G-RDEM: A GTAP-based recursive dynamic CGE model for long-term baseline generation and analysis

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Abstract

We motivate and detail the newly developed G-RDEM recursive-dynamic Computable General Equilibrium model as a tool for long-term counterfactual analysis and baseline generation from given GDP and population projections. It encompasses an AIDADS demand system with non-linear Engel curves, debt accumulation from foreign saving and during baseline generation introduces sector specific productivity changes, endogenous aggregate saving rates, as well as time-varying input-output coefficients. Parameters for all these relationships are econometrically estimated or taken from published econometric work. The core of the model is derived from the GTAP standard model and the whole system is seamlessly incorporated into the modular and flexible CGEBox modelling platform. Accordingly, it can be applied with various other extensions in CGEBox such as GTAP-AEZ, GTAP-Water, CO2 and Non-CO2 emissions or a regional breakdown for Europe to 280 NUTS2 regions. The newly developed G-RDEM module maintains the flexible aggregation from the GTAP data base to a user chosen sectoral and regional aggregation. It is open source, encoded in GAMS and can be steered by a Graphical User Interface, which also encompasses a tool to analyse results with tables, graphs and maps. Existing GDP and population projections for the Socio-Economic Pathways 1-5 can be directly incorporated for baseline construction. A comparison of the generated long-term structural composition of the economy against a simple recursive-dynamic variant, using the basic CDE demand system of the standard GTAP model, uniform productivity growth, fixed saving rates and technology parameters, and no debt accumulation shows that the introduction of the new features in G-RDEM brings about much more plausible results, as well as a more realistic, internally consistent representation of the economic structure in a hypothetical future.

Keywords

Computable General Equilibrium models, Long-run economic scenarios, Structural change.

JEL Codes

C68, C82, C88, D58, E17, F43, O11, O40.

Background and introduction

Due to issues such as climate change and depletion of global resources, there is an increasing demand for long-term quantitative analyses. Computable General Equilibrium models can contribute in that direction as they consistently consider the manifold interrelations occurring in the economy, while providing the often needed sectoral detail. They therefore complement approaches working at the more aggregate level (e.g. Dellink et al. 2017) or focusing in detail on specific sectors (e.g. Alexandratos and Bruinsma 2012). On the other hand, it should be noted that CGE models were not originally designed to this purpose, but rather for short-term policy assessment, like simulating the effects of a fiscal reform, or the implementation of a trade agreement. Accordingly, most parameters are usually "calibrated" to a relatively recent Social Accounting Matrix or Input Output Table, such that the observed structure of an economic system is taken as a benchmark, from which counterfactual experiments are conducted.

Of course, when the economy is analysed at a horizon of 20, 30 years, or even more, the economic structure as emerging from some past national accounts, which may refer to five years back, is no more a valid starting point. One should consider trends in structural adjustment, driven by changing preferences, demographic composition, new technologies, variations in the endowments of primary resources (including human capital), etc. The whole issue is not about forecasting: nobody actually knows which "breakthrough" technologies could emerge, or which unexpected phenomena could shape the economic structure in the future. What we do know from past observation is that a number of "slow" adjustment processes are active and therefore they should be taken into account in the generation of a credible and internally consistent future baseline.

The study of time evolution of the economic structure ("structural change") is a rather active research field in theoretical and applied economics (Matsuyama, 2008). Most of the studies in the literature, however, look at the past. Typical research questions are: the contribution of the changing industrial mix to aggregate productivity (e.g., Duarte and Restuccia 2010); the declining share of the agricultural sector in developing economies (e.g., Üngör 2013), etc., where some specific transition processes are identified. Here, rather than studying the past, we aim at drawing from some empirical findings and methodologies in this literature to infer, inside a CGE modelling framework, a possible future evolution of the economy.

To this end, a number of "unconventional" features have to be introduced into the standard CGE formulation, to create a model specifically designed for the generation and assessment of long-term economic scenarios. We present therefore in here a newly develop CGE model of this kind, termed G-RDEM (GTAP based Recursive Dynamic Economic Model). This model considers drivers of long run structural change, which we regard as especially relevant, namely: (1) non-linear Engel curves in household consumption, (2) productivity growth differentiated by sector, (3) debt accumulation from foreign savings and trade imbalances, (4) aggregate saving rates linked to population and income dynamics, and (5) time-varying and income dependent industrial cost shares.

G-RDEM extends the flexible and modular CGE modelling platform CGEBox (Britz and Van der Mensbrugghe 2016), from which it inherits some important features. Firstly, the code is open source, to ensure transparency and invite the community of modellers to use the tool and contribute to its further development. Secondly, it maintains full flexibility in sectoral and regional aggregation. Thirdly, G-RDEM as a seamless integrated module in CGEBox offers the possibility to combine it with other modules such as CO2 and Non-CO2 emissions, GTAP-Water, GTAP-AEZ etc.. All new features are based on econometrically estimated parameters, thereby making the implementation fully documented and transparent. G-RDEM is encoded in the GAMS modelling language and, as a module of CGEBox, shares its graphical user interface.

Overview

The construction of a long-term baseline in CGE models typically draws on population and GDP projections from other studies. Indeed, a recursive dynamic CGE only considers capital accumulation as an endogenous mechanism driving growth, while productivity changes and other drivers of structural change are usually kept exogenous. In order to let a CGE model replicate a given growth path, a total factor productivity shifter is endogenously determined during the construction of the reference baseline, by fixing GDP at each time period. In subsequent model runs and counterfactual simulations, productivity parameters are then maintained at those estimated levels, while national income is endogenously computed.

This simple methodology aligns the output of the CGE model to a pre-determined aggregate growth path, but of course does not capture some fundamental structural changes which may take place in the economy, i.e. in the composition of output and demand. Instead, we aim in here to address the key elements driving such compositional change (Figure 1).

To this end, we introduce an AIDADS demand system to consider how budget shares in household consumption adjust to the changing levels of per capita income, to capture "non-linear Engel curves", which are a salient feature of economic development. Secondly, the economy wide total factor productivity (TFP) shifter, aligning the model to the target GDP in any period, is here differentiated by sector. These two features are introduced through specific equations directly into the CGE framework itself (red boxes in Figure 1). Other elements are activated in between the solution points (blue boxes). Therefore, the intra-periodal equilibrium computed by the model, in combination with exogenous projections from the current period *t*, updates some parameters for the following period *t+1*. The labour force (by skill category) is adjusted to population and work force projections. Next year's capital stocks reflect last year's ending stocks and gross investments. International capital transfers reflect past foreign savings. Saving rates adjust to population and GDP growth, and I-O coefficients (factor shares in production processes) are updated on the basis of national income.

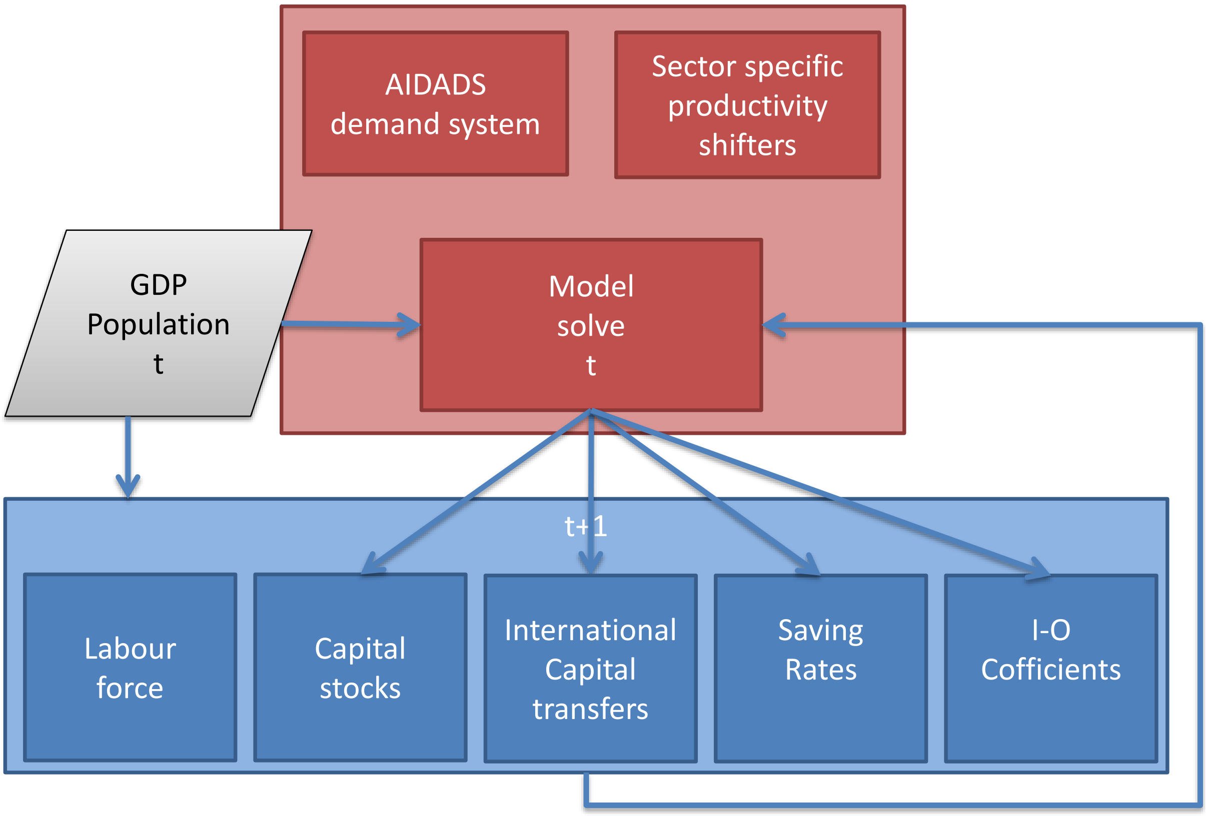

Figure 1: Overview of the recursive-dynamic modelling framework G-RDEM

The process thus requires some exogenous projections for GDP and population. G-RDEM offers the possibility to draw on a set of projections for the so-called SSPs (Shared Socio Economic Pathways) (Riahi et al. 2016), available online from the IIASA Shared Socio Economic Pathways Database.[1] These SSPs were developed in the context of the IPCC scientific assessment on Climate Change. For each of these five SSPs, a single population and urbanization scenario, jointly developed by IIASA and NCAR (National Center for Atmospheric Research), can be combined with GDP projections from either the OECD or IIASA. These GDP and population projections are available in 5-year steps up to 2100, at a single country basis. They are aggregated in G-RDEM to the desired regional aggregation level and interpolated to yield yearly time series. They can also be complemented by Climate Change impacts on yields for a set of RCPs (Representative Concentration Pathways) and various combinations of GCMs (Global Circulation Models) and global gridded growth models provided by the AgCLIM50 project (van Meijl et al. 2017).

A user might also add its own scenario assumptions during the construction of the baseline, such as about trade policies or alternative GDP projections. After the definition of the baseline, the software saves the resulting productivity shifters and other variables, which can subsequently be loaded as exogenous parameters for counterfactual analysis. The set of results from the baseline can also be directly employed, to get a much disaggregated definition of the economic scenario.

[1] https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about).

Non-linear Engel curves: An AIDADS demand system with detail for food consumption

Background

It is universally acknowledged that the relationship between consumption level and income (also known as Engel curve) can be complex and non-linear. Yet, many CGE models still adopt demand systems such as Cobb-Douglas (CD) or Linear Expenditure System (LES), having linear Engel curves. Those simplifying assumptions make the model easier to handle, but are defendable only if the model is used for simulations involving limited changes in income levels. Of course, this is not the case for long-term analyses. Keeping constant marginal budget shares would lead to an overestimation of the demand for necessities, such as food, while demand in other sectors will hence be underestimated. The consequences are implausible long-run structural changes in production, demand, and trade patterns. Some models employed for long-term analysis therefore use different demand systems and/or re-parameterize along the dynamic path. For instance, MAGNET (Woltjer et al. 2014, p. 84) incorporates a module for re-calibrating the parameters of a CDE (Constant Differences in Elasticity) demand system to given income elasticities. Nonetheless, the authors admit: "All of these parameters and functional forms are very much ad hoc, and should be improved.".

Following Roson and van der Mensbrugghe 2018, we rather implement an empirically estimated AIDADS demand system into the G-RDEM model, for broad product groups. The AIDADS is An Implicit, Directly Additive Demand System (Rimmer and Powell 1996). It can be understood as a generalization of a LES demand system, where marginal budget shares are not fixed, but are a linear combination of two vectors, depicting the marginal budget structure at very low and very high utility (income) levels. Given that the marginal budget shares in the two vectors fulfil the adding up condition to unity, any linear combination of the two vectors also leads to regular budget shares. In order to improve the detail inside the agri-food sector, we also took econometric estimates of income dependent marginal expenditure shares for food categories from Muhammad et al. 2011, and incorporate them in the AIDADS framework.

Cranfield et al. 2000 improve on the original Rimmer and Powell 1996 approach, by developing an estimation method that does not rely on an approximation of utility. We follow their notation in the following. The demand system is defined below. Equation (1) determines the Marshallian demand, which is similar to that of a LES. Here, however, the marginal budget shares δ_i are endogenous variables, defined by (2), expressed as a linear combination of two vectors α and β, function of the utility level u, implicitly defined by (3).

$$(1) \quad x_i = \bar{\gamma}_i + \frac{\delta_i}{p_i}\left[Y - \sum_j \bar{\gamma}_j p_j\right]$$

$$(2) \quad \delta_i = \frac{\bar{\alpha}_i + \bar{\beta}_i u}{1+u}$$

$$(3) \quad \ln(u) = \sum_i \delta_i \ln\left(x_i - \bar{\gamma}_i\right) + \bar{\kappa}$$

We first econometrically estimated α, β, γ und u using data from the International Comparison Program ICP 2015, for ten broader expenditure categories (food, beverages and tobacco, clothing, housing, furniture, transportation, recreation, communication, health, education). The integration in the CGE model requires mapping the parameter estimates to the commodity resolution of the model (see Table 6: Mapping between AIDADS categories and GTAP sectors, in the Annex). In order to get more detail for food demand, we combined estimates by Muhammad et al. 2011, taking their estimated marginal budget shares for the five lowest and highest income observations as proxies for the vectors α and β.

