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Climate Policy and Trade: Dynamics and the Steady-State Assumption in a multi-regional Framework

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Abstract

Most dynamic trade models assume steady state or balanced growth. This paper argues while this can be done in a single region model or a model without trade, the steady state assumption is problematic in a multi-regional setting with trade interactions. This paper shows the consequences of assuming a balanced growth path and discusses several problems which are connected to the calibration of recursive dynamic multi-regional trade models. Furthermore, it is demonstrated how different dynamic specifications of the base run path affect the results of a policy scenario by imposing the Kyoto Protocol. The simulations illustrate that a balanced growth path can not be maintained in a multi-regional trade model due to international trade spill-overs. It is shown that the model results and thus the assessment of climate policy options depend substantially on the dynamic specification.

Keywords: Growth of open economies, Steady-state, Multi-regional dynamic CGE Model, International environmental problems

JEL classifications: C68, D58, F43, O41

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1 INTRODUCTION

The increasing concentration of greenhouse gases in the atmosphere and the resulting climate change have become a main topic in the international environmental discussion. As the Kyoto environmental conference in December 1997 and the following conference in Buenos Aires in 1998 have shown, there exists a broad consensus about the necessity of considerably reducing greenhouse gas emissions in order to protect world climate. However, the specific aims, policy measures and instruments for reducing emissions are still under debate. The Kyoto Protocol contains quantified emission limitations and reduction objectives for the industrialized countries, i.e. Annex-B countries (UN 1997). The acceptance of the Kyoto Protocol by national legislative bodies and further commitments to emission reductions depend considerably on the economic costs related to the implementation of emissions control.

Alternative climate policy measures can be evaluated within a simulation model that integrates economic and natural science considerations. The integrated assessment approach allows to consider the impact of climate change on the economic development of economies, and to analyze the cost and benefits of climate protection policies (Fankhauser 1995). This can be done by linking an economic computable general equilibrium (CGE) model with an climate model, e.g. an ocean atmosphere model, and considering the climate impacts on regional economies.

For modeling climate change impacts the CGE framework is attractive because of its capacity to represent all relevant components of an economy and to model explicitly the interrelationships of these components. The change in climate variables as, for example, seasonal temperature, precipitation or extreme weather events may influence the factor endowment of economies, the productivity of factors, the parameters of production functions or the final demand. A CGE model may incorporate these direct climate impacts on production sectors or final demand. The resulting indirect impacts for all other components of the economy can be derived via the interactions in the general equilibrium framework. Furthermore, the CGE framework avoids the use of questionable price tags on climate impacts because economic activities are modeled in terms of physical units.[1]

For the purpose of climate policy evaluation the economic CGE model should cover multi-regional and multi-sectoral details as well as dynamic features. Regional detail enables the model user to analyze distributional impacts of different climate protection policies by considering the terms of trade effects. Furthermore, regional differences in climate vulnerability and adaptation levels can be taken into account. The sectoral disaggregation allows the

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[1] The questions of how to implement climate impacts on the economy into the CGE framework is discussed in Kurtze and Springer (1999).

analysis of structural change as a consequence of climate change and climate policies. The dynamic features allow to cover dynamic economic effects and the time dependent effects of greenhouse gas emissions and accumulation in the atmosphere, and the resulting climate change impacts.

The **D**ynamic **A**pplied **R**egional **T**rade General Equilibrium (DART) Model (Springer 1998) is such a global CGE model with regional as well as sectoral detail. Within every region the household and industry behavior is fully specified based on microeconomic foundations. All regions are linked by bilateral trade flows. It is recursive dynamic.

The DART model serves as a component of an integrated assessment project for evaluating global climate change impacts on economies in a common research project with the Max-Planck-Institute of Meteorology (Hamburg). The model can be used to project economic activities, energy use and trade flows for each of the specified regions according to exogenous assumptions about the dynamics of the model. Anthropogenic carbon dioxide emissions can be directly derived from the energy use projections by the DART model. These projections of energy use are inputs to a climate model of the Max-Planck-Institute and thereby form the first link in the integrated analysis of global climate change.

In the last years the number of dynamic CGE models has strongly increased. However, most of them are single country models. Most of the existent dynamic multi-regional CGE models consider only one sector, i.e. they have a macroeconomic production function, or ignore international trade relations. Very few deal with all that. One prominent example for recursive dynamic models is the GREEN model by the OECD (Burniaux et al. 1992), which is a global multi-regional, multi-sectoral trade model. The DART model stands in the tradition of the GREEN model, but will include in addition impacts from the climate system on the economy.

This paper focuses on the calibration procedure of a recursive dynamic trade model. Most of the dynamic models assume steady state or balanced growth. Diao and Somwaru (1997, p. 15) also point out that „(t)he steady-state assumption, though questionable for most developing economies, is systematically adopted in applied intertemporal general equilibrium models due to its extreme convenience for calibration.“ While this can be done in a single region model or a model without trade, the steady state assumption is problematic in a multi-regional setting with trade interactions irrespective of the analyzed time horizon. Also Yang (1999) states that the assumptions of balanced growth and myopic expectations are not satisfactory for the long-run, but are reasonable and acceptable for the short-run. However, he does not analyze this statement in detail, but concentrates more on the improvement of the performance of long-term CGE models by suggesting a coupled algorithm that combines CGE modeling with optimal growth modeling approach. In his suggestion of a full dynamic multi-regional model he ignores the influence of trade interactions by setting the balance of current account equal to zero for all regions, i.e. the regions behave like ‘island’ economies without interactions among each other.

This paper shows the consequences of assuming a balanced growth path and discusses several problems which are connected to the calibration of recursive dynamic multi-regional trade models by using the DART model. Furthermore, it is demonstrated how different assumptions of the specification of the base run dynamics affect the results of a policy scenario by imposing carbon dioxide emission reduction targets as specified in the Kyoto Protocol.

The simulations show that the assumption of a balanced growth path can not be maintained in a recursive dynamic, multi-regional, multi-sectoral trade model due to international trade spill-overs. The specification of the base run path is very important for the results of policy simulations, since these results are evaluated relative to the base run, and since the adaptation of the model to a policy shock is different according to the specification of the dynamics.

This paper is organized as follows. Section 2 gives an introductional overview of several approaches of modeling dynamics in CGE models. Section 3 presents a short description of the basic version of the DART model. Section 4 discusses the solution concept of recursive dynamic CGE models on the basis of three dynamic calibration scenarios and point out the problems related to the calibration of recursive-dynamic multiregional, multisectoral CGE models with different regional growth rates and their implications for trade. Section 5 analyzes the behavior of the model with two different calibration scenarios (regional steady state specification, off-steady state specification) to an imposed policy shock. For this policy experiment the Kyoto Protocol is used. The final section provides conclusions.

2 MODELING DYNAMICS

This section provides a brief overview of the different approaches to implement dynamics in CGE models and clarifies terms used in the CGE literature. A CGE model is defined by the following characteristics (Dixon and Parmenter 1996, p. 5): CGE models include explicit specifications of the behavior of several economic actors like households, firms, governments, importers and exporters. Therefore, they are „*general*“. They employ market „*equilibrium*“ assumptions, i.e. a CGE model finds a set of factor and commodity prices that balances demands added across all actors with total supplies. CGE models produce numerical results, i.e. they are „*computable*“. In particular CGE models use actual data for countries or regions and produce numerical results relating to specific real world situations.

There is a fast growing body of literature and surveys[2] about CGE models used for policy

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[2] See for instance Shoven and Whalley (1984), Pereira and Shoven (1988) for tax policy evaluation, Bhattacharyya (1996) for energy studies, Dervis et al (1982) and Bandara (1991) for development policy evaluation, Bergman (1990).

evaluation. Several criteria can be used to classify these models. Examples for these criteria are:

- spatial coverage (single regional - multiregional / national - multinational - global),
- sectoral disaggregation (one sector - multisector),
- periodicity (single period - multiperiod), or
- nature (static - dynamic).

This paper focuses on dynamic features of CGE models which are multi-period models.[3]

Traditional CGE models have paid relative little attention to dynamic effects of economic policies. Most of them were single country, single period models. The standard static general equilibrium model pioneered by Harberger (1962) does not model time and assumes that adjustment occurs instantaneously. In the last years the number of multi-period (dynamic) CGE models has grown considerably.

Dynamic modeling means that we have a time dependent process in which capital stocks available for use in year $t+1$ are determined by investment which takes place before year $t+1$. There are two main approaches how dynamic aspects have been incorporated into CGE models: the dynamic sequencing of static equilibria, i.e. the recursive dynamic approach, and the completely dynamic approach.

Both approaches can further specified by the way the agents handle economic decision problems. The behavior of the economic agents can be derived from myopic, i.e. static, expectations, from adaptive expectations, and from rational, i.e. model consistent, expectations. Myopic expectations assume that there is no change in decision parameters over time. Economic agents with adaptive expectations consider only the past for their optimizing problem, while actors with rational expectations uses the variables from the present and future for their optimizing decision problem. Therefore, a decision problem with rational expectations is not separable anymore.

Recursive dynamic CGE models solve a sequence of static equilibira. The equilibria are connected to each other through capital accumulation. Recursive CGE models do not consider intertemporal aspects of decision making. Therefore, only economic agents with myopic or adaptive expectations can be modeled in these kinds of models.

Models with forward-looking agents with perfect foresight cannot be solved recursively anymore. Here, decisions in year t influence parameters in subsequent years. On the other hand, the decisions depend on the expected development of these parameters. Hence, the

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[3] Recent trade models for quantifying the welfare effects of trade liberalization like Harrison et al. (1995) consider „dynamic“ effects by implementing a steady state condition as a constraint on the static CGE model. Nevertheless, the model remain static. Therefore, the term „dynamic“ as used in this paper refers to a multi-period setting.

dynamic system is interdependent and the model has to be repeatedly solved forward or solved simultaneously. The consequence is that these CGE models become more complex and have to incorporate less sectoral and regional details to be manageable. (Klepper et al. 1994)

Dixon and Parmenter (1996) distinguish altogether four cases of dynamic modeling. In the first case investment is exogenous. This case is consistent with myopic expectations, where savings rates are given and investment equals savings in one time period.

In the second case investment is endogenous. Investment and capital accumulation in year t depend on expected rates of return for year $t+1$ which are by assumption determined by actual returns on and cost of capital in year t. This approach involves adaptive expectations. The first two cases are recursive. They can be solved step by step for the first year $t=1$ and then for the next year $t=2$ and so on.

The third case comprises models with forward-looking behavior where we have endogenous investment with the expected rates of return for year $t+1$ are equal to the actual rates of return for year $t+1$. This means that the expectations are rational or model consistent. Such models can not be solved recursively. But a solution can be found by running an initial recursive simulation followed by a correction and so on.[4] Therefore, this case of dynamic modeling stands in between recursive and completely dynamic models.

Completely dynamic models, the fourth case, rely on intertemporal optimization.[5] Savings and investment decisions of the agents are modeled as intertemporal decision problems. Hence, intertemporal substitution possibilities are incorporated in these fully dynamic models.

The completely dynamic specification goes at the expense of more details in modeling. Hence, most of the fully dynamic models are single country models as surveyed by Pereira and Shoven (1988) or by Bhattacharyya (1996). Most of these models specify the decision behavior of only one agent intertemporally, usually the household, whereas the other agents are modeled in a static setting. An example of a global multi-country, completely dynamic model is the RICE model (Nordhaus and Yang 1996). As a shortcoming, the RICE model does not incorporate sectoral disaggregation.

