DART: A non-technical model description

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1 Introduction

The DART Model of the Kiel Institute for World Economics (IfW) is a recursive dynamic computable general equilibrium model of the world economy, covering multiple sectors and regions. It is designed for the analysis of international climate policies. At present, the most important applications are the implementation of the Kyoto Protocol either trough unilateral action or through emissions trading and the European emissions trading scheme. DART is used to assess and analyze the allocative and distributional impacts of the most recent agreements and developments.

The DART model stands, as the EPPA model of the MIT (Yang et al. 1996), in the tradition of the GREEN model by the OECD (Burniaux 1992), even though the models differ in several aspects. The first version of DART was developed in the late 1990's and used to simulate the implementation of the Kyoto Protocol via unilateral action (e.g. emission taxes) (Springer 1999) as well as to investigates the impacts of international capital mobility (Springer 2000; Springer 2002). In addition DART was coupled to an ocean-atmosphere model to assess the economic impacts of climate change (Deke et al. 2001; Kurtze and Springer 1999). Meanwhile more up to date data are available which provide for example disaggregated data for the Western and some Eastern European countries. At the same time prevailing issues in the debate on the Kyoto Protocol such as different regimes for international emission trading required several extensions of the model. Newer applications of DART are concerned with hot-air in Kyoto emissions trading (Klepper and Peterson 2002), the robustness of marginal abatement cost curves (Klepper and Peterson 2003) and the European Emissions Trading Scheme (Klepper and Peterson 2004).

This paper gives an overview over the present version of DART. Section 2 deals with the static part of DART. The following section 3 discusses the dynamics and the dynamic calibration. Section 4 addresses the simulation of climate policy scenarios with DART.

2 The Basic Model

The basic model, called **D**ynamic **A**pplied **R**egional **T**rade (DART) is a multi-region, multi-sector general equilibrium model of the world. It is written in the mathematical programming language GAMS and based on the GTAP5-E(nergy) data set. The 57 sectors and 66 regions of GTAP5 can be aggregated depending on the question at hand. Currently DART is used with a 11-sector aggregation and different regional aggregations covering from 12 to 16 regions (see Table 1). Among the 11 sectors are three fossil fuel production sectors, different 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.

For the static part of DART the original GTAP5 data are converted into a GAMS readable format with the help of the tool GTAPtoGAMS (Rutherford and Paltsev 2000). The dynamic framework is recursively-dynamic meaning the evolution of the economies over time is described by a sequence of single-period static equilibria connected through capital accumulation and changes in labor supply. In this paper a non-technical description of the static and dynamic part of the DART model is provided. For an algebraic description of the original DART model that is in most parts transferable to the present version, see Springer (1998).

The economic structure of DART is fully specified for each region and covers production, investment and final consumption by consumers and the government. Primary factors are labor and capital[1]. Both are in the basic version of DART intersectorally mobile within a region, but cannot move between regions. 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. The following sections describe the producer and consumer behavior, foreign trade, factor markets and finally the calculation of carbon dioxide emissions, that are the basis for climate policy analysis.

[1] Land is included in capital in some versions, and disaggregated in others. The same is true for resources.

