade off as relatively close substitutes in the lower nest of the energy composite; at the next level the oil and gas composite combines with coal at a lower rate. The zero-profit condition for the production of the industrial energy aggregate is:

$$\prod_{rt}^{EY} = p_{rt}^{EY} - \{\theta_r^{COA}(p_t^{COA} + pcarb_{rt}CO2_{COA})^{1-\sigma_r^{COA}} + (1-\theta_r^{COA})$$

$$[\theta_r^{OIL}(p_t^{OIL} + pcarb_{rt}CO2_{OIL})^{1-\sigma_r^{LQ}} + (1-\theta_r^{OIL})(p_t^{GAS} + pcarb_{rt}CO2_{GAS})^{1-\sigma_r^{LQ}}]^{\frac{1-\sigma_r^{COA}}{1-\sigma_r^{LQ}}}\}^{\frac{1}{1-\sigma_{COA}}} = 0$$

where:

$pcarb_{rt}$ carbon price in region *r* and period *t*,

$CO2_{ff}$ physical carbon coefficient for fossil fuels,

θ_r^{COA} benchmark share of coal input into industrial energy aggregate of region *r*,

θ_r^{OIL} benchmark share of the oil input into the gas and oil composite of industrial energy production in region *r*,

σ_r^{COA} elasticity of substitution between coal and the gas and oil composite in industrial energy production of region *r*,

σ_r^{LQ} elasticity of substitution between gas and oil in industrial energy production of region *r*,

and

EY_{rt} associated dual variable which indicates the activity level of industrial energy aggregate production in region *r* and period *t*.

Production of the Household Energy Aggregate

Energy demanded by the household is a CES aggregate of fossil fuels. The zero-profit condition for the production of the household energy aggregate has the form:

$$\prod_{rt}^{EC} = p_{rt}^{EC} - \left(\sum_{ff}\theta_{r,ff}^{EC}(p_t^{ff} + pcarb_{rt}CO2_{ff})^{1-\sigma_r^{EC}}\right)^{\frac{1}{1-\sigma_r^{EC}}} = 0$$

where:

p_{rt}^{EC} price of household energy aggregate for region *r* and period *t* ,

$\theta_{r,ff}^{EC}$ benchmark share of fossil fuel input *ff* in the household energy aggregate of region *r*,

σ_r^{EC} elasticity of substitution between fossil fuel inputs within the household energy aggregate,

and

EC_{rt} associated dual variable which indicates the activity level of household energy aggregate production in region *r* and period *t*.

Production of the Household Consumption Aggregate

In final consumption demand the household energy aggregate trades off with the macro good at a constant elasticity of substitution:

$$\prod_{rt}^{C} = p_{rt}^{C} - \left(\theta_r^C \, p_{rt}^{A\,1-\sigma_r^C} + (1-\theta_r^C)\, p_{rt}^{EC\,1-\sigma_r^C} \right)^{\frac{1}{1-\sigma_r^C}} = 0$$

where:

p_{rt}^{C} price of household consumption aggregate for region *r* and period *t*,

θ_r^C benchmark share of macro good into aggregate household demand of region r,

σ_r^C elasticity of substitution between macro good and energy aggregate in household consumption demand of region r,

and

C_{rt} associated dual variable which indicates the activity level of household consumption in region *r* and period *t*.

Backstops for Industry and Household Energy Aggregate

For each region there is a carbon-free backstop for the industrial energy aggregate and the household aggregate. This backstop is available in infinite supply at a price which is calculated to be a multiple of the macro good price. Below, we take explicit account of the non-negativity constraint for backstop production:

$$\prod_{rt}^{\tau} = p_{rt}^{\tau} - a_r^{\tau} p_{rt}^{A} \leq 0 \qquad \tau \in \{BC, BY\}$$

where:

p_{rt}^{τ} price of energy backstop for industry (τ = BY) or household (τ = BC) ,

a_r^{τ} multiplier of the macro good price index for industrial energy backstop (τ = BY) or household energy backstop (τ = BC),

and

BY_{rt} ,BC_{rt} are the associated dual variables which indicate the activity levels of backstop energy production in region *r* and period *t* for industries or households.

