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Benchmarking the Future: A Dynamic, Multi-Regional, Multi-Sectoral Trade Model for the Analysis of Climate Policies

by

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Benchmarking the Future:
A Dynamic, Multi-Regional, Multi-Sectoral Trade Model for the Analysis of Climate Policies*

Abstract:
For analyzing the impact of climate change and of international climate policies on the international division of labor and on regional welfare the use of a disaggregated multi–sectoral, multi–regional dynamic computable general equilibrium model is appropriate. This paper discusses the problems of defining an appropriate benchmark against which policy simulations and climate change impacts can be assessed. It explicitly considers regionally differentiated growth rates by basing the development of the parameters which determine human and physical capital growth, technical progress and technology diffusion as well as savings decisions on historical developments and estimates in the literature. A sensitivity analysis of important parameters is performed.

Keywords: Off-Steady-State Growth, Human Capital, Physical Capital, Calibration, Energy Supply, GTAP Data Set

JEL classification: C68, F43, O1, O3, O41, Q48

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1 INTRODUCTION

The Kyoto Protocol was a first step towards a concerted action for significantly reducing the use of fossil fuels in the world economy over the next few decades. This will be necessary if climate changes of a large scale are to be prevented to occur within the next century. However, the Kyoto Protocol has also revealed that concerted climate policies face the most serious draw–backs from controversies over the question who will need to share the burden of climate policies and who might possibly become a net gainer from the prevention of potential climate damages. Both of these issues heavily depend on the future economic development of the different regions in the world economy. An assessment of potential winners and losers from different climate policy scenarios and from their climate impact should be based on a dynamic, multi–regional model which can take into account interdependencies between countries as well as between sectors.

The analysis of the impact of climate change and of climate policies on the allocation of resources over time and space has a relatively short but intensive history. Due to the complexity of the problem, many modeling approaches have concentrated on specific issues while ignoring other features of the problem. There is quite a number of comparative static analyses. They are concerned with different energy policies, for example with the impact of CO_2 or energy taxes or with tradable emission certificates on the structure of the energy industry and the adoption of energy technologies. They can be either one country models which are concerned with the internal allocation of resources or multi country models concerned with the impact of global climate policies.

Among the dynamic optimization models there are two variants: The optimizing approach as it is used by Nordhaus (1991, 1996) in his DICE and RICE model has as a core a Ramsey–model. Other approaches use a steady–state growth model. Contributions are for example from Alan Manne and Tom Rutherford (1994). These models are concerned with the optimal level and time structure of climate policy interventions.

The recursive dynamic models such as the GREEN model of the OECD, the EPPA model of the MIT or the DART model of the Kiel Institute are designed to perform a comparative analysis of specific climate policies. Since such policies normally are not optimal an optimal growth framework is not appropriate. Instead, the proposed policy needs to be compared to an economic development without climate policies, the so called „benchmark" path of the world economy. Since climate policies are designed for long time horizons - e.g. the Kyoto Protocol as a first step in an international climate policy has already a time horizon to the year 2012 and further activities will run well into the second and third decade of this century - the benchmark needs to be forward looking over long time horizons.

There are considerable uncertainties involved in predicting the future growth path of the world economy. Especially political disturbances - from wars to major institutional changes and economic crises - can turn the world economy in unpredictable directions. Since such events are unpredictable one needs to develop scenarios which can be considered reasonable developments given the current situation and current structural trends of the different regions of the world but by neglecting such unpredictable disturbances.

The desired model structure is presented in the next chapter. The basic structure of the model is illustrated and the computation of regional CO_2-emissions is shown which is somewhat different and more precise than the usual approach. The calibration of the static model is also shown. Chapter three discusses the determinants of the growth of regional factor endowments and technologies and shows how they are implemented in the model. The results of the benchmark run of the model from 1993 until 2030 are documented and interpreted in chapter four. The sensitivity of this benchmark path to variations of important parameters is discussed in the next chapter. Finally, the controversies about the convergence of low-income countries towards the richer countries are taken up and the impact of a more pessimistic choice of parameters on the benchmark path and on the comparative impacts of climate policies is assessed.

2 THE DESIRED MODEL STRUCTURE

Since the policy issue is mainly a distributional one, a model should be able to assess the impact of climate change and climate policy on the interregional distribution of costs and benefits.

An appropriate modeling framework should therefore consist of:

- A multi–regional structure in order to assess the interregional distributional issues;
- a dynamic framework because otherwise important adjustment processes in terms of technological developments cannot become incorporated;
- an explicit trade–model since in a world with falling trade barriers and an increasing globalization of factor and goods markets international interdependencies become more and more important;
- a sectoral production, trade, and consumption structure for allowing an appropriate modeling of trade between regions and a structural adjustment process within regions; and finally
- a model which is formulated in such a way that it can be used for a numerical analysis based on existing data sets.

2.1 The Basic Model

The basic model, called **D**ynamic **A**pplied **R**egional **T**rade (DART) model, is a 10-sector, 11-region general equilibrium model of the world. Table 1 summarizes the regional and sectoral dimensions of the basic model. It distinguishes three fossil fuel production sectors, energy intensive sectors, agriculture, and other manufactures and services. Differentiating carbon intensive industries from non-carbon intensive industries allows to depict carbon intensity differences in production among regions and to cover the scope for substitutability across carbon-intensive goods and hence the potential for terms of trade effects caused by carbon abatement policies. The regional aggregation subsumes the main OECD and NON-OECD regions which are central to the climate policy issue.

The dynamic framework is recursively-dynamic meaning that the evolution of the economies over time is described by a sequence of single-period static equilibria connected through capital accumulation. Here, a non-technical description of the static and the dynamic part of the DART model is provided. For a detailed algebraic description of the DART model see Springer (1998).

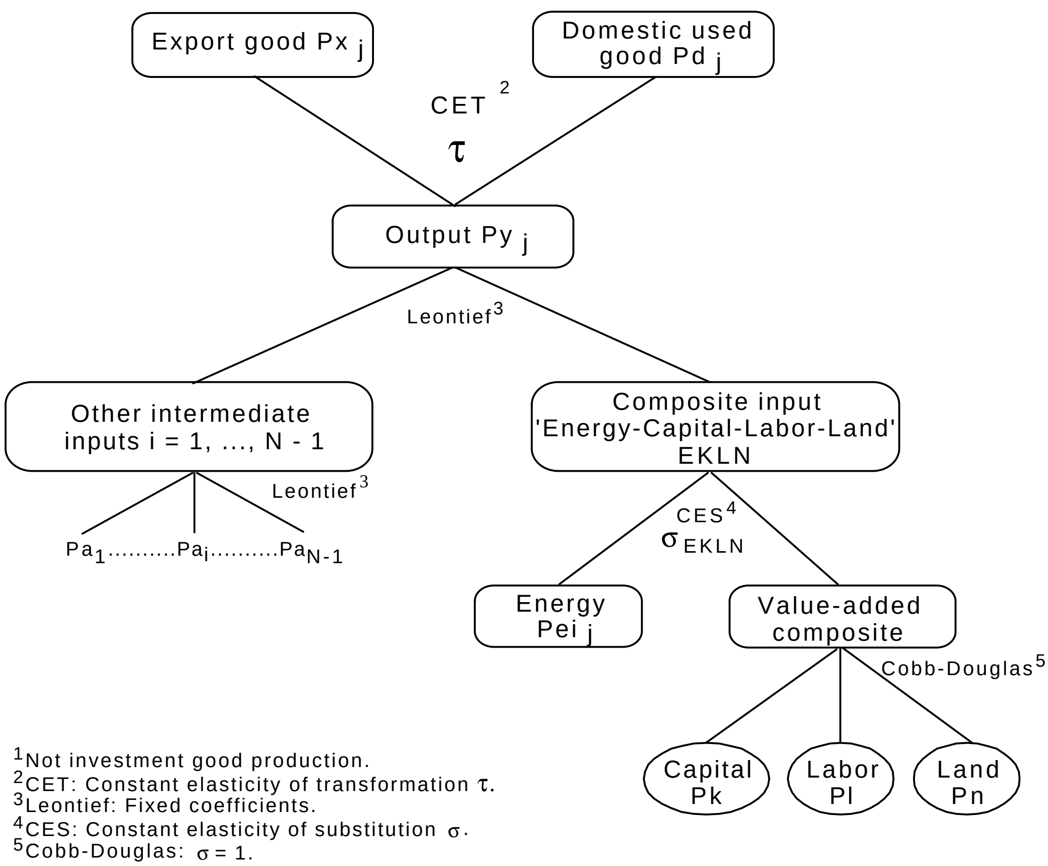
The economic structure is fully specified for each region and covers production, consumption, investment and governmental activity. Hence, the model incorporates three types of agents: the producers, distinguished by production sectors, the representative private household and the government. Primary factors include labor, capital, agricultural land and fossil-fuel resources. Labor and capital are intersectorally mobile within a region but cannot move between regions. Land is only used in the agricultural sector. Fossil fuel resources are specific to fossil fuel production sectors, i.e., coal, natural gas and crude oil, in each region. Each market is perfectly competitive. Output and factor prices are fully flexible.

Producer Behavior

Producer behavior is characterized by cost minimization for a given output. All industry sectors are assumed to operate at constant returns to scale.

For the non-fossil fuel industries, a multi-level nested separable constant elasticity of substitution (CES) function describes the technological substitution possibilities in domestic production.[1] Figure 1 shows the nested production structure. The top level of the production function is a linear function, i.e.

Figure 1 — Production Structure of Industry Sector j in Region r



[1] The nesting structure and nest elasticities of the production cost functions are based on the ETA-MACRO model (Manne and Richels, 1992, pp. 130).

Leontief function, of non-energy intermediate goods and a value added composite. The intermediate input of good *i* in sector *j* corresponds to a so-called Armington aggregate of non-energy inputs from domestic production and imported varieties. The value added composite is a CES function of the energy aggregate and the aggregate of the primary factors (capital, labor, agricultural land). On the lowest level labor substitutes with capital (and land in the agricultural sector) in a Cobb-Douglas technology. On the output side, products destined for domestic and international markets are treated as imperfect substitutes produced subject to a constant elasticity of transformation.

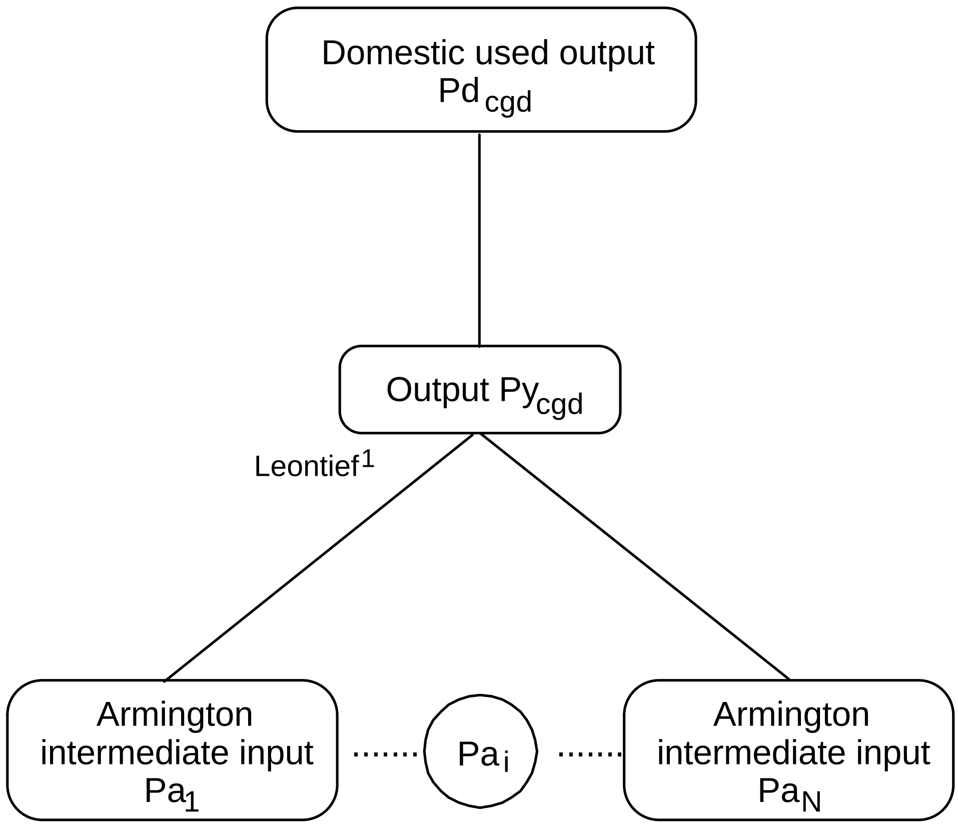
The differentiation between energy and non-energy intermediate products is useful in the context of climate change policy. Energy use in production and consumption produces varying amounts of the greenhouse gas (GHG) carbon dioxide (CO_2) depending on the fossil source and the policies assumed to be in place. Carbon dioxide, with large emission levels and a long lifetime in the atmosphere is the largest single contributor to the greenhouse effect. Other GHGs as methane, nitrous oxide, ozone, and halocarbons, as well as emissions of CO_2 from deforestation are not considered in this model.

Fossil fuels are produced from fuel-specific resources and the macro good (other manufactures and services). The production function is a CES function with a fixed factor - the fuel resource.

In each region, composite investment is a Leontief aggregation of Armington inputs by each industry sector. There is no sector-specific investment activity in this version of the model. The basic model does not contain cross border investment activities, i.e. investment goods are treated as non-tradables. Investment does not require direct primary factor inputs. Figure 2 shows the production structure of the investment activity.

Producer goods are directly demanded by regional households, governments, the investment sector, other industries, and the export sector.

Figure 2 — Production Structure of the Investment Good Sector CGD

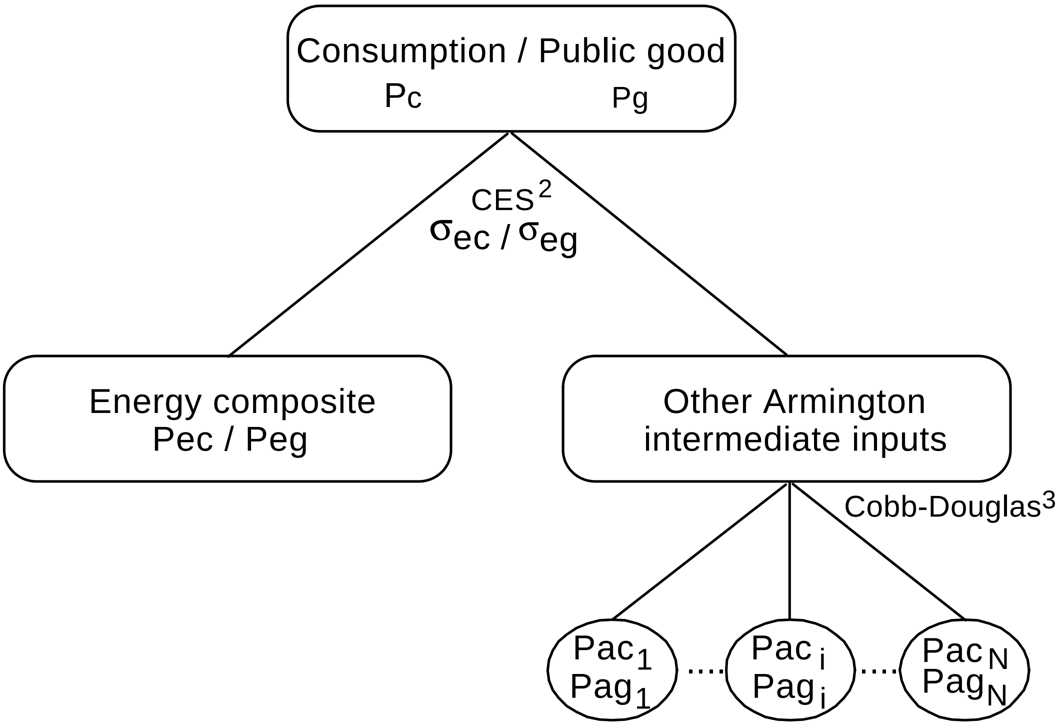


[1]Leontief: Fixed coefficients.

Consumption, and Government Expenditure

The representative household receives all income generated by providing primary factors to the production process. Disposable income is used for maximizing utility by purchasing goods after taxes and savings are deducted. The consumer decides between different primary energy inputs and non-energy inputs depending on their relative prices in order to receive this consumption with the lowest expenditures. The consumer saves a fixed share of income in each time period. These savings are invested in the production sectors.

Figure 3 — Household / Government Production Structure[1]



[1]Lower case roman letter *c* stands for household and *g* for government.
[2]CES: Constant elasticity of substitution σ_{ec}/σ_{eg}.
[3]Cobb-Douglas: $\sigma = 1$.

The expenditure function of the representative household is assumed to be a CES composite which combines consumption of an energy aggregate and a non-energy bundle. Within the non-energy consumption composite, substitution possibilities are described by a Cobb-Douglas function of Armington goods. Figure 3 shows the structure of household and government behavior.

The third agent, the government, provides a public good which is produced with commodities purchased at market prices. Public goods are produced with the same two level nesting structure as the household „production“ function (see Figure 3). The public good is financed by tax revenues.

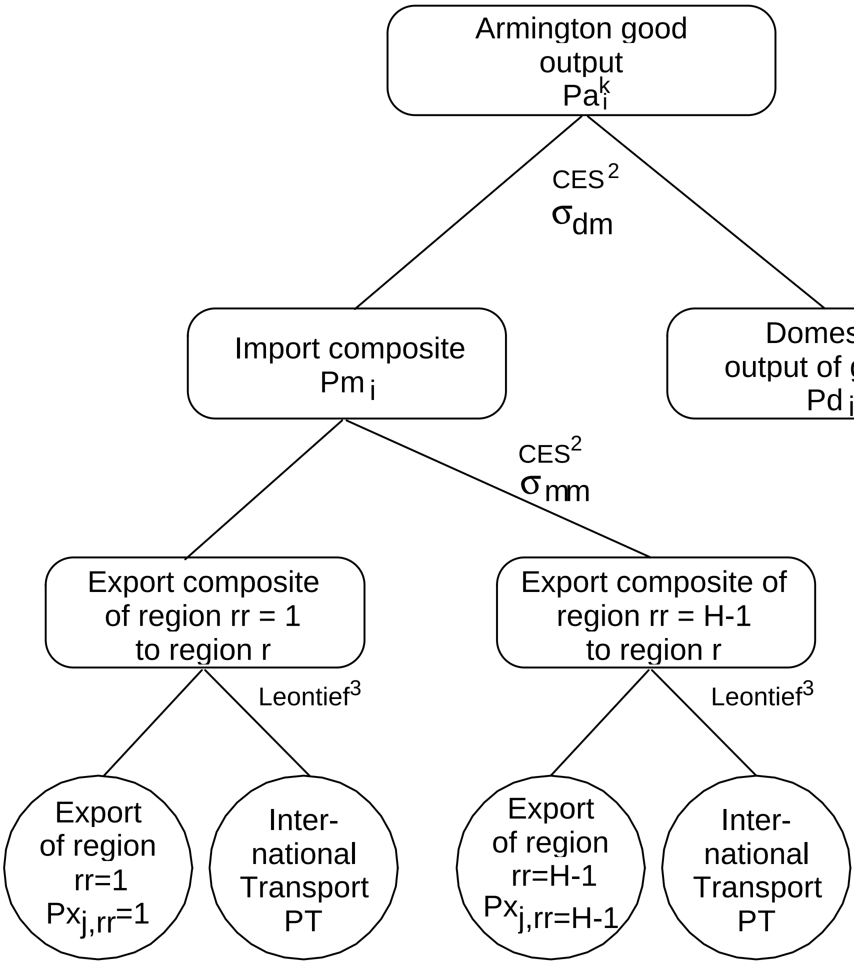
Foreign Trade

The world is divided into economic regions, which are linked through bilateral trade flows. All goods are traded among regions, except the investment good. Following the proposition of Armington (1969), domestic and foreign goods are imperfect substitutes, and distinguished by country of origin.

Import demand is derived from a three stage, nested, separable CES cost or expenditure function respectively and distinguishes between imported and domestically produced goods as well as between the country of origin of the import goods . The structure of foreign trade is shown in Figure 4. The imports of one region *r* are equivalent to the exports of all other regions *rr* into that region *r* including transport. Transport costs, distinguished by commodity and bilateral flow, apply to international trade but not to domestic sales. The exports are connected to transport costs by a Leontief function on the third level. International transports are treated as a worldwide activity which is financed by domestic production proportionately to the trade flows of each commodity. There is no special sector for transports related to international trade.

On the export side, the Armington assumption applies to final output of the industry sectors. Here, produced commodities for the domestic and for the international market are no perfect substitutes. Exports are not differentiated by country of destination.

Figure 4 — Structure of Foreign Trade (Armington Good Production of Good i in Region r)



[1]Armington output is distinguished by agent with k = {Y, C, G}
[2]CES: Constant elasticity of substitution.
[3]Leontief: Fixed coefficients.

Factor Markets

Factor markets are perfectly competitive and full employment of all factors is assumed. Hence, factor prices adjust so that supply equals demand. Labor is assumed to be homogenous, and mobile across industries within regions but internationally immobile. The equilibrium condition of the solution requires that the sum of all sectoral demands for labor is equal to the exogenous labor supply in each region. In the basic version of the DART model capital is inter-sectorally but not internationally mobile. There is no sector-specific capital. Capital stock is given at the beginning of each time period and results from capital accumulation. In every time period the regional capital stock, Kst_r, earns a correspondent amount of income measured as physical units in terms of capital services, K_r. The primary factor land is only used in agricultural sectors and exogenously given.