Table 1: Dimensions of DART

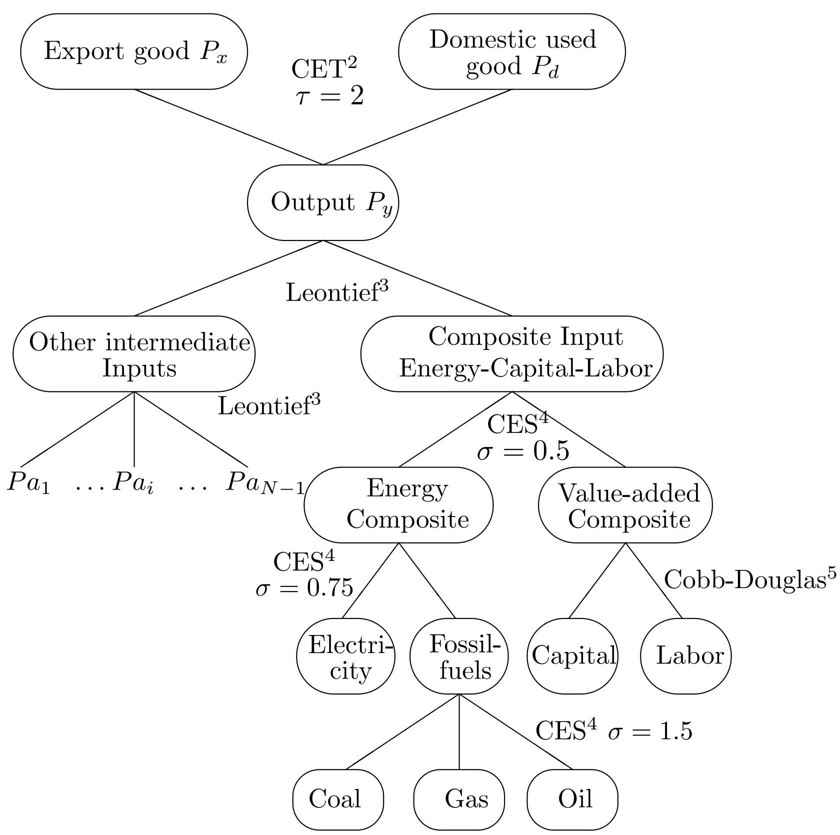
Production sectors/Commodities			
Energy Sectors		**Non-Energy Sectors**	
COL	Coal	AGR	Agricultural Production
CRU	Crude Oil	IMS	Iron Metal Steal
GAS	Natural Gas	CEM	Chemical Products
OIL	Refined Oil Prod.	PPP	Paper and Board Production
EGW	Electricity	Y	Other Manufactures & Services
		TRN	Transport Industries
		MOB	Transportation, Mobility

Countries and regions			
Annex B		**WEU disaggregation**	
USA	USA	BEN	Belgium, Luxemburg, Netherlands
WEU	West European Union	DEU	Germany
ANC	Canada, Australia, New Zealand	FRA	France
		GBR	United Kingdom
JPN	Japan	ITA	Italy
FSU	Former Soviet Union	SCA	Denmark, Finland, Sweden
		SEU	Greece, Portugal, Spain
Non-Annex B		REU	Austria, Ireland
LAM	Latin America	ACC	Bulgaria, Czech Republic, Hungary Poland, Rumania, Slovakia, Slovenia
IND	India		
PAS	Pacific Asia		
CPA	China, Hong Kong		
MEA	Middle East, N. Africa		
AFR	Sub-Saharan Africa		
ROW	Rest of the World		

2.1 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 possibilities in domestic production[2]. Figure 1 shows the nested production structure. On the top level of the



^{1} Not investment good
^{2} Constant elasticity of transformation τ
^{3} Leontief: Fixed coefficients
^{4} Constant elasticity of substitution σ
^{5} Cobb-Douglas: $\sigma = 1$

Figure 1: Production Structure of the non Fossil Fuel Industry Sectors

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

production function is a linear function, i.e. a Leontief function of non-energy intermediate goods and a value added composite[3]. 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. On the lowest level labor substitutes with capital 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 formation. 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 fuel 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. The other GHGs methane, nitrous oxide, ozone and halocarbons, as well as emissions from CO_2 deforestation are not considered in the model. The fossil fuels gas, coal and crude oil are produced from fuel-specific resources and the macro good (a composite of all other manufactures and services and factors). The production function is a CES function with a fixed factor - the fuel resource (Figure 2).

In each region composite investment is a Leontief aggregation of Armington inputs by each industry sector (Figure 2). In the basic version of DART there are neither sector-specific investments nor cross border investment activities, i.e. investment goods are treated as non-tradeable. Investment does not require direct primary factor inputs.

Producer goods are directly demanded by final consumers (comprising regional households and governments), the investment sector, other industries and the export sector.