Capital Stock Formation and Investment

An efficient allocation of capital, i.e. investment over time assures the following intertemporal zero-profit conditions which relates the cost of a unit of investment, the return to capital and the purchase price of a unit of capital stock in period *t:* [2]

$$\Pi_{rt}^{K} = p_{rt}^{K} - v_{r}^{\tau} - (1-\delta)\, p_{r,t+1}^{K} = 0$$

and

$$\Pi_{rt}^{I} = p_{r,t+1}^{K} - p_{rt}^{I} = 0$$

where:

P_{rt}^{K} value (purchase price) of one unit of capital stock in region *r* and period *t*,

δ_r depreciation rate in region r,

p_{rt}^{I} cost of a unit of investment in period *t* which in our case equals p_{rt}^{A},

and

K_{rt} associated dual variable, which indicates the activity level of capital stock formation in region *r* and period *t*,

I_{rt} associated dual variable, which indicates the activity level of aggregate investment in region *r* and period *t*.[3].

A.2 Market Clearance Conditions

Labor

The supply-demand balance for labor is:

$$\overline{L}_{rt} = Y_{rt} \frac{\partial \Pi_{rt}^{Y}}{\partial w_{rt}}$$

where:

$\overline{L}_{rt}$ exogenous endowment of time in region *r* and period *t.*[4]

Capital

The supply-demand balance for capital is:

$$K_{rt} = Y_{rt} \frac{\partial \Pi_{rt}^{Y}}{\partial v_{rt}}$$

[2] The optimality conditions for capital stock formation and investment are directly derived from the maximization of lifetime utility by the representative household taking into account its budget constraint, the equation of motion for the capital stock and the condition that output in each period is either invested or consumed. Note that in our algebraic exposition we assume an investment lag of one period.

[3] As written, we have taken explicit account of the non-negativity constraint for investment.

[4] Time endowment grows at a constant rate *g*, which determines the long-run (steady-state) growth rate of the economy.

Fuel-Specific Resources

The supply-demand balance for fuel-specific resources is:

$$\overline{Q}_{rt}^{ff} = F_{rt,ff} \frac{\partial \Pi_{rt,ff}^{F}}{\partial q_{rt}^{ff}} \qquad ff \in \{COA, OIL, GAS\}$$

where:

$\overline{Q}_{rt}^{ff}$ exogenous endowment with fuel-specific resource *ff* for region *r* and period *t*.

Fossil Fuels

The supply-demand balance for fossil fuels is:

$$\sum_r F_{rt}^{ff} = \left(\sum_r EY_{rt} \frac{\partial \Pi_{rt}^{EY}}{\partial (p_t^{ff} + pcarb_t CO2_{ff})} + EC_{rt} \frac{\partial \Pi_{rt}^{EC}}{\partial (p_t^{ff} + pcarb_t CO2_{ff})} \right) \qquad ff \in \{COA, OIL, GAS\}$$

Macro Output for Domestic Markets

The market clearance condition for the macro good produced for the domestic market is:

$$Y_{rt} \frac{\partial \Pi_{rt}^{Y}}{\partial p_{rt}} = A_{rt} \frac{\partial \Pi_{rt}^{A}}{\partial p_{rt}}$$

Macro Output for Export Markets

The market clearance condition for the macro good produced for the export market is:

$$Y_{rt} \frac{\partial \Pi_{rt}^{Y}}{\partial p_{rt}^{X}} = \sum_s A_{st} \frac{\partial \Pi_{st}^{A}}{\partial p_{st}^{X}}$$

Industrial Energy Aggregate

The market clearance condition for the industrial energy aggregate is:

$$EY_{rt} + BY_{rt} = EY_{rt} \frac{\partial \Pi_{rt}^{EY}}{\partial p_{rt}^{EY}}$$

Household Energy Aggregate

The market clearance condition for the household energy aggregate is:

$$EC_{rt} + BC_{rt} = EC_{rt} \frac{\partial \Pi_{rt}^{EC}}{\partial p_{rt}^{EC}}$$