2.2 CO_2-Emissions from Oil Resources

In order to determine the CO_2-emissions which originate from the use of crude oil in the different production and consumption processes one needs to know at which point in the value-added chain this fossil fuel is actually burned, i.e. leads to emissions. In the current model crude oil only enters the production of refined oil products where it is not burned. Only refined oil products are burned as inputs in production or as final consumption goods of households and government. One cannot use the domestic use of crude oil for determining CO_2-emissions since some of these oil products are exported and some are imported, hence there is no one-to-one correspondence between crude oil consumption and emissions.

Since crude oil is the emission relevant input in refined oil production, only the crude oil share can be used for determining CO_2-emissions. The emission coefficient for crude oil is set to (IPCC, 1996)

$$0.02\,\frac{\mathbf{kgC}}{\mathbf{MJ}}.$$

Refined oil consumption is composed of domestically produced oil products and imported oil products. Both may have different CO_2-contents due to different input shares of crude oil in the production of refined oil products. The crude oil share in the production of oil products by region is given by

$$CRUSH(R) = \frac{VAFM(CRU, OIL, R)}{VDM(OIL, R) + VXM(OIL, r)},$$

i.e. the quantity of crude oil in refined oil production as a share of the value of the output of refined oil products.

Total crude oil content (*TCRUDE*) in the domestic use of refined oil products is given by the content in the use of domestically produced refined oil products plus the sum of the contents in the imports of refined oil products.

$$TCRUDE(R) = VDM(OIL, R) \cdot CRUSH(R) + \sum_{S} \left[VXMD(OIL, S, R) \cdot CRUSH(S) \right]$$

TCRUDE is the total crude oil content of domestically used refined oil products, *VDM*(*OIL,R*) is domestically consumed production of refined oil products, *VXMD*(*OIL,S,R*) are the imports of refined oil products from Region *S*.

The regional CO_2-emission coefficient for oil products then depends on the regional crude oil share in oil products which are burned in a particular region.

$$CEC(OIL, R) = \frac{TCRUDE(R) \cdot 0.02}{\sum_{S} VXMD(OIL, S, R) + VDM(OIL, R)}$$

The denominator denotes all oil products which are used in region *R* by industry, government and households; the numerator denotes the amount of crude oil in these products multiplied by the emission coefficient for crude oil of 0.02 kgC/MJ.

Besides from the combustion of refined oil products CO_2-emissions stem from the use of coal and natural gas which are directly burned. Hence, the CO_2-emission coefficients for coal with 0.0258 kgC/MJ and for natural gas with 0.0153 kgC/MJ (IPCC, 1996) are the same for all regions.

2.3 Calibration

The DART model is calibrated on the Global Trade Analysis Project (GTAP) database version 3 for 1992 (GTAP, 1997). The GTAP data set is adjusted for primary energy flow data from the International Energy Agency (IEA, 1997a,b,c) which provides statistics on physical fossil fuel flows and fossil fuel prices for industrial and household demand. For reconciling the GTAP-IEA database we used the IEA-GTAP package by Rutherford (1998).

The fossil fuel crude oil (CRU) is only used as an input for producing refined oil (OIL). On average the cost share of crude oil input in refined oil production is around 75 percent. Only for the regions western Europe (WEU), consisting of the GTAP regions E_U and EU3, with 42 percent, and Pacific OECD (PAO), an aggregate of the GTAP regions JPN, AUS, NZL, with 48 percent the cost share of crude oil input into refined oil production is extremely low. In order to avoid unreasonable import and export flows of refined oil products caused by these outstanding cost structures in WEU and PAO we have introduced an output tax on total refined oil production in the WEU of 36.63 percent and in the PAO of 30.75 percent. This increases the cost share of crude oil inputs in the refined oil to 70 percent in both regions. This ad hoc tax seems justified since the GTAP-dataset does not seem to contain the mineral oil tax.

Table 1 — Regions and Commodities in the 11 by 10 GTAP Aggregation

Regions in the 11 by 10 GTAP Aggregation

WEU	**Western Europe**: European Union 12, Austria, Finland and Sweden
NAM	**North America**: United States of America, Canada
PAO	Australia, New Zealand, Japan
FSU	Former Soviet Union
MEA	Middle East and North Africa
CPA	China, Hong Kong
PAS	Republic of Korea, Indonesia, Malaysia, Philippines, Singapore, Thailand, Taiwan
IDI	India
LAM	**Latin America**: Mexico, Argentina, Brazil, Chile, Rest of South America
AFR	Sub Saharan Africa
ROW	Rest of South Asia, Central America and Caribbean, European Free Trade Area, Central European Associates, Rest of the World

Commodities in the 11 by 10 GTAP Aggregation

COL	Coal
CRU	Crude oil
OIL	Petroleum and coal products (refined)
GAS	Natural gas
EGW	Electricity
Y	**Other manufactures and services**: Beverages and tobacco, Other minerals, Textiles, Wearing apparel, Leather goods, Lumber and wood, Machinery and equipment, Other manufacturing products, Construction, Other services (private), Other services (public), Dwellings
ISM	**Iron, steel and minerals**: Non-metallic mineral products, Primary ferrous metals, Non-ferrous metals, Fabricated metal products
CPP	**Chemicals, Plastics and paper**: Pulp and paper, Chemicals, rubber and plastics
AGR	**Agriculture**: Paddy rice, Wheat, Grains, Non-grain crops, Wool, Other livestock, Processed rice, Meat products, Milk products, Other food products, Forestry, Fishing
TRN	**Transport industries**: Transport industries, Trade and transport
CGD	Capital goods demand

Regions and sectors can be aggregated as suitable for the research task. The version of the DART model used for this paper runs in a 11 regions by 10 sectors aggregation (see Table 1).

The supply functions for coal, crude oil and natural gas are calibrated to a given price elasticity of supply. The elasticity of fossil fuel supply is chosen in such a way that the carbon emissions resulting from the model meet the projections of scenario B by the IIASA and the World Energy Council (Nakicenovic et al., 1998) for each type of fossil fuel. The resulting price elasticities of fossil fuel supply are given in Table 2.

Crude oil is treated as an homogenous good. International trade in crude oil is then treated as in the Heckscher-Ohlin trade model, i.e. only net trade flows are considered. For all other traded goods the Armington assumption applies. The Armington elasticities used in this model are given in Table 2.

Table 2 — Key Elasticities

Fossil Fuel Supply Elasticities	
Coal	0.55
Gas	1.3
Crude Oil	0.25
Armington Elasticities	
• Elasticity of substitution domestic vs. imported goods δ^{DM}	4
• Elasticity of substitution imports from different destinations δ^{MM}	8
• Elasticity of transformation exports vs. domestic sales	2

3 THE FUTURE GROWTH OF NATIONS

In recent years a renewed interest has emerged in the determinants of the growth of an economy and of the per capita incomes it is able to attain. The research has lately focused on the empirics of historical growth processes. One of the controversies between the new growth theory and the traditional neoclassical approach has centered around the question as to whether historical growth processes and current income and productivity differences can be explained by the neoclassical model, or whether additional features developed in the new growth theory need to be included in order to improve the fit of growth models to the historical trends.

For the analysis of climate change empirical research on growth processes is extremely important as it identifies the crucial parameters which influence the structure and the speed of the growth of an economy. These findings should not only be of historical interest but they should provide some guidance for forward looking exercises. Therefore, these insights should be incorporated into the forward looking model. There are two issues to be dealt with in creating such a potential benchmark of the world economy.

- The structure of the model already determines the qualitative relationship between variables and it includes or excludes specific variables.
- The parameters which are important for the evolution of a specific model structure need to be chosen in a reasonable way.

As far as the model structure is concerned, a large variety of models can be envisaged. However, any specific choice needs to be made under the restriction that it can be calibrated with empirical data. This still leaves a substantial number of potential specifications. For the dynamic aspect the choice of the particular nesting structure of production, consumption, or trade functions are not as important. More fundamental issues concern the choice of factors of production and the choice of perfectly competitive versus an increasing returns framework.

Since one of the most limiting factors of the modeling of a multi–regional model is the availability of data, the present model is of the perfectly competitive type such that the social accounting matrices (SAMs) of the GTAP data set can be used and no further information on market structure and on economies of scale need to be derived.

So far, the only available data set for multi–regional and multi–sectoral models is the GTAP data set which we use. This data set already constrains significantly the modeling approaches that one can chose. For example, the choice of factors of production is quite limited by the GTAP data set. It contains stocks and flows of capital, labor, and land. This creates a number of problems namely that different qualities of labor – or in other words „human capital“ – are not explicitly included. The implications of this are discussed below. Another modeling problem occurs for those regions which are particularly rich in natural resources. The resource rent appears in the capital or labor income and thus these incomes do not correctly reflect pure factor income for labor or capital but also include the resource rents.

3.1 Human Capital Accumulation

The standard Solow–Swan model uses capital and labor as factors of production. For more realistic models the number of factors can, of course, be increased. However, since the laws of motion are different for these factors they lead to different growth dynamics. Recently, empirical studies have attempted to test the standard neoclassical growth model (e.g., Mankiw, 1995, Mankiw et al., 1992; Hall and Jones, 1996, 1999) and found that it is largely unable to describe historical growth processes. Their common conclusion was that, first, more factors of production are needed to explain actual growth processes, and that, second, the observed factor shares do not mix well with the neoclassical model. One of the major problems of the neoclassical model lies also in its inability to explain the large differences in productivity which can be observed throughout the world economy.

In the standard production function

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha}$$

the data produce an α of roughly one third with some variation. Regression results by Mankiw et al. (1992), however, lead to the conclusion that it should be rather two thirds or higher in order to be able to approximately explain productivity differences, differences in rates of return, and differences in the rate of convergence.

There are several possibilities for reinterpreting the neoclassical growth model. One can conclude that the high capital share is inclusive of human capital. Then the income data would need to be readjusted. Alternatively, there might be positive externalities of capital which accelerate the growth process.

Since it is practically impossible to adjust the income data and separate out the human capital content from standard labor income, another approach is possible. Hall and Jones (1999) interpret all labor income as human capital but adjust the labor input through a labor quality indicator.

Assume the production function in the nest of primary factors is given by

$$Y_t = A_t K_t^{\alpha} H_t^{1-\alpha}$$

where H_t is the amount of human capital–augmented labor input. If the labor input L_t is homogeneous within a country and if each unit of labor has experienced E_t years of schooling, then the human capital–augmented labor input can be written as

$$H_t = e^{f(E_t)} L_t.$$

The function $f(E)$ reflects the efficiency of a unit of labor with E years of schooling relative to no schooling, i.e. $f(0) = 0$. Hall and Jones assume that there are decreasing returns from schooling. They choose a piece–wise linear function $f(E)$ with a rate of return of 13.4 percent for the first 4 years of schooling, 10.1 percent for the next 4 years (the average for the world as a whole), and 6.8 percent for education of more than eight years.[2]

Based on the raw data for 127 countries of Hall and Jones, the adjustment to the standard labor input[3] the leads to the input of efficiency labor or human capital. The latest data for $f(E)$ are for 1990. In order to create a benchmark for the likely development of human capital throughout the simulation period the labor force growth needs to be adjusted to the exogenous increase in efficiency and the increase in human capital through education. The efficiency labor EL_t is given by

$$EL_t = A_t e^{f(E_t)} L_t$$

where A_t is the exogenous technology shifter.

The corresponding growth equation which will be used to update the factor input of labor is

$$g_{EL} = g_A + g_L + \dot{f}\ .$$

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2 These values are derived from regression results by Psacharopoulos (1994).

3 Labor input is measured in number of persons in the workforce since the number of hours worked is not available. For the dynamic calibration this is problematic since one has to assume that the workforce grows with the same growth rate as the population overall. This ignores demographic changes as well as changes in the participation rate of women.

g_A represents the growth rate of the total factor productivity, g_L that of the increase in population, and $\dot{f}$ the growth rate of human capital in the labor force.

The data for the growth rates of population are taken from the „World Population Projections“ of the World Bank (Bos et al., 1994). The current levels in the human capital endowments are taken from Hall and Jones (1999).[4] These are then aggregated to the 11 regions of the model.

For the future development of the regional human capital endowments, the following assumptions are made:

- The maximum number of years of schooling is 12.
- This maximum will be reached by each region in the year 2050.
- This process starts at the computed 1990 levels and continues in a linear fashion.

The starting values of the human capital intensity H_{1990}/L_{1990} are given in Table 3. The growth rates in efficiency labor are presented in the second column.

This approach can be criticized as being rather ad-hoc. Since we could not identify a reasonable indicator for the future development of human capital endowments we simply assume optimistically that there is complete convergence in human capital intensities over all regions in the long-run, i.e. in the year 2050.

4 The countries missing from the 127 country data set of Hall and Jones are determined by taking the human capital intensity from a neighboring similar country.

Table 3 — Human Capital Intensities*

	1990 level	Yearly Change (%)
NAM	3.27	0.15
WEU	2.60	1.26
PAO	2.77	0.98
MEA	1.83	2.55
PAS	2.10	2.10
CPA	2.23	1.88
IDI	1.73	2.72
LAM	1.96	2.33
FSU	3.03	0.54
AFR	1.46	3.16
ROW	1.99	2.30

* The maximum level is 3.36.

Source: Own calculations from Bos et al. (1994) and Hall and Jones (1999).

3.2 Physical Capital Accumulation

For the accumulation of physical capital the current period's investment augments the capital stock in the next period. The aggregated regional capital stock, *Kst*, in each time period t is updated by an accumulation function equating the next-period capital stock, Kst_{t+1}, to the sum of the depreciated capital stock of the current period and the current period's physical quantity of investment, $Iq_{r,t}$, given by $Iq_{r,t} = Inv_{r,t} / Pi_{r,t}$ where $Inv_{r,t}$ is the value of investment in region r in period t and $Pi_{r,t}$ denotes the costs of constructing a unit of capital. The equation of motion for capital stock $Kst_{r,t+1}$ in region r is given by:

$$Kst_{r,t+1} = (1-\delta_t)Kst_{r,t} + Iq_{r,t} \qquad \text{for } t \geq 1$$

where d_t denotes the exogenously given constant depreciation rate in period *t*. According to the GTAP dataset the parameter d_t is set to 0.04.

Since the model does not include international capital mobility, the level of regional investment is equal to regional savings, aside from an exogenously fixed current account deficit / surplus, according to the savings-investment identity in an economy. thus the endogenous rate of capital accumulation. The agents have myopic expectations, which is consistent with the in principle static nature of the DART model.[5] The savings behavior of regional households is characterized by a constant savings rate over time.[6] This rather ad-hoc assumption seems consistent with empirically observable, regional different, but nearly constant savings rates of economies, which adjust according to income developments over very long time periods (for savings rates cf. Schmidt-Hebbel and Servén, 1997). Therefore, the underlying growth model is the Solow-Swan Model with exogenous savings rates and human capital accumulation (cf. Barro and Sala-i-Martin, 1995).

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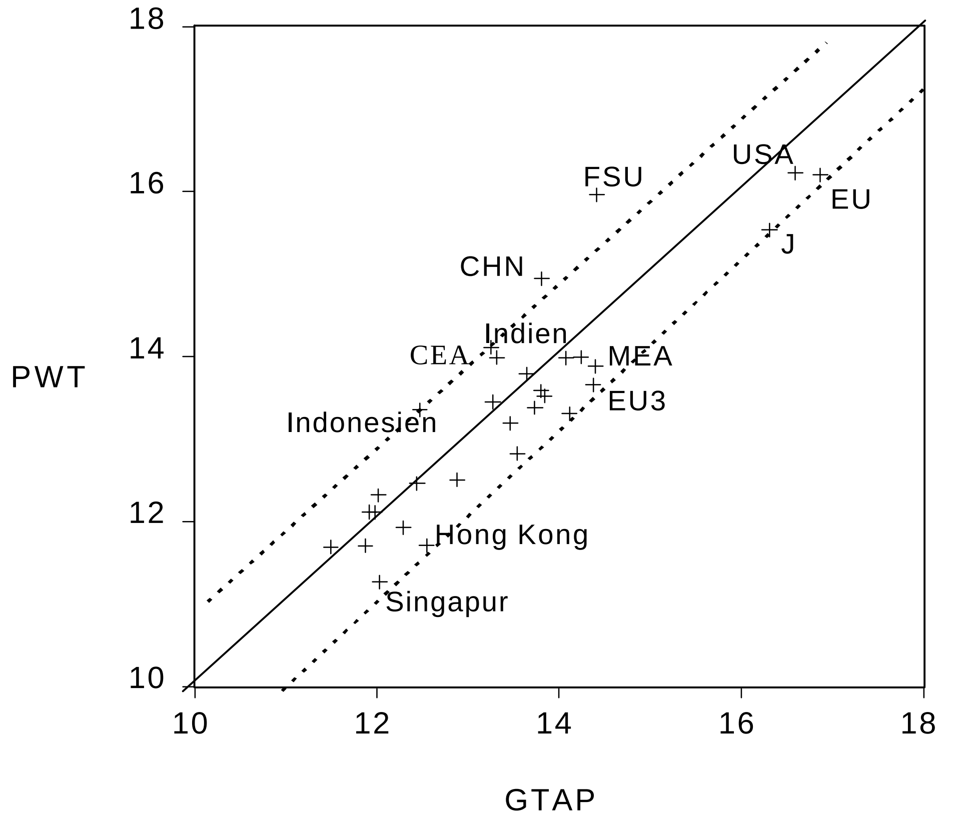
5 The DART model is recursive dynamic in the sense that it is solved stepwise in time without any ability to anticipate possible future changes in relative prices or in constraints.

6 The savings rate is allowed to adjust to income changes in some regions (see below).

Figure 5 — Capital Stocks According to Penn World Tables and the GTAP Data Set*



*In logarithms of million US$. The area beyond the dotted lines indicates a difference of a factor of two and more.

Source: Penn World Tables, GTAP.

There is little faith in any form of capital stock data for a large number of countries which are given comparable basis. The different methods of calculating capital stocks are open to different types of critique. They also lead to quite divergent results. Figure 5 presents a comparison of capital stock data from the GTAP data base to that of the Penn World Tables. It indicates that the GTAP data set overstates capital stocks in industrialized countries when compared to the Penn World Tables. To the contrary, developing country and especially transition country capital stocks turn out much lower in the GTAP dataset.

We have chosen to use the GTAP capital stocks for calibrating the model, mainly because the resulting key parameters seem to be plausible for most regions. There are two exceptions, however.

The two regions CPA and FSU mainly contain the states of China and former Soviet Union. The measures of capital stocks seem to refer to the capital stocks accumulated during the periods of a centrally planned resource allocation. With the introduction of markets and competition these capital stocks have become obsolete to a considerable degree. We, therefore, adjust the GTAP capitals stocks for the two regions downward by 50 percent.[7]

The key parameters for capital namely the capital/GDP ratio, the capital share and the gross rate of return on capital are given in Table 4.

Table 4 — Key Parameters for Calibration related to Capital

	Capital GDP Ratio	Capital Share (%)	Gross Rate of Return (%)
NAM	2.8	32.5	11.8
WEU	3.0.	39.6	13.0
PAO	3.3	36.3	10.9
MEA	2.7	45.4	17.1
PAS	2.3	41.8	18.4
CPA	1.3	30.1	22.3
IDI	2.4	35.0	14.9
LAM	3.1	50.8	16.2
FSU	1.7	32.0	18.7
AFR	2.8	42.2	14.8
ROW	3.1	36.9	12.0

Source: Own calculations from GTAP.

Summarizing the results, the growth path of the DART model is calibrated on the above derived assumptions about growth rates of population and technological change, change in human capital, and savings rates as shown in Table 5. The

[7] This correction factor of 50 percent is in line with Thimann (1996, pp. 45).

factor land is held constant over time in this version of the model. If one would like to depict qualitative differences in land endowments due to productivity or climate differences between regions, land becomes variable too. Thus, the impact of climate change on, e.g., agricultural production can be modeled via a change in regional land endowments (see Kurtze and Springer, 1999). The gross domestic product is then derived endogenously.

Table 5 — Dynamic key parameters for the year 1993

	Growth Rates for Efficiency Labor (in percent)				**Savings Rate (in percent)**
	Exogenous technical progress	**Human capital growth**	**Growth Rate of Population *****	**Total**	
WEU	1.00	1.20	0.40	2.60	20.3
NAM	0.70	0.15	1.00	1.85	16.1
PAO	0.70	1.00	0.40	2.10	30.1*
FSU	2.50	0.55	0.20	3.25	18.9
MEA	1.00	2.50	2.40	5.90	19.6
CPA	3.50	1.90	1.10	6.50	31.7**
PAS	2.50	2.10	1.70	6.30	31.5**
IDI	1.50	2.70	1.80	6.00	21.6
LAM	1.50	2.30	1.70	5.50	19.0
AFR	1.50	3.20	2.50	7.20	15.8
ROW	1.00	2.30	1.60	4.90	20.9

* Falls by 1 percentage point per year up to 2003.
** Falls by 0.5 percentage point per year up to 2013.
*** Taken from Bos et al. (1994).

4 RESULTS OF THE BENCHMARK RUN FOR 1993 TO 2030

Given the base year data set and the assumptions about the dynamic parameters, i.e. the development of regional savings rates, of exogenous technical progress, and about the accumulation of human capital, the recursive model produces the benchmark development for the 11 regions with 10 production sectors each and the bilateral trade flows among all regions. The Tables A1 to A6 summarize the base year data and illustrate the economic structure of the economies. The following Tables A7 to A16 present the results for the benchmark run in 2030.

The Figures A1 to A7 give a graphical summary of the expected development of the world economy.

Per capita incomes in all regions grow. However, the three industrialized regions start from a by factor 10 to 20 higher level then the other regions. Although the GDP of economies in the Third World grows at a higher rate some of that growth is needed to compensate for high population growth. Therefore, a catch-up of per capita income can not be observed and is unrealistic even under very optimistic growth scenarios.