The demand system is calibrated against the benchmark data of regional household consumption, from the GTAP v.9 data set. To this purpose, we regressed the utility levels u from our findings to total per capita consumption expenditure Y in each region. That allows us to estimate (from (2)) the marginal budget shares δ_i in the calibration point. We then discarded the previously estimated γ and instead solve (1) for γ at given x, Y, p and the calibrated marginal budget shares. In the case that this implies a negative γ, we use a penalty minimization approach, which minimizes the difference between the estimated α, β and the "corrected" ones, such that all γ turn out to be positive.

Differentiated productivity growth

Background and literature review

Productivity does not vary uniformly among industries and sectors. Harberger 1998 points out that the whole dynamics of economic progress actually resembles the growth process of "mushrooms", rather than the steady rise of "yeast". Indeed, differential productivity growth is one key factor of structural change in the economic systems, and probably the most important one (Swiecki 2017). Several implications of different growth rates have been investigated in the literature, e.g.: relevance and empirics of the so-called "Baumol's disease" (Baumol 1986, Triplett and Bosworth 2003, Young 2014); specialization and international trade (McMillan and Rodrik 2011, Caron and Markusen 2014); "premature deindustrialization" (Rodrik 2016).

To introduce differentiated productivity growth in the G-RDEM model, we build on Roson 2018, who estimated trends in labour productivity, using the Groeningen GGDC 10-Sector Database (de Vries et al. 2015). In that study, some trends and country specific dummies for labor productivity (VA/employment) are estimated. Results are subsequently employed in a cluster analysis, where three groups of countries with similar characteristics are identified. Table 1 below shows some of the findings used to obtain parameters for G-RDEM:

Table 1: Average labour productivity growth rates

Cluster	AGR	MAN	SER	TOT
Rising	6.23	11.43	5.65	8
Steady	7	7.88	5	5.93
Lagging	5.17	5.32	2.34	3.16

Source: Roson 2018

The last column in Table 1 (TOT) displays the average (yearly) growth rate in labor productivity in each group. It refers to value added per worker or hour, so it accounts for capital deepening and similar effects. Interestingly, the differences among industries depends on how fast an economy is growing.

Estimation

In the development of the G-RDEM model we are not concerned about labour productivity in itself, but rather on the relative differences among the three broad sectors of Agriculture, Manufacturing and Services. To this end, a correspondence between the three clusters and the annual GDP growth rates used in the SSPs was established. The distribution of IIASA SSP data (OECD) on GDP was considered, and it was assumed that the average GDP growth in the Lagging group of countries corresponds to the 20% percentile of the SSP distribution, 50% for Steady, 80% for Rising. This means 1.2%, 2.5%, and 4.9%, respectively.

Second, the ratio of each sector productivity rate, relative the slowest growing sector, which is Services, was computed. Third, for each industry a quadratic interpolation between the three multipliers and the references GDP growth rates was undertaken, thereby getting three parameters of a quadratic polynomial relationship between a sectoral productivity shifter (ratio between industry growth rate and the corresponding one in the Services) and GDP annual growth. This gives raise to the functions displayed in Figure 2.

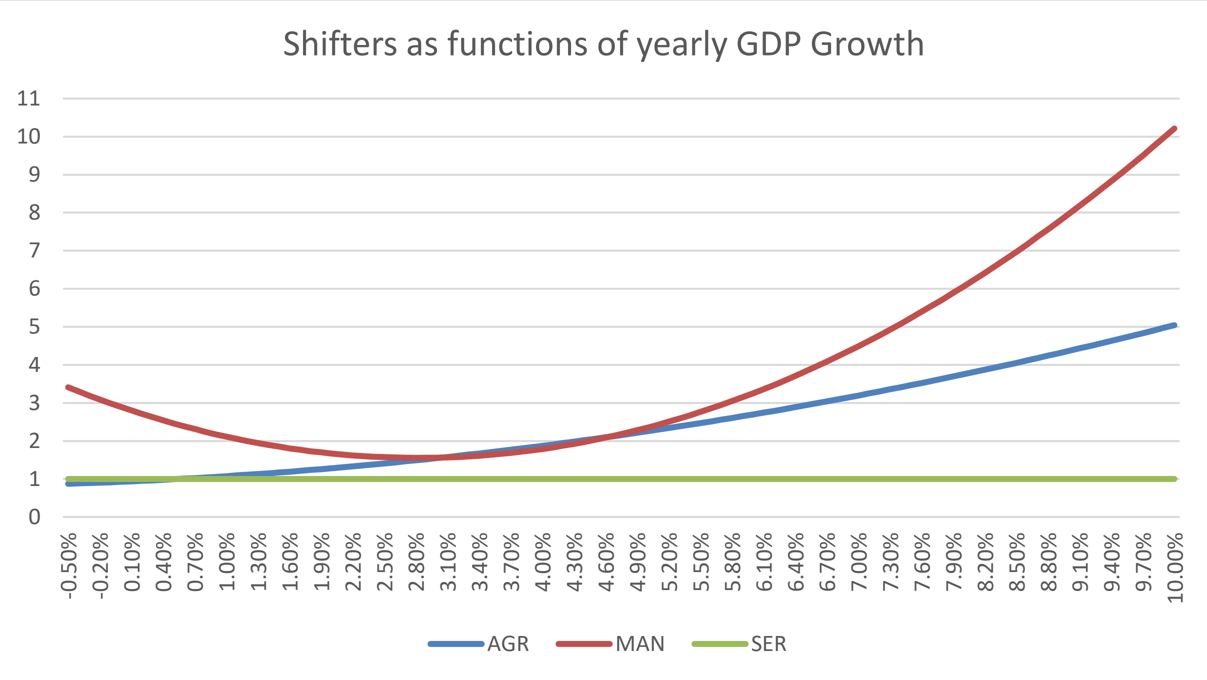

Figure 2 : Productivity growth relative to GDP growth

The key finding is that productivity differentials are minimized (although still significant) at a moderate GDP growth of around 2%. For higher or lower rates, we can see that differences amplify, with manufacturing becoming the key sector. Notice that the shifter is a multiplier: if aggregate growth is negative, it will likely become negative for the reference slow sector as well. When the shifter for Manufacturing is high and positive, this means that productivity is decreasing there more than in the rest of the economy. In other words, productivity growth in Manufacturing appears as strongly correlated with the aggregate productivity growth, which suggests the existence of inter-sectoral externalities.

Implementation in G-RDEM is straightforward. Total factor productivity in the Services *tfp(r)* becomes endogenous during the construction of the baseline and is kept then fixed during counterfactual simulations. Total factor productivity for other sectors (indexed by *i*) in region *r* at time *t+1* are defined as *tfp(r)*sh (i,r)*, where the latter is determined by equations like:

$$(4) \qquad Sh(i,r) = a + b\,\frac{gdp(r,t+1) - gdp(r,t)}{gdp(r,t)} + c\left(\frac{gdp(r,t+1) - gdp(r,t)}{gdp(r,t)}\right)^2$$

Here are the estimated values for the three parameters *a*, *b* and *c*:

Table 2: Estimated parameter for sector specific productivity growth

	AGR	MAN
a	0.925391	2.893917
b	11.99205	-94.8599
c	291.8147	1680.554

Endogenous saving rates

Background and literature review

We aim at developing a simple but robust mechanism to render aggregate saving rates in G-RDEM endogenous. One strand of literature, relying on cross-country differences of saving rates (e.g. Kisanova and Sefton 2007), works with micro-economic survey data. It explicitly accounts for factors such as demography, welfare state, retirement behaviour, borrowing constraints, income distribution over a lifetime and its uncertainty, as well as capital gains. The focus here is on the life-cycle hypothesis, which considers the change in available income over a lifetime. While these papers give robust evidence that the factors indeed explain the saving behaviour of individuals or households, they typically offer results only for one or a smaller group of countries.

Rather, we draw here on studies which employ cross-sectional analyses over countries to evaluate the factors affecting the economy-wide aggregate saving rates. Most of these works also take the lifecycle hypotheses into account (although indirectly) and find that even in cross-country analyses larger proportions of the young and the elderly compared to persons in working age (dependency ratios) generally decrease the saving rate (Doshi 1994, Masson et al. 1998, Laoayza et al. 2000).

Estimation

Instead of directly using parameter values from the literature, we carry out our own cross-section estimation, using GTAP 9 and other data used in our modelling framework, to overcome any potential divergence in definitions, measurement units etc.. The reader might note that we face a potential endogeneity issue: higher rates of GDP growth require increased capital accumulation, thus larger net investments and consequently higher saving rates. The saving rate and GDP growth are hence structurally dependent. However, this is not an issue of major concern in this context, since we are not integrating the estimated equation into the model, but only updating saving rates, given GDP projections. Hence, our aim is solely to ensure that correlation, not causation, is properly accounted for. Notice also that we obtained our estimates from a sectional data base, which would make it impossible the introduction of lagged variables as instruments.

The distribution of the national aggregate saving shares in the GTAP 9 data set reveals a large spread, as shown in the Figure 3. We regressed those saving rates with OLS against the following explanatory variables:

- Population composition by age group from the IIASA repository for 2010 (Lutz et al. 2017)
- GDP growth per capita from 2010 to 2011, in PPPs, from the OECD Env. Growth Model data base as found in the IIASA repository
- Foreign savings (trade balance) relative to regional income, from the GTAP 9 data base

We also tested, as a potential explanatory variable, the share of government consumption on regional income, but did not find a statistically significant relation.

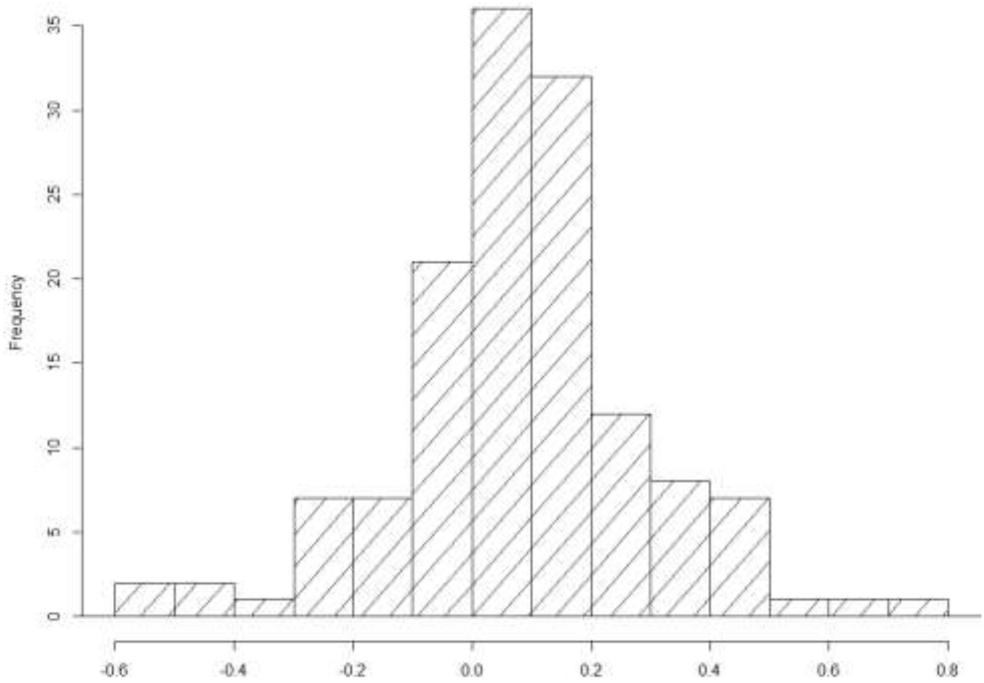

Figure 3 : Distribution of aggregated savings rates in GTAP 9

We found a very good fit for our sectional analysis, with a R^2 at 92% and all variables (with the exemption of the young dependency rate) statistically significant at <0.1%. The young DR is nonetheless significant at the 5% level. All variables have the expected sign: dependency ratios decrease the saving rates, as postulated by the life cycle hypothesis, while a higher income per capita and a higher growth rate increase the saving rate. A positive trade surplus (i.e. negative foreign savings) also tends to increase the saving rates.

Table 3: Regression output for saving rate estimation

```
Coefficients:
                   Estimate Std. Error t value Pr(>|t|)    
(Intercept)       0.2584670  0.0587350   4.401 2.22e-05 ***
gdpGrowth         2.2080586  0.3902076   5.659 9.18e-08 ***
GDPperCAP         0.0010213  0.0003523   2.899  0.00439 ** 
age_depOldSqrt   -0.3640043  0.0792999  -4.590 1.02e-05 ***
age_depYoungSqrt -0.1454039  0.0562902  -2.583  0.01089 *  
savfToRegy       -0.9674676  0.0473476 -20.433  < 2e-16 ***
savfToRegy2       0.3347001  0.0676960   4.944 2.30e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.05893 on 131 degrees of freedom
Multiple R-squared:  0.9213, Adjusted R-squared:  0.9177 
F-statistic: 255.5 on 6 and 131 DF,  p-value: < 2.2e-16
```

The good fit of the regression stems to a large degree from the inclusion of foreign savings relative to regional income, i.e. a trade surplus indicator, (see Table 4 below), while the contributions of the dependency ratios and GDPperCAp are in a similar range, with GDP growth trailing.