Armington Aggregate

The market clearance condition for Armington aggregate is:

$$A_{rt} = Y_{rt}\frac{\partial \Pi_{rt}^{Y}}{\partial p_{rt}^{A}} + C_{rt}\frac{\partial \Pi_{rt}^{C}}{\partial p_{rt}^{A}} + I_{r}\frac{\partial \Pi_{rt}^{I}}{\partial p_{rt}^{A}} + BY_{rt}\frac{\partial \Pi_{rt}^{BY}}{\partial p_{rt}^{A}} + BC_{rt}\frac{\partial \Pi_{rt}^{BC}}{\partial p_{rt}^{A}}$$

Household Consumption Aggregate

The market clearance condition for the household consumption aggregate is:

$$C_{rt} = D_{rt}$$

where:

D_{rt} uncompensated final demand which is derived from maximization of lifetime utility (see below).

A.3 Income Balance of Households

Consumers choose to allocate lifetime income across consumption in different time periods in order to maximize lifetime utility. The representative agent in each period solves:

$$\text{Max } \sum_{t}\left(\frac{1}{1+\rho_{r}}\right)^{t} u_{r}(C_{rt})$$

$$\text{s.t. } \sum_{t} p_{rt}^{C} C_{rt} = M_{r}$$

where:

u_r instantaneous utility function of representative agent in region *r*,

ρ_r time preference rate of representative agent in region *r*,

and

M_r lifetime income of representative agent in region *r*.

Lifetime income *M* is defined as:

$$M_{r} = p_{r0}^{K}\overline{K}_{r0} + \sum_{t} w_{rt}\overline{L}_{rt} + \sum_{ff} q_{rt}^{ff}\overline{Q}_{rt}^{ff}$$

$$+\sum_{t}\sum_{ff} pcarb_{rt}CO2_{ff}\left(EY_{rt}\frac{\partial \Pi_{rt}^{EY}}{\partial (p_{t}^{ff} + CO2_{ff}\, pcarb_{rt})} + EC_{rt}\frac{\partial \Pi_{rt}^{EC}}{\partial (p_{t}^{ff} + CO2_{ff}\, pcarb_{rt})}\right)$$

where:

$\overline{K}_{r0}$ initial capital stock in region *r*.

With isoelastic lifetime utility the instantaneous utility function is given as:

$$u_r(C_{rt}) = \frac{C_{rt}^{1-\frac{1}{\mu_r}}}{1-\frac{1}{\mu_r}}$$

where:

μ_r constant intertemporal elasticity of substitution.

The uncompensated final demand function D_{rt} is then derived as:

$$D_{rt}(p_{rt}^C, M) = \frac{(1+\rho_r)^{-t\mu_r}}{\sum_t (1+\rho_r)^{-t^{\mu_r}} p_{rt}^{C^{1-\mu_r}}} \frac{M}{p_{rt}^{C^{\mu_r}}}$$

A.4 Terminal Constraints

The finite horizon poses some problems with respect to capital accumulation. Without any terminal constraint, the capital stock at the end of the model's horizon would have no value and this would have significant repercussions for investment rates in the periods leading up to the end of the model horizon. In order to correct for this effect we define a terminal constraint which forces terminal investment to increase in proportion to final consumption demand:[5]

$$\frac{I_{Tr}}{I_{T-1,r}} = \frac{C_{Tr}}{C_{T-1,r}}.$$

A.5 Summary of Key Elasticities

Table A.1 summarizes the central values for key elasticities employed for the core simulations.

Table A1: Overview of key elasticities

Type of elasticity	Description	Central Value
Armington elasticity of substitution (σ_r^M, σ_r^A)	Degree of substitutability • Between macro imports from different regions • Between the import aggregate and the domestically produced macro good	 2 1
Armington elasticity of transformation (η_r)	Degree of substitutability between macro good produced for the domestic market and macro good destined for the export market	2

[5] This constraint imposes balanced growth in the terminal period but does not require that the model achieves steady-state growth.