The CO_2-emissions world-wide grow according to the imposed benchmark „B“ of the IIASA-study. The composition of emissions by regions is rather distinct. Currently, the industrialized regions (NAM, WEU, PAS) emit around 3 Gt C and the rest of the world another 3 Gt C. In the benchmark, the industrialized countries’ emissions will remain roughly constant, whereas all the increase of overall emissions will come from the rest of the world, i.e. mostly the developing countries. These regions will have emissions of about 6 Gt C in 2030, i.e. they will double their CO_2-emissions.

Figure A3 illustrates the speed at which CO_2-emissions grow in the different regions. Highest growth is in the Middle East and North Africa (MEA) as well as in the Asian NIC's (PAS) which is due to the high growth rates of GDP in these regions. The other developing countries experience a similar growth in emissions.

The level of per-capita emissions differs strongly between the industrialized and the developing countries. North America (NAM) with more than 5 tC in 1993 shows falling emissions due to a rise in energy prices. The per-capita emissions in the European Union (WEU) and Japan, Australia, and New Zealand (PAO) will remain roughly constant. The strongest growth is seen in Russia (FSU) where emissions will double from almost 3 tC to almost 6 tC. The per-capita emissions of the developing countries will remain below 1 tC and grow only slowly.

Figure A5 indicates the current levels and the improvements in energy efficiency for important groups of countries. It is remarkable that the CO_2-intensity of the transition economies - i.e. mainly Russia and China - starts at very high levels which seem to be the relict of an extremely inefficient use of energy in the periods of socialist planning and of the orientation of the economies towards heavy and energy intensive industries. Since these transition processes are not modeled here it may be possible that the fall in CO_2-intensity may be even stronger than predicted due to the continued adjustment of these economies to free market conditions. In contrast, the developing countries - they include Africa, Latin America, Asia without China and Japan, and the Middle East - show far lower CO_2-intensities and their intensities are predicted to fall below the world average. The technological changes which drive the CO_2-intensities follow the historical trend of progress in energy efficiency. In many studies more optimistic scenarios are used which are based on the expectation of large breakthroughs in energy technologies in the coming decades. Such positive surprises are not part of the benchmark run presented in Figure A5. However, even if they were included the question of the speed of diffusion of such technologies would have to be resolved. Future research might lead to a more explicit integration of specific energy technologies into the model.

The 11 regions have shown widely diverging growth rates of per capita income in the 1990s (Figure A6). The most dynamic economies being China (CPA) and the Asian NICs (PAS). The growth process in Russia (FSU) of course does not correspond to the actual development since the political and institutional problems with their impact on the economic performance are not modeled here. The long run path of the growth rates of per capita incomes shows a decline in the differences in growth rates. One can also see that most economies tend towards a steady state with an almost constant growth rate. However, the economies do not converge towards the same steady state. It is clear that the often used assumption of steady state growth in all economies is hardly justifiable when compared to the likely development based on the key parameters of economic development.

The development of the gross rate of return on capital relative to the wage rate is another indicator describing the interplay of important macro-variables in the different regions. Most pronounced is the apparent capital shortage in sub-Saharan Africa (AFR) and in Latin America (LAM) where savings apparently do not match the growth in population (Figure A7). On the other hand, the high savings rates in the formerly socialist economies lead to a fall in the relative price of capital. Western Europe (WEU) and North America (NAM) show a slow and small trend towards higher wages relative to capital. Overall it seems that the regions follow a reasonable growth path. The problems in Sub-Saharan Africa are not a problem of parameter choice in the model but a real one, i.e. if savings rates will not drastically increase in the future these region's economies will face a severe capital shortage. It should also be noted that the leveling off of the fall in the relative price of capital in the Asian countries (PAS, PAO, CPA) is due to our assumption of falling savings rates. Without this assumption, the rate of return on capital would fall to unrealistically low levels.

The region specific development of population, savings and investment, technological change, and human capital development will simultaneously determine the emergence of comparative advantage of the model regions. The resulting comparative advantage is determined by a mix of changing relative factor endowments and relative factor costs. Table A16 reveals that these changes are quite strong in that they result in significant changes in the revealed comparative advantage (RCA). As a general trend one can see a strengthening of already existing comparative advantage in the future, i.e. positive RCAs tend to rise further and negative ones tend to fall further. Industrialized countries will increase their comparative advantage in capital- and energy-intensive sectors whereas the labor-intensive goods and services will improve for the developing countries. The agricultural sector is an exception. Due to the increasing shortage of land in regions with a fast growing population the industrialized countries RCA improves although it remains negative (Figure A8 and A9).

5 SENSITIVITY ANALYSIS

5.1 Supply Elasticities for Fossil Energy

The model contains no intertemporal framework for the supply of the fossil fuels crude oil, natural gas, and coal. Instead supply over time depends on current prices only. The elasticities of the supply functions for the different fossil fuels are calibrated to the IIASA/WEC forecasts of fossil fuel production in the 21st century (Nakicenovic et al., 1998). Our central case has supply elasticities for crude oil of 0.25, for gas of 1.3, and for coal of 0.55. These elasticities result in emissions of CO_2 in the year 2030 which are a little more than 50 percent

above the 1993 levels. The contribution of the different fuels is given in Table 6, the regional CO_2-emissions are summarized in the appendix (Figure A2).
It is clear that these calibrated elasticities are somewhat arbitrary. For this reason, they are chosen in such a way that the expected future production coincides with the predictions of the large scale energy models of the IIASA and the WEC. A sensitivity analysis of alternative supply elasticities reveals that coal and crude oil supplies vary strongly with their own supply elasticity.

Table 6 — Benchmark Emissions of CO_2 - All countries

	Supply Elasticity eta	Emissions (Gt. C)	
		1993	2010
Crude Oil	0.25	2.7	3.1
Gas	1.30	1.0	1.6
Coal	0.55	2.4	3.3
Total		6.1	8.0

Figure A10 shows that an elasticity of roughly one would increase supplies in 2010 by almost 30 percent for crude oil and coal, respectively. Gas supplies which already have a higher elasticity do not react much to alternative supply elasticities.

Figures A10 to A13 present the result of the cross effects of varying supply elasticities. Since the supplies of fossil fuels not only depend on the supply but also on demand conditions it is clear that increasing the supply elasticity of, e.g., crude oil would lower crude oil prices and thus would through the cross price effect of energy demand reduce the demand and consequently production and emissions of other fossil fuels. As the Figures A10 to A13 show these effects are very small compared to the direct effect.

5.2 Armington Elasticities

International trade in goods is modeled by the Armington assumption on bilateral trade flows. This assumption implies that on the demand side domestic and imported goods and on the supply side domestically used and exported goods are no perfect substitutes. The trade in differentiated goods leads to segmentation of domestic and international goods markets, and therefore influences the amount of international spillovers. The degree of market segmentation depends on the substitutability between goods stemming from different regions.

For the benchmark case we assume an elasticity of substitution of 4 between domestic and import goods (d^{DM}) and of 8 between imports from different destinations for each type of good (d^{MM}). These values are at the higher end of the usually used Armington elasticities in the CGE literature. However, since the model serves as a tool for policy analysis in the medium to long run the higher elasticities correspond to the expected progress in world trade integration. The specified trade elasticities determine to what extend domestic price changes have an impact on international prices and thus on other regions. Hence, the value of the Armington elasticities may influence, via international trade spillovers, the total effect of a certain policy and the regional distribution of policy impacts. This influence was tested by varying the level of Armington elasticities (Table 7).

Table 7 — Scenario specification for sensitivity analysis of Armington elasticities

Scenario	Armington 1	Armington 2	Benchmark	Armington 3	Armington 4
Armington elasticities δ^{DM} / δ^{MM}	1 / 2 for all goods	2 / 4 for all goods	4 / 8 for all goods	6 / 12 [a]	8 / 16 [a]
[a] For the goods Coal, Gas and EGW the benchmark elasticities 4 and 8 are kept because of many zero entries in the bilateral trade matrix for these goods pointing to an inhomogeneous good character due to transaction costs in form of pipelines etc.					

The direct effect of varying the Armington elasticities can be illustrated by looking at the change in trade flows since Armington elasticities give the reaction of trade flows on changes in relative prices between domestic and import goods. It is evident that the lower the elasticity is (scenario “Armington 1“) the less trade flows react to a certain change in prices.

The comparison of the different benchmark runs under the five different Armington scenarios shows that the change in exports and imports is dominated by the growth effects, i.e. the effects induced by a change in relative factor endowments for each region over time. This change in relative factor endowments of regions caused by different growth rates for capital and labor leads to shifts in comparative advantage of countries. The shifts in revealed comparative advantage (RCA) caused by the growth process for the Benchmark Scenario, i.e. with Armington elasticities of 4 and 8, are shown in Figure A8 for the industrialized countries, which is an aggregate of WEU, NAM and PAO, and in Figure A9 for the developing countries for selected sectors.[8] The industrialized countries experience an increase in competitiveness in the refined oil sector (OIL), in the

[8] The aggregation of industrialized and developing regions into two regions for representation purposes leads partly to an offsetting of country-specific effects. This may dampen the impact of the Armington elasticities on trade flows. However, a comparison with region-specific data show that the aggregates represents the main behavior of the RCA’s and the change in export and import flows over time.

iron, steel metal (ISM) industry, and in the chemical, pulp and paper (CPP) industry while the developing countries improve their competitive position in the macro good sector (Y).

These changes in competitiveness are reflected in the variations of sectoral import shares in total imports and of sectoral export shares in total regional exports. For the industrialized countries one can see an increase of the export shares for the goods for which they have a comparative advantage, the ISM and the CPP sector (Figure A14), and an increase in import shares in those sectors, such as Y, where they have a comparative disadvantage in 2010 compared to 1993 (cf. Figure A15). One can observe the same reaction for the developing countries: an increase in the export share of the competitive sector, the Y sector (Figure A16), and an increase in the import shares of the less competitive sectors such as CPP, ISM over time (Figure A17).

The variation of Armington elasticities do not alter these results of the change in relative factor endowments, induced by the growth process, dramatically. They only deepen the growth effect on bilateral trade patterns which can be observed in amplified variations of export and import shares with rising Armington elasticities. An increase of the Armington elasticities allows a better exploitation of the comparative advantage since higher elasticities are equivalent to a decrease in barriers to trade. The growth impact on trade flows can also be seen in Figures A18 to A21 which show the absolute export and import quantities of industrial and developing countries over time in dependence of the Armington scenarios. The growth impact in connection with the change in RCA's is bigger the higher the Armington elasticities are. This effect is especially relevant for the developing countries where the increase of Armington elasticities from scenario 1 to scenario 4 results, e.g., in a rise in the total import levels by more than 50 percent while the composition of the import structure is nearly constant over the trade scenarios.

For the base run, the variation of Armington elasticities does not cause a substantial shift in region's export or import structure. However, policies affecting international prices and thus trade flows may lead to different model results for different trade elasticities. One example for such a policy is the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UN, 1997) which imposes different greenhouse gas emission reduction targets for the industrialized and the developing countries. The Kyoto Protocol is implemented into the model by specifying carbon dioxide emission reduction targets of 8 percent for the WEU, 7 percent for NAM, 3 percent for PAO and constant emissions for FSU by 2010 compared to the 1990 emission level. After 2010 the emissions remain constant for these four regions. The welfare effects of the Kyoto Protocol measured in Hicksian equivalent variation relative to the benchmark in 2010 are given in Figure A22 for the different Armington specifications.

Comparing the welfare effects of the Kyoto Protocol for the applied Armington elasticities, we can see that for some regions, mainly the abating regions, the results are fairly robust like for WEU, NAM, PAO, FSU, PAS, or IDI, while other regions experience substantial differences in welfare effects such as MEA, LAM, AFR, or ROW. China (CPA) even changes from a net looser to a net gainer of the Kyoto Protocol. All regions which show this high variability in welfare effects are relatively strongly exposed to the development in the industrialized economies (WEU, NAM, and PAO).

For example, the oil-exporting countries (MEA) suffer from the decrease in world demand for crude oil caused by CO_2-emission constraints. In a world with low Armington elasticities, the trade structure remain nearly fixed, and, therefore, the drop in world oil demand extends to negative effects in other sectors of the oil-exporting countries. With increasing substitution possibilities for trade in goods and among regions modeled by higher Armington elasticities the negative impacts are weakened.

Also Africa and Latin America suffer from the growth slow down, and connected with that, the reduction in demand of the abating countries. Africa and Latin America are characterized by low trade diversification and strong trade ties to the industrialized world. In these regions the effect of international spillovers on welfare decrease with rising trade elasticities.

The fast growing regions such as CPA, PAS, or IDI, on the other hand, are able to exploit their comparative advantages occurring during the growth process. However, China seems to need a certain degree of trade substitutability in order to be able to use their comparative advantage. These regions are not so dependent in their trade structure on industrialized countries and are thus not harmed by demand changes in the CO_2-abating regions. Hence, they are relative robust to changes in the Armington elasticities.

5.3 Alternative Growth Paths of Nations

As we have seen, the dynamic specification of the model is important for the development of relative factor endowments, and, thus, influences the trade structure and income distributions among countries over time. Since the specification of the dynamic parameters is somewhat arbitrary we have tested the impact of divergent dynamic scenarios on the macroeconomic behavior of the model. Therefore, two alternative dynamic scenarios are distinguished beside the benchmark case: the pessimistic growth scenario („Pessimist“) and the savings rate scenario („Savings“).

The *pessimistic growth scenario* assumes a lower degree of technology diffusion, and knowledge spillovers than in the benchmark case. This is operationalized by reducing the growth rate of the effective labor force, i.e., the sum of the growth rate of the total factor productivity, the population growth rate, and the growth rate of human capital in the labor force, by 30 percent in every region. [9]

The accumulation of capital is driven by the endogenous rate of return on capital and the exogenous savings rate. The savings or investment rate is chosen according to empirically observed data in the benchmark data set. For the analyzed time horizon we proceed from the assumption of constant savings rates according to the above mentioned arguments. However, for the countries China, Pacific OECD (PAO) and the pacific Asian countries (PAS) with very high savings rates we assume a convergence in their investment behavior to the high-income-countries. As in the benchmark case the region PAO starts from a savings rate of 30.1 percent which declines annually by 1 percent over a period of 10 years to 20.1 percent, while for the regions PAS and CPA the savings rates declines annually by 0.5 percent over a period of 20 years from 31.7 percent for PAS and 31.5 percent for CPA to 21.7 and 21.5 percent, respectively.

The *savings rate scenario* varies the assumption about the rate of decline of savings rates with rising income in PAO, PAS, and CPA. In this scenario a faster convergence in the savings behavior is assumed: The savings rate declines twice as fast, i.e., 2 and 1 percent per year, in half the time period, i.e., 5 and 10 years, as in the benchmark scenario.

As the pessimistic growth scenario reduces the growth in effective labor and the savings scenario reduces the growth rate of capital stock in three regions (PAO, PAS, China), relative factor endowments are influenced through these dynamic specifications, and thus, macro- and microeconomic results are expected to change relative to the benchmark scenario. The change in relative factor

[9] Since we consider our growth perspectives in the benchmark case as fairly optimistic we neglected the case of a further increase in the growth rates of the effective labor force.

endowments relative to the benchmark is depicted in Figures A23 and A24 which show the percentage change in relative factor prices (capital to labor) of the pessimistic and savings rate scenario, respectively, relative to the benchmark factor price ratio.

In the pessimistic growth scenario (Figure A23), the capital to labor price falls between 1.4 percent for North America and nearly 33 percent for China compared to the benchmark scenario in 2030. Effective labor becomes more expensive than capital because of lower growth in effective labor due to less technology and knowledge spillovers. However, the decline in the relative factor price relative to the benchmark scenario is differently pronounced for several regions. The differences in the shifts of the relative factor endowments compared to the benchmark are caused by different factor endowments in the base period, different scarcity of factors due to different production and technology patterns in several regions, the repercussions of international trade reactions to the change in relative factor endowments, and the differences in savings rates. All these effects lead to lower GDP growth and changes in other macroeconomic variables.

In the savings rates scenario (Figure A24) less capital is accumulated than in the benchmark case in the regions PAO, PAS, and China. Hence, the factor capital becomes scarcer than in the benchmark leading to an increase in the relative capital price (6 percent for PAO and around 14 percent for PAS and China). This increase reaches its peak after 10 years for PAO and 20 years for PAS and China and the price declines thereafter again, but remains on a higher level than in the benchmark. The other regions are barely affected be the difference in savings behavior in the dynamic Asian countries.

These differences in factor endowments across the dynamic scenarios result in lower growth rates of per capita income for the pessimistic growth scenario over the whole time horizon (Figure A25) while the picture for the savings rate scenario (Figure A26) looks pretty much the same as for the benchmark case. The only difference between the latter two scenarios is that the per capita income growth rate drops faster in the first five to ten periods for the three Asian regions in the savings rate scenario, but remains thereafter at nearly the same level as in the benchmark case. However, the special behavior of the per capita income growth rate for PAO, PAS and China is the same over all three dynamic scenarios, i.e., a decreasing growth rate which converges to certain value between two to three percent annually. This growth slow down is induced by an over-accumulation of capital due to very high investment rates in these countries - which leads to a sharp drop in gross rate of return on capital - and thus, to a decline in income. This process is restrained by the ad-hoc, but plausible, adjustments in the savings behavior of the Asian countries. Another, economically more interesting correction mechanism for regional capital accumulation would be the introduction of international capital mobility into the model.

Looking at the actual development of per capita income (Figure A1, A27, A28) we see that the gap between ICs and LDCs is increasing over time. Despite higher growth rates in LDCs, GDP growth is not sufficient to close the gap. In the benchmark scenario the per capita income of LDCs is 60 percent of the income in ICs in 2030. The development of income per capita is nearly the same in the benchmark and in the savings rate scenario. Only lower technology and knowledge spillovers in the pessimistic growth scenario lead to lower income per capita over time. With about US $ 37 000 yearly income per capita in ICs, the pessimistic growth scenario lies 20 percent under the income received in the benchmark or savings scenario in 2030. However, the gap between rich and poor countries widens in the pessimistic growth scenario. There, the average income per capita in LDCs is with US $ 21 000 only 77 percent of the LDCs income in the benchmark case. Concerning the income distribution, the three different dynamic scenarios barely change the relative income development over all regions .

The economic activity goes hand in hand with CO_2-emissions. Economic growth causes also increasing CO_2-emissions which rise most in the LDCs for the benchmark case (by 32 percent of the 1993 level in 2030). The savings rate scenario looks similar, and the increase in emissions is by 12 percent points lower in the LDCs with pessimistic growth assumptions. Higher GDP output in the ICs is connected with an emission increase by 5 percent of the 1993 level in the savings and benchmark case and only of 2.5 percent for the pessimistic growth scenario. This is shown in Figure A29.

However, the CO_2-intensity of producing one unit GDP is decreasing with increasing overall production. The countries with the highest growth in income per capita (Figure A30) show also the highest CO_2-intensity reduction over time (Figure A31). Hence, the LDCs in the benchmark and savings scenario reduce their CO_2-intensity by 61 percent in 2030 compared to the 1993 level while the LDCs with more pessimistic growth prospects are only able to reduce their emission-intensity by 54 percent. They are followed by the ICs, first benchmark and savings scenario with a reduction of 55 percent, and then the pessimistic growth scenario with a 47 percent lower CO_2-intensity compared to the 1993 level.

This reduction of CO_2-emissions per unit of output, however, is not sufficient to reduce total emissions (Figure A29) because this reduction is dominated by output growth. Here, we have a trade-off effect: On one hand, higher growth improves the CO_2-intensity, and thus, reduces the emissions per unit of production. On the other hand, higher growth is connected with an increased use of fossil fuels and, therefore, higher total emissions.

Because different assumptions about the future development determine the relative factor endowments over time, one would expect that the model reacts differently to an imposed policy shock since different levels of production and a different composition of factors of production and technology would lead to different reactions. Testing the dynamic specification against such a policy shock as the Kyoto Protocol, there are only minor quantitative differences in the policy results. The welfare effects (Figure A32) as well as the leakage effects (Figure A33) of the Kyoto Protocol look very similar over all three dynamic specifications. Hence, international spillovers are not much affected by different growth assumptions.

6 CONCLUDING REMARKS

For analyzing the impact of climate change and of international policies aimed at reducing such climate change on the international division of labor and on regional welfare the use of a disaggregated multi–sectoral, multi–regional dynamic computable general equilibrium model is appropriate. This paper has discussed the problems of defining a proper benchmark against which policy simulations and climate change impacts can be assessed. The results were discussed on the basis of the DART model, a recursive dynamic multi-regional trade model.

The different countries of the world economy apparently are not on a steady state growth path. Consequently, the standard identities of growth models can not be applied. Instead, one needs to determine plausible levels of key model parameters and make predictions about their likely changes over time. Crucial parameters in a recursively dynamic trade model are the forces determining technology, factor endowments, and factor shares. The role of exogenous technical progress, of savings rates, and of the development of human capital are discussed.

Computable general equilibrium models require large and detailed data sets, especially when a multi–regional framework is used. Besides problems of data availability, the quality of the data on which the model is calibrated can translate into implausible long–run growth processes. One of the most important, but also most critical, data concern the capital stocks in the different countries. The implications of adjustments to these stocks are discussed in the paper.

The DART model, as imposed here, is calibrated on the GTAP data set in a 11 region and 10 sector aggregation. It is shown how different qualities of labor can be considered in the model, namely via a human-capital augmented labor force. The development of the factor endowment of labor, measured in efficiency units, over time is given by the sum of the growth rate of total factor productivity, the population growth rate, and the growth rate of human capital in labor force. This approach allows to specify regionally differentiated growth perspectives for the labor endowment, and technological and knowledge spillovers.

Crucial parameters for physical capital accumulation are the capital stock to GDP ratio, the capital share, the gross rate of return on capital, and the investment rate. Since most of the regions are actually not on their balanced growth path, these figures differ widely among regions. In this paper a consistent data framework was derived which result in reasonable off-steady state GDP growth paths for several regions.