Table 4: Analysis of Variance for saving rate estimation

```
Response: betas
                   Df Sum Sq Mean Sq   F value    Pr(>F)    
gdpGrowth           1 0.0001  0.0001    0.0287    0.8658    
GDPperCAP           1 0.5271  0.5271  151.7686 < 2.2e-16 ***
age_depOldSqrt      1 0.5092  0.5092  146.6187 < 2.2e-16 ***
age_depYoungSqrt    1 0.3712  0.3712  106.8974 < 2.2e-16 ***
savfToRegy          1 3.8306  3.8306 1103.0480 < 2.2e-16 ***
savfToRegy2         1 0.0849  0.0849   24.4447 2.297e-06 ***
Residuals         131 0.4549  0.0035
```

Some scatter plots (visualizing the ANOVA results above) between the explanatory variables and the saving rate are shown below in Figure 4.

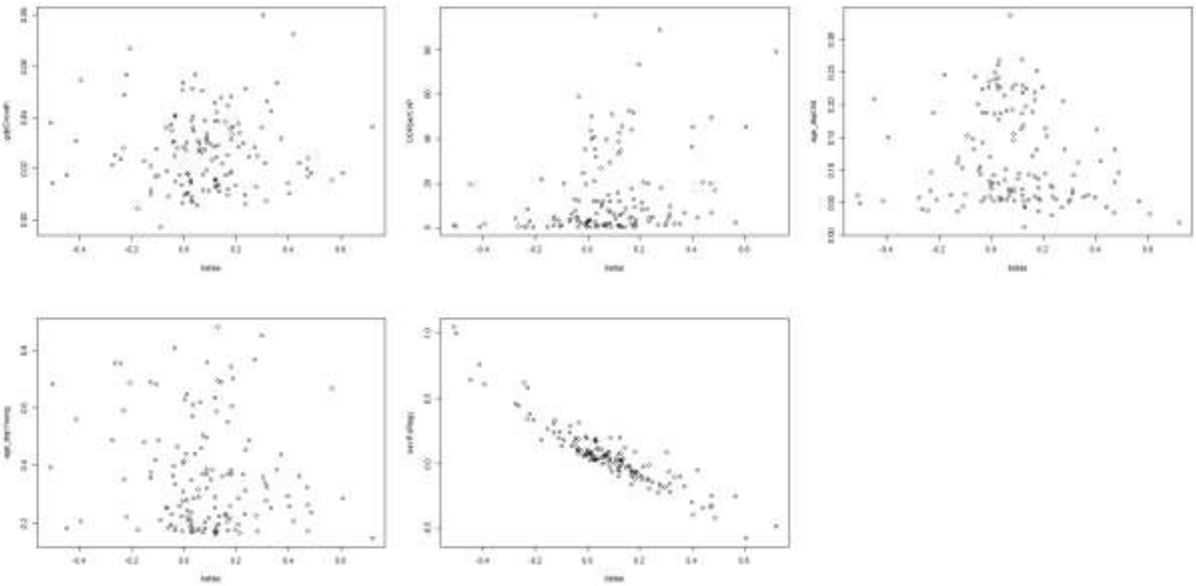

Figure 4 : Scatter plots of explanatory variables against the saving rate

The high contribution of the relation between foreign savings and regional income is not astonishing, because it controls for cases such as oil exporting countries (high saving rates) as well as some other countries, often developing ones, with very low saving rates. The foreign saving indicators can be hence rather understood as a control variable for country specific unobserved features (large receiver of development aid in a group a country with otherwise similar macro-economic indicators, rich oil and gas reserves, tax havens …). Accordingly, we do not use changes in the foreign savings during the process of baseline construction, to update the saving rates.

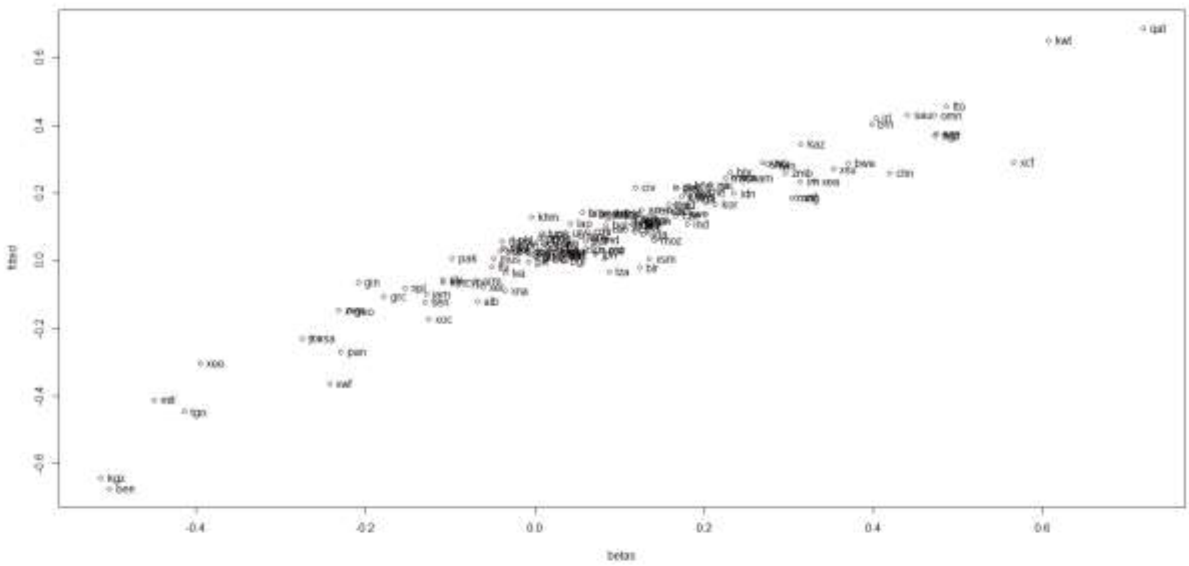

Figure 5 : Fitted against observed saving rates, GTAP region codes as labels

Note that the fitted values cannot be used as such, since we would then neglect any unexplained additional factors, which could imply large changes in the saving rates from the benchmark to subsequent simulation periods in some countries. Thus, we use relative changes in the estimates – neglecting foreign saving – to update the saving rates used in the model. Details of the implementation are further discussed in the Technical Annex.

Debt accumulation from foreign savings

Accounting identities in the model ensure (for each time period) that the sum of regional and foreign savings in each region equals gross investments, while foreign savings are equal to the foreign trade deficit. The latter is determined, in the GTAP model (Hertel and Tsigas 1997, Corong et al. 2017), which defines the intra-periodal equilibrium in G-RDEM) by the mechanism of regional allocation of investments. It turn, this is based on a distribution of global savings, driven by relative expected returns on capital, as it is briefly illustrated in the following.

Let denote the price of a homogeneous capital factor (services) as p_c and p_i as the price of investments (the cost of producing one unit of new capital good), κ the tax rate on capital earnings, *fdepr* the depreciation rate. The net rate of return in a region *r* (*rorc)* is defined in the GTAP model as:

$$(5) \qquad rorc_r = \frac{p_{c,r}\left[1-\overline{\kappa_r}\right]}{p_{i,r}} - \overline{fdepr}$$

The expected rate of return *rore* takes into account the difference between start and end of period capital stocks, k_s and k_e. The logic is that investors should become more cautious when aggregate investments lead to large changes in capital stocks:

$$(6) \qquad rore_r = rorc_r \left(\frac{k_{s,r}}{k_{e,r}}\right)^{\overline{rorFlex}}$$

The parameter *rorFlex* (whose default value is 10 for all for regions) dampens the relative differences in expected returns, thereby avoiding the generation of unrealistically large flows of (real) capital in international markets. In addition, a regional risk factor is introduced, to ensure that an arbitrage condition for the international investor holds in the calibration data set, meaning that a single global, risk-adjusted return *rorg* is identified:

$$(7) \qquad rore_r \, \overline{risk_r} = rorg$$

The condition (7) holds in all periods in G-RDEM, where *rorg* and *rore* are endogenous variables. Therefore, the relationships above drive the distribution of foreign savings *fsav* or, equivalently, the amount of investments in each region (which do not generally match with regional savings).

The global investor hence expects equal returns of *rorg* on his savings in any region. Accordingly, the returns in year *t* from foreign savings add up to zero as, by construction, the global economy is closed, and total investments equal total savings (equivalently, the global trade balance is zero):

$$(8) \qquad \sum_r fsav_r rorg \equiv 0$$

To keep track of the foreign debt dynamics, we assume that regions, which receive foreign savings (*fsav > 0*), will pay in any consecutive year the expected returns to their foreign debtors, while investing regions (*fsav < 0*) will be paid back:

$$(9) \qquad captrans_{r,t} = \sum_{tt<t} fsav_{r,tt} rorg_{tt}$$

The interest payments on the stock of foreign debt enter the equation defining the regional income *regy,* in addition to the factor income *facty* and the indirect tax income *yTaxInd*,:

$$(10) \qquad regy_{r,t} = factY_{r,t} + yTaxInd_{r,t} - captrans_{r,t}$$

A practical issue emerged when the mechanism above was applied to some special cases, where foreign savings account for a large share of investments or total final consumption. Examples are some developing countries, receiving large amounts of development aid or remittances, but also “tax havens” such as Malta. In such cases, we noticed that the mechanism above can lead, after some periods, to a situation where regional income gets unrealistically small. To avoid such extreme cases, while allowing for the existence of capital inflows or outflows determined by factors other than expected returns, we introduced a regional share parameter, such that only part of the debt may actually be served (see the Technical Annex for more details).

Cost-share adjustment

Background and literature review

If preferences are a function of income per capita, reflected in non-linear Engel curves, then the portfolio of products offered by the economy clearly changes. As Chenery et al. 1986 put it “On the demand side, a rise in income can only be sustained if the goods and services made available correspond to the proportions in which consumers wish to spend their income”. We already addressed this issue for the final demand through the introduction of an AIDADS demand system, but further adjustments are in order on the production side, to account for income-dependent variations in intermediate demand. Indeed, an often neglected aspect in CGE and input-output models is that industries internally include many diverse production processes, characterized by different technologies. Variations in demand patterns therefore occur not only *between* the macro-industries, but also *inside* them: aggregate industrial cost structures should be better interpreted as reflecting the internal composition of a sector, rather than describing the production function of a representative firm. Consequently, input-output coefficients can well evolve over time, following changes in income, prices, foreign trade, demography, etc., in a way not too different from the one affecting household final consumption.

Already Arrow and Hoiffenberg 1959 decomposed changes in input-output coefficients into variations due to real disposable income and variations due to technology and tastes. Skolka 1989 provides a structural decomposition analysis for Austria along these lines, thereby explicitly considering that I-O coefficients are not static, but actually change along the process of economic development. This contrasts with the approach followed in most dynamic CGE models, where changes in the industrial cost shares are only attributed to two causes: non-Hicksian technological progress and changes in relative prices.

To illustrate the point, consider the case of distributional services (retail trade and wholesale trade), which are a separate sector in input-output tables and SAMs. A large share of final demand expenditures of households is accounted there. However, those expenditures relates to purchases of food, clothes and other goods, all of which are accounted for separately in most household surveys, and are very likely characterized by significant differences in income elasticity. As a consequence, any shift in the pattern of household consumption should bring about a change in the structure of intermediate demand for the services sector.

We conclude that I-O coefficients should be not be considered as static in the long-term. Since the model already accounts for price-induced compositional changes in intermediate demand, and possibly Hicksian non-neutral technical progress, we concentrate here on the issue of modelling income-related variations.

Econometric analysis

Our basic hypothesis is that I-O coefficients are income dependent, likewise final consumption shares. To estimate the relationship with income, however, we adopt a different strategy. This is because time series consistent with the GTAP industrial classification are not available, and input-output tables are limited. We thus test our hypothesis using a sectional approach, using again the GTAP 9 data base. To keep the analysis manageable, we first aggregated to 10 sectors, while keeping the maximum spatial detail of 140 countries and regions. We then regressed the intermediate input-output coefficients on the log of per capita income in each country, including only data entries with a median cost share of at least 1%. This leaves 65 coefficients out of the potential 100, i.e. 10 sectors times 10 commodities.

Since part of the demand stems from abroad, we constructed (for each sector) a GDP-per-capita index for the average “buyer”, as a weighted average of domestic GDP per capita and GDP per capita in export destinations, taking domestic and export sales as weights.

If input-output coefficients change in the process of economic development, we should find regression coefficients relating to per capita income with a low significance level of being zero. The distribution of these probabilities is plotted in Figure 6. Out of the 65 coefficients with a cost share of at least 1%, more than 40 displays have probabilities below 1% of being zero which supports the assumption that they have a relation with per capita income.

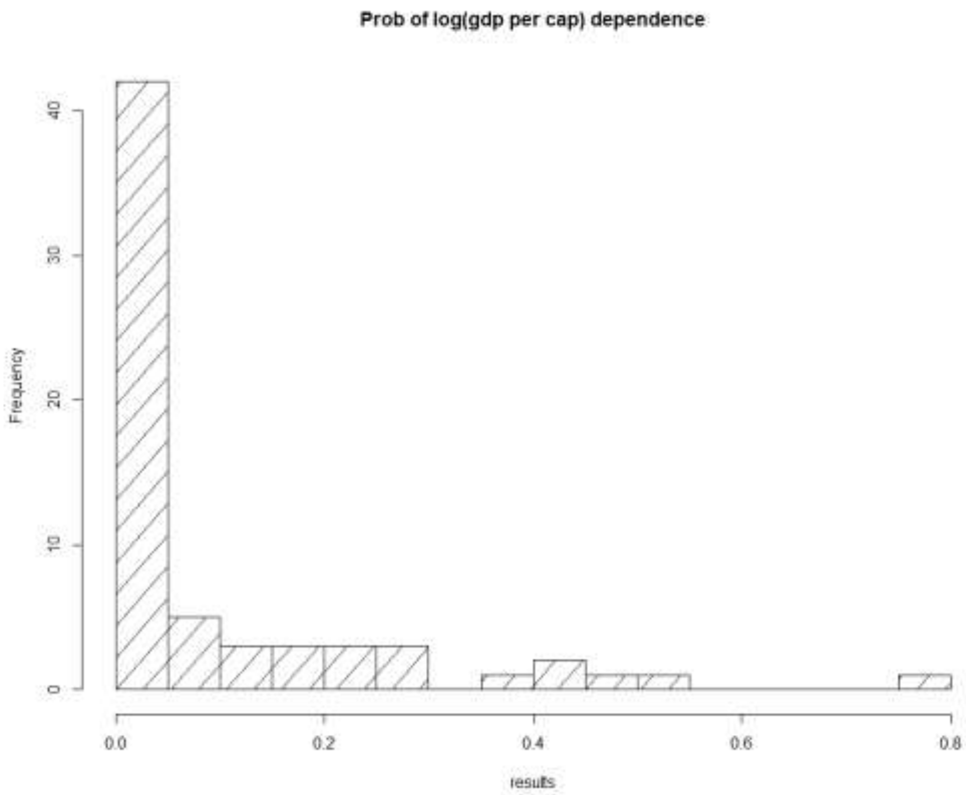

Figure 6: Distribution of significance levels of the regression coefficient between the IO-coefficients and GDP per capita being zero

We conclude from the analysis that fixing the I-O coefficients in long-term analysis hence will mostly likely over-estimate the intermediate demands for product groups will lower income elasticity and vice-versa.