Price elasticity of fossil fuel supply (ε_r^{ff})	Degree of response of international fossil fuel supply to changes in fossil fuel price	1 (coal), 4 (gas) 8 (oil)
Elasticity of substitution between non-energy and energy composite in production (σ_r^{KLE}) and final demand (σ_r^{C})	This value increases linearly over time between a short-run value of 0.2 and the long-run value of 0.8 to reflect empirical evidence on differences between short-run and long-run adjustment costs (Lindbeck, 1983)	0.2 (short run: 2000) 0.8 (long run: 2050)
Interfuel elasticity of substitution (σ_r^{ff})	Degree of substitutability between fossil fuels (fuel switching)	0.5 (final demand) 2[a],1[b] (industry)

[a] between oil and gas [b] between coal and the oil-gas aggregate

References

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Appendix B: Sensitivity Analysis

To evaluate the sensitivity of our results, we have run additional simulations for alternative assumptions on (i) long-term emission reduction targets, (ii) energy demand responsiveness, (iii) oil price responsiveness, (iv) trade impacts (ease of substitution for the traded macro-good), and (v) discount rate. We find that all of our insights based on the central case simulations remain robust. This section reports the detailed quantitative welfare impacts expressed as Hicksian equivalent variation (HEV) in income (% present value of *BaU* consumption).

B.1 Long-term Emission Reduction Target:

The central case global emission reduction target in 2050 amounts to more than 60 % of the *BaU* emission level. In the sensitivity analysis, we investigate less ambitious cutback requirements of 50 %, 40 %, and 30 % global emission reduction in 2050 vis-à-vis the *BaU* emission level.

B.2 Energy Demand Responsiveness

The adjustment costs of emission constraints depend on the ease of substitution between energy and other factors in production and consumption. The end-use demand elasticity determines how total energy demand responds to increases in the price of energy in both the short- and long-run. The substitution elasticity between energy and other factors (i.e. the implicit energy demand elasticity) rises linearly over time between a lower short-run value and a higher long-run value to reflect empirical evidence on differences between short-run and long-run adjustment costs. In the sensitivity analysis, we reset the short-run value (central case: 0.2) to 0.1 (low) and 0.5 (high), respectively.

B.3 Oil Price Responsiveness

The supply elasticity for oil determines how its price responds to changes in the demand for crude oil. The lower the supply elasticity is, the more responsive the price of oil to a change in the demand for oil is. For a given reduction in global crude oil demand, the price drops more for lower elasticity values than it does for higher values. Increasing the price response (decreasing the supply elasticity), thus, causes oil exporting nations to suffer more when a carbon abatement policy is enacted. Conversely, higher price responses (lower supply elasticities) lead to greater benefits for oil importing countries. In the sensitivity analysis, we halve (low) or double (high) the central case value of 8.

B.4 Trade Impacts (Armington Elasticity)

Non-energy macro goods are treated as imperfect substitutes with substitution possibility between the domestically produced good and the import aggregate from other regions being characterized by a constant (Armington) elasticity of substitution. The Armington elasticities together with the respective bilateral trade shares, are important determinants for the region-specific terms-of-trade effects on the non-energy market. In the sensitivity analysis, we decrease or increase the central case Armington elasticities (central case values: 2 - between macro imports from different regions; 1 - between the import aggregate and the domestically produced macro good) to assess the robustness of our results concerning trade impacts (terms-of-trade effects) on non-energy markets.

B.5 Discount Rate

The discount rate as the pure rate of time preference between current and future consumption determines the intertemporal allocation of consumption. In equilibrium, the representative agent in each region is indifferent between consuming one unit of consumption today or consuming the value of one unit of consumption that is adjusted for time preference tomorrow. In the sensitivity analysis, we decrease or increase the discount rate vis-à-vis the central case value (5 %) by 0.25 %.