2.2 Consumption expenditure

The representative household, that comprises private households and the government sector, receives all income generated by providing primary factors to the production process. After deducting taxes and savings, the disposable income is used for maximizing utility by purchasing goods. The final consumer decides between different primary energy input and non-energy inputs depending on their relative price in order to receive its consumption (utility) with the lowest expenditures. A fixed share of income is saved in each period and is invested in the production sector. The expenditure function of the representative household is assumed to be a Cobb-Douglas composite of an energy

[3]In the case of refined oil products, the intermediate input of crude oil and refined oil products are

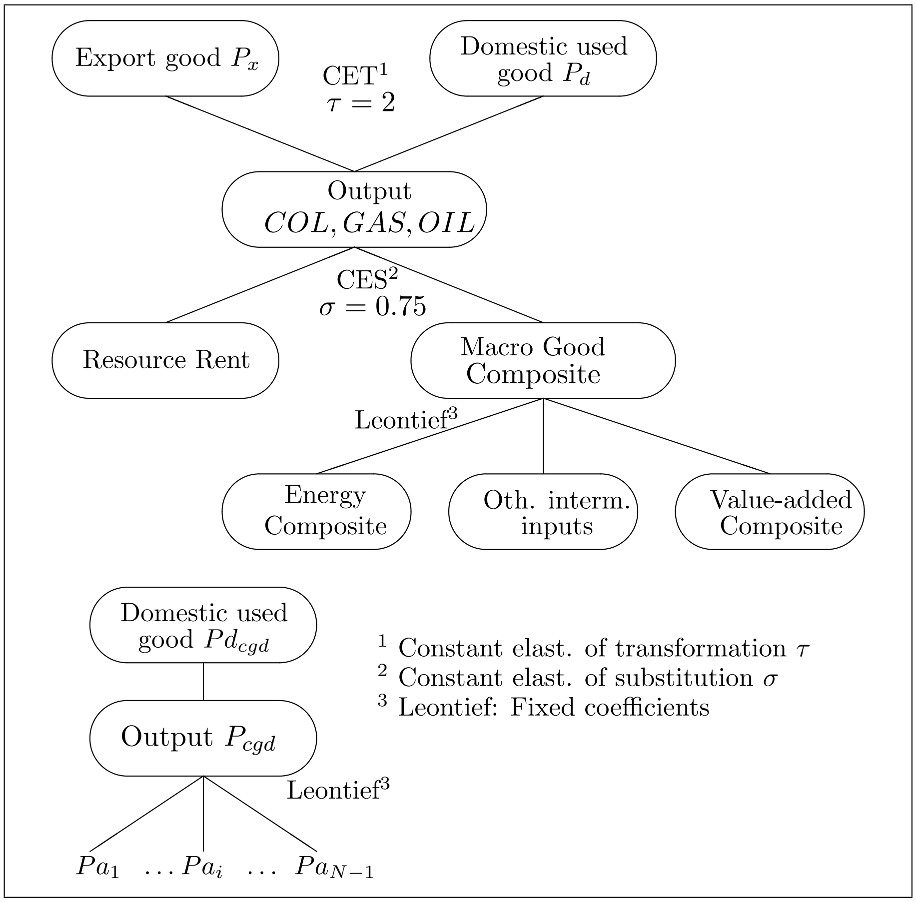


Figure 2: Production Structure of the Fossil Fuel Sectors and the Investment Good *cgd*

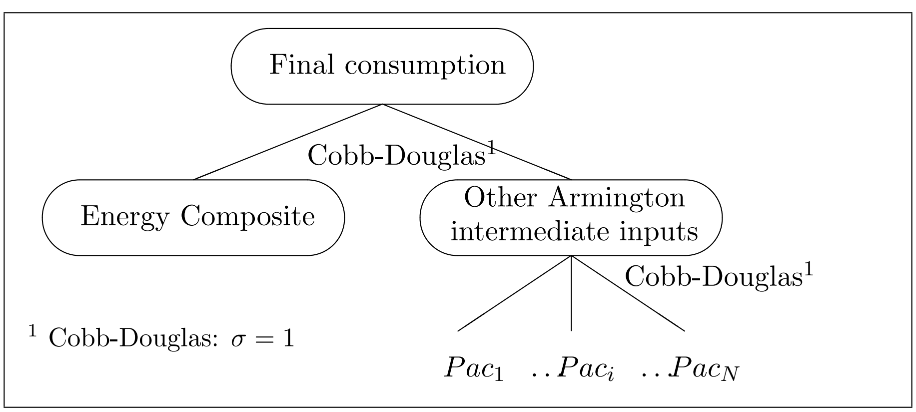


Figure 3: Final Consumption Production Structure

also on the top level.

aggregate and a non-energy bundle. Within the non-energy consumption composite, substitution possibilities are described by a Cobb-Douglas function of Armington goods.