The actual estimation procedure uses a Mean-Absolute Deviation as a robust estimator, which is not very sensitive to outliers. It uses sectoral output as a weight, assuming that larger sectors are statistically better monitored and reported. More details can be found in the Technical Annex.

Assessing the G-RDEM model

To illustrate how the peculiar features of the G-RDEM model affect the results, we present here a set of comparative simulation exercises, under different model configurations. We also contrast our findings with those obtained from a standard GTAP model, linked recursively over time periods only by a simple mechanism of capital accumulation. To this end, we use (for the initial parameters calibration) the global SAM of GTAP 9 with full sectoral detail (57 industries) but 10 aggregated macro-regions. For the exogenous projections of GDP and population, we adopt the SSP3 scenario.

When all features of G-RDEM are "switched off", the model becomes a rather simple recursive-dynamic one. The key characteristics of the two model types are reported in Table 5. By selecting the various characteristics in G-RDEM, we obtain seven different model configurations: (1) the complete G-RDEM implementation with all its five features (AIDADS demand system, productivity shifters, updated saving rates, updated I-O coefficients, debt accumulation; (2) five versions of G-RDEM, having only one of those modules active, and (3) the GTAP Recursive Dynamic variant, where only capital accumulation is considered and the demand system is a CDE (Constant Differences in Elasticity).

Table 5: Common and differentiated features of compared model layouts

	GTAP-RecDyn	G-RDEM
Sector and regional aggregation	GTAP 9, 57 sectors, 10 regions	
Trade modelling	Aggregated Armington agents, two-level nesting	
Time horizon and resolution	40 years in four year steps	
Production function nesting	Mild substitution between value added and the intermediate composite, for value added: sub-nests between labour categories, between capital and natural resources, and total labour and land Mild substitution between intermediates Sub-nests for agri products in feed and food processing with higher substitution elasticity	
Demand	CDE, CES sub-nests for cereals and meats, and domestic-import	AIDADS, CES sub-nests for cereals and meats, and domestic-import
Productivity shifters	Uniform	Differentiated for three major sectors, depending on GDP growth
Saving rates	Fixed, rom calibration	Driven by age composition, GDP per capita and GDP growth
I-O Coefficients	Fixed, from calibration	Driven by GDP per capita index
Foreign debt accumulation	not considered	considered, giving raise to interest payments

Differences between generated baselines – global scale

Figure 7 shows the evolution of the aggregate capital stock, for the whole world, over the forty years simulation horizon (2011 – 2051, in four year steps) obtained from the six variants of G-RDEM. We found that when savings rates are endogenously adjusted (in the full model version and when only this mechanism is taken into account), capital accumulation gets considerably lower.

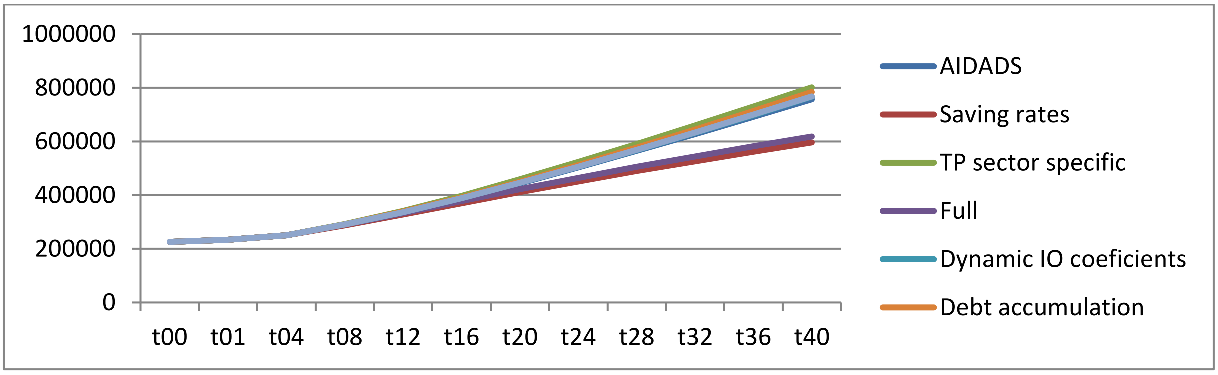

Figure 7 : Global capital stock projection

The development of the capital stock in these two cases might fit better to the assumed GDP dynamics of SSP3, which were generated by the OECD ENV-Growth model, and shown in Figure 8. That scenario implies that growth rates are relatively high up to around twenty years and flatten afterwards. The evolution of the capital stock in G-RDEM appears to follow a similar pattern.

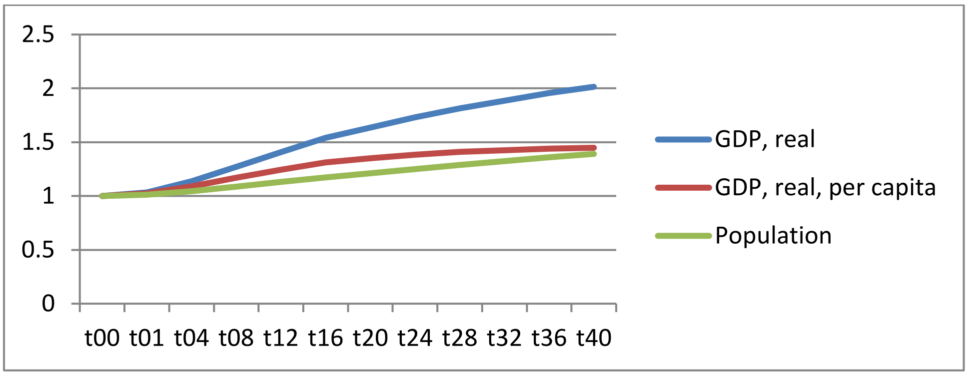

Figure 8 : GDP, Population and GDP per capita projections from SSP3

The lower capital accumulation is linked to a reduction in gross global savings (Figure 9), which equal global investments, therefore the growth in capital stock. But investments are also a component of the GDP. Since the latter is exogenously given, any reduction in investments must be compensated by increments in other elements, most notably private and public consumption.

Similarly, since a lower capital stock would bring about lower production output, ceteris paribus, a second compensation mechanism is needed to keep up with the given GDP growth: larger gains in total factor productivity, which is endogenous during the generation of the baseline. This is necessary, because growth rates of other primary factors, such as labour, are kept exogenous.

To sum up, two immediate consequences of the slower capital accumulation, when GDP is given, are: more consumption (by private households and government) and higher productivity.

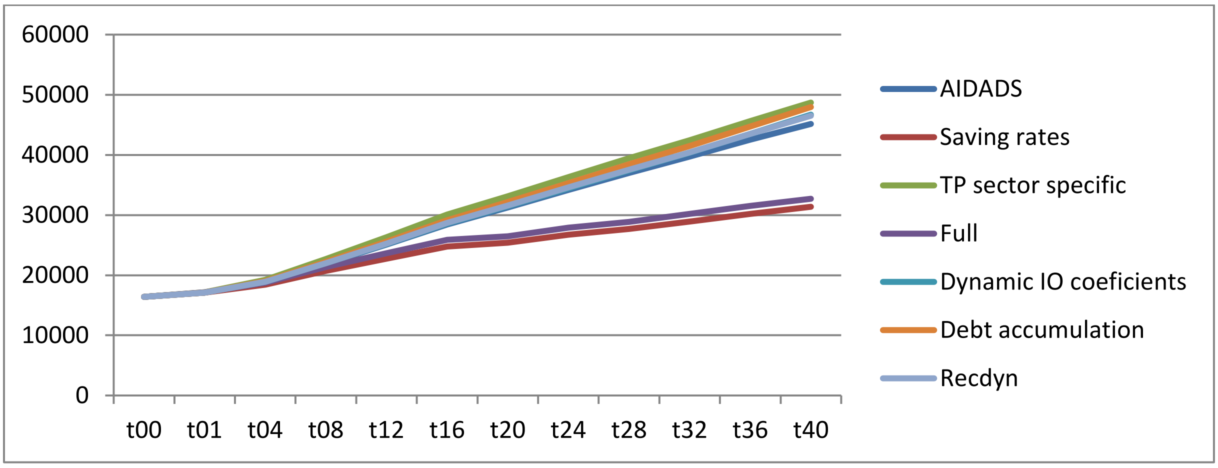

Figure 9: Aggregate gross investments

The effect of the reduced investments on private consumption is visualized in Figure 10. Consumption levels, however, are also affected by other effects. In particular, we found that interest payments on foreign debt reduce consumption, and when both endogenous saving rates and foreign debt are jointly considered, the differences between G-RDEM and the benchmark recursive dynamic GTAP model are not very significant, at least in terms of global aggregate private consumption.

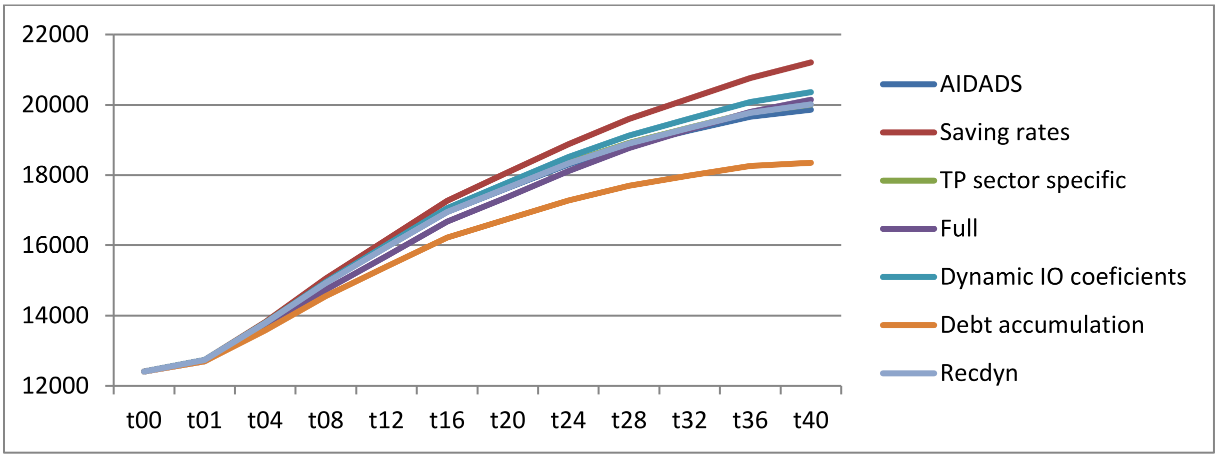

Figure 10: Aggregate demand by private household

We also found that the complete G-RDEM model generates a considerably smaller increase in intermediate demand than GTAP-RecDyn. This seems to be due to two mechanisms: (a) lower saving rates imply higher TFP growth, therefore less intermediate factors; (b) changing cost shares, which on average reduce the amount of intermediates.

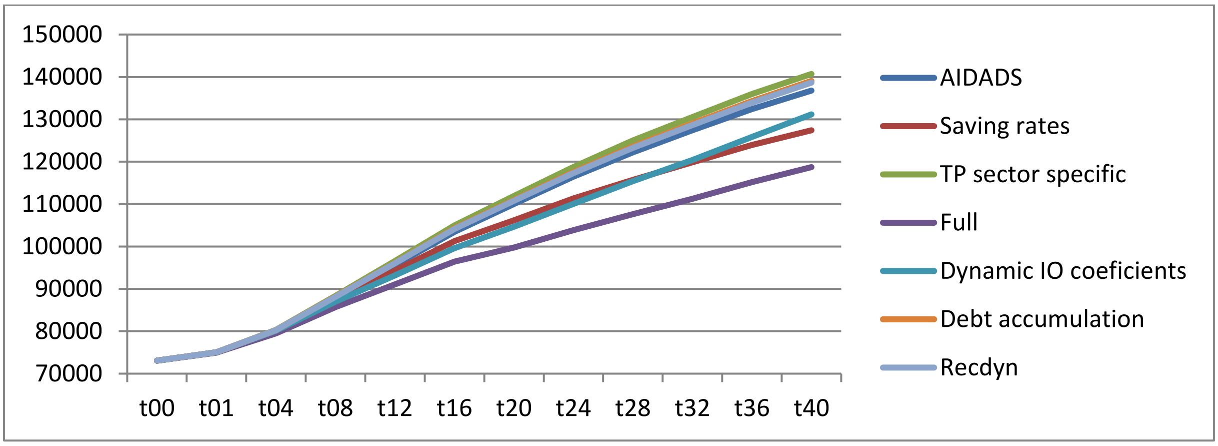

Figure 11: Aggregate intermediate demand

Regional and sectoral impacts

We now turn to analyzing differences at the sectoral and regional level. Remind that regional GDP and population projections are identical across the variants, so that the various baselines only distribute the given regional growth differently between the sectors.

Errore. L'origine riferimento non è stata trovata. below shows the differences in global production volumes for 10 aggregated sectors. It highlights that the demand system matters, especially for primary agricultural products (contrast AIDADS only G-RDEM with GTAP-RecDyn), while differences between other categories are less pronounced.