Table 1 summarizes the different approaches of dynamic modeling in a multi-period setting and their inherent constraints on the way how expectations are formed by the economic agents.

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[4] This method has been developed and applied by Michael Malakellis (1992, 1994).

[5] Overlapping Generations (OLG) models can be subsumed under the fourth case.

Table 1: Modeling approaches of dynamics

Recursive Dynamic Models	Completely Dynamic Models = Intertemporal Optimization
• Myopic Expectations • Adaptive Expectations	• Rational Expectations
Sequential Optimization	

Despite the theoretical disadvantages of recursive dynamic models, e.g. the neglecting of intertemporal substitution possibilities and the inconsistent specification of the optimization behavior of agents between the static and the dynamic equilibrium, a recursive dynamic specification is chosen for the integrated assessment framework. The recursive structure simplifies the linkage between the climate and economic model and allows a coupling step by step of both models. The economic impacts to the climate system and the climate impacts to the economic system can be incorporated, and the optimal solution can be found for every time step. Otherwise, in a completely dynamic setting the climate and the economic model would have to be solved simultaneously.

3 THE DART MODEL

This section describes the basic version of the **D**ynamic **A**pplied **R**egional **T**rade (DART) General Equilibrium Model as an example for a recursive dynamic trade model which is used in an integrated assessment project of climate policies. Here, for simplicity the detailed specification of the energy sector and the resulting carbon dioxide emissions is omitted. Due to the focus of this paper on modeling dynamics, the single period equilibrium of the DART model is briefly described whereas this and the following sections elaborate on the dynamic specification. For the detailed algebraic description of the DART model see Springer (1998)

3.1 Overview

The DART model is a multi-region, multi-sector, recursive dynamic CGE model. The economic structure is fully specified for each region and covers production, consumption, investment and governmental activity. Each market is perfectly competitive. Output and factor prices are fully flexible. For each region, the model incorporates three types of agents: the producers, distinguished by production sectors, the representative private household and the government.

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 each industry, a multi-level nested separable constant elasticity of substitution (CES) function describes the technological substitution possibilities in domestic production.[6] Figure 1 shows the nested production structure. The top level of the production function is a linear function, i.e. 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 the 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. Thus, other GHGs as methane, nitrous oxide, ozone, and halocarbons, as well as emissions of CO_2 from deforestation are not considered in this model.[7]

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 DART 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.

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

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

[7] For a comprehensive overview of the science and politics of climate change see Mabey et al., 1997.

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.

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 by 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. The structure of foreign trade is shown in Figure 4. On the top level, the import aggregate and the domestic output of good *i* can be substituted with a constant elasticity. On the second level, the import composite of a good *i* into region *r* is derived as an aggregate of imports from all other regions *rr* which are substituted with a constant elasticity. 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 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.

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 a homogenous good, 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. 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 the capital accumulation equation. 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.

3.2 Dynamics

The CGE model above describes the economic behavior of the agents for all regions participating in trade for one period in time. This section deals with the dynamics of the DART model.

The DART model is dynamic meaning that it solves for a sequence of static one-period equilibria for future time periods connected through capital accumulation. The dynamics of the DART model are defined by equations which describe how the endowments of the primary factors evolve over time. The major driving exogenous factors in the model are population change, the rate of labor productivity growth, the change in human capital, the savings rate, 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 in relative prices or in constraints.

The agents have myopic expectations, which is consistent with the in principle static nature of the DART model. The savings behavior of regional households is characterized by a constant savings rate over time.[8] 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 cf. Schmidt-Hebbel and Servén 1997). 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. Campbell and Mankiew (1990), for example, reexamined the consistency of the permanent income hypothesis with aggregate postwar US data. They estimated that the fraction of income which accrues to individuals who consume their current income rather than their permanent income is about 50 percent.

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). Recently, empirical studies have attempted to test the standard neoclassical growth model, i.e. the standard Solow-Swan model with capital and labor, (e.g., Mankiew, Romer, Weil 1992; Hall, Jones 1998) and

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[8] The savings rate is allowed to adjust to income changes in regions in some calibration runs.

found that it is largely unable to describe historical growth processes. Their common conclusions were 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. Mankiew, Romer, Weil (1992) found also that the augmented Solow model which includes accumulation of human as well as physical capital provides an excellent description of the cross-country data.

There are several possibilities for reinterpreting the neoclassical growth model. One can conclude that the empirically observed high capital share is inclusive human capital. Then the income data would need to be readjusted. Alternatively, there might be positive externalities of capital which accelerates 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 (1998) interpret all labor income as human capital but adjust the labor input through a labor quality indicator.

Supply of Labor and agricultural Land

Like Hall and Jones (1998) I assume that labor, measured in physical units $\tilde{L}_{r,t}$ (here, number of workers instead of hours per worker is used as a unit), is homogenous within a region r and that each unit of labor has been trained with F_r years of schooling (education). The amount of human capital-augmented labor, HK_r, used in production in region r is given by:

$$HK_r = e^{\mathrm{f}(F_r)}\tilde{L}_r$$

where the function $\mathrm{f}(F_r)$ reflects the efficiency of a unit of labor with F years of schooling relative to one with no schooling ($\mathrm{f}(0) = 0$).[9] The derivative $\mathrm{f}'(F_r)$ yields the return to schooling estimated in a Mincerian wage regression (Mincer 1974), i.e. an additional year of schooling raises a worker's efficiency proportionately by $\mathrm{f}'(F_r)$.

Furthermore, we assume labor-augmenting technical progress with constant rates in order for the model to possess a steady state.[10] Hence, labor supply in region r , $L_{r,t}$, is derived by:

$$L_{r,t} = HK_{r,t} \cdot A_r$$

where $HK_{r,t}$ denotes the amount of human capital-augmented labor and A_r is a labor-augmenting measure of productivity specific for region r. That means labor is measured in efficiency units or in effective amount of labor.

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[9] Note that if $\mathrm{f}(F) = 0$ for all F we have the standard case with undifferentiated labor in a region.

[10] For the proof see Barro and Sala-i-Martin (1995), pp. 54.

In the DART model, the labor supply in efficiency units, $L_{r,t}$, evolves exogenously over time. Therefore, exogenous labor supply $\overline{L}$ for each region *r* at the beginning of time period *t*+1 is given by:

$$(1) \qquad \overline{L}_{r,t+1} = \overline{L}_{r,t} \cdot \left(1 + gp_{r,t} + ga_r + gh_r\right) \quad .$$

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 improvement, ga_r, or the sum of all.

In the basic version of the DART model we assume constant, but regionally different labor productivity improvement rates, ga_r, constant but regionally different growth rates of human capital, gh_r, and declining population growth rates over time, $gp_{r,t}$, according to the World Bank population growth projections (World Bank, 1998). For the derivation of the growth rates of human capital see Springer (1998). Because of the lack of data for the evolution of the labor participation rate in the future I use the growth rate of population instead of the labor force which implies that the labor participation rate is constant over time.

The supply of the sector-specific primary factor land is held fixed to its benchmark level over time in the basic version of the DART model.

Capital Formation

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:

$$(2) \qquad Kst_{r,t+1} = \left(1 - d_t\right) Kst_{r,t} + Iq_{r,t} \qquad \text{for } t \geq 1$$

where d_t denotes the exogenously given constant depreciation rate in period *t.* The allocation of capital among sectors follows from the intra-period optimization of the firms.

4 DYNAMIC CALIBRATION

Normally, the CGE literature amplifies on the calibration of the single-period equilibrium, but is very short in describing the calibration procedure of dynamic models and the assumptions behind it. Calibration in a dynamic context is generally interpreted as requiring two properties: first, replication of the benchmark data base; second, the model is parameterized in such a way that the balanced growth path is simulated when the base policy is maintained (cf. Pereira and Shoven 1988).

For specifying and using CGE models the following steps are commonly used: The economic regions under consideration are assumed to be in equilibrium, i.e. the benchmark equilibrium. The behavior of the economic agents has been analytically formulated. Then, the parameters of the model are chosen through a calibration procedure. Calibration of the model involves specifying values for certain parameters based on outside estimates, and deriving the remaining ones from the restrictions posed by the equilibrium conditions. Thus, it is assumed that the benchmark data base reflect period equilibrium. The calibrated parameter values can then be used to solve the model for alternative equilibria associated with exogenous changes in policy variables. The so-called „counterfactual" scenarios are imposed on the model to explore and evaluate the impacts of different policy measures and shocks by comparing the results of the benchmark equilibrium with the counterfactual.[11]

A recursive dynamic CGE model can also be interpreted as a sequence of counter factuals to the base year run by altering the factor endowments holding everything else constant. The first step in calibration of a recursive dynamic model is the same as in the static case (for the calibration procedure of a single period model see Shoven and Whalley 1992, pp. 115). The data in the benchmark dataset are in value terms, i.e. they are the products of prices and quantities. Unit conventions are adopted to deal separately with prices and quantities. These unit conventions tell us, for example, what constitutes a unit of primary factor. Usually, physical units of factors of production are taken as the amount that earns a reward of one currency unit, e.g. $1, in equilibrium, abstracting from taxes. Units of commodities are then defined as those amounts that sell for $1 net of all taxes and subsidies in equilibrium. The assumption that in equilibrium marginal revenue products of factors are equalized in all uses permits the direct incorporation of factor payments data by industry as observations of physical quantities of factors in the calibration.

After having calibrated the first, i.e. benchmark, period of the model, the dynamics come in by updating the factor endowments after every time step. The equilibria in any sequence are connected to each other through capital accumulation. Each single period equilibrium calculation begins with an initial capital services endowment resulting from the end of the period t-1. A new equilibrium of supply, demand and relative prices is calculated for the next time period t based on the exogenous and endogenous changes in endowments. Savings of the current period t will augment the capital-services endowment at the end of period t available in the next period t+1. (cf. Shoven and Whalley 1992)

Model dynamics are calibrated in each region on exogenous growth rates. Therefore, the

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[11] For further details see Shoven; Whalley (1992).

benchmark solution of a recursive dynamic model consists of the benchmark equilibrium, and the calculated equilibria for the following one year time steps, i.e. the baseline path.

Define a physical unit of capital in period *t* used in region *r*, $Kst_{r,t}$, as the amount of capital that costs \$1 to construct in period 0, i.e. the benchmark period. Often the data for regional capital stocks, $Kst_{r,0}$, are not available or not reliable. Hence, the capital accumulation equation (2) has to be rearranged by exploiting the unit price convention and using physical capital services, $K_{r,t}$, i.e. return to capital, instead of the capital stock, $Kst_{r,t}$. Assume that in period 0, we can observe the return to capital, $K_{r,0}$, and the capital stock, $Kst_{r,0}$. Using the stock-to-flow-conversion, the rate of return for region *r* are given by:

(3)
$$rk_{r,0} = \frac{K_{r,0}}{Pi_{r,0} \cdot Kst_{r,0}}$$

where $rk_{r,0}$ denotes the benchmark gross rate of return on capital and $Pi_{r,t}$ is the cost of constructing a unit of capital. Set $Pi_{r,0} = 1$, the usual unit price convention.