Table B.1: Sensitivity to emission reduction target in 2050

	Scenario *SOVEREIGNTY*		Scenario *EGALITARIANISM*		Scenario *CONVERGENCE*	
	NoTrade	*Trade*	*NoTrade*	*Trade*	*NoTrade*	*Trade*
50 % global emission reduction in 2050 from *BaU* level						
Sub-Saharan Africa	-1.75	-1.51	-2.67	17.26	-1.68	12.15
China	-1.97	-1.39	-1.76	0.59	-1.59	-0.16
India	-1.11	-0.76	-0.02	19.34	-0.07	13.84
Latin America	-0.76	-0.73	-1.49	1.03	-0.8	0.51
Middle East and N. Africa	-1.56	-1.38	-3.99	2.89	-2.43	1.97
North America	-0.45	-0.48	-6.47	-2.14	-2.46	-1.59
Pacific OECD	-0.19	-0.23	-2.35	-0.87	-1.03	-0.7
Other Pacific Asia	-0.22	-0.35	-0.05	0.71	0.07	0.36
Former Eastern Bloc	-2.03	-1.8	-12.01	-6.83	-6.28	-5.23
Western Europe	-0.16	-0.19	-2.86	-0.99	-1.18	-0.77
WORLD	-0.51	-0.49	-3.76	-0.42	-1.61	-0.41
40 % global emission reduction in 2050 from *BaU* level						
Sub-Saharan Africa	-1.39	-1.23	-2.62	14.4	-1.64	10.29
China	-1.38	-1.03	-1.39	0.63	-1.16	0.02
India	-0.74	-0.48	-0.11	17.08	-0.14	12.31
Latin America	-0.5	-0.48	-1.49	0.97	-0.8	0.56
Middle East and N. Africa	-1.11	-0.99	-3.84	2.53	-2.3	1.81
North America	-0.27	-0.28	-6.28	-1.64	-2.3	-1.22
Pacific OECD	-0.11	-0.14	-2.25	-0.67	-0.94	-0.53
Other Pacific Asia	-0.07	-0.18	-0.06	0.69	0.09	0.42
Former Eastern Bloc	-1.26	-1.12	-10.82	-5.27	-5.34	-4.02
Western Europe	-0.06	-0.07	-2.71	-0.74	-1.05	-0.57
WORLD	-0.31	-0.3	-3.59	-0.23	-1.47	-0.23
30 % global emission reduction in 2050 from *BaU* level						
Sub-Saharan Africa	-1.07	-0.97	-2.56	11.63	-1.58	8.43
China	-0.91	-0.74	-1.16	0.6	-0.87	0.14
India	-0.47	-0.28	-0.18	14.51	-0.2	10.53
Latin America	-0.33	-0.31	-1.48	0.87	-0.8	0.54
Middle East and N. Africa	-0.76	-0.68	-3.72	2.13	-2.17	1.57
North America	-0.15	-0.15	-6.09	-1.24	-2.16	-0.91
Pacific OECD	-0.05	-0.07	-2.14	-0.5	-0.85	-0.39
Other Pacific Asia	0.01	-0.07	-0.11	0.63	0.05	0.42
Former Eastern Bloc	-0.7	-0.62	-9.8	-3.93	-4.54	-2.98
Western Europe		-0.01	-2.59	-0.54	-0.94	-0.41
WORLD	-0.18	-0.17	-3.45	-0.1	-1.35	-0.11

Table B.2: Energy demand responsiveness – short-run substitution elasticities (σ_r^{KLE} , σ_r^{C})