Some more differences can be found in the full implementation of G-RDEM. First, the reduced intermediate demand implies that global output gets lower by about 9%. The reduction is especially evident in Light and Heavy Manufacturing, because these industries are mainly producing intermediates and because the differentiated productivity growth is stronger in the manufacturing sector.

Table 6: Total global production of aggregate product categories

	G-RDEM with only AIDADS	Full G-RDEM	GTAP-RecDyn
Total	**283706**	**262761**	**287400**
Grains and Crops	4615	4603	5375
Livestock and Meat Products	3775	3931	4443
Mining and Extraction	8106	7558	8211
Processed Food	9584	11028	9577
Textiles and Clothing	4878	5088	4882
Light Manufacturing	27258	23777	27733
Heavy Manufacturing	57739	47517	59919
Utilities and Construction	33569	28336	33844
Transport and Communication	47710	46391	47658
Other Services	86472	84532	85759

The indirect effect of considering non-linear Engel curves and other dynamic adjustments on specific variables can be quite pronounced, as shown below for the evolution of the price of land in the Sub-Saharan region (Figure 12). Both G-RDEM and a simple recursive-dynamic model predict increases, but the simpler model let the price increase by as much as 1600%.

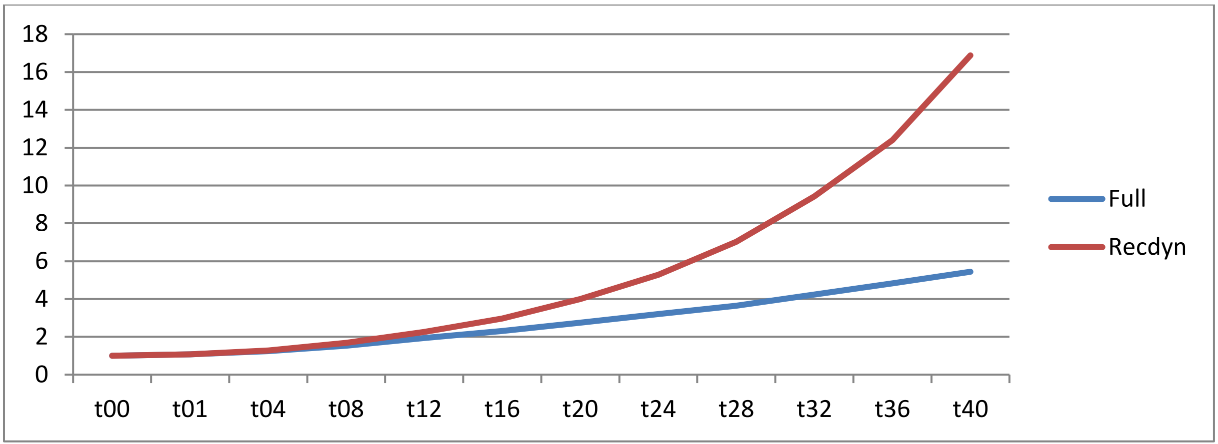

Figure 12: Land price development in Sub-Saharian Africa

The main underlying reason behind the differences has to do with the CDE and AIDADS demand systems. The latter considers consumption of grains and crops as rather income inelastic. As a consequence, per capita demand of the private household is projected to stay more or less stable (Figure 13) in G-RDEM; whereas the CDE system, along with its parameterization inherited from the standard GTAP model and used in the recursive dynamic version, shows a considerable increase.

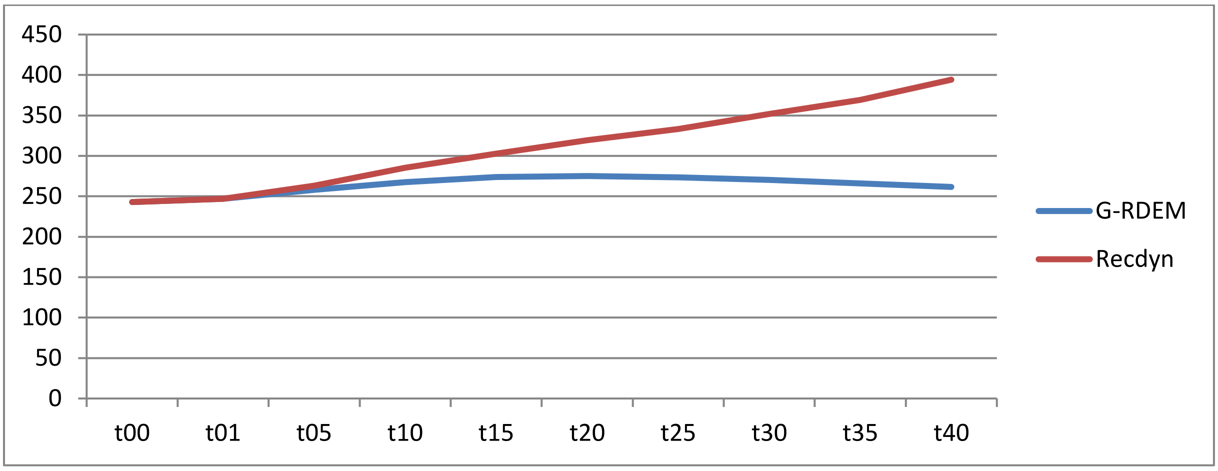

Figure 13: Per capita demand for grains and crops in Sub-Saharan Africa

Summary and conclusion

G-RDEM (GTAP-derived Recursive Dynamic Extended Model) is a dynamic CGE model explicitly developed to generate baselines and to study long-term structural change processes, from given projections of regional GDP and population. To this end, G-RDEM introduces five salient features: an AIDADS demand system with non-linear Engel curves, productivity growth differentiated by sector, income and population composition dependent saving rates, debt accumulation from foreign savings and dynamic cost shares. These features are parameterized drawing on own empirical work or available literature, and they are transparently integrated into the flexible and modular modelling platform CGEBox.

We have assessed the newly develop tool by comparing results for a baseline under the SSP3 scenario, against a simpler recursive-dynamic model, derived from the standard GTAP one. We regard the results from G-RDEM as more plausible and informative. Compared to the more conventional model, we found that the economy moves away from primary agriculture and food, and accumulates less capital. The reduced capital stock also implies that total factor productivity must contribute more to growth, which reduces intermediate demand and output volumes.

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Technical Annex

The following annex provides a technical documentation of how the different elements discussed above are integrated into the CGEBox modelling platform and details how a user can use the G-RDEM module when working with CGEBox.

Steering of model runs

The screenshot presented in Figure 14 below shows how the user can select which data base aggregation to use, decide the time horizon of the baseline as well as the report frequency. For instance, retaining the flexible aggregation approach from GTAP in G-RDEM allows the user to develop a long-term baseline with a focus on only one country, while aggregating the rest of the world into a single aggregate. So far, the G-RDEM module has been tested with resolution with up to 80 countries.

Figure 14 : Main steering panel of CGEBox

The set of years to run will always include the benchmark (t0), the last year (eq card(t)) and the first year of the simulation period, which can be used e.g. for estimations from the initialized variables.

```
$iftheni "%dynMode%"=="Recursive dynamic"

    trun(t0) = YES;
    trun(t) $ (t.pos eq card(t)) = YES;
    trun(t) $ (t.pos eq 2)       = YES;
    trun(t) $ (mod(t.pos-1,%timeStep%) eq 0) = YES;
```

For the above input, the resulting years to run are:

```
----    1406 SET trun

t00,    t01,    t05,    t10,    t15,    t20,    t25,    t30,    t35,    t40
```

In order to construct the baseline, the user selects (Figure 15) the desired SSP scenario for population and GDP, as well some procedural modules to use.

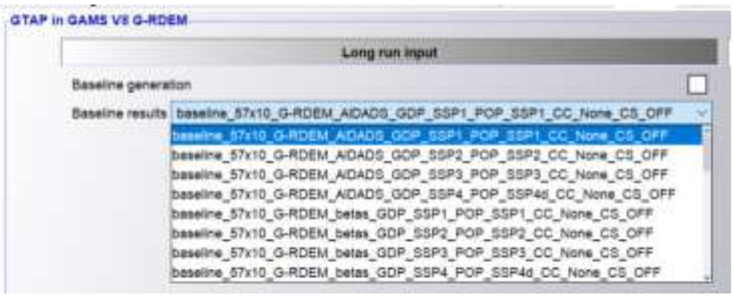
Figure 15 : Main steering panel of the G-RDEM module in CGEBox

Using the baseline for counterfactual analysis

Besides analysing the baseline itself or comparing different baselines against each other, they also might serve as starting point for some counterfactual analysis. Two types of simulations are currently supported in the CGEBOX CGEBox platform. The first one uses the shifters generated during the baseline construction (changes in saving rates, productivity shifters, updated I-O coefficients), as well as population projections, as given parameters into a recursive-dynamic simulation. That would make only sense if the structural set-up of the model is unchanged (production function nesting, bi-lateral trade, etc.). During such a run, GDP would no longer be fixed, but endogenous and, as usual, shocks can be introduced, such as changes in policies or productivity, like climate change impacts on agricultural yields. Parameter estimates for some impacts (like those of climate) are already available in CGEBox and can be readily inserted during the simulation runs, by means of the graphical interface.

The second type of possible utilization of G-RDEM is in the provision of input data for comparative-static analysis. In this case, the global SAM and parameters for one of the simulated time points could be loaded as a replacement for benchmark data from GTAP. The full modular flexibility of CGEBox could then be exploited, allowing to modify several characteristics of the model. That approach might be also interesting to produce not a long-run, but a rather a medium-term baseline as an ex-ante benchmark, which is for instance the usual practice in partial equilibrium modelling of agri-food markets.

The first option is to use the G-RDEM module in non-baseline generation mode:



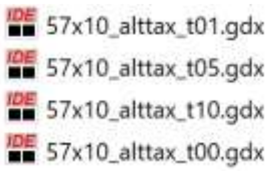
In the case, the user can select the baseline results to employ. That will load the necessary shifters and exogenous parameters into the GAMS code:

```
variable  axpPrev(r,a,t),betasPrev(r,t),betagPrev(r,t),betapPrev(r,t);
parameter ioPrev(r,i,a,t),ioNestPrev(r,i,a,*,t),avaPrev(r,a,t),andPrev(r,a,t);
$$GDXIN "%resdir%/run/%baselineRes%"
$$LOAD axpPrev     = axp
$$LOAD betasPrev   = betas
$$LOAD betagPrev   = betag
$$LOAD betapPrev   = betap
$$LOAD ioPrev      = io
$$LOAD ioNestPrev  = ioNest
$$LOAD andPrev     = and
$$LOAD avaPrev     = ava
$$LOAD p_timeStep
$$LOAD p_growthRate
$$GDXIN
```

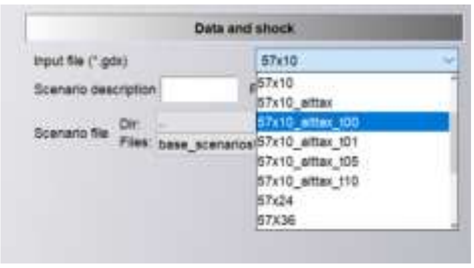
We have checked that without additional shocks, the existing baseline will be recovered without that GDP is fixed.

The second option requires that during baseline generation, altertax output is activated:

That will output the SAM and other information required for a benchmark calibration of the model are stored in “build” directory:



These benchmark data can be used similarly to the output from the data preparation step. If the user wants to use the specific module, which requires additional information (AEZ, CO2 and Non-CO2 emissions, NUTS2), these modules must have been selected during the generation of the baseline. The data can therefore be chosen as a starting point for comparative (or even recursive-dynamic) analysis:



That makes the layout of the model fully adjustable (e.g., by adding myGTAP for several household types, a different production nesting, changes in how bi-lateral trade is modelled).

Technical implementation of the AIDADS demand system

Due to its resemblance with the LES system, which was already available in CGEBox, the code is a direct extension of the existing code both for the calibration to the benchmark and implementation of the demand system in the model’s equation (see model\cal_les.gms and model\dem_les.gms).

The demand equations for both systems are indeed identical:

```
*
*  --- demand equations
*
   xacLesEq(rs(r),i,h,ts(t)) $ (xaFlag(r,i,h) $ alphaLES.l(r,i,h,t)) ..
    xa(r,i,h,t) /xa.scale(r,i,h,t)
      =e= (gammaLES(r,i,h,t)*pop(r,h,t) + alphaLES(r,i,h,t)/m_pa(r,i,h,t) * yCNonCom(r,h,t))/xa.scale(r,i,h,t);
-
```

The demand is equal to a constant term *gammaLES* per head multiplied with population plus the marginal budget share times the non-commited income *yCNonCom*, divided by the Armington price index for the private household aggregate, defined in the macro *m_pa*.