Given the base year data set and the assumptions about the dynamic parameters, i.e. the development of regional savings rates, of exogenous technological progress, and about the accumulation of human capital, the model produces the benchmark path for the 11 regions and 10 sectors each and the bilateral trade flows among all regions. The benchmark development is characterized by higher growth in the developing countries than in the industrialized countries. However, the growth is not sufficient for a catching-up of the Third World within the next

30 years. While the industrialized countries emit most of the worlds CO_2, the developing countries produce with higher CO_2-intensities which are declining with rising incomes. Nevertheless, total CO_2-emissions increase over time due to high growth in world's output. The development of relative factor endowments is rather different among regions as it can be seen in the development of relative factor prices. The region specific development of population, savings and investment, human capital development, and technical change simultaneously determines the emergence of comparative advantage of the model regions. As a general trend one can see a strengthening of already existing comparative advantages in the future.

An important outcome of the model for climate policy analysis are the CO_2-emissions. CO_2-emission stem from the combustion of fossil fuels. The model considers coal, natural gas, and refined oil, which is produced from crude oil, as emission relevant fuels. Besides demand, the important determinant of the use of fossil fuels is supply. The model contains no intertemporal framework for fossil fuel supply. Instead supply over time depends on current prices. The choice of the elasticity of supply for different fossil fuels is somewhat arbitrary. We have decided to calibrate the supply functions on the energy projections by IIASA and the WEC due to the lack of empirical data about the supply price elasticities. A sensitivity analysis has revealed that coal and crude oil supplies vary strongly with their own supply elasticity. Hence, further research on the empirical justification of the parameters, and on more sophisticated fossil fuel supply models is needed.

Furthermore, different assumptions about the growth perspectives and about the trade elasticities were tested. To summarize the results from the sensitivity analysis, the variation of Armington elasticities has not a large impact on the benchmark path which is mainly determined by the underlying dynamic factors driving human and physical capital accumulation. Hence, the change in comparative advantage in the benchmark is mainly propelled by the assumptions about dynamics and not so much by the degree of substitutability in demand. However, the reaction to a certain policy shock is dominated by the trade elasticities used, although the interaction with the dynamic setting remains important.

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8 APPENDIX

Table A1 — Production Structure by Region 1993 (in billion 1990 US$)

	CRU	COL	GAS	EGW	OIL	ISM	CPP	AGR	TRN	CDG	Y
NAM	7.6	3.3	5.6	16.6	16.4	45.5	73.7	68.4	254.0	103.1	630.2
WEU	2.3	2.3	2.5	17.6	22.2	75.5	105.4	117.0	309.2	153.2	755.8
PAO	0.5	0.5	0.7	9.2	7.9	48.4	55.1	56.9	159.3	119.4	394.2
MEA	14.3		1.6	1.4	5.0	3.6	5.5	10.7	15.5	13.2	56.8
PAS	1.6	0.2	1.5	3.0	5.1	13.4	14.8	28.9	31.3	28.9	93.6
CPA	2.0	3.2	0.2	3.6	2.2	6.4	5.7	20.4	14.3	15.0	47.0
IDI	0.4	0.7	0.2	1.5	1.1	1.8	2.3	11.7	6.2	5.2	18.4
LAM	5.7	0.1	0.8	3.2	5.9	14.0	16.8	38.1	43.7	23.7	97.6
FSU	1.3	0.8	1.2	2.0	1.1	4.9	6.3	7.7	17.2	10.1	50.5
AFR	2.3	1.6	0.2	1.9	1.1	2.8	3.2	12.4	8.0	5.1	25.6
ROW	4.2	2.0	0.7	2.9	1.4	9.9	12.7	28.6	33.0	20.1	86.2

Table A2 — Production Structure 1993 (in percent of total output)

	CRU	COL	GAS	EGW	OIL	ISM	CPP	AGR	TRN	CDG	Y
NAM	0.6	0.3	0.5	1.4	1.3	3.7	6.0	5.6	20.7	8.4	51.5
WEU	0.1	0.1	0.2	1.1	1.4	4.8	6.7	7.5	19.8	9.8	48.4
PAO	0.1	0.1	0.1	1.1	0.9	5.7	6.5	6.7	18.7	14.0	46.37
MEA	11.2	0.0	1.3	1.1	3.9	2.8	4.3	8.4	12.2	10.4	44.5
PAS	0.7	0.1	0.7	1.3	2.3	6.0	6.7	13.0	14.1	13.0	42.1
CPA	1.7	2.7	0.1	3.0	1.9	5.3	4.7	17.0	11.9	12.5	39.2
IDI	0.7	1.4	0.3	3.0	2.2	3.7	4.6	23.7	12.6	10.5	37.2
LAM	2.3	0.1	0.3	1.3	2.4	5.6	6.7	15.3	17.5	9.5	39.1
FSU	1.2	0.7	1.1	2.0	1.0	4.8	6.1	7.5	16.7	9.8	49.0
AFR	3.7	2.5	0.2	2.9	1.7	4.3	4.9	19.4	12.4	8.0	39.9
ROW	2.1	1.0	0.4	1.4	0.7	4.9	6.3	14.2	16.3	9.9	42.8

Table A3 — Sectoral Exports by Region 1993 (in billion 1990 US$)

	COL	GAS	EGW	OIL	ISM	CPP	AGR	TRN	Y
NAM	0.5	0.5	0.2	1.7	3.5	9.4	6.3	18.1	32.4
WEU	0.1	0.6	1.2	8.3	6.8	13.0	5.8	19.0	45.8
PAO	0.4	0.1		0.5	3.2	3.2	2.0	11.5	21.8
MEA		0.4	0.0	2.3	0.3	1.1	0.6	1.5	11.8
PAS	0.1	0.6	0.0	1.6	2.1	2.9	3.3	4.7	22.7
CPA	0.1		0.0	0.1	0.7	0.9	1.1	0.6	10.6
IDI	3.6		7.3	0.1	0.2	0.2	0.4	0.2	1.4
LAM	0.1	0.0	0.2	1.6	1.9	1.6	3.7	3.2	7.6
FSU	0.0	0.1	0.0	0.1	0.6	0.6	1.0	0.5	1.2
AFR	0.5	4.9	0.0	0.2	0.7	0.3	1.0	0.5	3.1
ROW	0.1	0.4	0.2	0.5	2.3	3.1	2.3	4.0	12.5

Table A4 — Export Structure 1993 (in percent of total exports)

	COL	GAS	EGW	OIL	ISM	CPP	AGR	TRN	Y
NAM	0.7	0.7	0.2	0.4	4.8	13.0	8.6	24.9	44.6
WEU	0.1	0.6	1.2	8.2	6.7	13.0	5.8	18.9	45.6
PAO	0.9	0.2		1.2	7.4	7.6	4.8	27.0	50.1
MEA		2.4	0.1	12.8	1.7	6.0	3.3	8.3	65.5
PAS	0.2	1.6	0.0	4.2	5.6	7.5	8.6	12.3	59.9
CPA	0.4		0.3	0.8	4.9	6.1	7.9	4.0	75.6
IDI	0.0		0.0	3.8	6.4	7.3	14.9	9.7	57.8
LAM	0.4	0.1	0.9	8.2	9.3	8.3	18.7	16.1	38.1
FSU	0.9	4.1	0.4	3.2	17.3	16.7	12.0	13.8	31.7
AFR	7.9	0.0	0.5	3.9	11.3	4.1	15.1	8.2	49.0
ROW	0.5	1.7	0.8	1.4	9.0	12.3	9.0	15.9	49.3

Table A5 — Primary Factor Supply – Factor Income 1993 (billion 1990 US$)

	Land	Labor	Capital	Rent
NAM	2.0	372.4	208.0	8.2
WEU	3.0	410.7	298.5	3.5
PAO	3.3	213.7	144.1	0.8
MEA	0.3	21.8	30.6	7.9
PAS	4.1	35.1	38.4	1.7
CPA	2.7	18.5	14.2	2.7
IDI	1.7	11.0	8.4	0.6
LAM	2.8	42.9	63.6	3.3
FSU	0.5	29.6	17.0	1.6
AFR	0.6	12.8	13.7	2.1
ROW	2.8	44.0	35.4	3.5

Table A6 — Factor Income Structure in Percent 1993

	Land	Labor	Capital	Rent
NAM	0.3	63.1	35.2	1.4
WEU	0.4	57.4	41.7	0.5
PAO	0.9	59.0	39.8	0.2
MEA	0.5	36.0	50.4	13.1
PAS	5.2	44.2	48.5	2.1
CPA	7.0	48.6	37.4	7.0
IDI	7.9	50.5	38.8	2.7
LAM	2.5	38.1	56.5	2.9
FSU	0.9	60.8	35.0	3.3
AFR	2.0	43.9	47.0	7.1
ROW	3.2	51.4	41.3	4.0

Table A7 — Production Structure (real) 2030 in Percent of Total Output

	CRU	COL	GAS	EGW	OIL	ISM	CPP	AGR	TRN	CDG	Y
NAM	0,4	0,2	0,5	1,3	0,5	4,0	6,5	5,9	19,9	8,9	51,9
WEU	0,1	0,1	0,2	1,1	0,7	5,2	7,1	7,5	20,1	10,2	47,9
PAO	0,0	0,1	0,1	0,9	0,4	6,3	7,2	7,4	20,5	10,0	47,1
MEA	2,7	0,0	0,9	0,6	1,2	3,4	5,3	10,0	12,9	13,0	49,9
PAS	0,2	0,0	0,4	1,0	1,1	8,8	7,3	9,9	16,1	8,8	46,3
CPA	0,4	0,9	0,1	2,4	0,5	2,3	4,5	21,0	14,7	8,5	44,8
IDI	0,2	0,5	0,3	2,2	0,7	3,9	3,9	23,4	13,1	10,5	41,3
LAM	0,7	0,0	0,3	1,0	0,9	6,4	7,2	14,7	16,5	10,2	42,1
FSU	0,4	0,3	0,9	1,6	0,3	4,8	5,8	6,7	17,4	10,4	51,3
AFR	0,8	0,8	0,2	1,7	0,8	2,5	5,1	25,2	13,7	8,5	40,6
ROW	0,7	0,4	0,2	0,8	0,1	5,4	5,4	12,2	17,9	10,7	46,3

Table A8 — Production Structure (values) 2030 in Percent of Total Output

	CRU	COL	GAS	EGW	OIL	ISM	CPP	AGR	TRN	CDG	Y
NAM	2,9	0,6	0,6	1,5	2,8	3,8	6,3	5,5	20,8	8,2	47,1
WEU	0,6	0,3	0,3	1,6	3,8	5,2	7,2	7,3	19,9	9,5	44,4
PAO	0,3	0,2	0,1	1,6	2,2	6,2	7,4	7,6	20,6	9,5	44,4
MEA	16,4	0,0	1,6	1,7	6,1	3,0	4,5	8,3	11,4	10,2	36,7
PAS	1,2	0,1	0,8	2,0	5,7	8,6	8,0	11,8	14,6	7,8	39,3
CPA	3,0	4,8	0,3	4,0	3,7	4,5	5,4	17,8	12,2	7,2	36,9
IDI	1,7	3,3	0,5	4,3	4,4	4,8	4,9	21,5	12,1	9,0	33,5
LAM	5,0	0,1	0,5	1,6	4,8	6,0	6,9	14,4	16,7	8,9	35,0
FSU	3,0	1,5	1,7	2,9	2,1	5,3	6,3	6,9	15,9	9,2	45,1
AFR	6,0	4,2	0,4	4,1	3,8	3,5	5,3	19,1	12,4	7,4	33,9
ROW	4,9	1,7	0,3	2,0	0,7	5,6	6,0	13,2	16,6	9,4	39,5

Table A9 — Export Structure (quantities) 2030 in Percent of Total Exports*

	CRU	COL	GAS	EGW	OIL	ISM	CPP	AGR	TRN	Y	Total
NAM	0,3	1,0	0,9	0,3	1,0	6,0	15,9	10,0	22,5	42,2	100
WEU	0,0	0,1	0,7	1,5	4,9	8,6	14,8	6,4	20,3	42,6	100
PAO	0,0	0,7	0,1	0,0	0,5	10,3	9,3	5,0	28,8	45,3	100
MEA	12,1	0,0	1,3	0,0	3,3	2,0	7,1	3,6	7,1	63,6	100
PAS	0,0	0,0	0,8	0,0	1,9	8,7	7,6	5,0	14,6	61,3	100
CPA	0,0	0,1	0,0	0,2	0,2	1,1	4,5	10,7	5,4	77,9	100
IDI	0,0	0,0	0,0	0,0	0,9	5,0	4,5	15,9	10,3	63,3	100
LAM	0,9	0,2	0,1	0,6	3,1	12,2	9,5	17,5	14,7	41,2	100
FSU	3,9	0,4	2,7	0,2	0,6	17,2	16,0	10,4	15,8	32,7	100
AFR	3,8	1,8	0,0	0,1	2,1	4,9	4,1	25,0	9,3	48,7	100
ROW	4,5	0,3	0,8	0,2	0,2	9,3	9,3	6,7	18,0	50,8	100
World	1,7	0,3	0,6	0,4	2,2	7,5	10,2	8,0	16,7	52,3	100

*Crude Oil (CRU) only net exports.

Table A10 — Export Share in World Exports 2030 by Region and Commodity (quantities, in percent)

	CRU	COL	GAS	EGW	OIL	ISM	CPP	AGR	TRN	Y	Total
NAM	2,1	39,4	16,4	8,7	5,4	9,7	18,8	15,1	16,3	9,8	12,1
WEU	0,0	7,6	24,6	74,2	47,8	24,5	31,1	17,3	26,1	17,5	21,5
PAO	0,0	19,0	1,1	0,0	1,9	11,4	7,5	5,2	14,3	7,2	8,3
MEA	60,8	0,0	16,7	0,2	12,6	2,2	5,8	3,8	3,6	10,2	8,4
PAS	0,0	2,6	24,8	0,1	18,3	24,1	15,5	13,0	18,2	24,4	20,8
CPA	0,0	2,2	0,0	3,0	0,6	1,2	3,7	11,2	2,7	12,5	8,4
IDI	0,0	0,0	0,0	0,0	0,5	0,8	0,5	2,3	0,7	1,4	1,2
LAM	3,6	3,3	0,9	8,6	9,2	10,6	6,1	14,2	5,7	5,1	6,5
FSU	2,6	1,3	4,7	0,6	0,3	2,5	1,7	1,4	1,1	0,7	1,1
AFR	6,5	16,3	0,0	0,8	2,7	1,9	1,2	8,9	1,6	2,6	2,8
ROW	24,3	8,3	10,6	3,7	0,6	11,1	8,2	7,5	9,7	8,7	8,9
World	100	100	100	100	100	100	100	100	100	100	100

Table A11 — Export Structure (values) 2030 in Percent of Total Exports

	CRU	COL	GAS	EGW	OIL	ISM	CPP	AGR	TRN	Y	Total
NAM	1,9	3,2	1,3	0,4	5,1	5,9	15,5	9,5	21,9	35,4	100
WEU	0,0	0,4	1,1	2,2	22,4	7,6	12,9	5,4	16,8	31,2	100
PAO	0,0	2,7	0,1	0,0	2,7	11,4	9,8	5,0	28,6	39,7	100
MEA	49,2	0,0	1,2	0,0	9,9	1,2	3,9	1,9	3,7	29,0	100
PAS	0,0	0,2	1,3	0,0	10,3	9,1	8,2	5,3	13,9	51,7	100
CPA	0,0	0,4	0,0	0,3	1,0	1,7	5,7	11,4	5,8	73,6	100
IDI	0,0	0,0	0,0	0,0	5,1	5,9	5,5	16,7	10,6	56,3	100
LAM	5,9	0,5	0,1	0,8	14,2	11,1	8,5	15,1	13,1	30,6	100
FSU	22,0	1,1	3,6	0,3	2,9	14,9	13,5	8,2	11,7	22,0	100
AFR	22,3	5,9	0,0	0,2	8,4	4,5	3,4	16,8	6,8	31,7	100
ROW	26,8	1,0	1,1	0,3	0,8	7,8	8,1	5,5	13,9	34,8	100
World	10,5	1,1	0,9	0,7	10,5	7,0	9,5	6,9	14,5	38,5	100

Table A12 — Import Structure (quantities) 2030 in Percent of Total Imports

	CRU	COL	GAS	EGW	OIL	ISM	CPP	AGR	TRN	Y	Total
NAM	0,0	0,0	0,3	0,0	0,6	3,6	6,0	4,2	15,8	69,5	100
WEU	2,8	0,7	1,7	0,7	2,0	4,0	7,7	7,9	14,4	57,9	100
PAO	2,1	1,1	4,9	0,0	1,5	2,8	5,5	18,8	17,8	45,4	100
MEA	0,0	0,1	0,1	0,1	1,0	8,0	8,3	10,7	24,1	47,6	100
PAS	3,2	0,9	0,8	0,0	1,0	7,7	12,7	16,2	7,7	49,7	100
CPA	0,5	0,6	0,0	0,0	1,2	31,0	18,4	3,0	4,3	40,9	100
IDI	6,0	1,5	0,0	0,2	2,7	18,5	29,8	3,2	7,0	31,0	100
LAM	0,0	0,3	0,3	0,6	1,1	5,6	12,5	8,3	28,3	43,0	100
FSU	0,0	0,0	1,0	0,0	0,8	5,0	8,3	23,9	11,3	49,6	100
AFR	0,0	0,2	0,0	0,8	0,7	15,5	13,1	5,5	27,0	37,2	100
ROW	0,0	0,2	1,1	1,2	5,6	7,6	15,8	10,5	11,8	46,1	100
World	1,4	0,5	1,1	0,4	1,7	7,7	10,3	9,8	15,1	52,1	100

Table A13 — Import Share in World Imports 2030 by Region and Commodity (quantities, in percent)

	CRU	COL	GAS	EGW	OIL	ISM	CPP	AGR	TRN	Y	Total
NAM	0,0	0,7	4,2	2,0	5,5	7,2	8,9	6,6	16,1	20,4	15,3
WEU	45,4	30,1	36,6	45,7	27,7	11,7	16,9	18,3	21,5	25,1	22,5
PAO	11,0	16,2	33,8	0,0	6,7	2,7	3,9	13,9	8,6	6,3	7,3
MEA	0,0	1,5	0,5	3,3	6,5	10,8	8,3	11,3	16,5	9,5	10,4
PAS	37,1	30,1	12,6	0,6	10,1	16,2	19,8	26,6	8,2	15,4	16,1
CPA	2,6	9,0	0,0	0,8	5,0	28,7	12,7	2,2	2,0	5,6	7,2
IDI	3,8	2,7	0,0	0,4	1,4	2,1	2,5	0,3	0,4	0,5	0,9
LAM	0,0	4,9	1,7	11,2	4,9	5,2	8,7	6,1	13,5	5,9	7,2
FSU	0,0	0,0	1,5	0,0	0,8	1,0	1,2	3,6	1,1	1,4	1,5
AFR	0,0	1,0	0,0	6,2	1,2	5,7	3,6	1,6	5,1	2,0	2,9
ROW	0,0	3,9	9,0	29,8	30,0	8,7	13,5	9,5	6,9	7,8	8,8
World	100	100	100	100	100	100	100	100	100	100	100

Table A14 — Import Structure (values) 2030 in Percent of Total Imports

	CRU	COL	GAS	EGW	OIL	ISM	CPP	AGR	TRN	Y	Total
NAM	0,0	0,1	0,5	0,1	3,3	4,1	6,8	4,4	17,3	63,5	100
WEU	16,8	2,0	2,4	0,9	8,9	3,5	6,8	6,3	11,8	40,8	100
PAO	13,0	3,5	6,7	0,0	6,7	2,5	4,9	15,8	14,7	32,3	100
MEA	0,0	0,3	0,1	0,2	5,8	8,5	8,7	10,5	24,4	41,5	100
PAS	19,1	2,8	1,1	0,0	4,5	6,8	11,0	13,1	6,4	35,2	100
CPA	3,5	2,2	0,0	0,1	5,7	31,1	18,1	2,8	4,0	32,5	100
IDI	28,5	3,7	0,0	0,2	9,8	13,0	20,5	2,1	4,5	17,7	100
LAM	0,0	1,1	0,4	1,0	6,1	5,7	12,8	8,1	27,9	36,8	100
FSU	0,0	0,0	1,3	0,0	2,9	5,5	9,2	24,8	11,8	44,5	100
AFR	0,0	0,6	0,0	1,4	4,0	16,5	13,7	5,3	26,5	32,0	100
ROW	0,0	0,6	1,5	1,8	24,8	6,7	13,7	8,5	9,7	32,8	100
World	9,0	1,6	1,5	0,5	7,9	7,3	9,8	8,6	13,6	40,1	100

Table A15 — Income Shares –Factor Income Structure 2030 (in percent)

	Land	Labor	Capital	Rent
NAM	0,3	59,6	33,2	6,9
WEU	0,4	56,9	40,7	2,0
PAO	1,1	59,1	38,8	1,1
MEA	0,5	28,1	38,9	32,4
PAS	5,7	42,6	46,7	4,9
CPA	8,1	39,9	26,3	25,7
IDI	8,1	45,9	34,3	11,6
LAM	2,5	34,7	51,5	11,2
FSU	0,9	56,5	32,5	10,1
AFR	1,9	37,5	39,7	21,0
ROW	3,1	45,7	36,6	14,6

Table A16 — Revealed Comparative Advantage (RCA)