If data for regional capital stocks are not available the initial, i.e. benchmark, gross rate of return, $rk_{r,0}$, can be derived by dividing the regional capital value share, $KVSH_{r,0} = K_{r,0} / GDP_{r,0}$, by the exogenous assumed capital stock to GDP ratio, $\overline{KGDP}_{r,0} = Kst_{r,0} / GDP_{r,0}$:

(3')
$$rk_{r,0} = \frac{KVSH_{r,0}}{\overline{KGDP}_{r,0}}.$$

Now, equation (2), the capital accumulation equation, can be rewritten in terms of physical units of capital services by using the stock-to-flow-conversion (equation (3)). This gives:

(4)
$$K_{r,t+1} = (1 - \delta_t) K_{r,t} + Iq_{r,t} \cdot Pi_{r,t} \cdot rk_{r,0}$$

where $K_{r,t}$ denotes the physical unit of the return on capital in period *t* which earns \$1 in the initial time period. For using return on capital instead of capital stock, the actual value of real gross investment has to be scaled by the initial gross rate of return, $rk_{r,0}$.

Usually, dynamic CGE models are calibrated on a balanced growth, i.e. steady state, path. The steady state is defined as a situation in which the various quantities grow at constant rates (cf. Barro and Sala-i-Martin 1995, p. 19). The steady state assumption implies that all regions and sectors grow at the same pace. However, this assumption is questionable in case of simulating climate protection policies with several regions due to their different levels of development as, e.g., OECD countries, China, Pacific Asian Countries, Energy Exporting Countries, or Africa. Furthermore, the steady state assumption for developing countries does not seam relevant for a model which aims to describe the impacts of policy measures in a 25 or 50 years' time span.

However, the steady state assumption is necessary if the model includes agents with model-consistent, forward-looking behavior because the agents would have to form expectations over the infinite horizon and end point conditions have to be imposed.

In the following part of the paper it will be shown how different assumptions of the specification of the baseline path, i.e. dynamic calibration, affect the results of policy scenarios. For analyzing the implications of the specification of the base run path three different dynamic scenarios are compared. First, case (i) hypothetically assumes that all regions satisfy the steady state condition in the benchmark period and that all regions grow with the *same* rate. This case is called „the single global growth rate case“. This dynamic specification is chosen because the calibration is straightforward. However, the assumption of an identical growth rate for all regions is neither empirically relevant nor theoretically challenging. Therefore, case (ii) assumes that each region is in its steady state which may differ according to exogenous factors - „the regional specific steady state scenario“. This case covers the most common assumption in forward looking, dynamic models. Case (iii) - „the DART model case“ - takes into account the empirical facts. There, economic regions are not necessarily in their steady state. Exogenous growth paths are specified for each region according to reasonable expectations about the future.

Hence, for the first two dynamic scenarios it is assumed, as in the GREEN model (Burniaux et al. 1992, p. 13), that the economy is on a balanced growth path, i.e. the model assumes a constant capital stock to labor ratio (in efficiency units) over the simulation period. The model is calibrated to these growth paths. Thus, the first two scenarios mimic regional growth in the steady state in the above described model setting which is not forward looking or intertemporal.

A problem with this steady state specification arises in the agricultural sector which uses land besides capital and labor as a primary factor. Agricultural land, $\overline{B}$, is a fixed factor, i.e. $\hat{B} = 0$ where the hat ^ denotes change over time. Considering first a one-sector model in which the output is produced by a Cobb-Douglas production function[12] that combines land, labor, L, and capital, K. The law of motion for capital is then given by:

$$\hat{K}_t = AK_t^{\alpha} L_t^{\beta} B^{\gamma} - C_t - \delta K_t \quad \text{with} \quad \alpha, \beta, \gamma \geq 0, \ \delta > 0,$$

where C_t denotes consumption in period t. The equation for the growth rate of capital, g_{kt}, shows that under the assumption of constant returns to scale $(\alpha + \beta + \gamma = 1)$, perpetual growth is unfeasible whenever L_t and B are required to produce output ($\beta > 0, \ \gamma > 0$):

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[12] Replacing the Cobb-Douglas technology with a more general form of neoclassical production functions would imply no substantial changes (Rebelo 1991).

$$g_{kt} = AK_t^{\alpha-1} L_t^{\beta} B^{\gamma} - \frac{C_t}{K_t} - \delta .$$

The presence of decreasing returns to the only factor that can be accumulated, K_t, implies that the growth rate of capital has to converge to zero. Perpetual growth can be sustained if the nonreproducable factors are nonessential to production ($\gamma = 0$), if the production function has increasing returns to scale ($\alpha + \beta + \gamma > 1$), or if the production function is time dependent, i.e. there is labor-augmenting technical progress in the production function which growth rate is increasing over time.

Rebelo (1991) has shown that as long as there is a „core“ of capital goods whose production does not involve nonreproducable factors, perpetual growth is compatible with production technologies that exhibit constant returns to scale. Furthermore, in multi-sector models which include sectors where the fixed factor is nonessential for production, the role that a nonreproducable factor can play is restricted. Thus, the fixed factor is no key determinant of long-run growth.

This is the case in the DART model: capital goods are a composite good of other industry goods which in turn are produced without the fixed factor. Additionally, the fixed factor land is only essential for production in the agricultural sector, not in the other sectors. Therefore, for the sake of simplicity the existence of the fixed factor is ignored in the following debate.

The economies are on a balanced growth path when the capital stock grows at the same rate as the effective labor force: $K\dot{s}t = \dot{L}$, where a dot over the variable denotes differentiation with respect to time. In per capita terms, *k=(Kst/L),* the growth rate of *k* is zero on a balanced growth path. By assuming a Cobb-Douglas production function, using the condition:

$$\dot{k} \equiv \frac{d(Kst/L)}{dt} = \frac{K\dot{s}t}{L} - (ga + gh + gp)k = 0$$

where $\dot{L}/L = (ga + gh + gp)$, substituting $K\dot{s}t/L$ and rearranging terms we get (cf. Barro and Sala-i-Martin 1995, pp. 15) the steady state condition:

$$\dot{k} = s \cdot f(k) - (ga + gh + gp + \delta)k = s \cdot \frac{GDP}{L} - (ga + gh + gp + \delta)\frac{Kst}{L} = 0 .$$

If we rearrange this fundamental condition of the Solow-Swan model we can derive the steady state value for the savings rate of region *r*, $\hat{s}_r$, as:

(5) $$\hat{s}_r = \frac{Inv_{r,0}}{GDP_{r,0}} = \frac{Kst_{r,0}}{GDP_{r,0}}(gp_r + ga_r + gh_r + \delta_r)$$

where the zero in the subscript denotes the initial time period, here the year 1992 according to the GTAP data base. Here, we can see the typical outcome of neoclassical growth models where the steady state of the model is determined by a single aspect of the technology, the growth rate of exogenous technical progress $\left(gp_r + ga_r + gh_r\right)$.

For the comparison of the three calibration scenarios in a multiregional CGE model with international trade[13] the DART model is used. The DART model is programmed in the GAMS (Generalized Algebraic Modeling System - Brook et al., 1992) / MPSGE (Mathematical Programming System for General Equilibrium analysis - Rutherford, 1994) language. All three scenarios are calibrated on the Global Trade Analysis Project (GTAP) database version 3 for 1992 (GTAP, 1997) which is adjusted for primary energy flow data by the International Energy Agency - the GTAPIEA database. Regions and sectors can be aggregated 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 2). The growth path of the DART model is calibrated on exogenous assumptions concerning growth rates of population and technological change, change in human capital, savings rates, and capital to GDP ratios.

Table 2: 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

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[13] The case of a small country with given world market prices is excluded here.

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

Case (i) - „the single growth rate case“ assumes that all regions satisfy the steady state condition in the benchmark period. Furthermore, it is assumed that all regions grow with the *same* rate, i.e. the sum of the annual human capital growth rate, gh_r, the population growth rate, gp_r, and the total factor productivity improvement, ga_r. That means equation (5) is identical for all regions and all regions face the same steady-state conditions. For deriving these steady state properties from the GTAPIEA data set all regional data have been summed up to global figures. The results are given in Table 3. The identical growth rate assumption for all regions implies that all regions would have the same marginal propensity to save and equal capital-stock-to-GDP ratios. A simulation would require to readjust the data set in that way that the date would reproduce the same steady state properties for each region according to the numbers listed in Table 3.

Table 3: Parameter values for the single growth rate case

Region	s_r (GTAP)	δ_r (GTAP)	Kst/GDP (GTAP)	gp_r (exogn.)	gh_r (exogn.)	**ga_r (TFP) (endog.)**
World	21.3 %	4 %	2.968	1.44 %	2.05 %	**-0.3 %**

For case (i) the calibration of a multiregional recursive dynamic CGE model is straightforward. The definition of the steady state implies that on the steady state path all relative prices remain constant.[14] This is a convenient property for updating the factor endowments in a recursive

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[14] As mentioned above, due to homogeneity of cost and demand functions only relative prices matter. Hence, all prices have to be measured by a numeraire.

dynamic setting. According to the unit conventions the base year price is used to normalize factor quantities. Once the quantities are normalized all updates in quantities use the same normalization, i.e. $1 per physical factor unit.

The single growth rate assumption for all regions and the initial steady state properties imply that there is no change in structure over time. All prices remain constant; only the quantities grow with the same constant rate. No trade spill-overs apply. Therefore, the multiregional trade model can be regarded as a single region CGE model and can be calibrated like a one region CGE model with more than one (regional) household and without trade.

However, the assumption of equal growth rates among several regions like for example the OECD, oil exporting countries, Pacific Asia, China and Africa is rather hypothetical because of substantial differences in empirically observable human capital growth, gh_r, population growth, gp_r, or total factor productivity improvement, ga_r, as well as in the relative factor endowments of the eleven regions as specified in the GTAP database.[15] Because of this hypothetical character the „single growth rate case" is skipped from further analysis.

For the second calibration scenario, case (ii) - „the region specific steady state scenario", different growth rates for each of the eleven regions are assumed. The initial values for each region are specified in a way that they represent the steady state conditions according to the region specific exogenous growth rate. Hence, equation (5) holds for each region separately. The used parameter values are listed in Table 4. The investment rate, s_r, the regional capital-stock-to-GDP ratio, $KGDP_r$, and the depreciation rate, d_r, are derived from the GTAPIEA data set version 3 which is the basis for al three scenarios.[16] The growth rates of population are exogenously specified according to the World Bank population projections (Bos et al. 1994). The growth rates of human capital accumulation are exogenously derived from Hall and Jones (1998). Then, the total factor productivity is derived so that the steady state condition (5) holds for each region in every year of the simulation period.

The deduced rates for total factor productivity improvement, ga_r, (last column of Table 4) are rather unrealistic. Compared to numbers find in the literature (cf. Table 5 for scenario (iii)), the ga_r for the MEA, the LAM, the AFR, and the ROW regions are much higher (around 1 % excluding human capital growth) and much lower for the regions CPA, PAS and FSU (around 3 %), whereas WEU and NAM are nearly in their steady state. Hence, one can see that either the GTAP data for capital stocks and investment (cf. column one and three in Table 4) need to

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[15] For the controversy on the convergence and divergence of growth rates see Durlauf (1996) and the following papers in *The Economic Journal* 106:1016-1069. Ventura (1997) provides another explanation for different growth rates. There trade is the source of long persistent growth.

[16] Here, it can be seen that the GTAP data for investment and capital stock need careful treatment and adjustments in a dynamic setting.

be readjusted[17], or the regional steady state assumption (which leads to these numbers for ga_r) is not plausible, or both.