The non-committed income is the difference between the given expenditures for final consumption and the value of the commitments:

```
*
*  --- non committed income: total expenditure for private consumption minus
*      value of commitments
*
   yCNonComEq(rs(r),h,ts(t)) $ sum(i,xaFlag(r,i,h))  ..
     yCNonCom(r,h,t)/yc.scale(r,h,t)
      =E= (yc(r,h,t) - sum(i $ (xaFlag(r,i,h) $ alphaLES.l(r,i,h,t)), gammaLES(r,i,h,t)*pop(r,h,t) * m_pa(r,i,h,t))
                     - sum(dNest_n_fd("top",dNest,h), gammaLES(r,dNest,h,t)*pop(r,h,t) * pdNest(r,dNest,h,t)))/yc.scale(r,h,t);
-
```

We allow for demand nests which are CES aggregates of other nests or individual commodity demands. In the case of AIDADS, the marginal budget shares *alphaLES* are not fixed (as in the LES), but are a function of utility:

```
*
*  --- AIDADS: marginal budget shares are a function of utility
*
   alphaAIDADSeq(rs(r),i,h,ts(t)) $ (xaFlag(r,i,h) $ (alphaAIDADS.l(r,i,h,t) + betaAIDADS.l(r,i,h,t)) $ (p_demSystem eq AIDADS))..

       alphaLES(r,i,h,t) =E=   [ alphaAIDADS(r,i,h,t) + betaAIDADS(r,i,h,t) * ( uh(r,h,t)*p_uh0(r,h)) ]
                             / [ 1 + uh(r,h,t)*p_uh0(r,h) ];
```

The two vectors *alphaAIDADS* and *betaAIDADS* are the limiting cases for the marginal budget shares at very low and very high utility levels. The utility of the (representative) private household is set at one in the benchmark. In order to line up with the empirical implementation (see next section), the parameter p_uh0 is introduced. Cardinal utility is thus defined as follows:

```
*
*  --- indirect utility definition in AIDADS
*
   uhAIDADSeq(rs(r),h,ts(t)) $ (sum(i,xaFlag(r,i,h)) $ (p_demSystem eq AIDADS)) ..

    log(uh(r,h,t)) +p_uh0(r,h) + p_uh1(r,h) =E=
           sum[i        $ alphaLES.l(r,i,h,t),      alphaLES(r,i,h,t)     * log( xa(r,i,h,t)          - gammaLES(r,i,h,t)*pop(r,h,t))]
       +   sum[dNest    $ alphaLES.l(r,dNest,h,t), alphaLES(r,dNest,h,t) * log( xdNest(r,dnest,h,t) - gammaLES(r,dNest,h,t)*pop(r,h,t))];
```

where *p_uh1* is an additional parameter in the demand system (corresponding to the parameter *A* in Cranfield et al. 2000, see their equation (10)). Note the equivalence of the utility definition to the one in the LES system: only consumption quantities exceeding the commitments *gammaLES* generate utility.

Calibration

The calibration code can be found in "model/cal_les.gms". The estimated parameters are inserted as a table in the code:

```
table p_parAIDADS(AIDADS_grps,parAIDADS)
              alpha       beta
  Food        0.52313    0.00001
  Bevtob      0.03450    0.02630
  Cloth       0.05301    0.03485
  Hous        0.05881    0.24270
  Furn        0.05962    0.04136
  Health      0.04325    0.11203
  TransP      0.09732    0.11424
  Commun      0.03123    0.03423
  Recreat     0.00001    0.09093
  Educ        0.07626    0.07458
  RestHot     0.01413    0.07788
  Other       0.00874    0.15090
;
```

We add to these estimates the marginal budget shares obtained by the Economic Research Service of the United States Department of Agriculture (https://www.ers.usda.gov/data-products/international-food-consumption-patterns/, see Muhammad et al. 2011). We take the five lowest and five highest per capita countries in their sample, to derive the marginal expenditure shares for food categories at low and high income, relative to expenditure on food:

```
Table p_ERSEst(parAIDADS,Ers_Grps)
          Cereals    Meats     Fish      Dairy     Oils_Fats         Fruits_Vegs        Food_Other
alpha      0.150     0.147     0.064     0.078     0.056             0.217              0.150
beta      -0.014     0.141     0.028     0.086     0.001             0.062              0.419
;
```

The entries for "cereals" and "food_other" for the low income case where manually corrected to consider that the estimates refer to functional groups, where cereals also comprise, e.g. bread.

Integration into a GTAP model with flexible sectoral aggregation requires a mapping from these categories to the current sectors in the model. That is achieved in two steps:

1. The commodity groups from the AIDADS estimation and from Muhammad et al. 2011 are mapped to the 57 GTAP sectors (non-aggregated):

```
set AIDADS_to_GTAP(AIDADS_grps,iDat) /

*         FOOD     . (pdr,wht,gro,v_f,osd,c_b,pfb,ocr,ctl,oap,rmk,fsh,cmt,omt,vol,mil,pcr,sgr,ofd)
        BEVTOB   . b_t
        CLOTH    . (tex,wap,lea,wol,pfb)
        HOUS     . (obs,dwe,wtr,gdt,ely,coa,oil,gas,isr)
        Furn     . (p_c,frs,omn,lum,crp,nmm,i_s,nfm,fmp,cns,ele,ome,omf)
        TRANSP   . (otp,wtp,atp,mvh,otn,isr,p_c)
        COMMUN   . cmn
        RECREAT  . (ros,ppp)
        Educ     . osg
        Health   . osg
        RestHot  . trd
/;

set ERS_to_GTAP(Ers_Grps,iDat) /

    cereals.(pdr,wht,gro,pcr)
    meats  .(ctl,oap,cmt,omt)
    Fish   .(fsh)
    dairy  .(rmk,mil)
    oils_fats.(osd,vol)
    fruits_vegs.(v_f,ocr)
    food_other.(c_b,sgr,ofd)
/;
```

We link the estimates from Roson and van der Mensbrugghe 2018 of marginal budget shares relating to total final consumption by private households to the marginal expenditures from the ERS estimates relating to food expenditures as follows:

```
*
*       --- apply marginal budget shares inside food + bev_tobacco to ERS estimates
*
        p_parAIDADS(ers_grps,parAIDADS) = p_parAIDADS("food",parAIDADS) * p_ERSEst(parAIDADS,ers_grps);

        p_parAIDADS("food",parAIDADS)    = 0;

        AIDADS_to_GTAP(ers_grps,iDAT)   = ERS_to_GTAP(Ers_Grps,iDat);
*
```

Next, the mapping *mapi* from the 57 GTAP sectors to the current aggregation is used to assign parameters to the commodities, as defined in the current run:

```
set AIDADS_to_i(AIDADS_grps,i) "Link to current sectoral aggregation";
    AIDADS_to_i(AIDADS_grps,i) $ sum(AIDADS_to_GTAP(AIDADS_grps,iDat),mapi(iDat,i)) = YES;

alphaAIDADS(rNat,i,h,t0) $ xcshr.l(rNat,i,h,t0)
   = sum(AIDADS_to_i(AIDADS_grps,i), p_parAIDAS(AIDADS_grps,"alpha")*xcshr.l(rNat,i,h,t0) )
    /sum(AIDADS_to_i(AIDADS_grps,j) $ AIDADS_to_i(AIDADS_grps,i),xcshr.l(rNat,j,h,t0));

betaAIDADS(rNat,i,h,t0)  $ xcshr.l(rNat,i,h,t0)
   = sum(AIDADS_to_i(AIDADS_grps,i), p_parAIDAS(AIDADS_grps,"beta")*xcshr.l(rNat,i,h,t0) )
    /sum(AIDADS_to_i(AIDADS_grps,j) $ AIDADS_to_i(AIDADS_grps,i),xcshr.l(rNat,j,h,t0));
```

Note that the aggregation might define an intersection such that, for some aggregates, the original sectors comprised belong to multiple estimation groups. Using the benchmark consumption shares as weights corrects for that In order to ensure that both vectors fulfil the adding up condition exactly, they are then scaled to unity:

```
alphaAIDADS.fx(r,i,h,t)  = alphaAIDADS(r,i,h,t)/sum(j,alphaAIDADS(r,j,h,t));
betaAIDADS.fx(r,i,h,t)   = betaAIDADS(r,i,h,t)/sum(j,betaAIDADS(r,j,h,t));
```

The cardinal utility level, which drives the marginal budget composition, is an estimated parameter. To this end, Roson and van der Mensbrugghe 2018 regress the estimated utility levels on real GDP per capita. Their regression results are here employed to derive the utility level at the benchmark and thus the marginal budget shares:

```
*
*       --- define u in calibration point. Note the estimation in AIDADS defines
*           log(u)!
*
        p_uh0(rnat,h)  = exp( -7.1471 +  0.8415 * log(p_perCap(rnat,h)));
*
*       --- define marginal budget share from equation (9)
*
        alphaLes(rnat,i,h,t0) $ xaFlag(rNat,i,h)
            = [alphaAIDADs(rnat,i,h,t0)+betaAIDADS(rnat,i,h,t0)*p_uh0(rnat,h)]
                   /[ 1 + p_uh0(rnat,h)    ];
```

The obtained marginal budget shares are then used to define the commitment terms. The code is not shown here as it was already comprised in CGEBox code and it is illustrated in the associated documentation.

Whenever that calibration procedure becomes infeasible, some deviations from the given alphas and betas are allowed:

```
         if ( (fitLes.suminfes ne 0) and ( p_demSystem eq AIDADS) ,
*
*            --- AIDADS failed, GAMMA bounds became binding, release bounds on alpha and beta
*

             alphaAIDADS.lo(rNat,i,h,t0) = min(alphaAIDADS.l(rNat,i,h,t0) * 0.00001,alphaAIDADS.l(rNat,i,h,t0) * 1000);
             alphaAIDADS.up(rNat,i,h,t0) = max(0.1,alphaAIDADS.l(rNat,i,h,t0) * 0.00001,alphaAIDADS.l(rNat,i,h,t0) * 1000);

             betaAIDADS.lo(rNat,i,h,t0) =  min(betaAIDADS.l(rNat,i,h,t0) * 0.00001,betaAIDADS.l(rNat,i,h,t0) * 1000);
             betaAIDADS.up(rNat,i,h,t0) =  max(0.1,betaAIDADS.l(rNat,i,h,t0) * 0.00001,betaAIDADS.l(rNat,i,h,t0) * 1000);
             solve fitLES using NLP minimizing fit;
         );
```

Minimizing the squared relative differences in the objective function:

```
*
*          --- squared relative deviations from given parameters in case of AIDADS
*              if gamma bounds become binding
*
         + sum ( (rs(rNat),i,h,t0) $ xaFlag(rNat,i,h),
              sqr(   (alphaAIDADs(rnat,i,h,t0) - alphaAIDADs.l(rnat,i,h,t0))/max(1.E-4,abs(alphaAIDADs.l(rnat,i,h,t0))) )
            + sqr(   (betaAIDADs(rnat,i,h,t0)  - betaAIDADs.l(rnat,i,h,t0) )/max(1.E-4,abs(betaAIDADs.l(rnat,i,h,t0)))  ))
```

Finally, a multiplier (termed *A* in Cranfield et al. 2000, eq 10) is calculated:

```
$$ifTheni.AIDADS "%demSystem%" == "AIDADS"


   Uh.lo(r,h,t0) = 0.001;
   Uh.up(r,h,t0) = inf;

   p_uh1(r,h)   = ( sum(i       $ alphaLES(r,i,h,"%t0%"),
                         alphaLES(r,i,h,"%t0%")       * log( xa(r,i,h,"%t0%") - gammaLES(r,i,h,"%t0%")*pop.l(r,h,"%t0%")))
                  +sum(dNest  $ alphaLES(r,dNest,h,"%t0%"),
                         alphaLES(r,dNest,h,"%t0%") * log( xdNest(r,dNest,h,"%t0%") - gammaLES(r,dNest,h,"%t0%")*pop.l(r,h,"%t0%")))
                    )
                  - (log(uh.l(r,h,"%t0%"))+p_uh0(r,h));

$$endif.AIDADS
```

The code allows introducing aggregates of individual commodities under which CES-sub-nests can be defined, which comprise these individual commodities.

Table 6: Mapping between AIDADS categories and GTAP sectors

AIDADS category	GTAP 9 sector	Detailed description
Cereals	pdr wht gro pcr	Paddy Rice: rice, husked and unhusked Wheat: wheat and meslin Other Grains: maize (corn), barley, rye, oats, other cereals Processed Rice: rice, semi- or wholly milled
Meats	Ctl oap cmt omt	Cattle: cattle, sheep, goats, horses, asses, mules, and hinnies; and semen thereof Other Animal Products: swine, poultry and other live animals; eggs, in shell (fresh or cooked), natural honey, snails (fresh or preserved) except sea snails; frogs' legs, edible products of animal origin n.e.c., hides, skins and furskins, raw , insect waxes and spermaceti, whether or not refined or coloured Cattle Meat: fresh or chilled meat and edible offal of cattle, sheep, goats, horses, asses, mules, and hinnies. raw fats or grease from any animal or bird Other Meat: pig meat and offal. preserves and preparations of meat, meat offal or blood, flours, meals and pellets of meat or inedible meat offal; greaves
Fish	fsh	Fishing: hunting, trapping and game propagation including related service activities, fishing, fish farms; service activities incidental to fishing
Dairy	Rmk mil	Raw milk Milk: dairy products
Oils_Fats	Osd	Oil Seeds: oil seeds and oleaginous fruit; soy beans, copra

AIDADS category	GTAP 9 sector	Detailed description
	vol	Vegetable Oils: crude and refined oils of soya-bean, maize (corn),olive, sesame, ground-nut, olive, sunflower-seed, safflower, cotton-seed, rape, colza and canola, mustard, coconut palm, palm kernel, castor, tung jojoba, babassu and linseed, perhaps partly or wholly hydrogenated,inter-esterified, re-esterified or elaidinised. Also margarine and similar preparations, animal or vegetable waxes, fats and oils and their fractions, cotton linters, oil-cake and other solid residues resulting from the extraction of vegetable fats or oils; flours and meals of oil seeds or oleaginous fruits, except those of mustard; degras and other residues resulting from the treatment of fatty substances or animal or vegetable waxes.
Fruits_vegs	v_f ocr	Veg & Fruit: vegetables, fruitvegetables, fruit and nuts, potatoes, cassava, truffles Other Crops: live plants; cut flowers and flower buds; flower seeds and fruit seeds; vegetable seeds, beverage and spice crops, unmanufactured tobacco, cereal straw and husks, unprepared, whether or not chopped, ground, pressed or in the form of pellets; swedes, mangolds, fodder roots, hay, lucerne (alfalfa), clover, sainfoin, forage kale, lupines, vetches and similar forage products, whether or not in the form of pellets, plants and parts of plants used primarily in perfumery, in pharmacy, or for insecticidal, fungicidal or similar purposes, sugar beet seed and seeds of forage plants, other raw vegetable materials
Food_other	c_b,sgr,ofd	
Cothing	tex wap lea wol pfb	Textiles: textiles and man-made fibres Wearing Apparel: Clothing, dressing and dyeing of fur Leather: tanning and dressing of leather; luggage, handbags, saddlery, harness and footwear Wool: wool, silk, and other raw animal materials used in textile Plant Fibres: cotton, flax, hemp, sisal and other raw vegetable materials used in textiles
Housing	dwe obs wtr gdt ely coa oil gas isr	Dwellings: ownership of dwellings (imputed rents of houses occupied by owners) Other Business Services: real estate, renting and business activities Water: collection, purification and distribution Gas Distribution: distribution of gaseous fuels through mains; steam and hot water supply Electricity: production, collection and distribution Coal: mining and agglomeration of hard coal, lignite and peat Oil: extraction of crude petroleum and natural gas (part), service activities incidental to oil and gas extraction excluding surveying (part) Gas: extraction of crude petroleum and natural gas (part), service activities incidental to oil and gas extraction excluding surveying (part) Insurance: includes pension funding, except compulsory social security
Furniture, Maintenance, appliances	p_c frs omn lum	Petroleum & Coke: coke oven products, refined petroleum products, processing of nuclear fuel Forestry: forestry, logging and related service activities Other Mining: mining of metal ores, uranium, gems. other mining and quarrying Lumber: wood and products of wood and cork, except furniture;