	Oil Products		Other manufactures and services		Transport industries		Iron, steel and minerals		Chemicals, plastics and paper		Agriculture	
WEU	0.20[a]	0.52[b]	-0.04	-0.20	0.14	0.15	0.18	0.33	0.24	0.33	-0.39	-0.24
NAM	0.54	0.43	-0.30	-0.41	0.41	0.36	-0.24	-0.01	0.31	0.51	0.45	0.75
PAO	-1.17	-1.10	0.30	0.24	0.31	0.37	0.51	0.86	-0.02	0.22	-1.39	-1.26
FSU	3.10	1.23	-0.38	-0.42	-0.20	-0.06	1.37	1.34	0.72	0.66	-0.69	-0.69
MEA	1.76	1.42	0.31	0.31	-0.96	-1.07	-1.56	-1.42	-0.41	-0.27	-1.17	-1.00
CPA	-0.74	-1.40	0.25	0.51	-0.93	-0.31	-0.49	-1.68	-0.86	-0.99	0.22	-0.05
PAS	0.50	0.70	0.11	0.14	0.05	0.36	-0.46	-0.21	-0.36	-0.37	-0.21	-0.78
IDI	-0.44	-0.72	0.23	0.40	-0.11	0.13	-0.62	-0.79	-0.95	-1.22	0.99	1.12
LAM	1.00	1.02	-0.12	-0.13	-0.41	-0.56	0.32	0.47	-0.50	-0.45	0.86	0.86
AFR	0.28	0.68	0.28	0.18	-1.31	-1.30	0.50	0.10	-1.06	-1.13	0.35	0.99
ROW	-2.12	-2.82	0.11	0.19	0.08	0.32	0.22	0.34	-0.03	-0.09	0.12	0.05

[a]1993 Benchmark / [b]2010 Benchmark

Figure A1 — Per Capita Income by Region

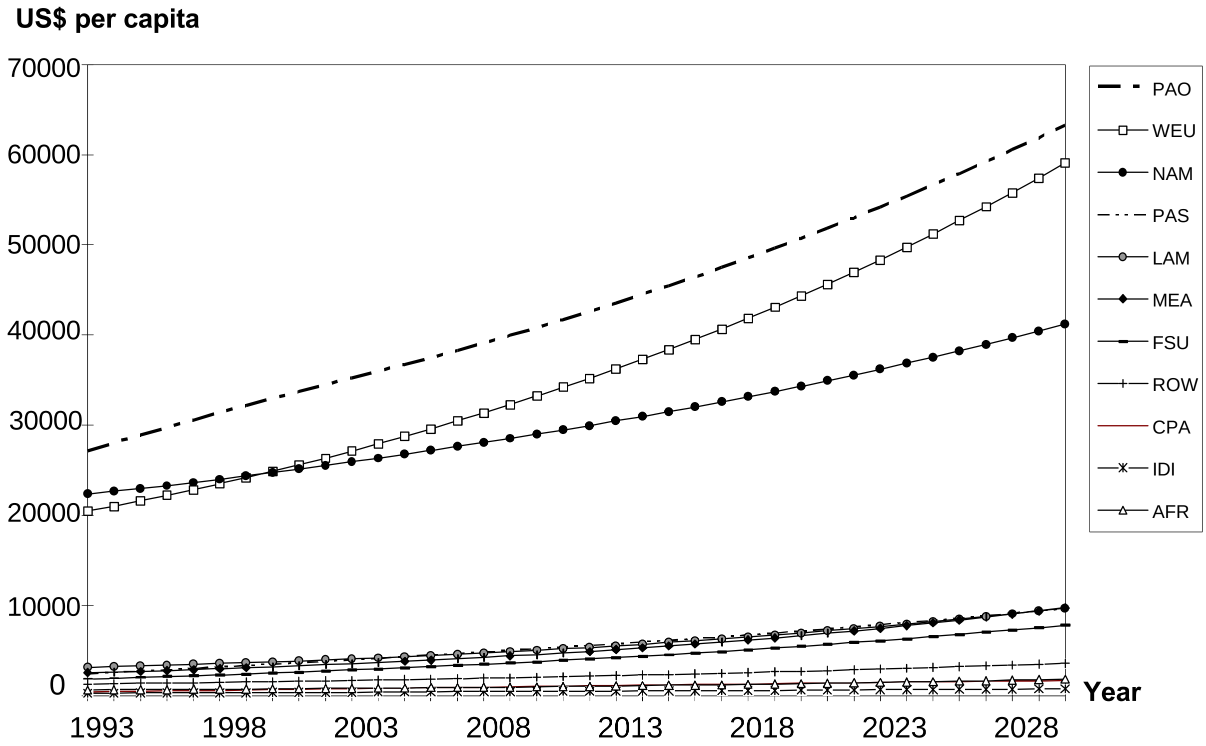

Figure A2 — CO_2-Emissions

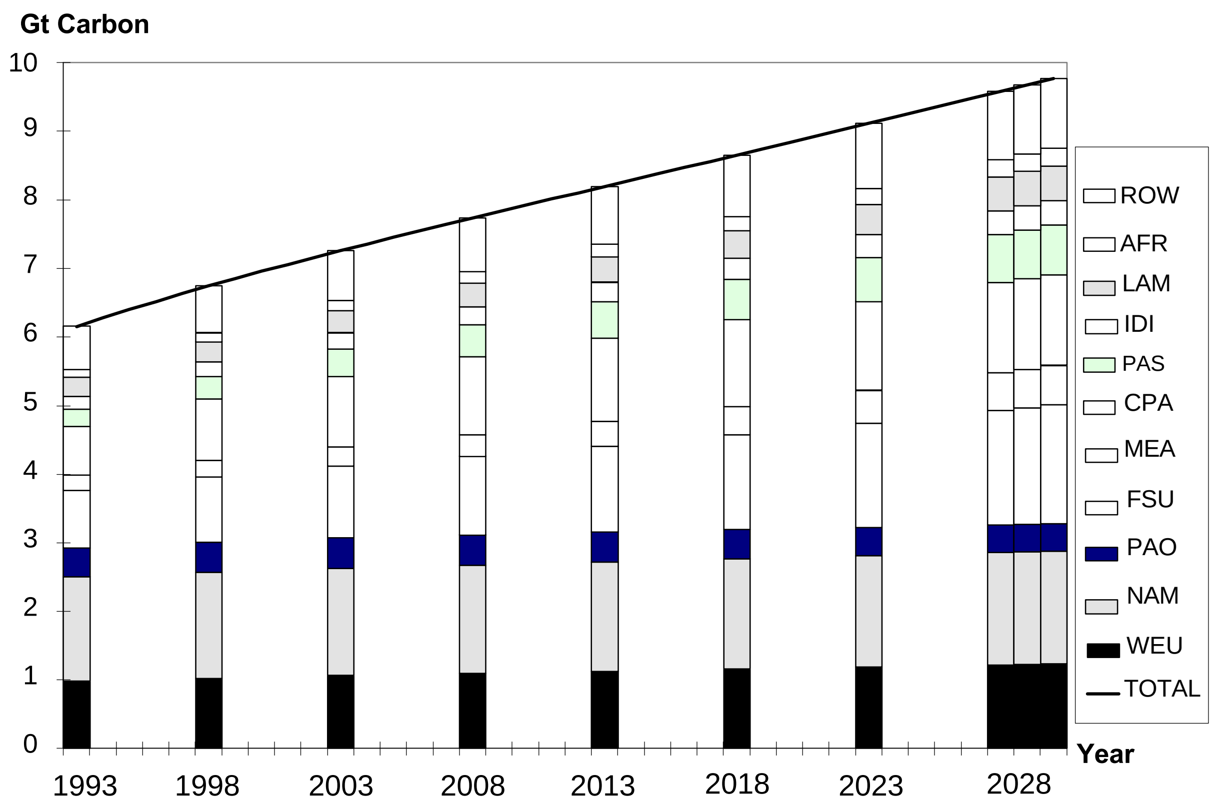

Figure A3 — Index CO_2 Emissions

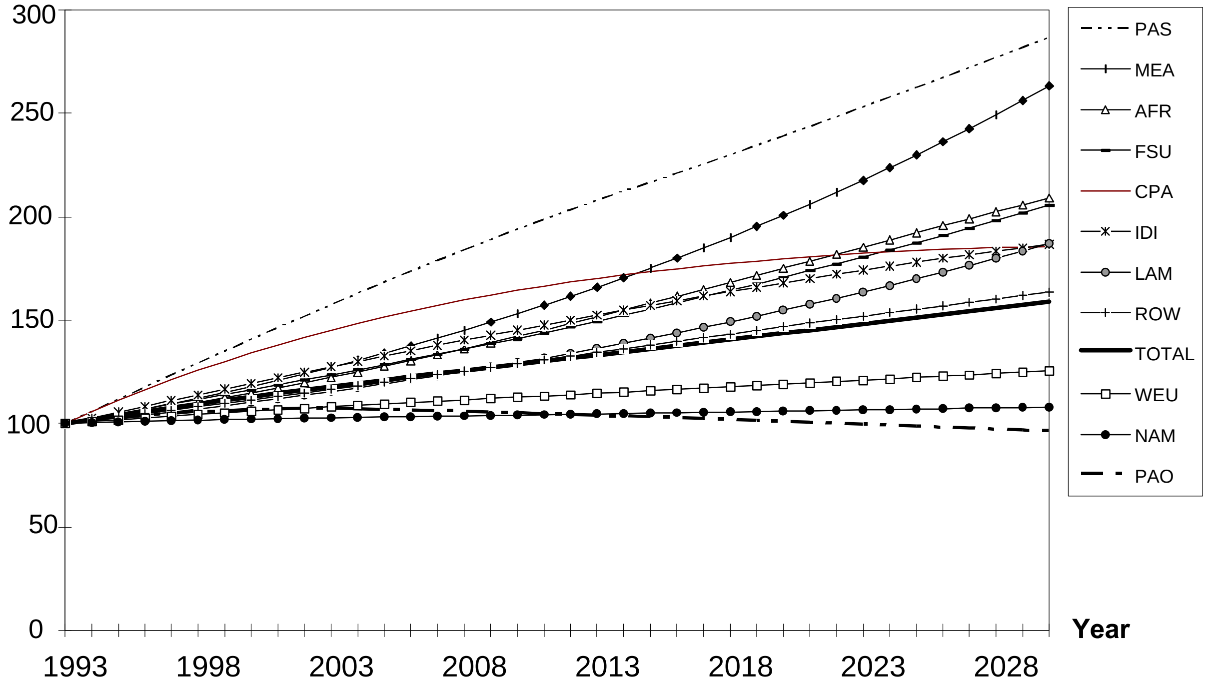

Figure A4 — Per-Capita CO_2 Emissions

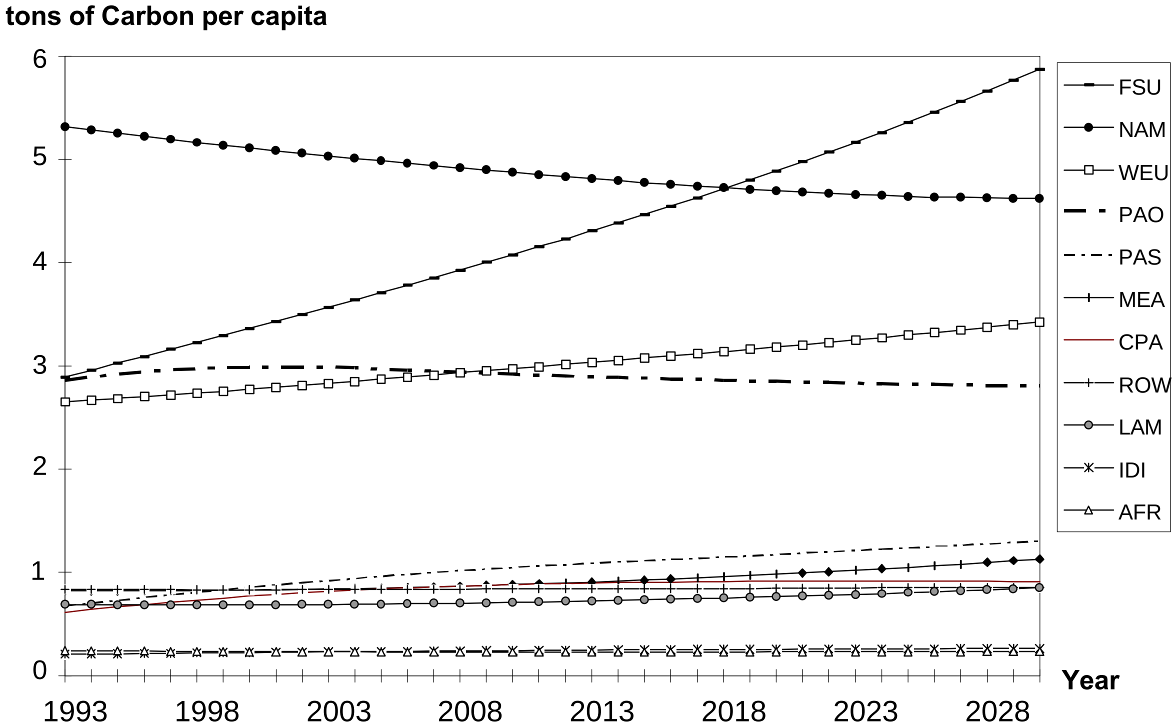

Figure A5 — CO_2-Intensities Major Regions

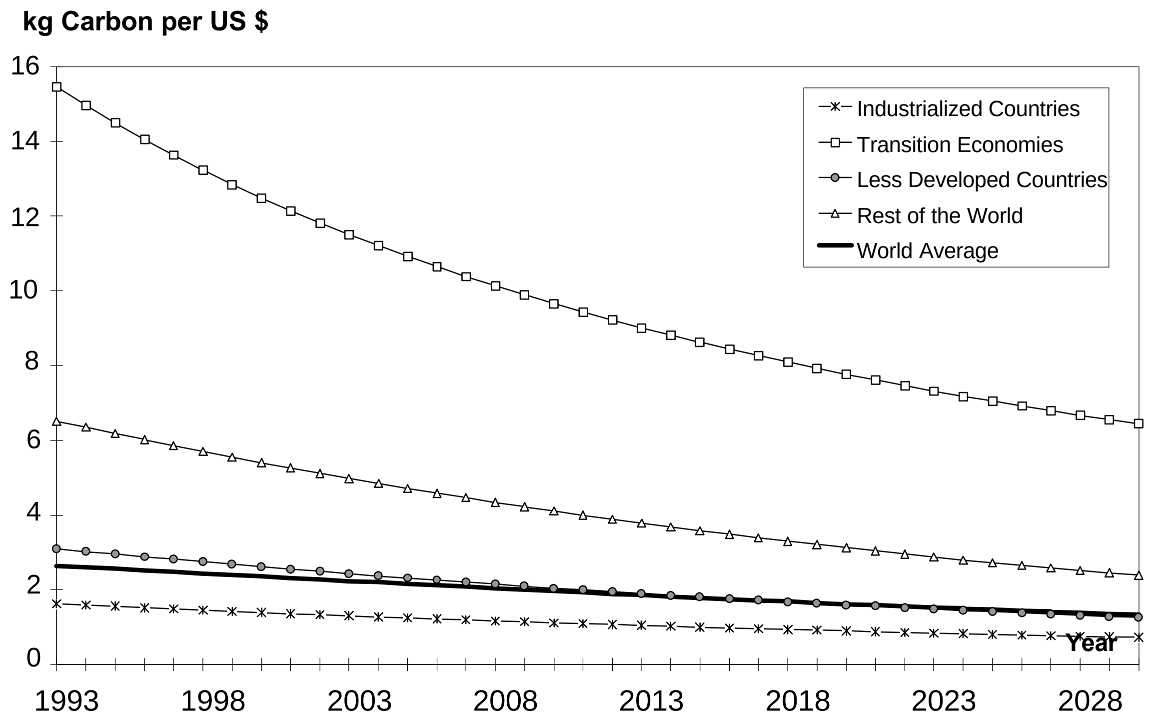

Figure A6 — Growth Rate Per Capita Income

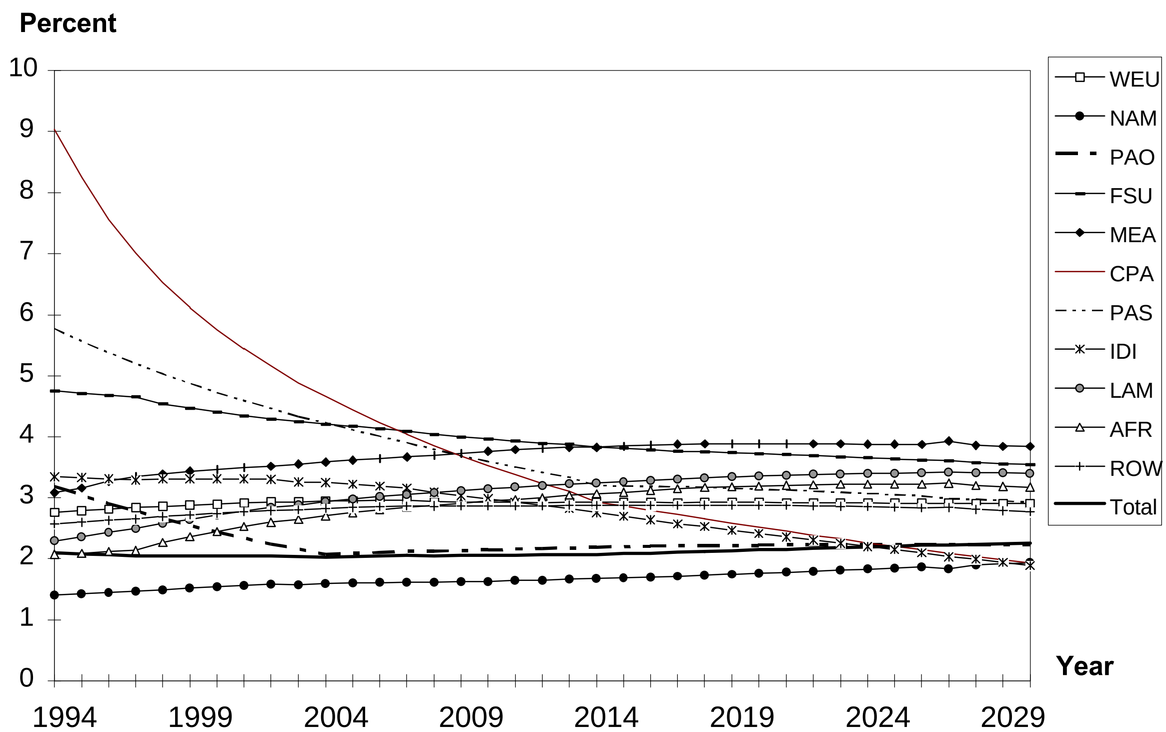

Figure A7 — Relative Factor Prices

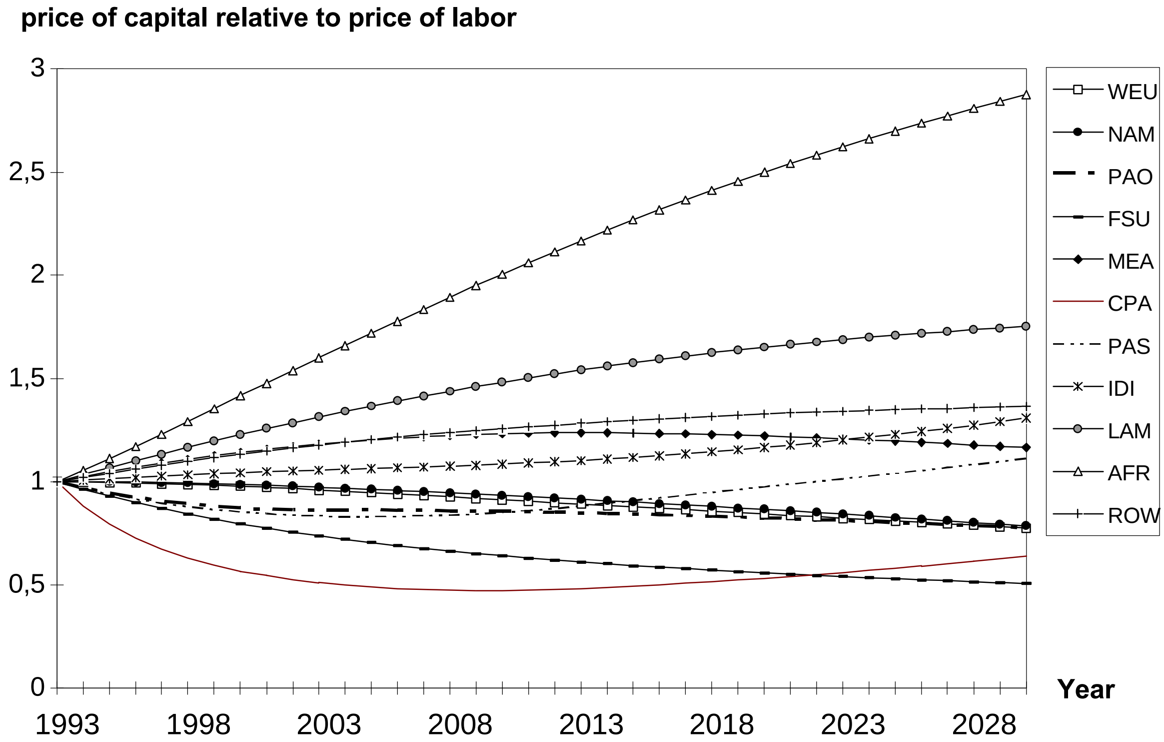

Figure A8 — Revealed Comparative Advantage (RCA) – Industrial Countries for 1993 and 2010