2.3 Foreign Trade

The world is divided into economic regions, which are linked by bilateral trade flows. All goods are traded among regions, except for 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 of expenditure function respectively and distinguishes between imported and domestically produced goods as well as between the country of origin. 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

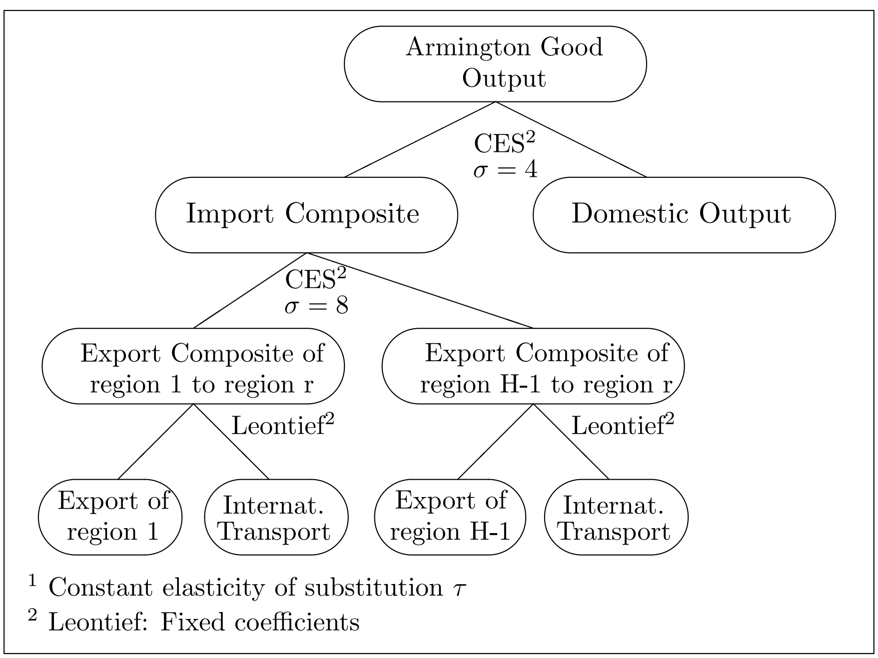


Figure 4: Structure of Foreign Trade (Armington Production of Good i in Region r)

proportional 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 destined for domestic and international markets. Here, produced commodities for the domestic and for the international market are no perfect substitutes. Exports are not differentiated by country of destination.

2.4 Factor markets

Factor markets are perfectly competitive and full employment of all factors is assumed. Labor is assumed to be a homogenous good, mobile across industries within regions but internationally immobile. In the basic version of the DART model capital is also inter-sectorally but not internationally mobile. Regional capital stocks are given at the beginning of each time period and results from the capital accumulation equation. In every time period they earn a correspondent amount of income measured as physical units in terms of capital services.

2.5 Carbon dioxide emissions

Gas and coal each have a fixed carbon content. To calculate the associated carbon dioxide emissions one simply has to multiply the physical quantity of gas and coal used in either domestic production or domestic consumption (which is given in the GTAP data) and multiply it by its emission coefficient. DART uses the recommendations from the IPCC (1996) which are 0.0258 kgC/MJ for coal and 0.0153 kgC/MJ for gas.

For oil emissions the calculation is more complicated. In order to determinate 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. 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 KgC/MJ. Refined oil consumption is composed of domestically produced and imported oil products. Both may have different carbon 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 in region r 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, denoted here $vafm(CRU, OIL, R)$, as a share of the value of the output of refined oil products (domestic $vdm(OIL, R)$ and exports $vxm(OIL, R)$).