AIDADS category	GTAP 9 sector	Detailed description
		articles of straw and plaiting materials
	crp	Chemical Rubber Products: basic chemicals, other chemical products, rubber and plastics products
	nmm	Non-Metallic Minerals: cement, plaster, lime, gravel, concrete
	i_s	Iron & Steel: basic production and casting
	nfm	Non-Ferrous Metals: production and casting of copper, aluminium, zinc, lead, gold, and silver
	fmp	Fabricated Metal Products: Sheet metal products, but not machinery and equipment
	cns	Construction: building houses factories offices and roads
	ele	Electronic Equipment: office, accounting and computing machinery, radio, television and communication equipment and apparatus
	ome	Other Machinery & Equipment: electrical machinery and apparatus n.e.c., medical, precision and optical instruments, watches and clocks
	omf	Other Manufacturing: includes recycling
Transport	Otp	Other Transport: road, rail ; pipelines, auxiliary transport activities; travel agencies
	wtp	Water transport
	atp	Air transport
	mvh	Motor Motor vehicles and parts: cars, lorries, trailers and semi-trailers
	otn	Other Transport Equipment: Manufacture of other transport equipment
		nsurance: includes pension funding, except compulsory social security
	Isr	Petroleum & Coke: coke oven products, refined petroleum products, processing of nuclear fuel
	p_c	
Communication	cmn	Communications: post and telecommunications
Recreation	ros	Recreation & Other Services: recreational, cultural and sporting activities, other service activities; private households with employed persons (servants)
	ppp	Paper & Paper Products: includes publishing, printing and reproduction of recorded media
Education	osg	Other Services (Government): public administration and defense; compulsory social security, education, health and social work, sewage and refuse disposal, sanitation and similar activities, activities of membership organizations n.e.c., extra-territorial organizations and bodies
Health	Osg	See above
Restaurants and hotels	Trd	Trade: all retail sales; wholesale trade and commission trade; hotels and restaurants; repairs of motor vehicles and personal and household goods; retail sale of automotive fuel
Rest		Other Financial Intermediation: includes auxiliary activities but not insurance and pension funding (see next)

Specific nestings

We add some specific nestings for the production function (see gams\gtaprdem\gtaprdem.gms):

```
set natResA(a); natResA(a) $ sum(r, SAM0(r,"natRes",a)) = YES;

sigmap(r,natResA) = 0.20;
tNest("CAP+NATRES") = YES;
tNest_n_a("VA","CAP+NATRES",natResA)        = YES;
tNest_f_a("CAP+NATRES","capital",natResA) = YES;
tNest_f_a("CAP+NATRES","natRes",natResA)  = YES;
sigmaNest(r,"CAP+NATRES",natResA)           = 0.20;

tNest_n_a(tNest,"CAP+NATRES",a) $ ((not sameas(tNest,"CAP+NATRES")) $ tNest_f_a(tNest,"capital",a)) = YES;
tNest_f_a(tNest,"capital",a)     $ (not sameas(tNest,"CAP+NATRES")) = no;
tNest_n_a("VA","CAP+NATRES",a)   $ sum(tNest_n_a(tNest,"CAP+NATRES",a),1) = NO;


$$include 'extensions\labor_nest.gms'

set landA(a); landA(a) $ sum(r, SAM0(r,"land",a)) = YES;
tNest("labLand") = YES;
tNest_n_a("VA","LabLand",landA)      = YES;
tNest_f_a("LabLand","Land",landA)    = YES;
tNest_n_a("LabLand","Labor",landA)   = YES;
tNest_n_a("VA","Labor",landA)        = NO;
sigmaNest(r,"LabLand",landA)      = 0.5;
```

GTAP-AGR has proven to work badly with some long-term projections, because of limited factor mobility between agricultural and non-agricultural sectors. Therefore, only the technology nests from GTAP-AGR are taken over:

```
$if not defined rOecd $include 'gtapAgr\GtapAgr_def.gms'
*
*  --- define feed demand sub-nest in livestock production
*
   if ( card(feed),
     tNest("feed") = yes;
     tNest_i_a("feed",feed,lstk) = yes;
     tNest_n_a("ND","feed",lstk)    = YES;
     sigmaNest(r,"Feed",lstk) = 2;
   );

   if ( card(agr_c),
     tNest("foodPrc") = yes;
     tNest_i_a("foodPrc",agr_c,foodPrc) = yes;
     tNest_n_a("ND","foodPrc",foodPrc)   = YES;
     sigmaNest(r,"FoodPrc",foodPrc) = 0.5;
  );
```

In order to reflect stronger substitutional relations between animal and crop based products, two final demand nests are constructed:

```
set cropD(i); cropD(i) $ sum(mapi(iCrops,i),1) = YES;
cropD(i) $ mapi("vol",i) = YES;
cropD(i) $ mapi("pcr",i) = YES;
cropD(i) $ mapi("sgr",i) = YES;
cropD(i) $ mapi("ofd",i) = YES;
cropD(i) $ mapi("b_t",i) = YES;

dNest("cropD") = YES;
dNest_i_fd("cropD",cropD,fdn)           = YES;
dNest_n_fd("top","cropD",fdn)           = YES;
sigmaFDNest(r,"cropD",fdn)              = .50;

set animD(i); animD(i) $ sum(mapi(lstk0,i),1) = YES;

animD(i) $ mapi("cmt",i) = YES;
animD(i) $ mapi("omt",i) = YES;
animD(i) $ mapi("mil",i) = YES;

dNest("animD") = YES;
dNest_i_fd("animD",animD,fdn)           = YES;
dNest_n_fd("top","animD",fdn)           = YES;
sigmaFDNest(r,"animD",fdn)              = .50;
```

Implementation of foreign debt accumulation

The debt accumulation is a more or less straightforward translation of the equations discussed in the main text into the GAMS code.

```
$$iftheni.debt "%debtAccumulation%"=="on"
*
*   --- store results for debt accumulation
*
    p_debt(rNat,"savf",tSim) = savf.l(rNat,tSim);
    p_debt(rNat,"rorg",tSim) = rorg.l(tSim);
    p_debt(rNat,"debt",tSim) = p_debt(rNat,"debt",tSim-1) + p_debt(rNat,"savf",tSim);
    p_debt(rNat,"paym",tSim) = sum(trun $ (tRun.pos le tSim.pos), p_debt(rNat,"savf",tRun)*p_debt(rNat,"rorg",tRun)*p_timeStep(tSim));

    p_capTrans(rnat,tsim) = p_debt(rNat,"paym",tSim) * p_debtAccum(rnat,"share");
*
*   --- scale capital transfer to zero (due to countries where accounted share < 0)
*
    p_capTrans(rnat,tsim) $ p_capTrans(rnat,tsim)
      = p_capTrans(rnat,tsim)
        + abs(p_capTrans(rnat,tsim)) * sum(rnat1,p_capTrans(rnat1,tsim))/sum(rnat1,abs(p_capTrans(rnat1,tsim)));

    p_debt("wor","sum",tSim) = sum(rnat1,p_capTrans(rnat1,tsim));

$$endif.debt
```

Note the scaling of *p_capTrans* to ensure the global expenditures to serve the debt and related revenues add up to zero.

Implementation of the sector specific productivity shifters

The production shifter equation derives from the economy wide, regional specific ftp shifter *axpreg* sector specific shifters *axp* based on the quadratic function as detailed above (see model.gms):

```
prodShifteq(rs(r),aIn(a),ts(tRun)) $ (xpFlag(r,a) $ (axp.range(r,a,tRun) ne 0) $ (not disr(r))) ..

   axp(r,a,tRun) =E= axp(r,a,tRun-1) + sum(r_r(r,rNat), axpreg(rNat,tRun))

                        * (      p_prodShft("a",a)
                             + p_prodShft("b",a) *     [ (rgdpmp(r,tRun)-rgdpmp(r,tRun-1))/rgdpmp(r,tRun-1)]
                             + p_prodShft("c",a) * sqr[ (rgdpmp(r,tRun)-rgdpmp(r,tRun-1))/rgdpmp(r,tRun-1)] };
```

The parameters are derived from estimates in “GTAPRDEM\diffProdGrowth.gms”:

```
  set tfpPars / a,b,c/

  Table p_diffProdShifters(tfpPars,globSec)

            AGR       MAN         SER
    a       0.925391  2.893917      1
    b       11.99205  -94.8599
    c       291.8147  1680.554
 ;

 p_prodShft(tfpPars,a) = sum( (globSec_iOri(globSec,iOri),mapa(iOri,a)),p_diffProdShifters(tfpPars,globSec))
                         /sum( (globSec_iOri(globSec,iOri),mapa(iOri,a)),1);
```

Which requires a mapping from the original GTAP sectors *iOri* to the currently active sector aggregation defined in the same program, of which here only an extracted part is shown:

```
  set globSec / AGR,MAN,SER /;

  set globSec_iOri(globSec,iOri) /

     AGR.    pdr       "Paddy rice"
 ------------------------------------------------------------- 13 line(s) not display
     MAN.    coa       "Coal"
 ------------------------------------------------------------- 31 line(s) not display
     SER.    trd       "Trade"
 ------------------------------------------------------------- 10 line(s) not display
 /;
```

Implementation of the endogenous saving rates

The GAMS code does not use the estimated intercept, but rather updates over the simulation horizon the "betas" for the individual countries in terms of the difference between two consecutive time periods.

```
betas.l(rNat,tSim) $ (tSim.pos gt 2)
   =    betas.l(rNat,tSim)
             +      (    p_driver(rNat,"age15_49",tSim) * log(p_perCapIncome(rNat,tSim)) * 0.16648
                       + p_driver(rNat,"age50_64",tSim) * log(p_perCapIncome(rNat,tSim)) * (-0.17403)
                       + p_growthRate(rNat,"GDPPerCAP",tSim)/(100*p_timeStep(tSim))   * 3.10925)

             -      (   p_driver(rNat,"age15_49",tSim-1) * log(p_perCapIncome(rNat,tSim-1)) * 0.16648
                       + p_driver(rNat,"age50_64",tSim-1) * log(p_perCapIncome(rNat,tSim-1)) * (-0.33158)
                       + p_growthRate(rNat,"GDPPerCAP",tSim-1)/(100*p_timeStep(tSim-1)) * 0.16648);
```

That restrict the application to simulation exercises where a projection of the population by age group is available. Given that the IIASA repository features these projections for SSP1-SSP5, we suggest to use one of these SSPs population scenarios directly, or at least the projected age composition.

Implementation of dynamic I-O and factor share coefficients

A similar approach is used to simulate possible changes in:

- I-O coefficients
- I-O coefficients in technology nests
- The intermediate composite share

The estimated relationship links the I-O coefficients in the different sectors to per capita income, using production output as weight:

```
*
*    --- io coefficient is a linear function of log(per capita income)
*        (MAD estimator, output weighted)
*
   e_fitIO(rNat,i,a) $ io(rNat,i,a,"%t0%") ..
       io(rNat,i,a,"%t0%")  =e= v_cnstA(i,a) + v_slopeA(i,a)
                                  * log(regy.l(rNat,"%t0%")/p_popt(rNat,"%t0%")) + v_errAp(rNat,i,a)-v_errAn(rNat,i,a);

   e_madIO ..             v_mad * sum( (rNat,i,a) $ io(rNat,i,a,"%t0%"), xp.l(rNat,a,"%t0%")  )
                               =E= sum( (rNat,i,a)  $ io(rNat,i,a,"%t0%"),
                                        (v_errAp(rNat,i,a)+v_errAn(rNat,i,a))*xp.l(rNat,a,"%t0%") );
   model fitIo / e_fitIO,e_MadIO/;
   fitIo.solprint = 1;
```

Using production output as weight should prevent that outliers from small sectors with suspicious values dominate the estimation outcome.

The resulting estimates are used to update the I-O coefficients:

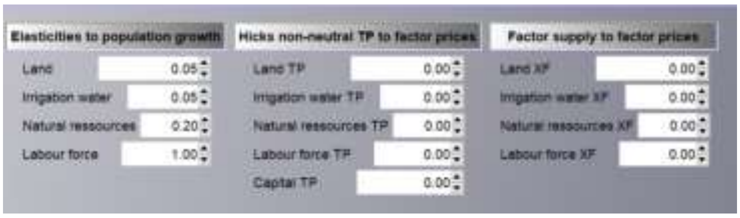
```
*
*  --- update input coefficients based on updated income
*      (not more than doubled, and at least 20% of original value)
*
   io(r,i,a,tsim) $ io(r,i,a,tsim)
      = min(io(r,i,a,"%t0%")*2,
            max(io(r,i,a,"%t0%")*0.5,
                v_cnstA(i,a)
                    + sum(r_r(r,rNat),v_slopeA(i,a)*log(p_perCapIncome(rNat,tSim-1)))
                     + v_errAp(r,i,a)-v_errAn(r,i,a)));
*
*  --- keep original sum
*
   p_scale(r,a,"") $ sum(j,io(r,j,a,tsim))
                  =  sum(j,io(r,j,a,tsim-1))
                    /sum(j,io(r,j,a,tsim));

   io(r,i,a,tsim) $ io(r,i,a,tsim-1)
     = io(r,i,a,tsim) * p_scale(r,a,"");
```

Similar statements estimate and apply shifters for the other elements.