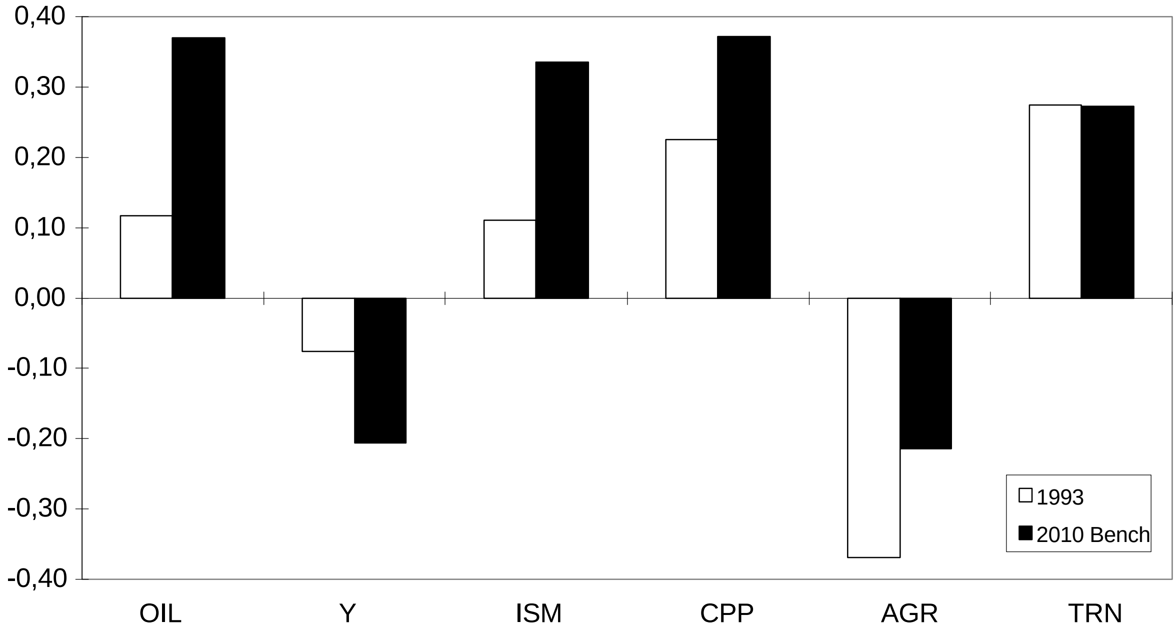

Figure A9 — Revealed Comparative Advantage (RCA) – Developing Countries for 1993 and 2010

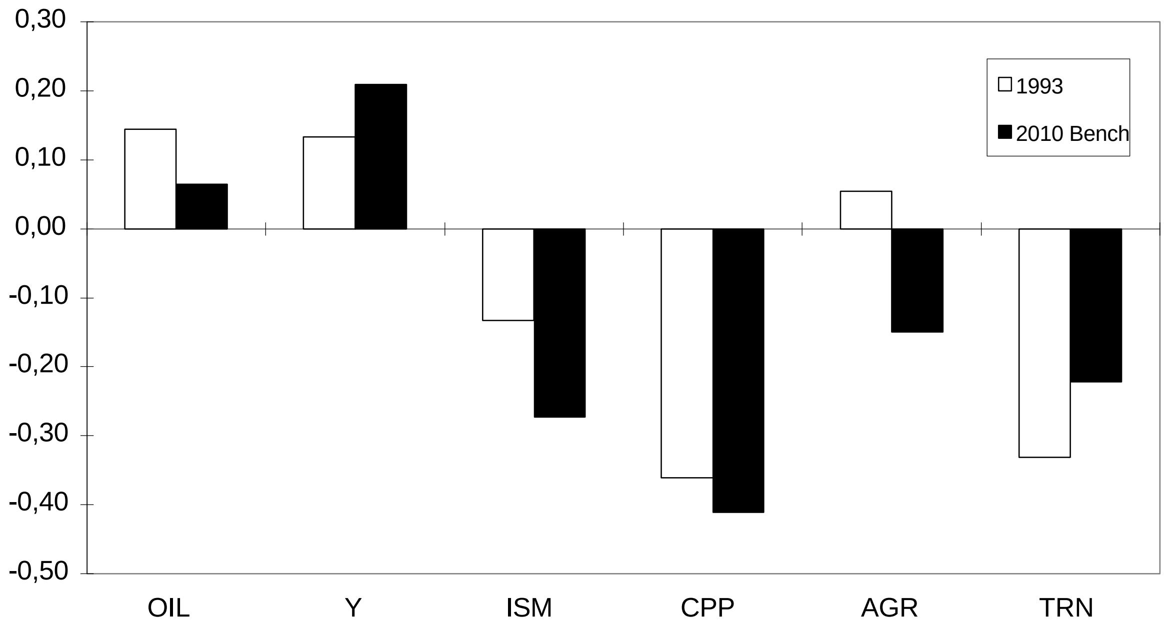

Figure A10 — Variation of Fossil Fuel Supply Elasticity - Direct Effects

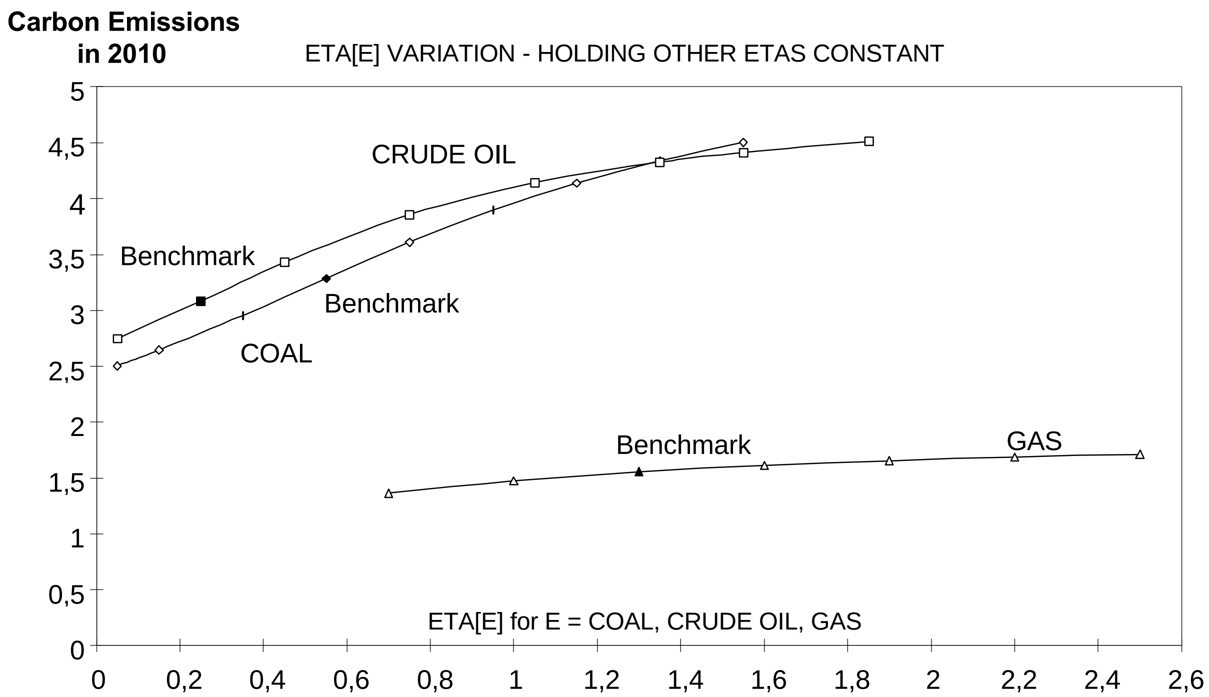

Figure A11 — Variation of Gas Supply Elasticities - Cross Effects (Eta [Coal]=0.55 / Eta [Oil]=0.25)

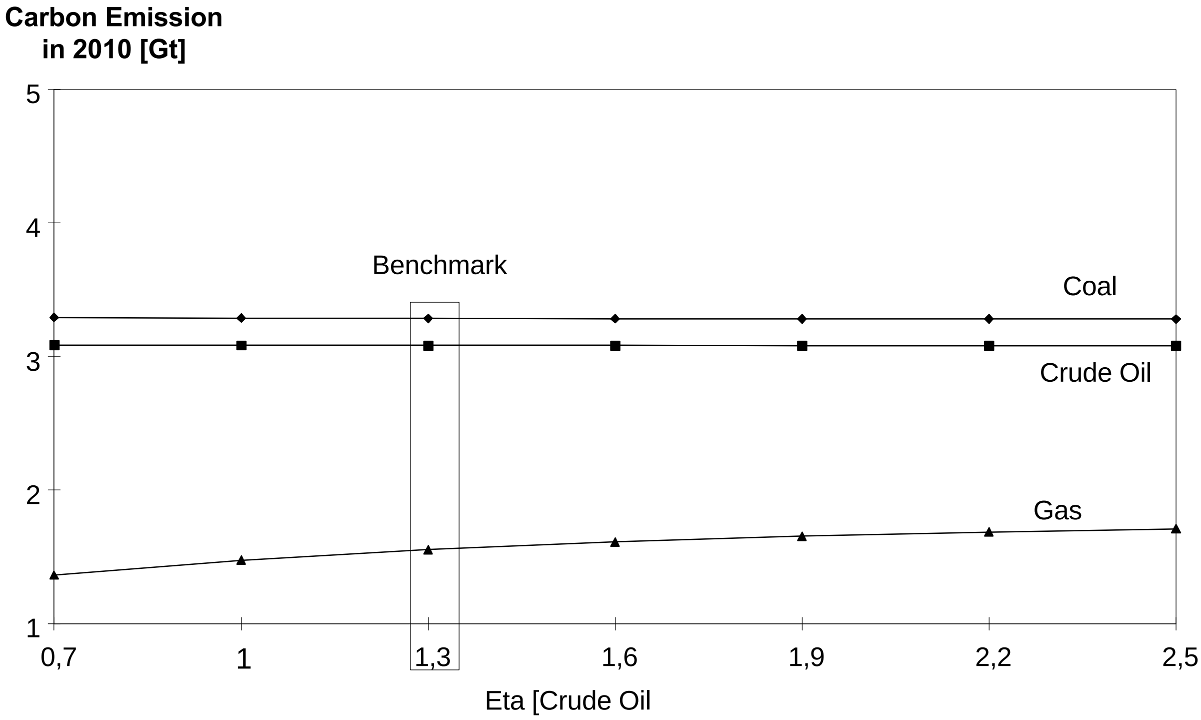

Figure A12 — Variation of the Crude Oil Supply Elasticity - Cross Effects (Eta[Coal]=0.55 / Eta[Gas]=1.3)

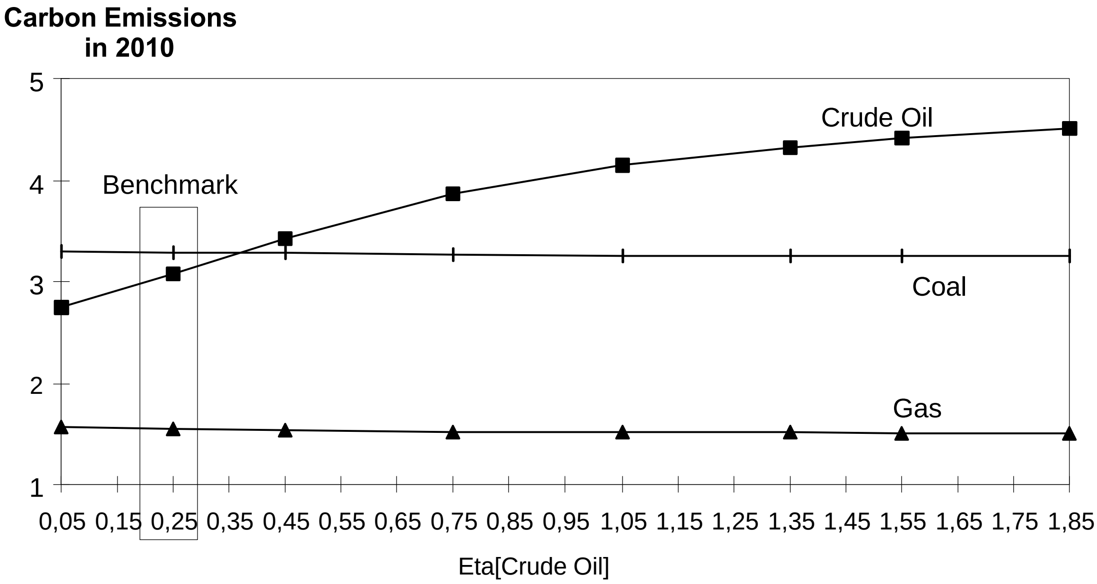

Figure A13 — Variation of the Coal Supply Elasticity - Cross Effects (Eta[Gas]=1.3 / Eta[Crude Oil]=0.25)

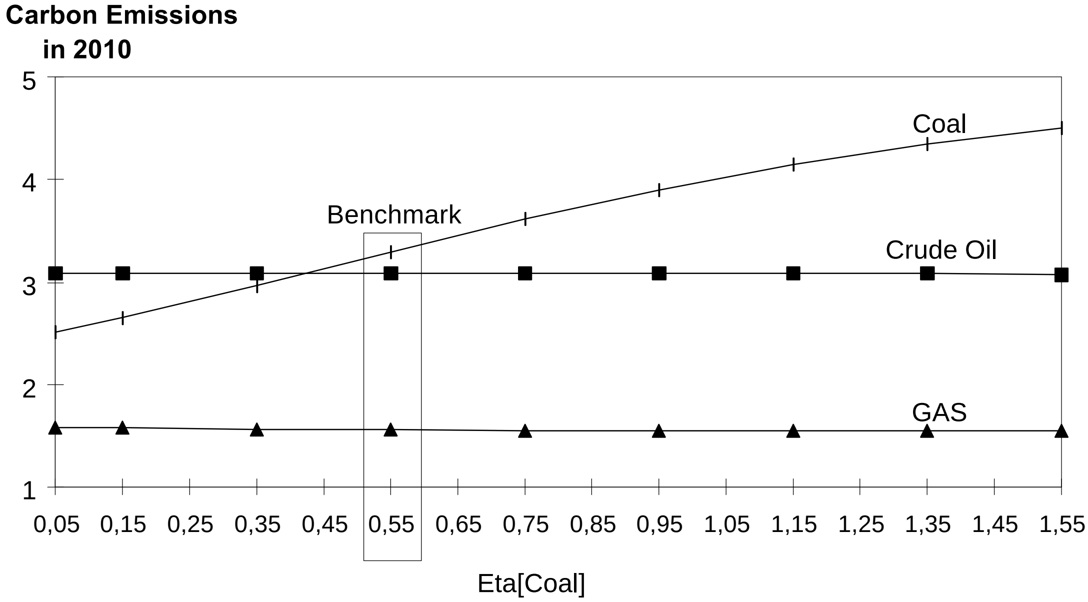

Figure A14 — Variation of Export Shares in ICs in 2010 Depending on the Armington Elasticities

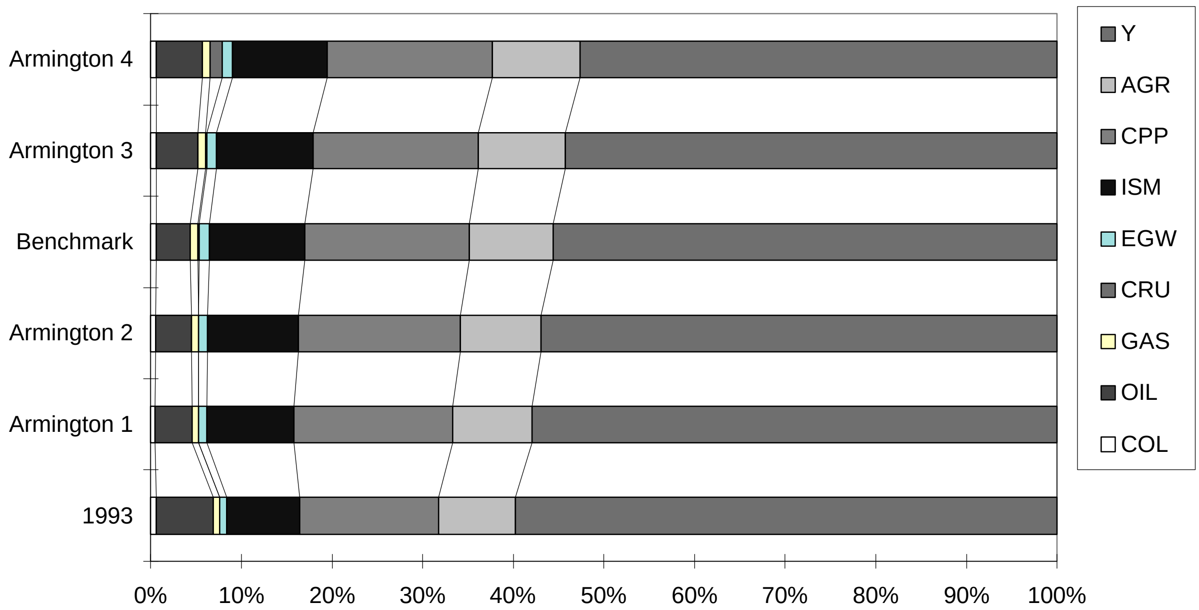

Figure A15 — Variation of Import Shares in ICs in 2010 Depending on the Armington Elasticities

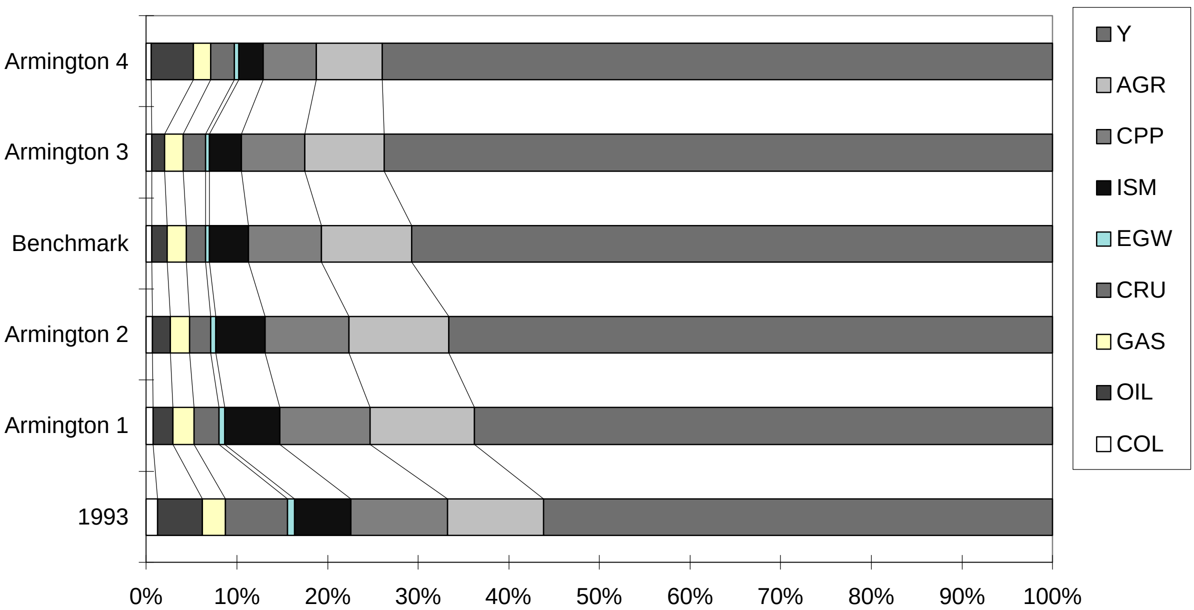

Figure A16 — Variation of Export Shares in LDCs in 2010 Depending on the Armington Elasticities

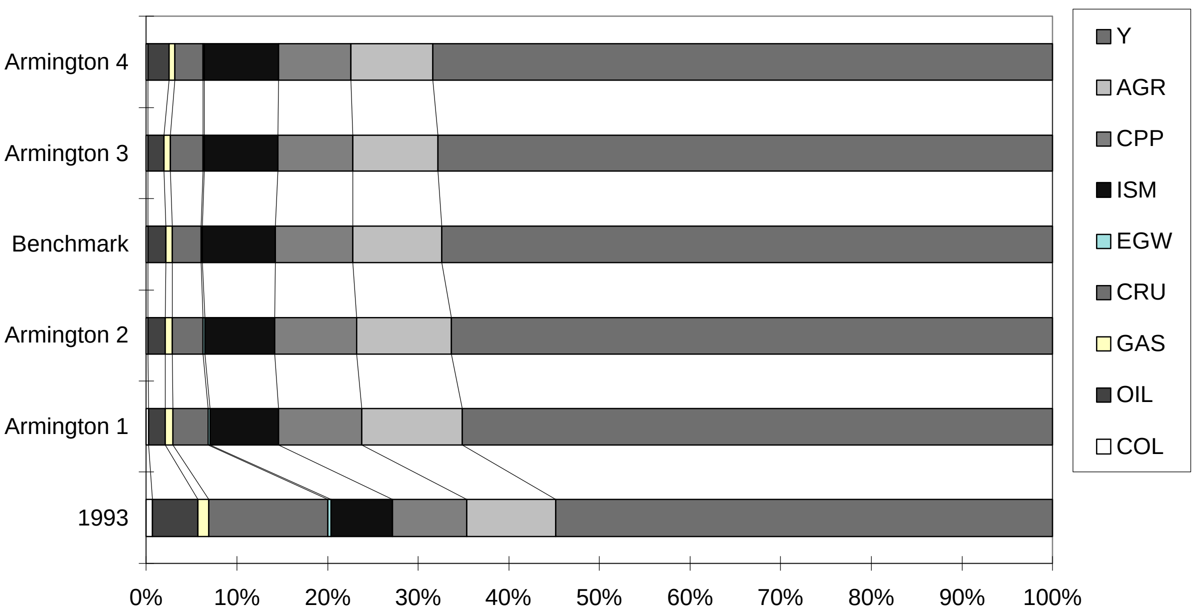

Figure A17 — Variation of Import Shares in LDCs in 2010 Depending on the Armington Elasticities