Table 4: Parameter values for the regional specific steady state scenario for the year 1993

Region	s_r (GTAP)	δ_r (GTAP)	Kst/GDP (GTAP)	gp_r (exogn.)	gh_r (exogn.)	**ga_r (TFP) (endog.)**
WEU	20.3 %	4 %	3.034	0.40 %	1.20 %	**1.1 %**
NAM	16.1 %	4 %	2.753	1.00 %	0.15 %	**0.7 %**
PAO	30.1 %	4 %	3.344	0.40 %	1.00 %	**3.6 %**
FSU	18.9 %	4 %	1.705	0.20 %	0.55 %	**6.3 %**
MEA	19.6 %	4 %	2.657	2.40 %	2.50 %	**-1.6 %**
CPA	31.7 %	4 %	1.348	1.10 %	1.90 %	**16.5 %**
PAS	31.5 %	4 %	2.272	1.70 %	2.10 %	**6.1 %**
IDI	21.6 %	4 %	2.355	1.80 %	2.70 %	**0.7 %**
LAM	19.0 %	4 %	3.145	1.70 %	2.30 %	**-2.0 %**
AFR	15.8 %	4 %	2.849	2.5 %0	3.20 %	**-4.1 %**
ROW	20.9 %	4 %	3.077	1.60 %	2.30 %	**-1.2 %**

Nevertheless, let us for this scenario (ii) accept the numbers as they are. Then the relative prices would remain unchanged for each country if there were no trade between regions. In that case all regions evolve along „their“ balanced growth path.

With international trade and different growth rates relative prices change in every time period. Due to the different growth rates the relative factor endowment of regions change. In the version of the DART used here model primary factors are internationally immobile. Therefore, the relative prices for commodities produced at home or abroad change, leading to a change in international prices. This induces trade in commodities and, in a multisectoral model, a changed sectoral allocation according to the terms of trade effects. Summarizing these effects, in a multiregional model with regional different „balanced“ growth there are trade spill–overs which result in changing relative prices and thus in another sectoral allocation compared to the non-trade case where the per capita numbers would remain constant.

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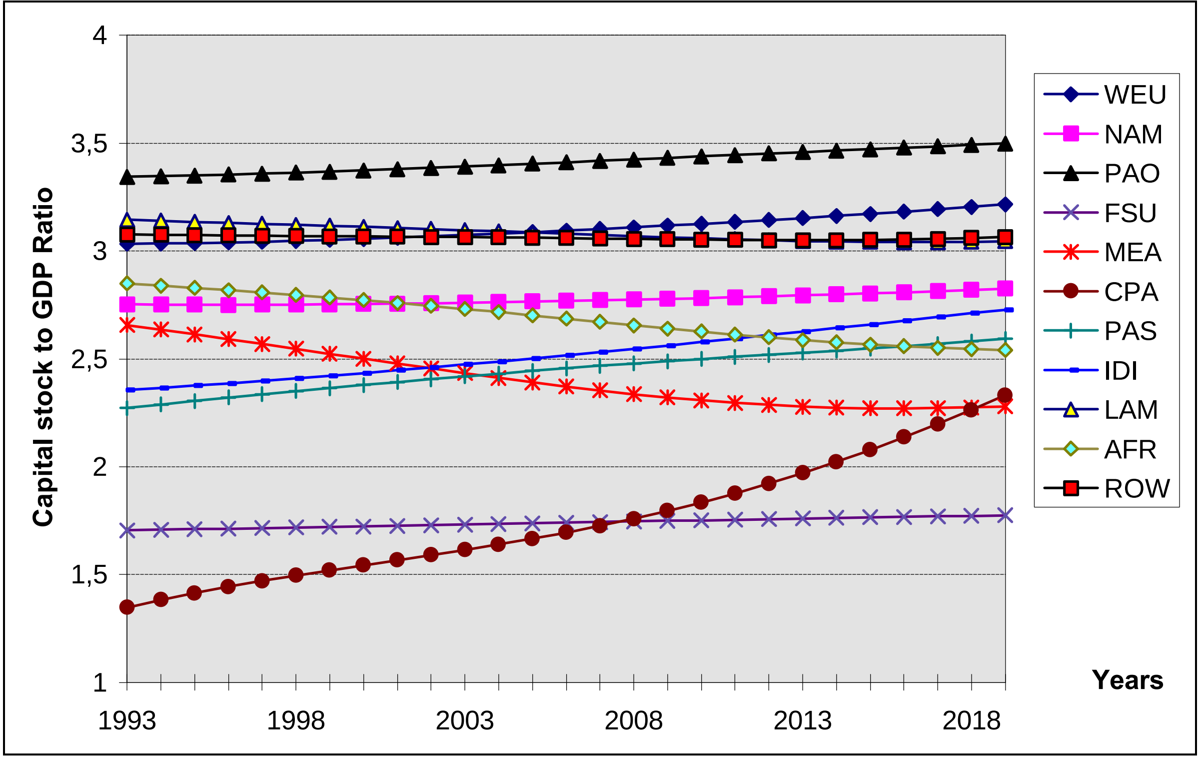
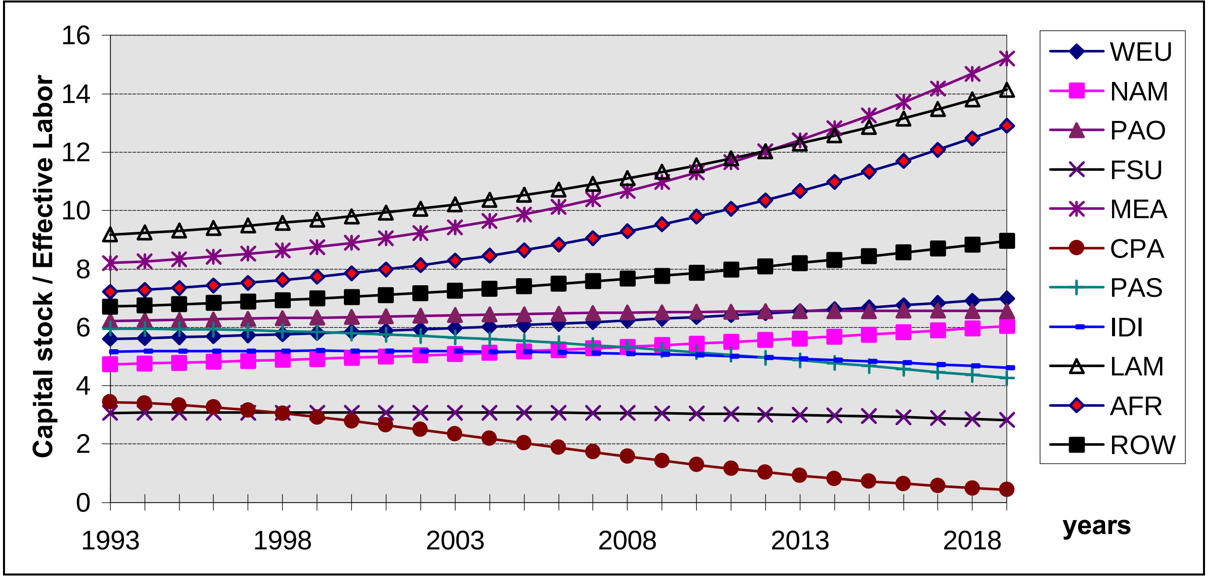
[17] The capital stock data for CPA and FSU used in the simulations are already adjusted downward by 50 percent compared to the GTAP capital stock numbers. The measures of capital stocks of the GTAP database seem to refer to the capital stocks accumulated during the periods of a centrally planed resource allocation. With the introduction of markets and competition these capital stocks have become obsolete to a considerable degree.

Figure 5: Capital stock-to-GDP-ratio in regional specific steady state scenario



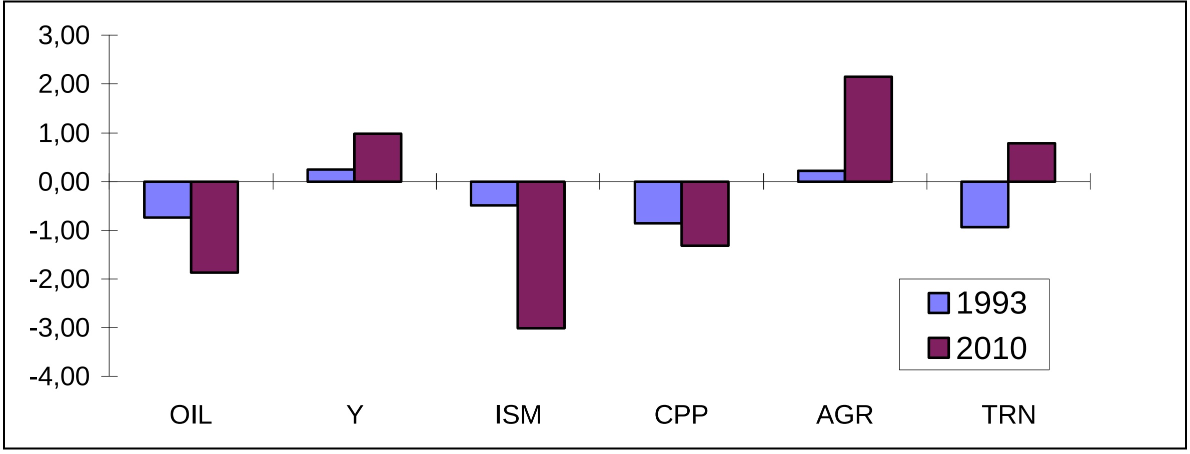
As a consequence of these trade spill–overs, the regions do not evolve along „their potential“ balanced growth path anymore: relative prices change and the quantities do not grow at constant rates. As can be seen in figure 5 the capital-stock-to-GDP ratio is not constant over time, i.e. capital stock and GDP grow with different rates which implies a change in the gross rate of return on capital over time, i.e. a basic condition for the steady state is not fulfilled anymore.

Figure 6: Capital stock-to-effective labor force ratio in regional specific steady state scenario



The capital stock-to-effective-labor ratio, which should be constant according to the definition of a balanced growth path, also shows this off-steady state behavior caused by changes in terms of trade (cf. Figure 6). Here it can be seen that highly developed regions like PAO, WEU, or NAM remain on their steady state growth path while regions like LAM, MEA, AFR experience an increase in the capital-stock-to-effective-labor ratio, and China (CPA) a decrease. A look at the endogenously derived „steady state" technological progress rates, ga_r, (cf. Table 4) reveals that LAM, MEA, and AFR are the regions with the lowest, i.e. negative, ga_r whereas CPA has the highest ga_r. This implies that CPA may has gained a comparative advantage in labor-intensive products through changes in international prices leading to a faster growth of the labor force compared to capital. This is confirmed by the development of the revealed comparative advantage (RCA) for China over the benchmark simulation period. Figure 7 shows an increase of the RCA in relative labor-intensive sectors like AGR, Y, or TRN and a fall of the RCA in capital-intensive sectors like OIL, ISM, CPP. The opposite arguments hold for MEA, LAM, and AFR.

Figure 7: Revealed Comparative Advantage of China in 1993 and 2010 for scenario (ii)



If regions grow with different growth rates, myopic expectations are not appropriate to the dynamic context. Myopic expectations are correct only if the economy is on a balanced growth path; they are incorrect on any transition path (Shoven and Whalley 1992, p. 189). Hence, if the steady state assumption is used for calibrating a multi-regional, multi-sectoral trade model one has to incorporate agents with forward looking, instead of myopic, expectations.