	Scenario *SOVEREIGNTY*		Scenario *EGALITARIANISM*		Scenario *CONVERGENCE*	
	NoTrade	*Trade*	*NoTrade*	*Trade*	*NoTrade*	*Trade*
Low substitution elasticity (0.1)						
Sub-Saharan Africa	-2.26	-2.13	-2.78	21.85	-1.74	14.58
China	-3.01	-2.21	-2.49	0.42	-2.41	-0.73
India	-1.83	-1.75	0.23	22.52	0.16	15.45
Latin America	-1.22	-1.19	-1.59	1.1	-0.9	0.33
Middle East and N. Africa	-2.27	-2.05	-4.27	3.48	-2.57	2.11
North America	-0.81	-0.84	-7.36	-3.08	-2.72	-2.24
Pacific OECD	-0.37	-0.41	-2.76	-1.27	-1.21	-1
Other Pacific Asia	-0.54	-0.72	-0.12	0.72	-0.05	0.18
Former Eastern Bloc	-3.51	-3.21	-14.63	-9.41	-8.04	-7.15
Western Europe	-0.38	-0.4	-3.37	-1.47	-1.4	-1.14
WORLD	-0.88	-0.85	-4.34	-0.81	-1.88	-0.78
High substitution elasticity (0.5)						
Sub-Saharan Africa	-2.24	-2.03	-2.67	18.99	-1.75	13.65
China	-2.7	-1.77	-2.36	0.07	-2.24	-0.65
India	-1.62	-1.62	0.22	20.18	0.16	14.67
Latin America	-1.18	-1.11	-1.53	0.83	-0.9	0.28
Middle East and N. Africa	-2.28	-1.93	-4.12	2.9	-2.64	1.93
North America	-0.8	-0.83	-5.79	-2.62	-2.55	-2.06
Pacific OECD	-0.32	-0.38	-2.14	-1.09	-1.11	-0.9
Other Pacific Asia	-0.45	-0.59	-0.12	0.56	-0.01	0.19
Former Eastern Bloc	-2.91	-2.35	-12.22	-8.45	-7.38	-6.59
Western Europe	-0.36	-0.4	-2.58	-1.25	-1.28	-1.04
WORLD	-0.82	-0.78	-3.48	-0.71	-1.76	-0.7

Table B.3: Oil price responsiveness – oil supply elasticity (ε_r^{oil})

	Scenario *SOVEREIGNTY*		Scenario *EGALITARIANISM*		Scenario *CONVERGENCE*	
	NoTrade	*Trade*	*NoTrade*	*Trade*	*NoTrade*	*Trade*
Low responsiveness – high oil supply elasticity (16)						
Sub-Saharan Africa	-2.12	-2.05	-2.4	20.84	-1.56	14.13
China	-2.86	-2.1	-2.39	0.16	-2.33	-0.79
India	-1.8	-1.81	0.15	21.51	0.14	15.07
Latin America	-1.09	-1.05	-1.32	0.98	-0.72	0.34
Middle East and N. Africa	-1.87	-1.67	-3.44	3.4	-2.08	2.23
North America	-0.83	-0.85	-6.71	-2.82	-2.65	-2.12
Pacific OECD	-0.37	-0.42	-2.53	-1.2	-1.19	-0.96
Other Pacific Asia	-0.55	-0.72	-0.25	0.57	-0.12	0.11
Former Eastern Bloc	-3.13	-2.77	-13.34	-8.85	-7.48	-6.77
Western Europe	-0.39	-0.41	-3.05	-1.39	-1.35	-1.11
WORLD	-0.84	-0.82	-3.94	-0.75	-1.79	-0.73
High responsiveness – low oil supply elasticity (4)						
Sub-Saharan Africa	-2.43	-2.14	-3.13	20.69	-1.94	14.39
China	-2.95	-2.07	-2.48	0.28	-2.38	-0.69
India	-1.64	-1.56	0.52	21.66	0.32	15.32
Latin America	-1.38	-1.33	-1.8	0.93	-1.06	0.22
Middle East and N. Africa	-2.93	-2.6	-5.5	2.89	-3.47	1.64
North America	-0.77	-0.8	-6.71	-2.95	-2.63	-2.19
Pacific OECD	-0.32	-0.37	-2.48	-1.18	-1.14	-0.95
Other Pacific Asia	-0.43	-0.62	0.09	0.72	0.09	0.24
Former Eastern Bloc	-3.57	-3.18	-14.46	-9.43	-8.29	-7.31
Western Europe	-0.34	-0.38	-3.04	-1.36	-1.34	-1.08
WORLD	-0.87	-0.84	-4.06	-0.8	-1.86	-0.77

Table B.4: Sensitivity to Armington elacticities (σ_r^M , σ_r^A)