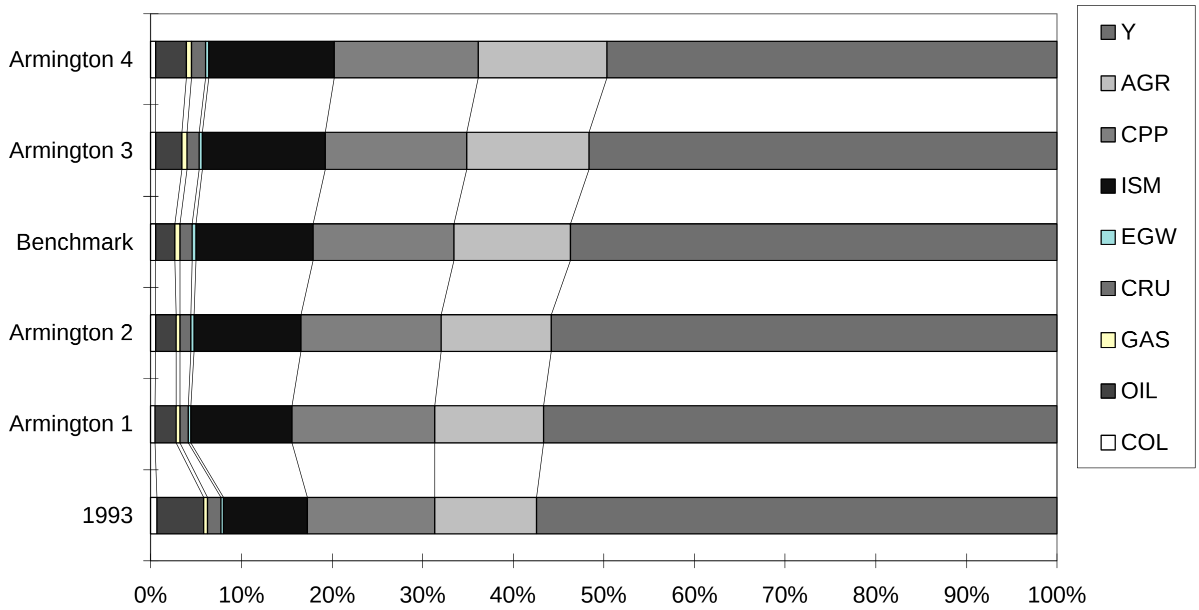

Figure A18 — Variation of Export Levels in ICs Depending on the Armington Elasticity in Million US$ in 2010

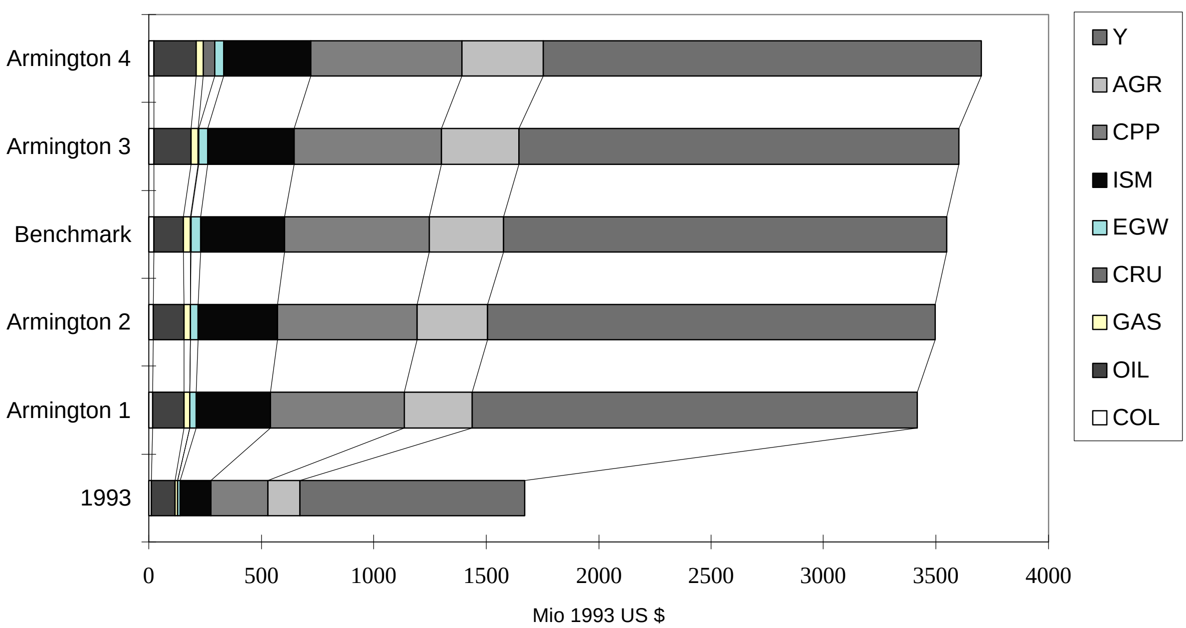

Figure A19 — Variation of Export Levels in LDCs Depending on the Armington Elasticity in Million US$ in 2010

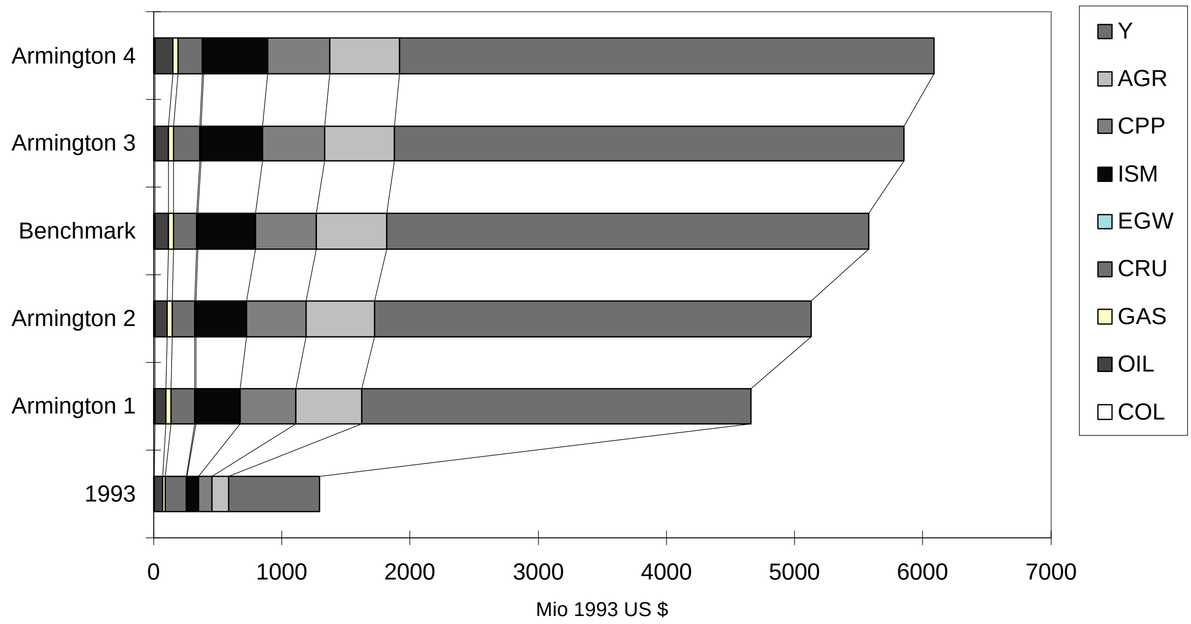

Figure A20 — Variation of Import Levels in ICs depending on the Armington Elasticity in Million US$ in 2010

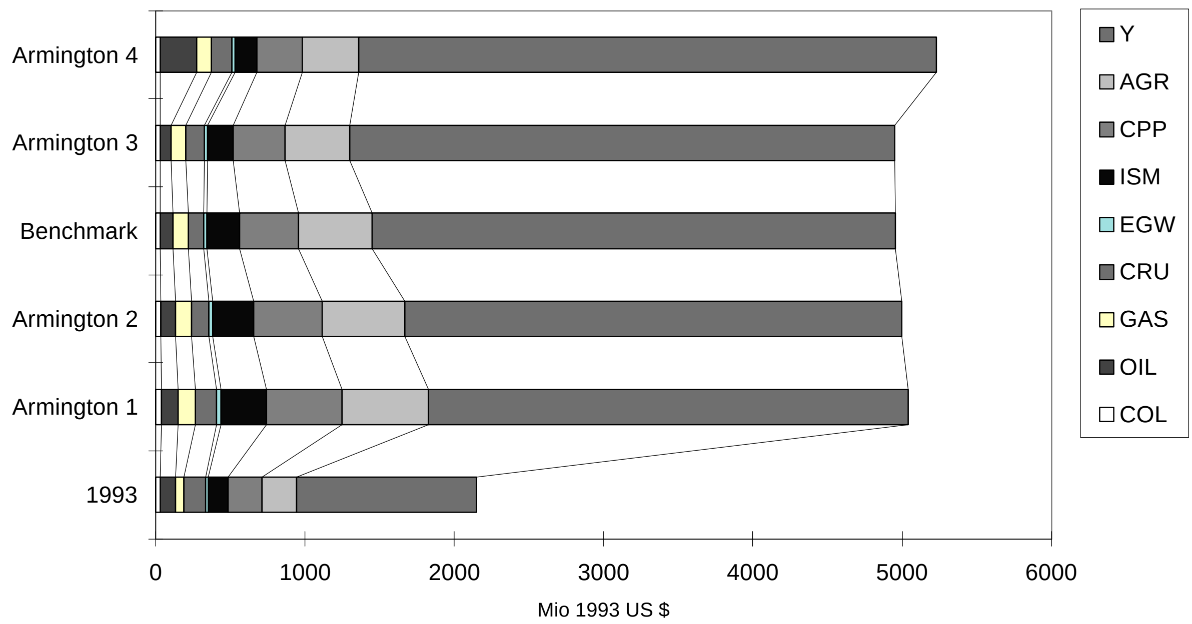

Figure A21 — Variation of Import Levels in LDCs Depending on the Armington Elasticity in Million US$ in 2010

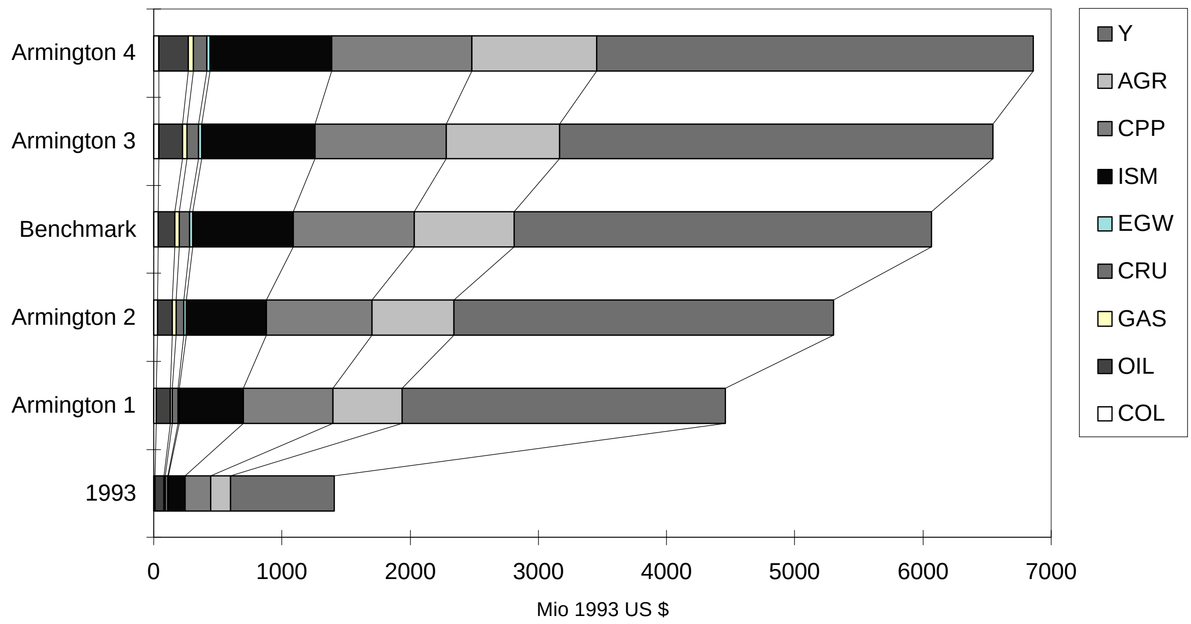

Figure A22 — Comparison of Welfare Effects of the Kyoto Protocol in 2010 Over All Armington Scenarios

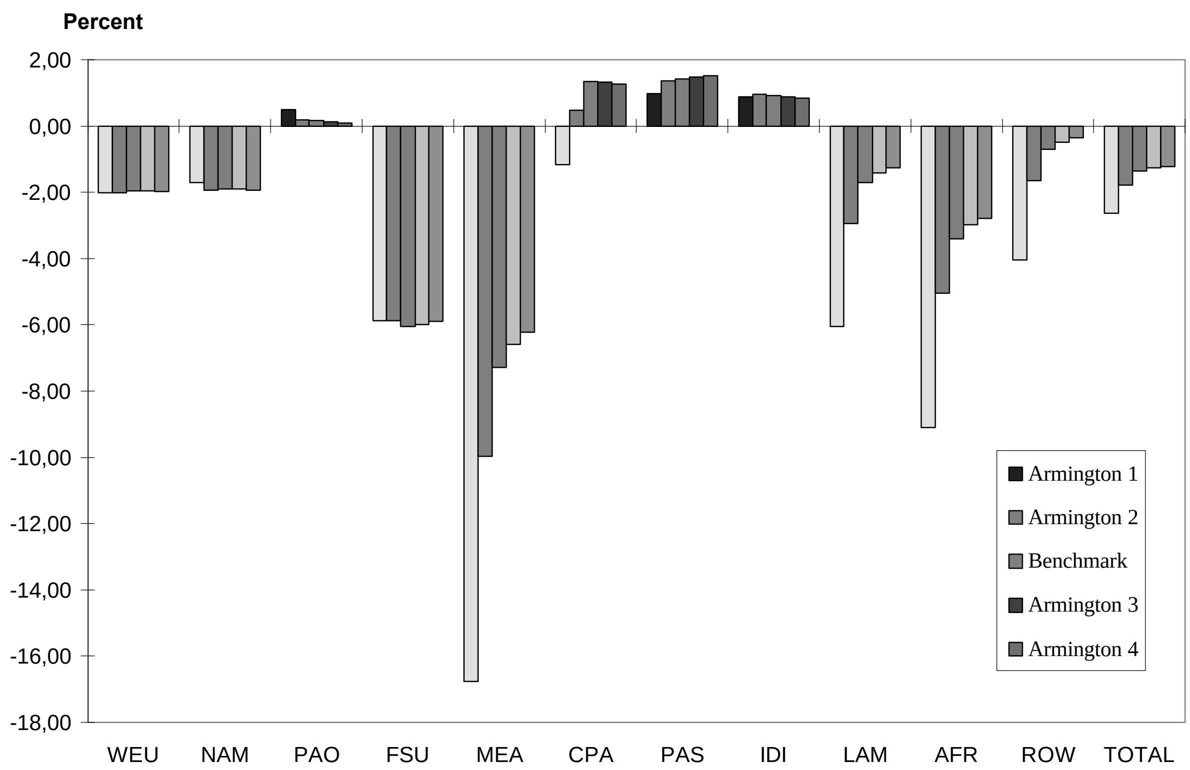

Figure A23 — Percentage Change in Relative Factor Prices Pessimistic Growth Scenario Versus Benchmark Scenario

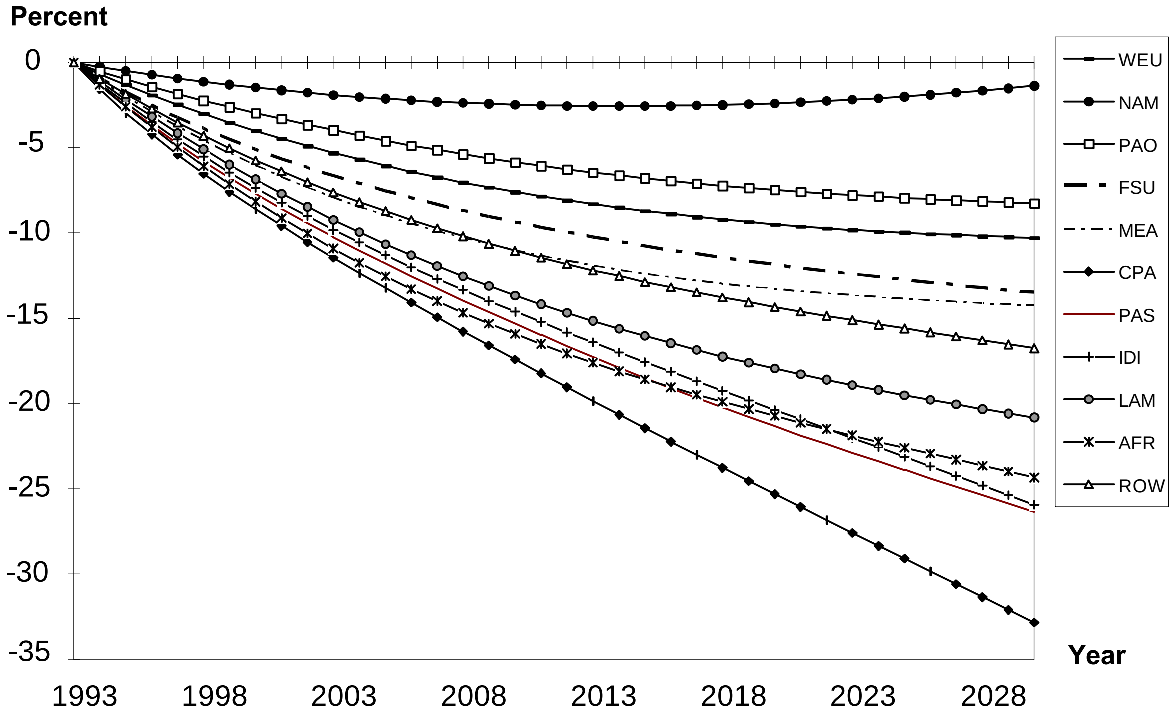

Figure A24 — Percentage Change in Relative Factor Price (Capital to Labor Ratio) - Savings Versus Benchmark Scenario

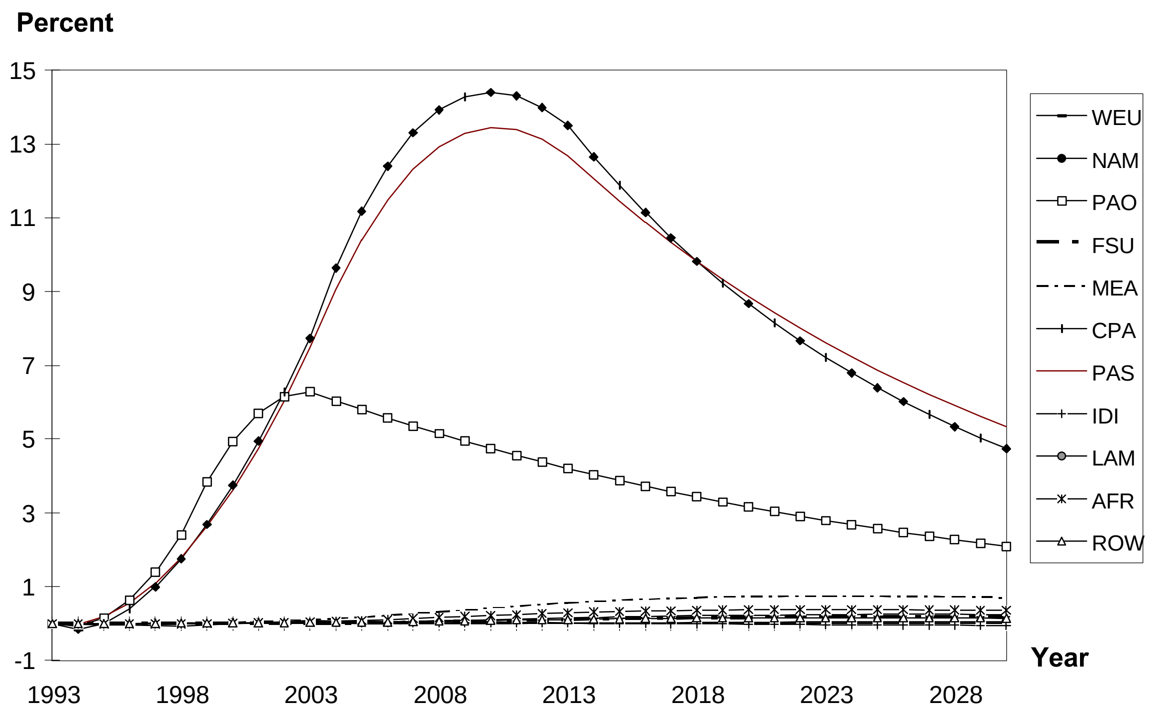

Figure A25 — Growth Rate of Per Capita Income in Percent - Sensitivity Analysis Pessimistic Growth Scenario