As in most other dynamic CGE models, convergence to a balanced growth path is not guaranteed in the recursive dynamic framework, but can be imposed by a suitable calibration of the parameters of the model. The resulting path is not necessarily unique, since there may be several ways to calibrate the model in order to ensure convergence. (Burniaux et al. 1992, p. 62)

An alternative approach to the steady state calibration which represents case (iii) is to calibrate each region on exogenously assumed growth rates of population, human capital accumulation, total factor productivity, saving rates, and initial capital-stock-to-GDP ratios. These ad-hoc specifications of growth rates and key parameters reflect plausible development paths of the economies. For the derivation of economically reasonable growth paths all relevant information from the literature can be used. The GDP is then derived endogenously. A detailed discussion of the dynamic benchmarking of the DART model is given in Klepper and Springer (1999). The dynamic key parameters for case (iii) are represented in Table 5.

Other CGE models used for climate policy analysis calibrate their benchmark path on exogenous carbon dioxide emission projections while GDP growth is endogenous (e.g. Bernstein et al. 1997). However, such emission projections already incorporate certain assumptions about GDP growth which may be not consistent with the calibration outcome.

Table 5: Dynamic key parameters for the off-steady state scenario for the year 1993

	Growth Rates for Efficiency Labor (in percent)				Savings Rate (in percent)
	Exogenous technical progress	Human capital growth (1993)	Growth Rate of Population (1993)***	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 2010.
** Falls by 0.5 percentage point per year up to 2010.
*** Taken from Bos et al. (1994).

Again the development of macroeconomic ratios is used to describe the baseline path of the dynamic calibrations scenario. The capital-stock-to-GDP ratio (shown in Figure 8) like the capital-stock-to-effective-labor ratio (cf. Figure 9) are not constant implying an off-steady state growth path. Here, the relation between the savings (or investment) rates and the growth rate of effective labor is relevant for the development of macroeconomic properties. China, for example, with a very high initial savings rate and a high growth rate of the effective labor force faces a faster growth of capital compared to labor, i.e. an increase of the capital-stock-to-effective-labor ratio which declines after 2008. The decline is due to the fact that the savings rate exogenously falls by 0.5 percent per year while the annual growth rate of labor remains constant. The high savings rate leads also to an increase in the capital-stock-to-GDP ratio over time.

Furthermore, the initial growth rate of China's per capita income is very high compared to other regions (cf. Figure 10). This can be attributed to high growth rates of capital and labor in China relative to the other regions. According to the specified growth rates and the initial capital-stock-to-GDP ratio a convergence process can be simulated.

Figure 8: Capital stock-to-GDP-ratio in the off-steady state scenario

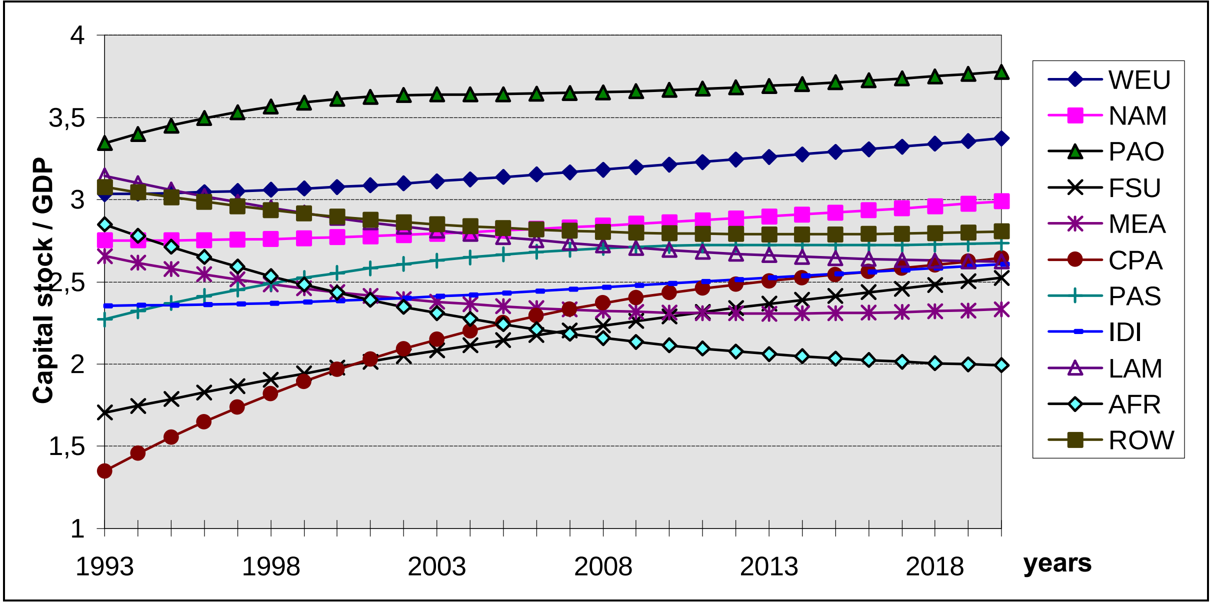


Figure 9: Capital stock-to-effective labor force ratio in off-steady state scenario

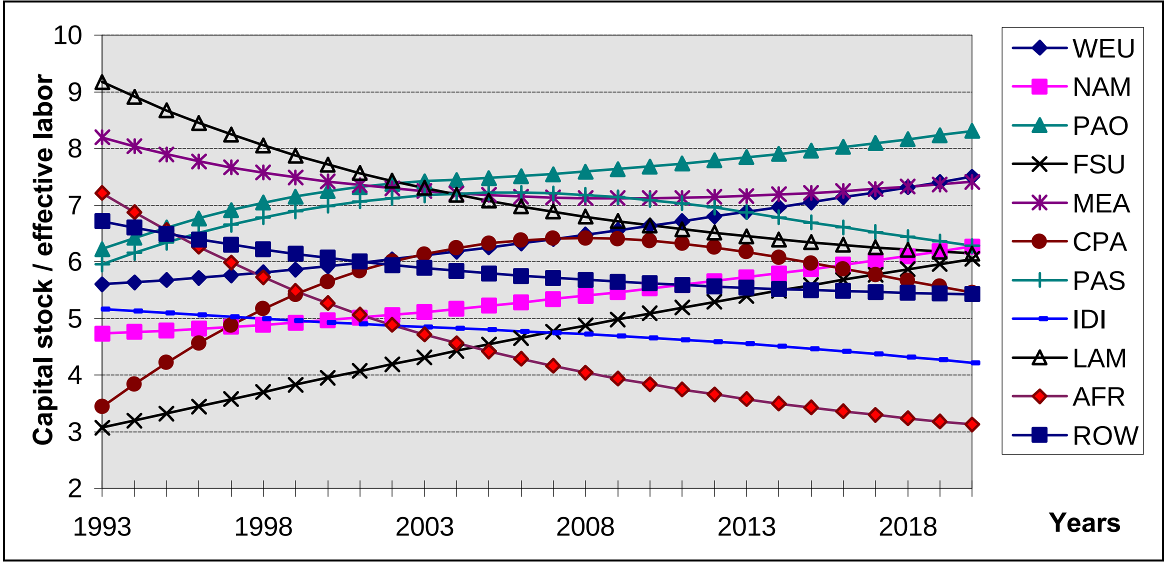
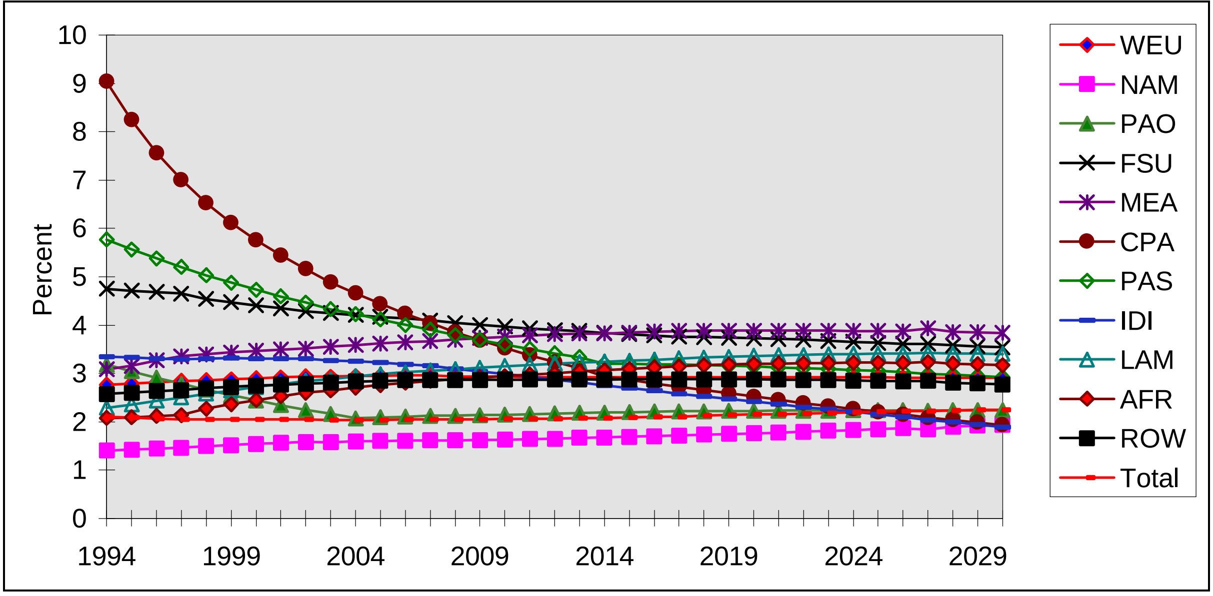
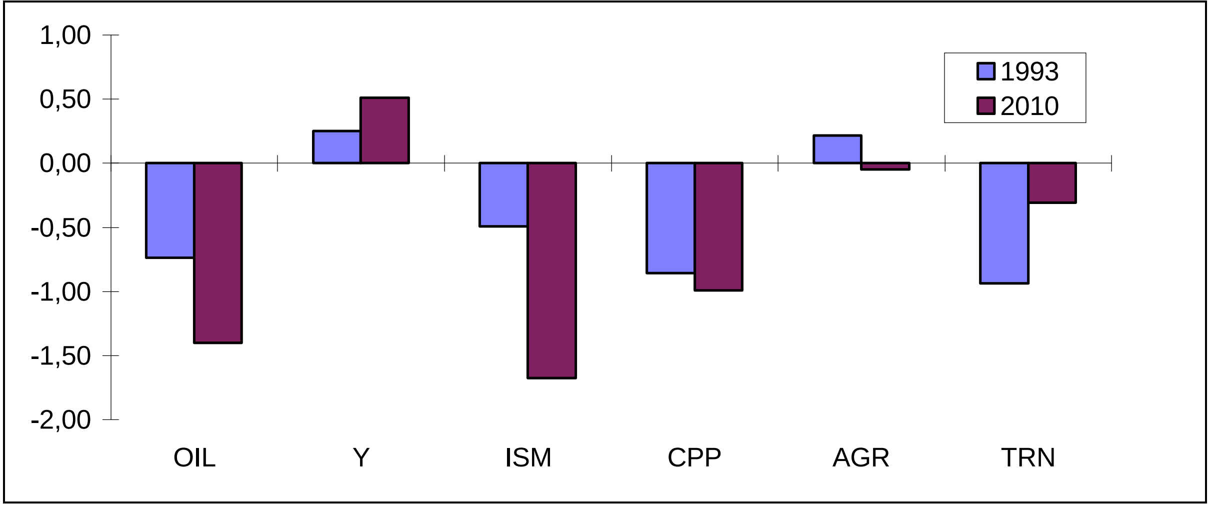


Figure 10: Growth Rate of Per-Capita Incomes in the off-steady state scenario



The change of the dynamic specification of the CGE model leads, besides of a change in the macroeconomic behavior, to a quantitatively as well as qualitatively different development of the RCA's for the off-steady state calibration compared to the dynamic scenario (ii), as Figure 11 shows.