Originally the regional carbon emissions in DART were calculated at the point where the Armington aggregate of domestic and foreign fossil energy (gas, coal resp. refined oil) enters domestic production or consumption (see Springer (2002)). This was only possible though, as oil could be treated as a homogeneous good so that only net exports and imports had to be considered. Now, in the GTAP5 data, the implicitly given oil prices are not the same across countries, but differ considerably. Thus, assuming a homogeneous good would lead to miscalculations. For this reason oil is now treated as an Armington good, too with bilateral trade flows. As these trade flows change in every time period it is now necessary to calculate the emissions at the point where the imports enter the Armington aggregation by multiplying the imported quantity of region S by its crude oil share $Crush(S)$ and the emission coefficient.

3 Dynamics

The DART model is recursive-dynamic, meaning that it solves for a sequence of static one-period equilibria for future time periods connected through capital accumulation and changes in labor supply. The dynamics of the DART model are defined by equations which describe how the endowments of the primary factors capital and labor evolve over time. The major driving exogenous factors of the labor dynamic are population change, the rate of labor productivity growth and the change in human capital. The driving forces for capital accumulation are the savings rate and the gross rate of return on capital, and thus the endogenous rate of capital accumulation. The DART model is recursive in the sense that it is solved stepwise in time without any ability to anticipate possible future changes relative prices or constraints.

The savings behavior of regional households is characterized by a constant savings rate over time. This rather ad-hoc assumption seems consistent with empirical observable, regional different, but nearly constant savings rates of economies, which adjust according to income developments over very long time periods (for savings rates see Schmidt-Hebbel and Serven 1997). Additionally, a wide range of empirical evidence in macroeconomic literature neglect the theoretically elegant permanent income hypothesis and shows that a huge fraction of the consumption decisions are based entirely on current after tax income. The following sections describe the evolution of labor and capital supply in more detail.

3.1 Labor supply

Labor supply considers human capital accumulation and is, therefore, measured in efficiency units, $L_{r,t}$. It evolves exogenously over time. Hence, labor supply for each region r at the beginning of time period t+1 is given by:

$$\bar{L}_{r,t+1} = \bar{L}_{r,t} * (1 + gp_{r,t} + ga_{r,t} + gh_r)$$

where the bar denotes exogenous variables. An increase of effective labor implies either growth of the human capital accumulated per physical unit of labor, gh_r, population growth gp_r or total factor productivity ga_r, or the sum of all.

DART assumes constant, but regionally different labor productivity improvement rates ga_r and declining population growth rates over time, $gp_{r,t}$, according to the World Bank population growth projections. Because of the lack of data for the evolution of the labor participation rate in the future the growth rate of population instead of the labor force is used implying that the labor participation rate is constant over time. The human growth rates of human capital gh_r are also assumed to be constant over time and regionally different. The 1990 levels of human capital endowments are taken from Hall and Jones (1999)[4]. They are then aggregated to the regions of the model. For the future development of the endowments, we assume that the maximum endowment of 12 years of schooling will be reached in 2050 and that this process starts at the computed 1990 levels and continues in a linear fashion. 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 assumed optimistically that there is complete convergence in human capital intensities in the long run.

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

3.2 Capital formation

Current period's investment augments the capital stock in the next period. The aggregated regional capital stock, Kst at 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, $Iq_{r,t}$. The equation of motion for capital stock $Kst_{r,t+1}$ in region r is given by:

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

where δ_t denotes the exogenously given constant depreciation rate. According to the GTAP5 data set $\delta = 0.04$, and we use the same value for all time periods. The allocation of capital among sectors follows from the intra-period optimization of the firms.