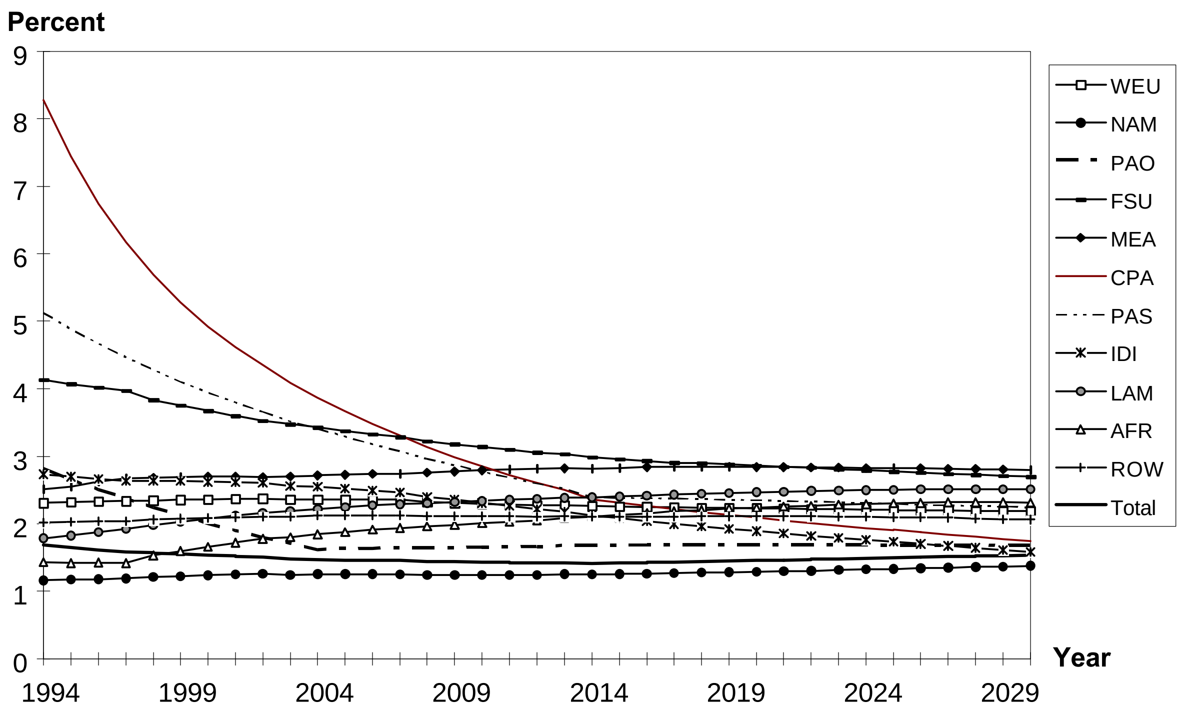

Figure A26 — Growth Rate of Per Capita Incomes in Percent - Sensitivity Analysis Savings Rate Scenario

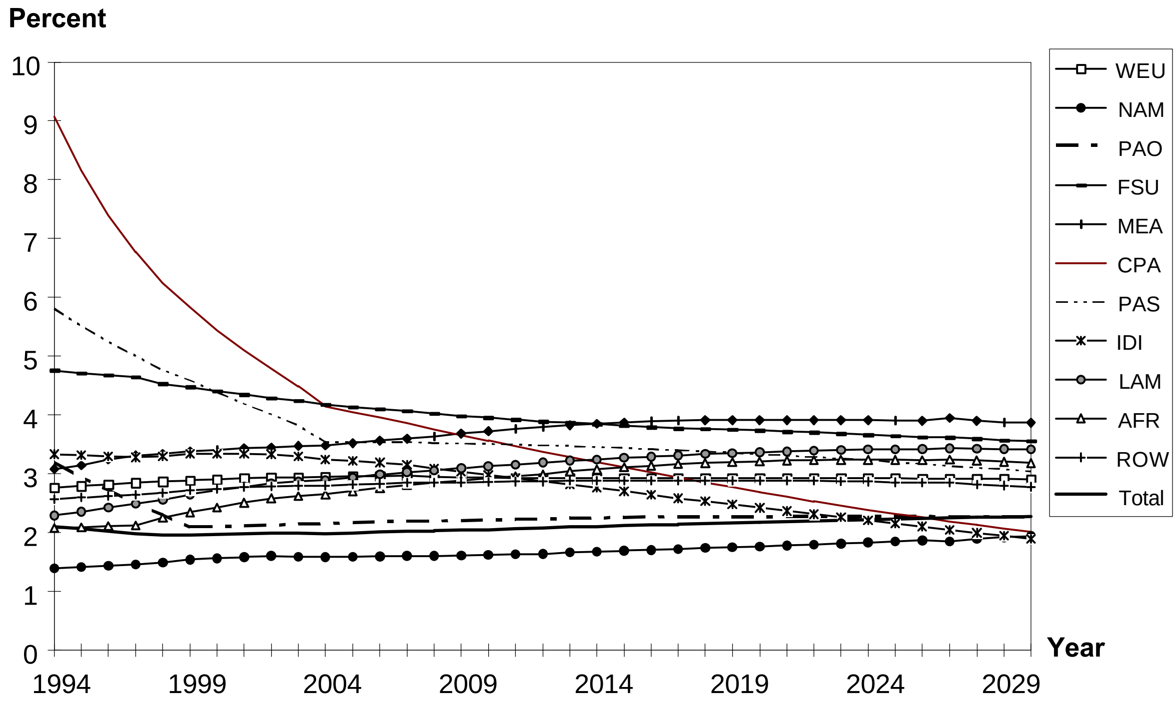

Figure A27 — Regional Per-Capita Income (in 1993 US$) - Sensitivity Analysis Savings Rate Scenario

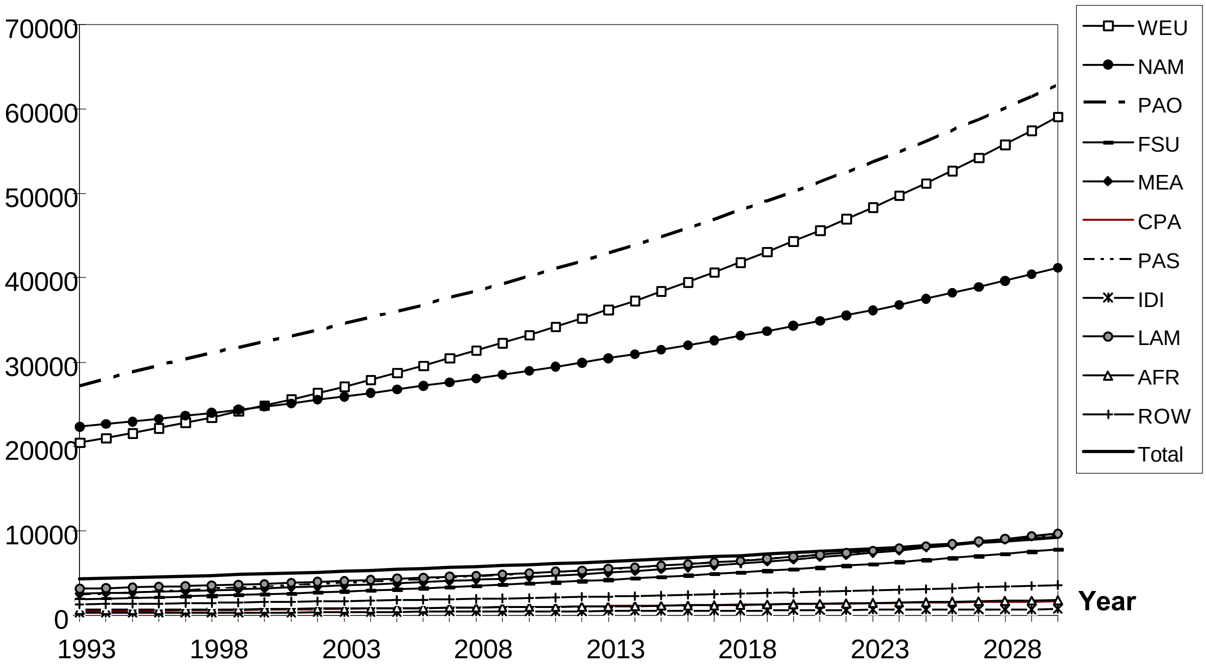

Figure A28 — Regional Per-Capita Income (in 1993 US$) - Sensitivity Analysis Pessimistic Growth Scenario

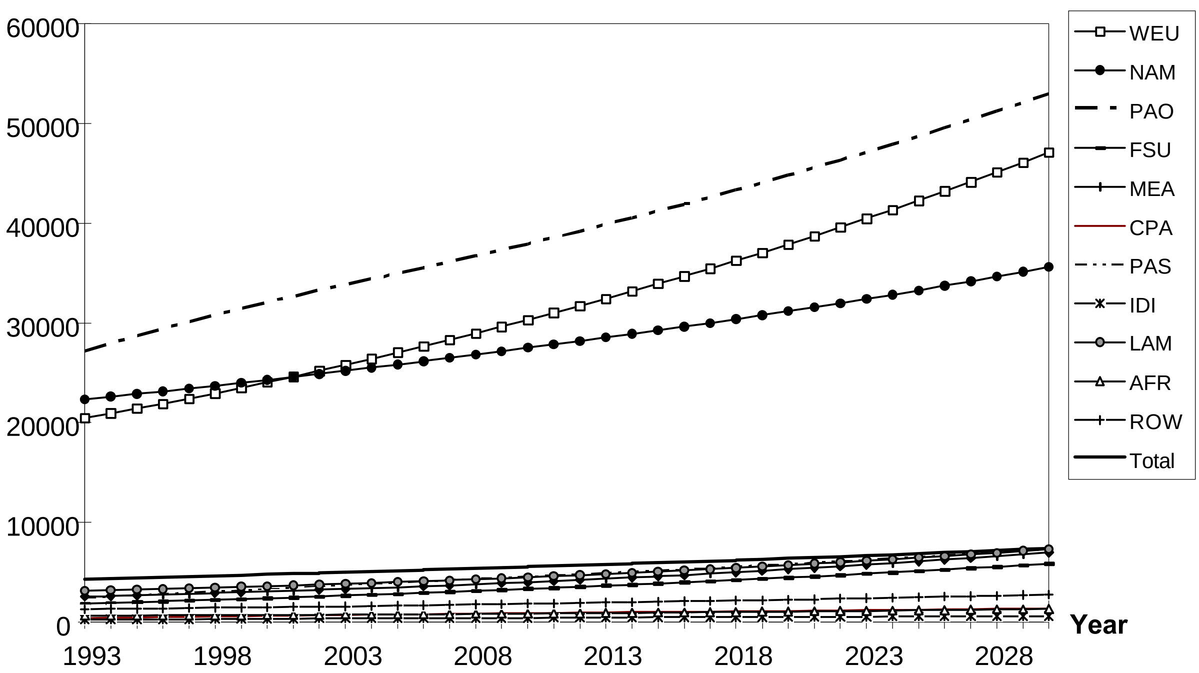

Figure A29 — Development of Per Capita Emissions: Sensitivity Analysis
(Industrialized (IC) and Developing Countries (LDC); (1993=100)

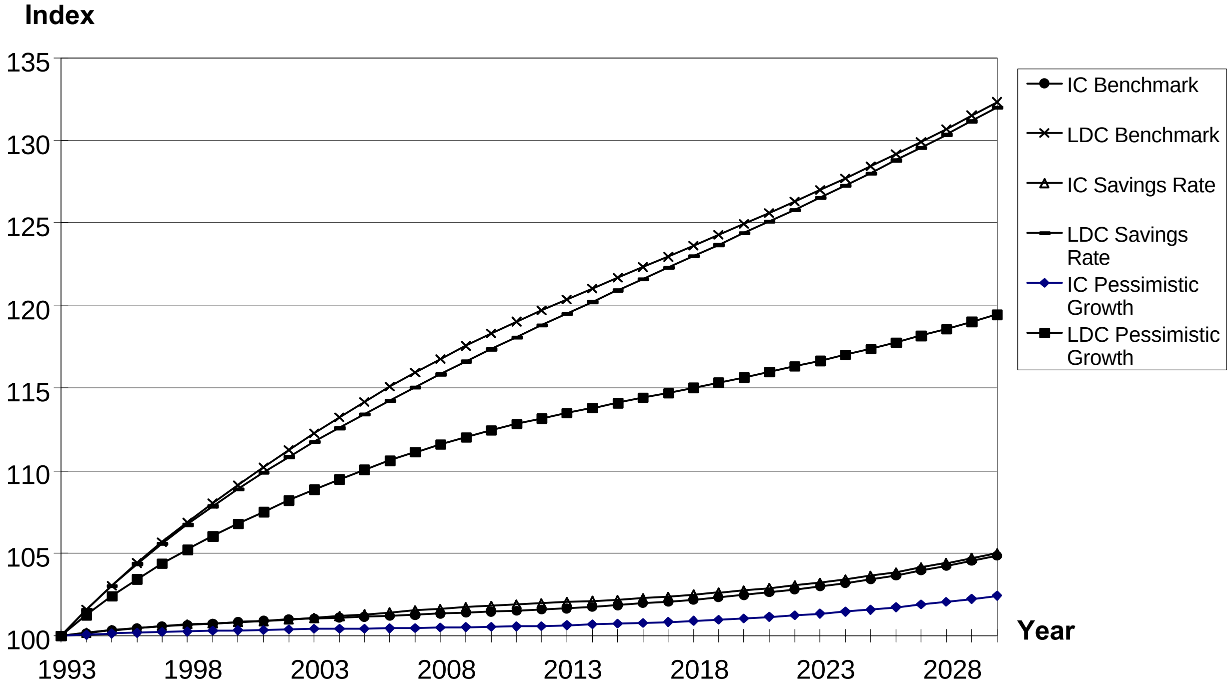

Figure A30 — Development of Per Capita Income: Sensitivity Analysis
(Industrialized (IC) and Developing Countries (LDC); (1993=100)

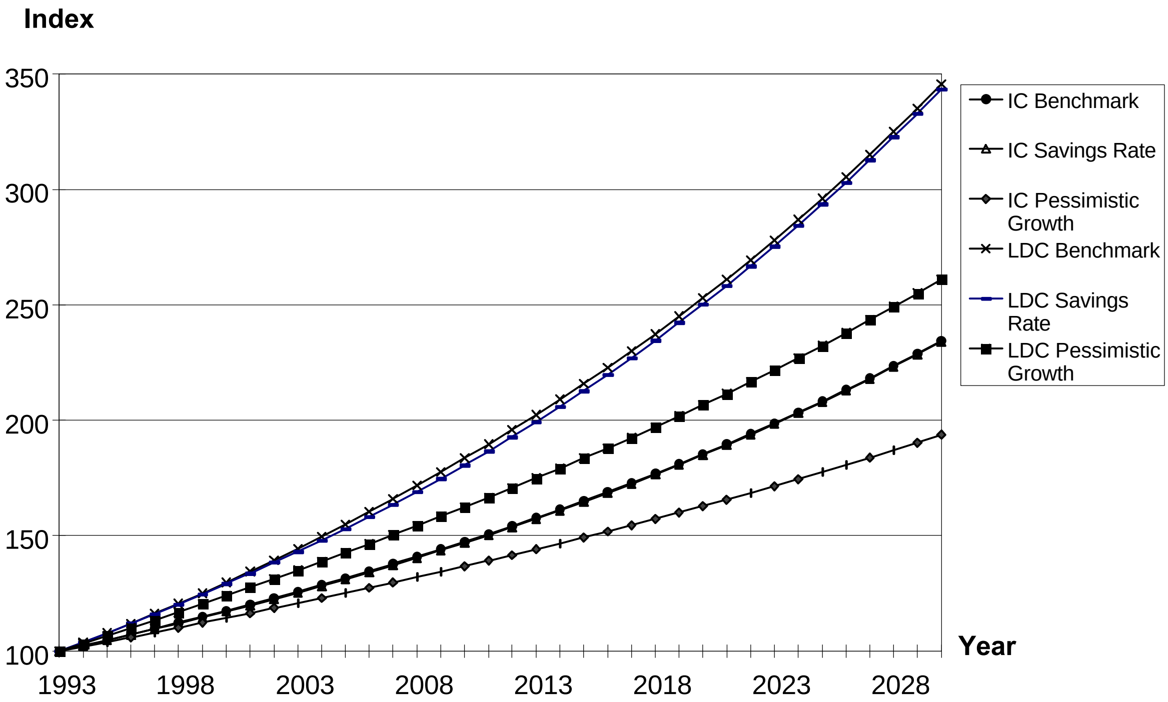

Figure A31 — Development of CO_2-Intensity: Sensitivity Analysis
(Industrialized (IC) and Developing Countries (LDC); (1993=100)

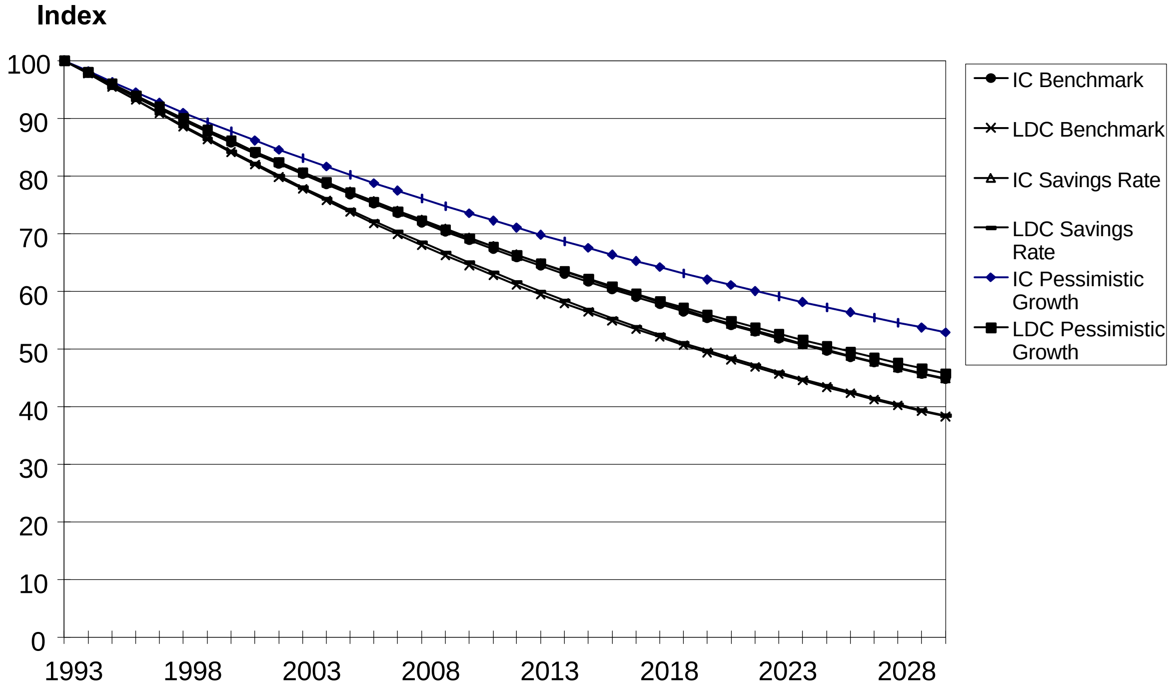

Figure A32 — Comparison of Welfare Effects of the Kyoto Protocol in 2010 Over All Growth Scenarios
(Equivalent Variation relative to 2010 Benchmark)

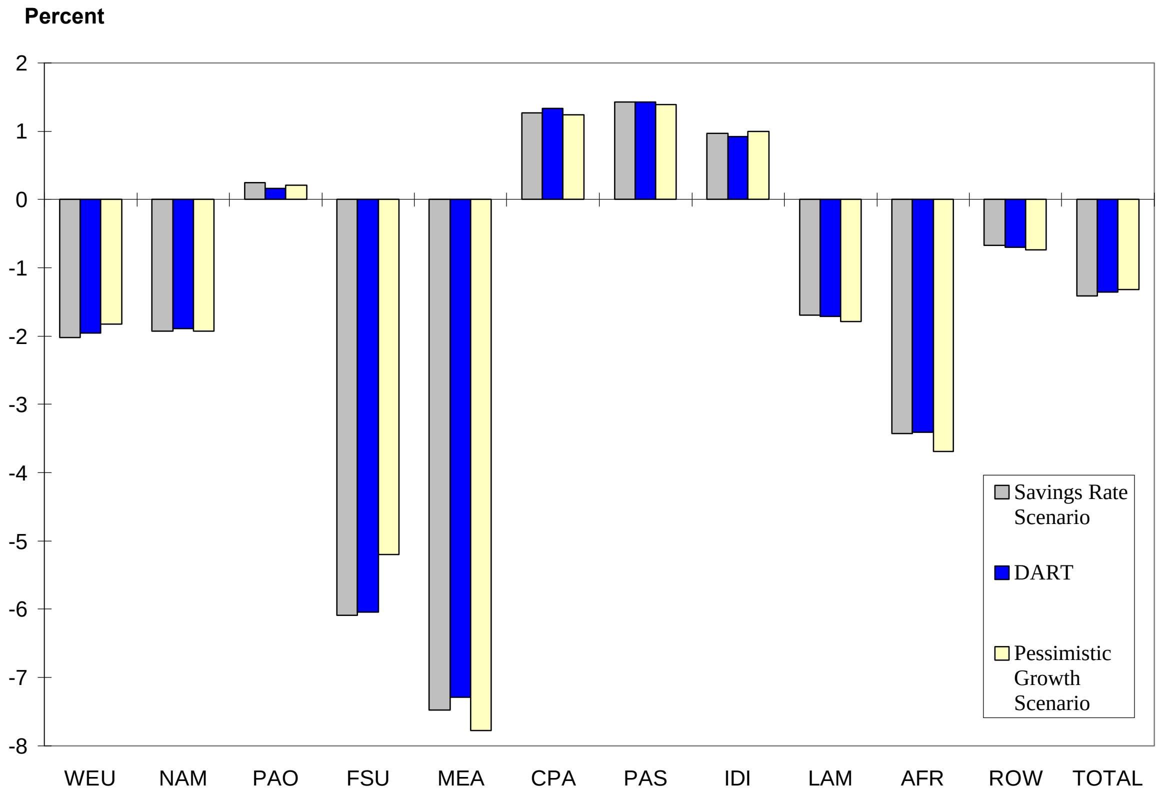

Figure A33 — Comparison of the Leakage Rate Over All Growth Scenarios