Figure 11: Revealed Comparative Advantage for China in 1993 and 2010 for scenario (iii)



5 POLICY SIMULATION

For the evaluation of different dynamic calibration scenarios not only the empirical plausibility is relevant, but also the behavior of the model to exogenously imposed policy shocks. The policy change will alter the initial steady state (or base run) path and set the economy on a transition path to the new steady state. Then both steady state paths can be compared.

The Kyoto Protocol is used for the policy experiment and is implemented in the following way. The policy simulation imposes carbon dioxide emission reduction targets of 8 percent for

WEU, 7 percent for NAM, 3 percent for PAO, and 0 percent for FSU by 2010 compared to the 1990 emission level. It is assumed that the reduction has started in 1990. From 1993 until 2010 carbon dioxide emission reduction takes place at a constant rate. Thereafter, the emissions remain constant for the four Annex I regions. In this setting of differentiated emission targets for Annex-I (WEU, NAM, PAO, FSU) and non-Annex-I countries trade spill-overs are likely to occur. Therefore, the welfare impacts of the Kyoto Protocol on the different world regions are estimated and compared for the different calibration scenarios.

The regional welfare effect of the Kyoto Protocol is measured in percentage change of Hicksian equivalent variation relative to the base run for the year 2010. The results for both dynamic specifications, (ii) steady state and (iii) off-steady state, are presented in Figure 12. Concerning the behavior of the model to an exogenously imposed policy shock, it is apparent that the reaction of the model to the same policy scenario, i.e. the Kyoto Protocol, is different in magnitude and direction depending on the dynamic specification. For the steady state scenario, the regions CPA, PAS, and IDI are the winner of the imposed Kyoto Protocol while the other countries loose in terms of welfare measured in equivalent variation. Just by changing the dynamic specification, the region PAO benefits from the Kyoto Protocol in the off-steady state scenario while it looses in the steady state case.

On one hand, these differences in policy results are caused by a different base run paths. In the steady state scenario, the higher growth rate of technological progress for PAO leads to greater economic activity compared to the off-steady state scenario. Imposing now a carbon dioxide emission reduction target for PAO of 3 percent by 2010 compared to 1990 means the same carbon dioxide emission level in 2010 for the steady state and the off-steady state policy scenario, but a higher emission reduction objective relative to the base run in absolute terms for the steady state scenario. Due to the higher economic activity in the benchmark of the steady state scenario (ii) the emission reduction for PAO in absolute terms is ten times higher than in the off-steady state scenario (iii) where PAO has to reduce the lowest amount of carbon dioxide emissions in absolute terms compared to the other three abating regions. Hence, cutting carbon dioxide emissions by 3 percent to the 1990 level forces PAO to a considerable reallocation of resources and leads to a loss in output because of restricted substitution possibilities from carbon-intensive to less carbon-intensive products. Relative high adjustment costs and loss in welfare are the consequence for PAO in the steady state scenario.[18]

On the other hand, the differences in policy outcomes between both dynamic specifications are not only due to different levels of the base run path but also due to different ways of reaction

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[18] The same argument applies for explaining the high welfare loss of the FSU region. Keeping emissions constant to their 1990 carbon dioxide emission level means for the FSU the highest emission reduction relative to the base run in absolute terms since the industries in the FSU produce relative carbon-intensive compared to other countries.

to the same policy shock. As can be seen from Figure 6 and 9 or from Table 4 and 5, the difference between the off-steady state scenario and the steady state scenario lies in the different growth rates for labor augmenting technological progress while capital accumulates with the same rate. This implies that PAO is more capital-intensive in the off-steady state scenario compared to the steady state scenario. This difference in relative factor endowments between the two dynamic specifications and the interactions with the development of relative factor endowments of other regions lead to a different shift in comparative advantages of sectors over time for both dynamic specifications as it was shown for the example of CPA in the previous section. Hence, the same policy shock like the Kyoto Protocol causing changes in international prices has an asymmetric effect on a certain region for the steady state case and for the off-steady state case, and thus, leads to an other reallocation of resources and sectoral adjustments.

In the base run, PAO, for example, experiences a higher increase in comparative advantage in the carbon-intensive sectors ISM and CPP in the steady state scenario compared to the off-steady state scenario (same RCA’s in 1993 - ISM (0.5), CPP (-0.05); RCA’s in 2010 - ISM (1.7 for steady state scenario, 0.8 for off steady state scenario), CPP (0.5 for steady state case, 0.2 for off steady state case)). Therefore, for the same emission reduction target PAO is more negatively affected in the steady state case than in the off steady state case through changes in international prices. These for PAO more disadvantageous terms-of-trade effects in the steady state scenario are revealed by a sharper decrease of total trade, i.e., the sum of imports and exports, relative to the base run level (ISM: -10.66 %, CPP: -2.11% in 2020) compared to the off steady state scenario (ISM: -2.08 %, CPP: -0.94 % in 2020). The changes in international competitiveness lead to a different sectoral adjustment, and hence, welfare change to a policy shock in PAO depending on the dynamic specification.

To summarize, different dynamic specifications lead to different relative factor endowments which causes different comparative advantages for regions. A change in international prices induced by a climate policy entails then other allocational and distributional adjustments for the respective dynamic specification. Hence, the same climate policy leads to other policy outcomes caused by a different adjustment behavior of the model depending on dynamic specification.

Figure 12: Welfare Effect of the Kyoto Protocol in 2010 measured in Equivalent Variation relative to the Base Run in 2010

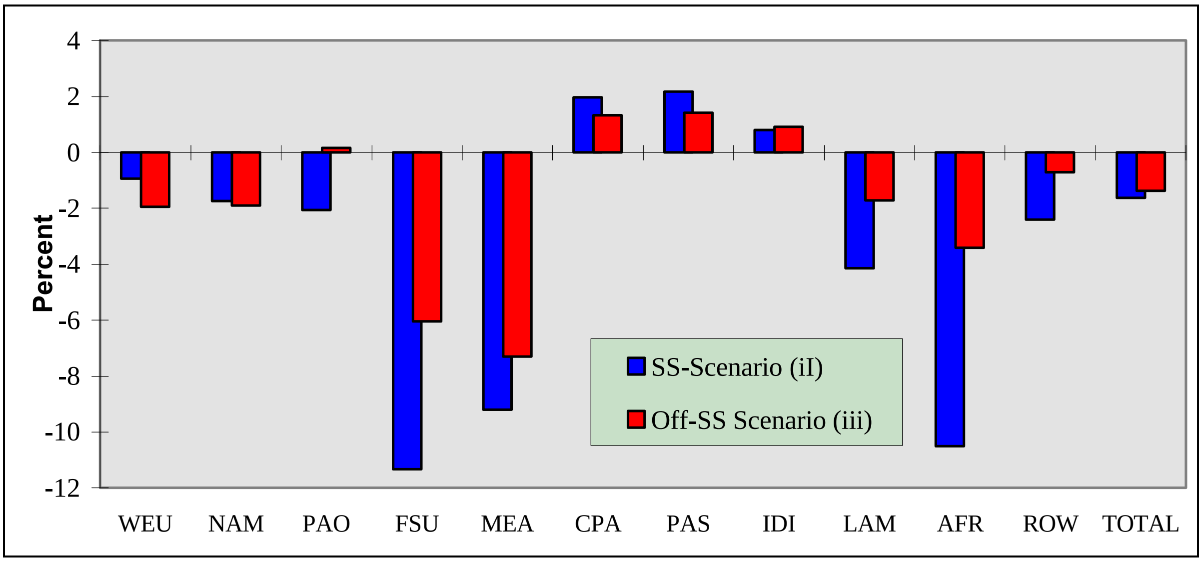


Figure 13 compares the benchmark as well as the from the climate policy resulting income per capita for every region. This Figure reveals the difference in the income per capita due to the dynamic calibration in the base run as well as the different model reaction to the Kyoto Protocol. The different reaction of both calibration scenarios to the same policy shock can better be seen in Figure 14 which shows the change in income per capita for the Kyoto Protocol relative to the base run in the year 2020 for calibration case (ii) and (iii). Here again, quantitative as well as qualitative differences due to the underlying base run path and the different adjustment mechanism to a policy shock can be recognized.