	Scenario *SOVEREIGNTY*		Scenario *EGALITARIANISM*		Scenario *CONVERGENCE*	
	NoTrade	*Trade*	*NoTrade*	*Trade*	*NoTrade*	*Trade*
Low Armington elacticities (0.75; 1.5)						
Sub-Saharan Africa	-2.4	-1.91	-3.79	22.05	-2.27	15.17
China	-2.97	-1.69	-3.24	1.56	-2.62	0.25
India	-1.74	-0.96	-0.88	22.96	-0.46	16.57
Latin America	-1.29	-1.18	-2.34	1.22	-1.23	0.46
Middle East and N. Africa	-2.41	-2	-5.46	3.47	-3.2	2.2
North America	-0.8	-0.84	-6.65	-2.98	-2.63	-2.21
Pacific OECD	-0.31	-0.41	-2.53	-1.23	-1.15	-0.98
Other Pacific Asia	-0.54	-0.62	-0.74	1.22	-0.34	0.57
Former Eastern Bloc	-3.28	-2.93	-14.1	-9.05	-7.86	-6.9
Western Europe	-0.35	-0.41	-3.03	-1.44	-1.32	-1.14
WORLD	-0.85	-0.8	-4.19	-0.69	-1.9	-0.67
High Armington elacticities (1.5; 3)						
Sub-Saharan Africa	-2.15	-2.22	-1.83	19.72	-1.25	13.54
China	-3.05	-2.62	-2.13	-0.99	-2.39	-1.68
India	-1.83	-2.21	0.85	20.79	0.62	14.15
Latin America	-1.15	-1.14	-0.93	0.78	-0.61	0.18
Middle East and N. Africa	-2.18	-2.02	-3.13	3.04	-2.03	1.9
North America	-0.81	-0.81	-6.74	-2.8	-2.63	-2.11
Pacific OECD	-0.39	-0.4	-2.49	-1.16	-1.18	-0.94
Other Pacific Asia	-0.53	-0.7	0.26	0.22	0.13	-0.11
Former Eastern Bloc	-3.34	-2.92	-13.48	-9.09	-7.78	-7.04
Western Europe	-0.39	-0.39	-3.07	-1.32	-1.36	-1.06
WORLD	-0.87	-0.86	-3.84	-0.84	-1.76	-0.81

Table B.5: Sensitivity to discount rate

	Scenario *SOVEREIGNTY*		Scenario *EGALITARIANISM*		Scenario *CONVERGENCE*	
	NoTrade	*Trade*	*NoTrade*	*Trade*	*NoTrade*	*Trade*
Low discount rate (4.75 %)						
Sub-Saharan Africa	-2.44	-2.21	-2.89	22.14	-1.9	15.6
China	-3.12	-2.24	-2.61	0.11	-2.54	-0.85
India	-1.88	-2.2	0.25	22.58	0.18	16.25
Latin America	-1.3	-1.27	-1.64	1.04	-0.97	0.35
Middle East and N. Africa	-2.44	-2.17	-4.39	3.4	-2.8	2.2
North America	-0.86	-0.89	-6.84	-3.09	-2.84	-2.35
Pacific OECD	-0.37	-0.42	-2.57	-1.27	-1.25	-1.04
Other Pacific Asia	-0.53	-0.73	-0.1	0.68	-0.02	0.2
Former Eastern Bloc	-3.52	-3.11	-14.48	-9.66	-8.44	-7.52
Western Europe	-0.4	-0.43	-3.13	-1.47	-1.45	-1.19
WORLD	-0.92	-0.9	-4.1	-0.84	-1.97	-0.81
High discount rate (5.25 %)						
Sub-Saharan Africa	-1.17	-1.11	-1.52	20.5	-0.58	14.2
China	-2.29	-1.55	-1.82	0.7	-1.74	-0.24
India	-0.11	0.36	1.36	23.08	1.38	16.55
Latin America	-0.89	-0.86	-1.16	1.17	-0.53	0.51
Middle East and N. Africa	-2.34	-2.16	-3.88	2.86	-2.43	1.67
North America	-1.53	-1.55	-7.23	-3.49	-3.22	-2.8
Pacific OECD	-0.85	-0.9	-2.93	-1.64	-1.61	-1.42
Other Pacific Asia	1.05	0.88	1.43	2.15	1.51	1.69
Former Eastern Bloc	-3.7	-3.38	-13.76	-9.15	-7.94	-7.15
Western Europe	-2.77	-2.78	-5.48	-3.66	-3.7	-3.4
WORLD	-1.72	-1.69	-4.78	-1.64	-2.62	-1.61