As data on the regional physical capital stocks are not available with the GTAP data, the capital accumulation has to be rearranged by using physical capital earnings $K_{r,t}$ i.e. return to capital, instead of the capital stock $Kst_{r,t}$. Using the stock-flow-conversion, the capital earnings in period 0 for region r are given by

$$K_{r,0} = rk_{r,0} * Kst_{r,t}$$

where $rk_{r,0}$ denotes the gross rate of return on capital in region r in period 0 defined as

$$rk_{r,0} = \frac{K_{r0}}{pi_{r,0} * Kst_{r,0}}$$

$pi_{r,0}$ is the actual price of investment or in other words, the price of constructing a unit of capital. Exploiting the unit price convention $pi_{r,0} = 1$ we can use $rk_{r,0}$ as a (fixed) scaling factor. Thus, the capital accumulation equation can be rewritten in terms of physical units of capital services.

$$(*)K_{r,t+1} = (1 - \delta_t)K_{r,t} + Iq_{r,t} * pi_{r,t} * rk_{r,0}$$

where $K_{r,t}$ denotes the physical unit of the factor capital in period t which earns 1$ in the initial time period and $Iq_{r,t} * pi_{r,t}$ the value of real gross investment. Once the variables have been scaled, the physical, i.e. quantity, units of capital services can be updated according to equation $(*)$ whereas the actual value of gross investment has to be scaled with the benchmark gross rate of return in every time period.

3.3 Dynamic Calibration

The dynamics of the DART model are driven by saving rates, population growth, and total factor productivity.

For the capital accumulation we assume constant, but regional different saving rates. The rates from CPA and PAS are allowed to adjust to income changes so that the originally high rates fall over time and become comparable to the saving rates in the other regions. These adjustments make sure that these two regions tend to converge towards a balanced growth path. Without these adjustments capital stocks will grow far beyond any realistic level with he consequence that either the rates of return on capital would collapse, or - in the case of capital mobility - these regions would become major exporters of capital.

Table 2: Dynamic key parameters for selected regions for 1997 in %

	Total growth in labor efficiency	**techn. progr.**	**Hum. capital**	**Popu- lation**	**Sav. Rate**
USA	2.20	1.20	0.10	1.00	17.6
WEU	2.00	0.60	1.20	0.20	18.9
BEN	2.10	0.50	1.10	0.50	20.6
DEU	1.70	0.60	1.00	0.10	20.4
FRA	2.40	0.60	1.40	0.40	17.4
GBR	2.00	0.60	1.10	0.30	17.1
ITA	2.40	0.60	1.70	0.10	17.2
SCA	1.50	0.50	0.80	0.20	15.7
SEU	2.20	0.60	1.50	0.10	21.8
REU	2.40	0.60	1.40	0.40	24.1
ACC	3.20	2.50	0.90	-0.20	23.2
ANC	2.20	0.50	0.60	1.10	19.9
JPN	1.80	0.50	1.00	0.30	28.8
FSU	2.90	2.50	0.50	-0.10	21.1
LAM	5.40	1.50	2.30	1.60	20.2
IND	5.90	1.50	2.70	1.70	24.1
PAS	6.50	2.50	2.50	1.50	31.1*
CPA	6.30	3.50	1.90	0.90	36.5**
MEA	5.70	1.00	2.60	2.10	22.6
AFR	6.10	1.50	2.40	2.20	16.7

Falls by 1 (*) resp. 0.5(**) percentage point per year up to 2010

Given these adjustments, the yearly growth rates of GDP in some developing countries

(LAM, MEA, AFR and ROW) are still much higher than recent projections as the assumption that the maximal human capital endowment will be reached in 2050 leads to a fast growth in human capital endowments in these regions. We thus assume, that the maximal human capital endowment will only be reached in 2090. Table 2 summarizes the choice of the key parameters from the dynamics.

Finally, the supply elasticities of fossil fuels are chosen in such a way that the carbon emission in 2030 resulting from the model in the business as usual scenario meet the newest projections of the IEA (IEA 2002). The resulting elasticities for a regional aggregation without the WEU disaggregation are 0.6 for coal, 2.8 for gas and 0.37 for crude oil.

4 Concluding Remarks

The DART model of the Kiel Institute for World Economics is a powerful tool to simulate and assess the implications of different climate policy issues such as emissions trading under the Kyoto Protocol or in the European Union. This paper presents a non-technical summary description of the basic DART model. As DART is constantly revised and augmented, it is possible that for some applications the model departs from this general description, uses different regional and sectoral aggregations or includes further details to analyze prevailing questions.

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