Figure 13: Comparison of the Regional Income per Capita in 2020

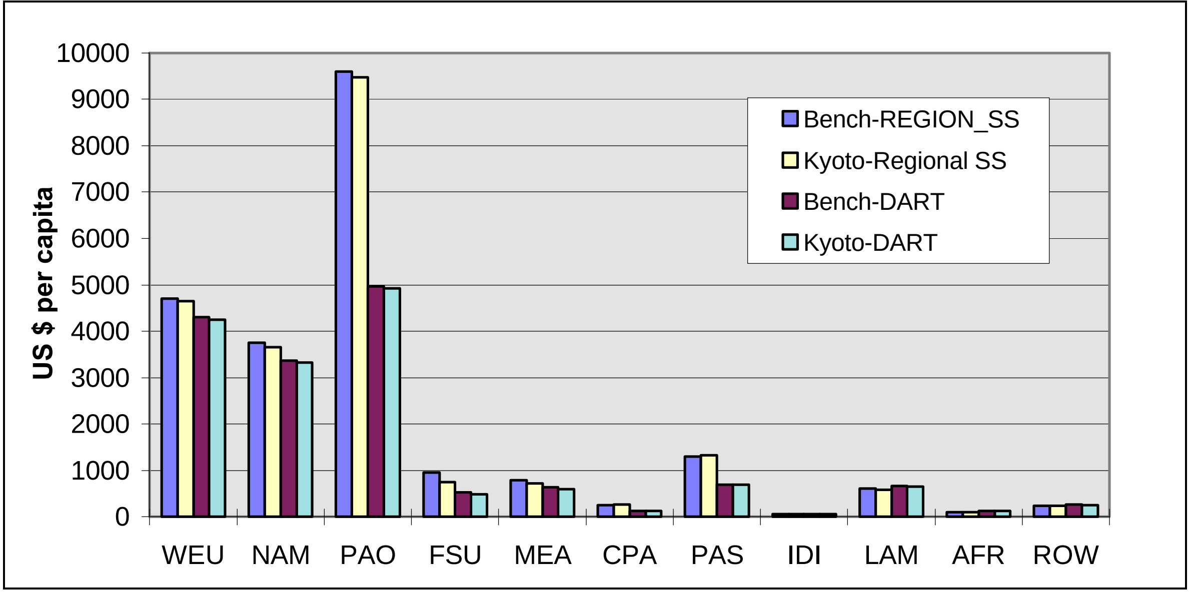
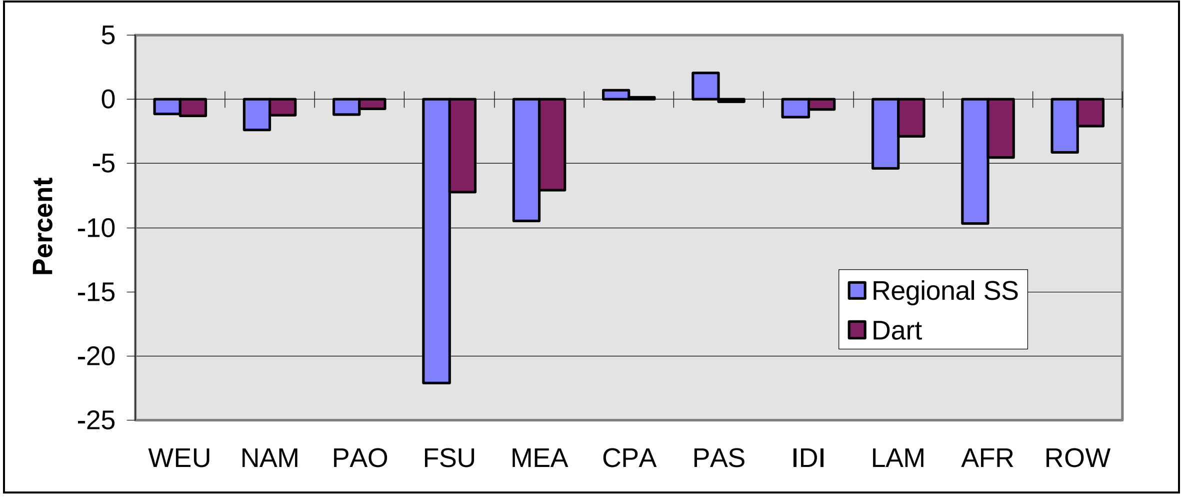
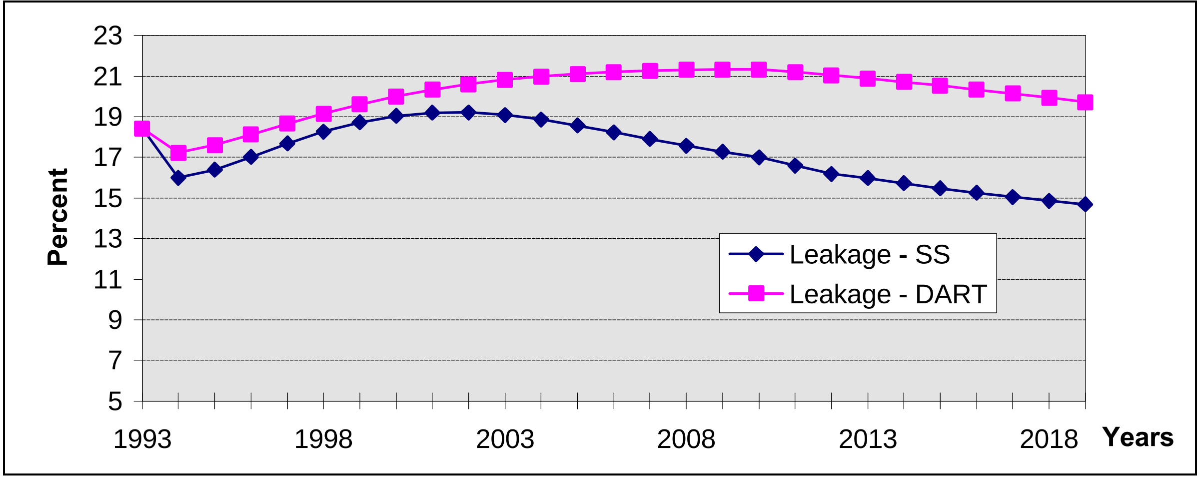


Figure 14: Relative Change of Income per Capita Kyoto Protocol vs. Benchmark in Percent



The leakage rate is a measure for the effectiveness of a climate policy and gives the increase in carbon dioxide emissions of the non-abating regions relative to the reduced carbon dioxide emissions of the abating region in percent. Differentiated emission targets for Annex-I and non-Annex-I countries cause a change in international prices and competitiveness, and, thus, leads to an off-set of the reduction targets through an increase of emissions in the non-abating regions. This increase is higher in the off steady state (DART) scenario compared to the steady state scenario. The difference in the leakage rate is caused, on one hand, by higher emission reductions in PAO and FSU in the steady state case because of high base run emissions, and on the other hand, by a greater emission increase relative to the benchmark in MEA, IDI, LAM, and ROW in the off steady state (DART model) case compared to the steady state case. Remember that MEA, IDI, LAM, and ROW experience a faster growth in effective labor in the DART specification relative to the steady state scenario.

Figure 15: Carbon Leakage Rate in Percent



Hence, it can be concluded that the specification of the base run path is very important for the results of policy simulations, since these results are evaluated relative to the base run path. Furthermore, the adaptation of the model to a policy shock depends on the dynamic specification of the benchmark growth path. Here, different relative factor endowments of regions caused by different dynamic specifications induce a distinct distribution of comparative advantages over regions and, thus, an other adjustment of the model to a change of international prices. Therefore, the assumptions behind and the implications of the calibration procedure and the used parameters have an influence on the results.

There are several ways of calibrating multiregional recursive trade models. In the GREEN model, for instance, model dynamics are calibrated in each region on exogenous GDP and population growth rates and on given Autonomous Energy Efficiency Improvements (AEEI). Under the maintained hypothesis of balanced growth, implied growth rates are calculated for the total factor productivity (TFP). In counterfactual runs, this technical progress path is exogenous while GDP growth rates become endogenous. The balanced growth path assumption in the GREEN model, i.e. constant capital-labor-ratio over time, is necessary for calibrating on the total factor productivity. But, as it was shown above the balanced growth assumption can not be maintained in this multiregional setting with international trade due to trade spill-overs.

6 CLOSING REMARKS

This paper has dealt with recursive dynamic multi-sectoral trade models. Multi-regional, multi-sectoral CGE models are an appropriate tool for analyzing the allocational and distributional impacts of climate policies on regions and sectors. Thereby, terms of trade effects have to be considered in order to measure the right magnitude of these impacts and to include leakage effects.

However, several problems are connected to the calibration of a recursive dynamic multi-regional trade model. The calibration and interpretation of model results is straight forward if all regions are on their steady state growth path and grow with the same rate. If different growth rates, i.e. convergence between regions, are taken into account, trade spill–overs occur which lead to a change in relative prices and a changed sectoral production structure. In this setting no steady state simulations are possible. These off-steady-state dynamics may lead to economically meaningless results, in the sense that they are not intertemporally consistent. Hence, if the steady state assumption is used for calibrating a multi-regional, multi-sectoral trade model one has to incorporate agents with forward looking instead of myopic expectations.

For the evaluation of different dynamic calibration scenarios not only the empirical plausibility is relevant, but also the behavior of the model to exogenously imposed policy shocks. Here, the Kyoto Protocol was used for the policy experiment. It was shown that the policy results for different dynamic calibration scenarios differ considerably because different assumptions about model dynamics cause other base run paths and different model adjustment mechanisms to a policy shock.

An alternative approach to the steady state calibration was suggested by Pereira (1988, p.62): the qualitative calibration. There, structural parameters are exogenously chosen so that the economy follows a reasonable path into the future. The strategy of qualitative calibration is well appropriate to exploit the recursive nature of CGE models. Furthermore, it minimizes the amount of information necessary to run the model. Aside from the structural parameters, only initial stock values are needed. Additionally, it allows comparisons of different, not necessarily steady state, equilibrium path. This strategy is applied to the dynamic calibration of the DART model.

A major advantage of recursive dynamic models compared to fully dynamic models is their simplicity which allows to implement a more sophisticated model structure and more empirically realistic dynamic behavior. Furthermore, recursive dynamic CGE models are quite convenient in an integrated assessment framework where several models have to be linked.

Also completely dynamic models with full intertemporal optimization have their shortcomings especially in a multi-regional, multi-sectoral framework. In completely dynamic multi-regional models only steady state relations can be considered because off-steady state situations can not be mathematically explicitly solved anymore.

Furthermore, usually the equilibrium of the economy is described in terms of a single numéraire. With recursive models, this form of aggregation seems appropriate as Manne and Rutherford (1994) pointed out in their paper. With intertemporal CGE models difficulties are encountered unless the rate of return is identical in all regions (what means perfect capital mobility; a rather unrealistic assumption). Otherwise, there would be no way to define an international numéraire in the model. Differential rates of return within a dynamic CGE framework are manageable if period-by-period constraints on capital flows are assumed. But these ad-hoc assumptions are not suitable for purposes of sectoral analysis. In this case it is far more convenient to assume that there is an international numéraire, i.e. a uniform rate of return on capital in all regions (cf. Manne and Rutherford 1994).

Another point for the integrated assessment of climate policies is that in CGE models with full intertemporal optimization the system is fully determined in the first period. This implies linking problems in an integrated assessment framework.

In conclusion, all dynamic approaches have their shortcomings. Therefore, it depends on the research task which approach is appropriate. Nevertheless, the assumptions behind and the inherent implications of the dynamic calibration approach chosen should be explicitly mentioned.

For policy conclusions, the specification of the base run path is very important since the results of the policy scenario are evaluated relative to the base run path. Furthermore, the adaptation of the model to a policy shock in magnitude and quality depends not only on exogenously specified parameters like. e.g. elasticities, but also on the assumptions about model dynamics since allocational and distributional adjustments in the model are heavily influenced by the dynamic specification.

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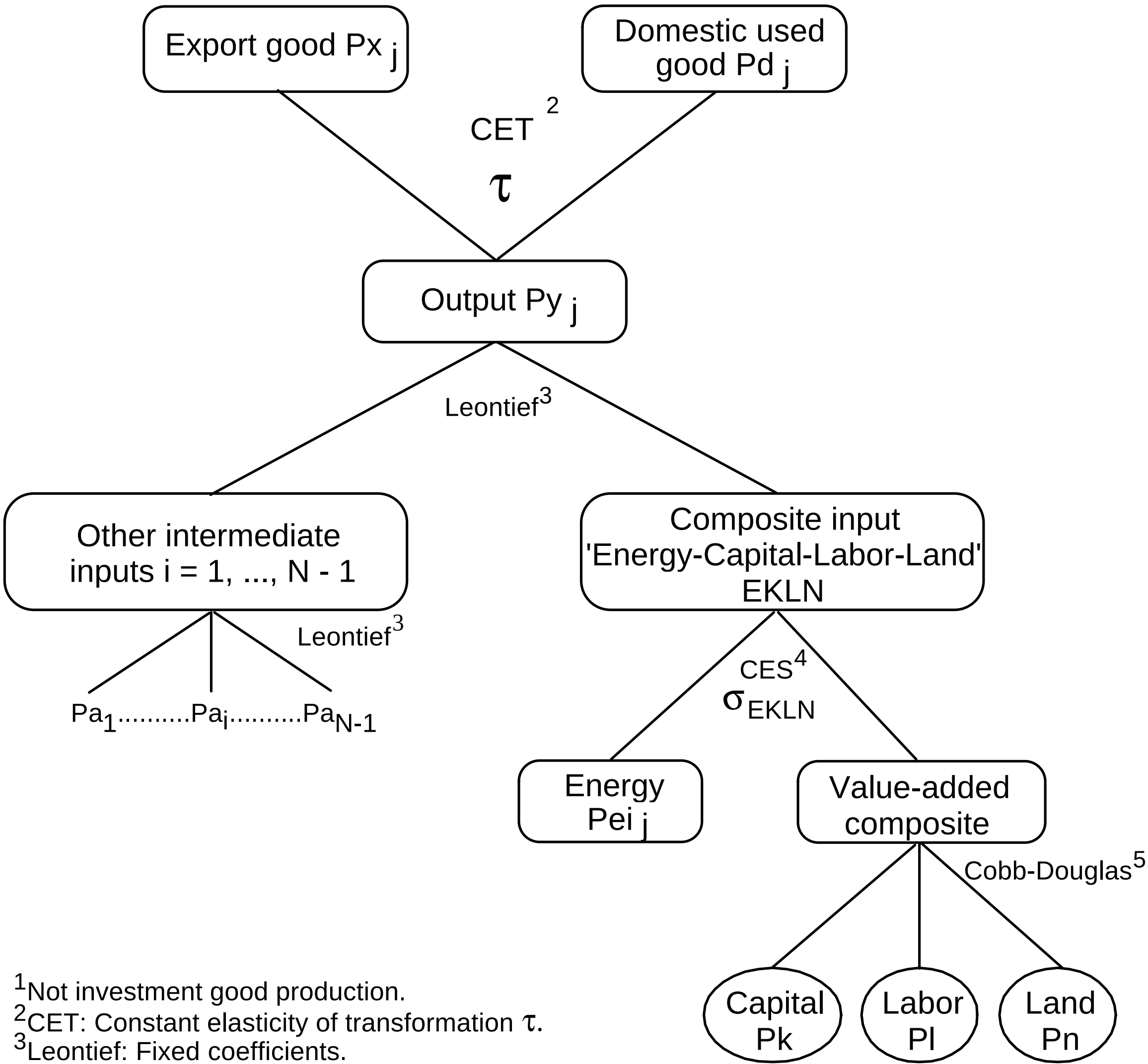
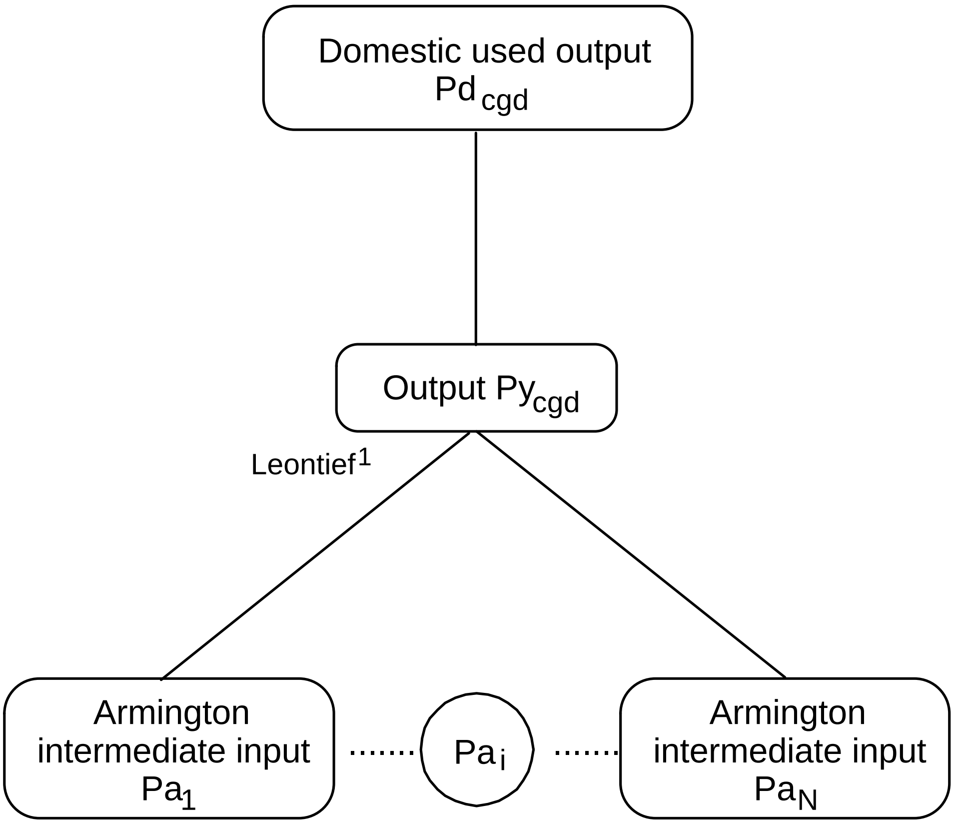
Appendix I - Production structure

Figure 1: Production structure of industry sector j in region r[1]



[1] Not investment good production.
[2] CET: Constant elasticity of transformation τ.
[3] Leontief: Fixed coefficients.
[4] CES: Constant elasticity of substitution σ.
[5] Cobb-Douglas: $\sigma = 1$.

Figure 2: Production structure of the investment good sector cgd in region r



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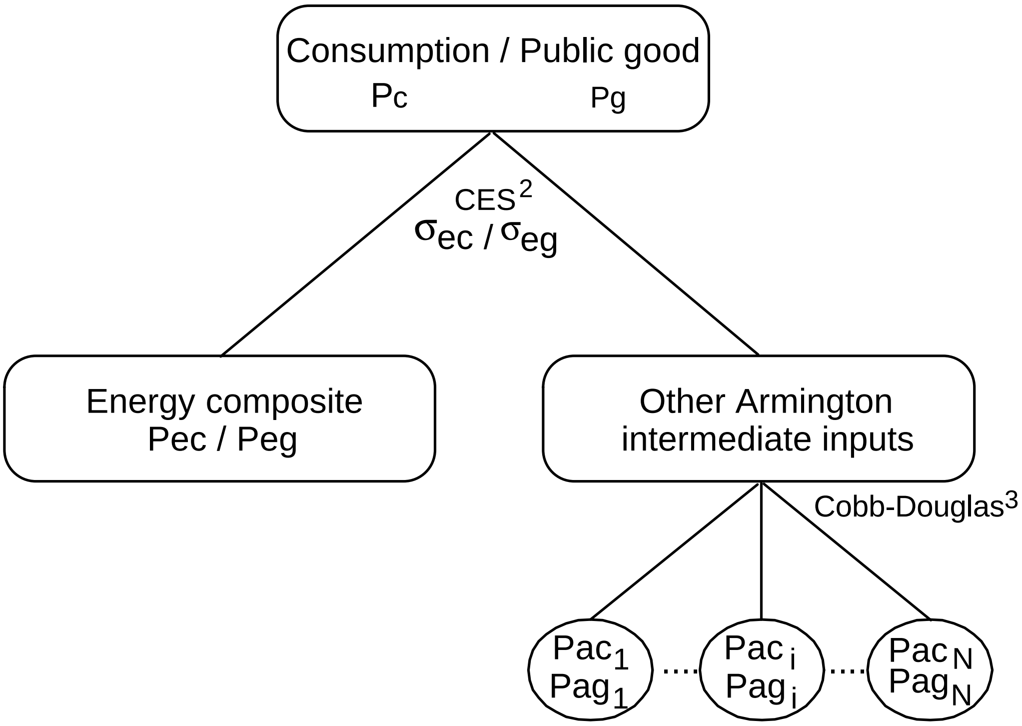
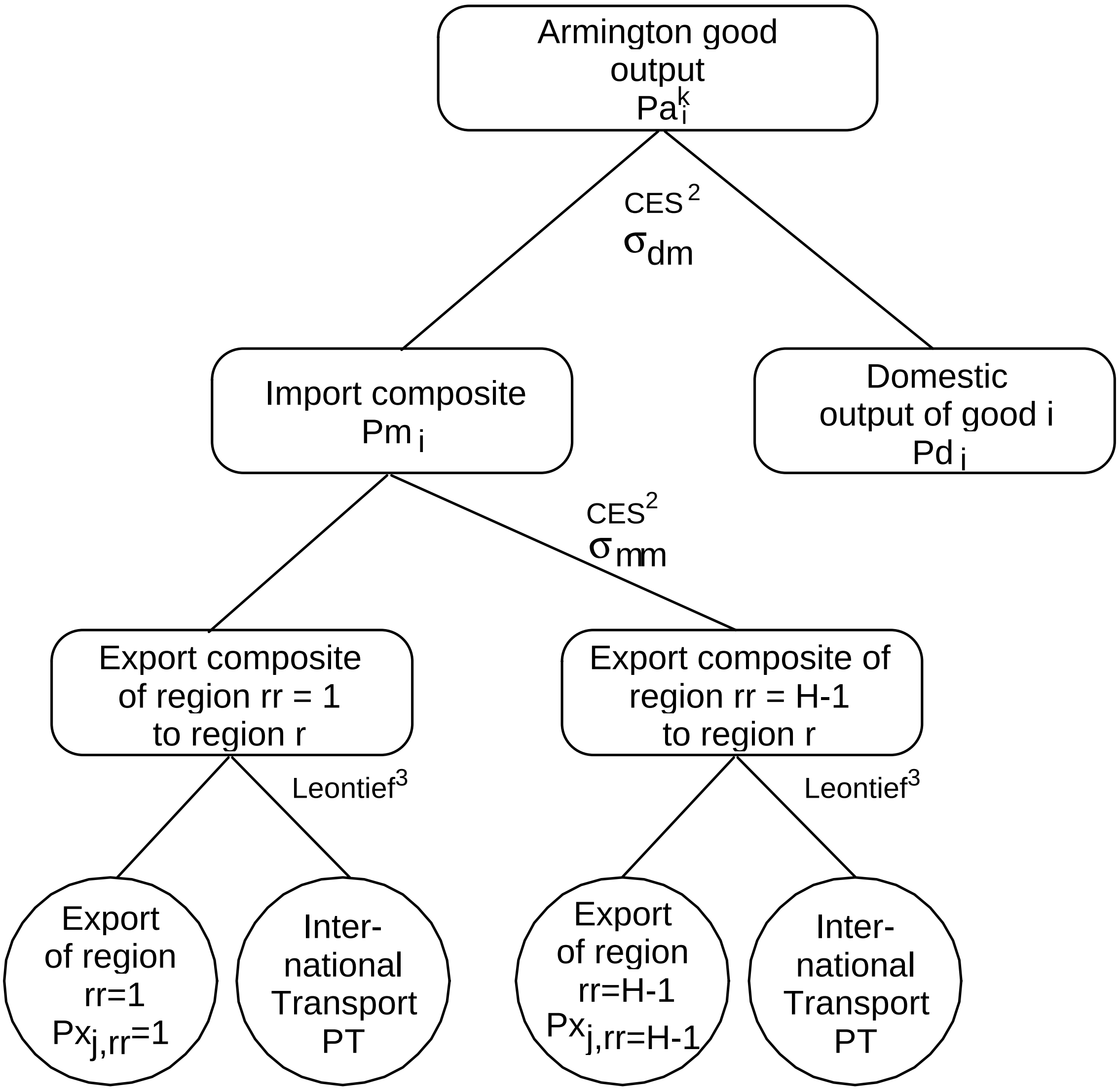
[1] Leontief: Fixed coefficients.

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: $\sigma = 1$.

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.