Endogenous non-Hicks neutral technical progress, primary factors depending on population growth and price dependent factor supply

In addition to price driven changes in endowments, the marginal productivity can also be rendered price dependent. In the default setting, the labour force is reacting to population changes fully, while land, irrigation water and natural resources follow to a limited extend (positive changes) in population. The other element are by default switched off.



The input from the GUI is mapped to the following symbols in the GAMS code:

```
*
*   --- link changes in factor endowments to changes in population,
*
    p_popShift(r,"land")      =  %landToPopElas%;

    $$ifthene.GTAPWATER %nFactors%>8
       p_popShift(r,"water")    =  %WaterToPopElas%;
    $$endif.GTAPWATER
    p_popShift(r,"natres")   =  %natResToPopElas%;
*
*   --- labour shares follow population growth
*
    p_popShift(r,l)           =  %labToPopElas%;

*   --- factor expansion depending on factor price developments:
*       labor participation rates react to wage rate changes

    set dummyPS / xf,tp /;
    option kill=p_priceShift;

*
*   --- endogenous non-Hicks neutral progress to depending on development of factor prices
*
    p_priceShift(r,"tp","land")            = %landTpToPfElas%;
    $$ifthene.GTAPWATER %nFactors%>8
       p_priceShift(r,"tp","water")        = %waterTpToPfElas%;
    $$endif.GTAPWATER
    p_priceShift(r,"tp","natres")          = %natResTpToPfElas%;
    p_priceShift(r,"tp",l)                 = %labTpToPfElas%;
    p_priceShift(r,"tp",cap)               = %capTpToPfElas%;
*
*   --- factor supply to factor price
*
    p_priceShift(r,"xf","land")            = %landXfToPfElas%;
    $$ifthene.GTAPWATER %nFactors%>8
       p_priceShift(r,"xf","water")        = %waterXfToPfElas%;
    $$endif.GTAPWATER
    p_priceShift(r,"xf","natres")          = %natResXfToPfElas%;
    p_priceShift(r,"xf",l)                 = %labXfToPfElas%;
-
```

We also take changes in education levels into account:

```
*
  $$ifthene.GTAPVersion %GTAPNO%<9
    p_popShift(rnat,l) $ ff("skLab",l)
       = (1+p_growthRate(rnat,"tertiary",tSim)/100) / (1+p_growthRate(rnat,"population",tSim)/100);
    p_popShift(rnat,l) $ ff("unskLab",l)
       = (1+p_growthRate(rnat,"primary",tSim)/100) / (1+p_growthRate(rnat,"population",tSim)/100);

  $$else.GTAPVersion
     p_popShift(rnat,l) $ ff("off_mgr_pros",l)
        = (1+p_growthRate(rnat,"tertiary",tSim)/100) / (1+p_growthRate(rnat,"population",tSim)/100);
     p_popShift(rnat,l) $ ff("ag_othlowsk",l)
        = (1+p_growthRate(rnat,"primary",tSim)/100) / (1+p_growthRate(rnat,"population",tSim)/100);
  $$endif.GTAPVersion
```

The population and factor price shifters are implemented as follows:

```
*
*  ---- shift factor supply depending on population and factor prices
*
   aft(r,fm,tSim)   $ aft(r,fm,tSim)
         = aft(r,fm,tSim-1)
             *   (1  + sum(r_r(r,rNat) $ (p_popt(rNat,tSim) gt p_popt(rNat,tSim-1)),
                                    p_popShift(rNat,fm)   * (p_popt(rNat,tSim)/p_popt(rNat,tSim-1)-1))
                   + sum(r_r(r,rNat),p_priceShift(rNat,"xf",fm)) * min(10.0,max(-0.90+0.9 $ (not 1(fm)),(pft.l(r,fm,tSim-1)-1))) );

   gf(r,fnm,a,tSim) $ xf.l(r,fnm,a,tSim-1)
        = gf(r,fnm,a,tSim-1)
             * (1 + sum(r_r(r,rNat) $ (p_popt(rNat,tSim) gt p_popt(rNat,tSim-1)),
                                  p_popShift(rNat,fnm)   * (p_popt(rNat,tSim)/p_popt(rNat,tSim-1)-1))
                  + sum(r_r(r,rNat),p_priceShift(rNat,"xf",fnm))  * min(10,max(-0.90+0.9 $ (not 1(fnm)),(pf.l(r,fnm,a,tSim-1)-1))) );
*
```

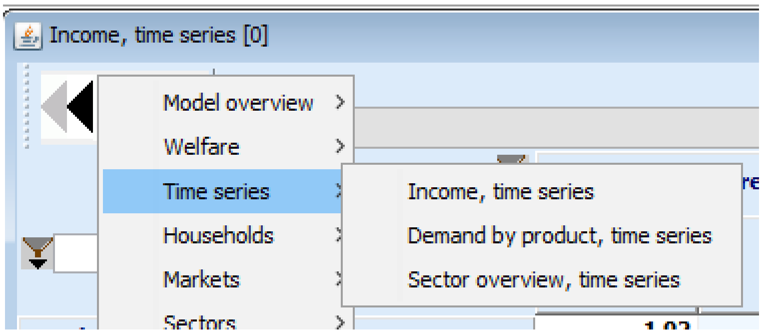
The resulting technical progress changes are calculated as follows:

```
 *
 *  --- productivity of factors is updated depending on factor price changes and GDP growth
 *
   lambdaf.fx(r,f,a,tSim) $ xf.l(r,f,a,tSim-1)
      = m_lambdaf(r,f,a,tSim-1) * (1.0 + sum(r_r(r,rNat),p_priceShift(rNat,"tp",f)
           * min(10,max(-0.90,(      pf.l(r,f,a,tSim)  $ (fnm(f) or (omegaf(r,f) ne inf))
                                   + pft.l(r,f,tSim)   $ (fm(f)    $ (omegaf(r,f) eq inf))  -1)))
           +   p_growthRate(rNat,"GDPPerCAP",tSim)/100* 0.5*0
           +   p_GrowthRate(rNat,"Population",tSim)/100*(1-p_popShift(rNat,f))*0.5)*0);
```

Analysis of simulation output (exploitation)

Loading all results from long time recursive dynamic with detailed global SAMs might require amounts of memory exceeding most personal computer configurations. Therefore, the exploitation selection allows to pick up only a few years for inspecting the results. Therefore, while all output variables are stored in the GDX repository output file, only the selected ones will be loaded into the memory.

Generally, any view existing in the exploitation tool can be changed to a time series using the pivot facility. In order to ease the exploitation, three views have been pre-configured, under the heading "Time series":



The first one reports changes in GDP, price indices etc:

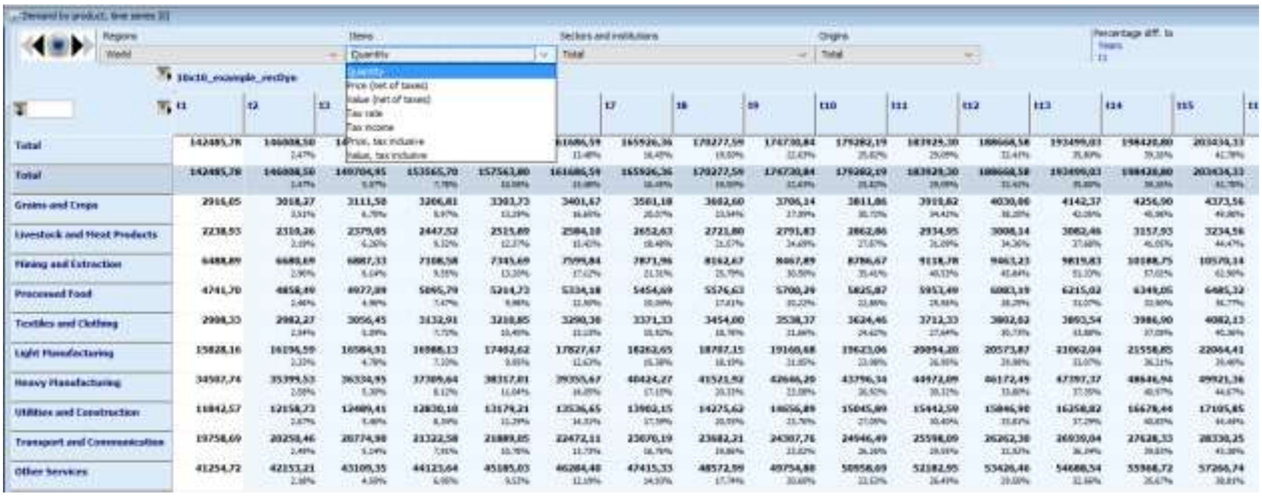
Income, time series [0]

Regions: World — Total or household groups: Total

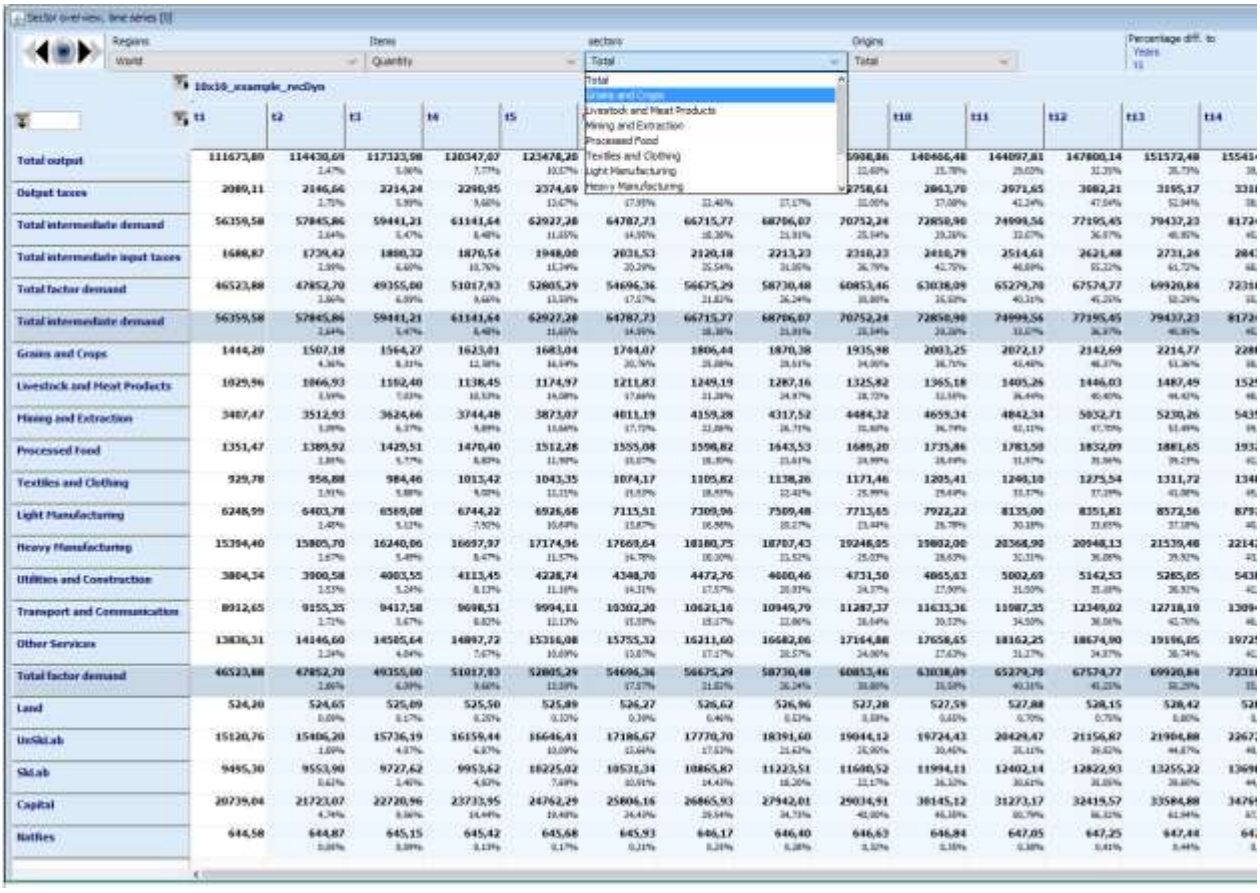
10x10_example_recDyn

	t1	t2	t3	t4	t5	t6	t7	t8
Total utility [Index]	1,02	1,04 2,03%	1,06 4,13%	1,09 6,31%	1,11 8,57%	1,13 10,92%	1,16 13,35%	1,18 15,86%
Utility of private household [Index]	1,02	1,04 2,25%	1,06 4,64%	1,09 7,09%	1,11 9,64%	1,14 12,26%	1,17 14,98%	1,20 17,78%
Utility of government [Index]	1,03	1,06 2,50%	1,08 4,81%	1,11 7,24%	1,13 9,77%	1,16 12,40%	1,19 15,11%	1,22 17,91%
Utility of saving [Index]	1,04	1,05 1,08%	1,06 2,21%	1,07 3,46%	1,09 4,80%	1,10 6,21%	1,12 7,72%	1,13 9,31%
GDP [Bio $]	50969,86	52256,51 2,52%	53722,55 5,40%	55362,24 8,62%	57135,19 12,10%	59017,39 15,79%	60990,06 19,66%	63039,17 23,68%
GDP, normalized with price index [Bio $]	50444,38	51762,22 2,61%	52973,64 5,01%	54201,20 7,45%	55445,69 9,91%	56709,14 12,42%	57994,27 14,97%	59302,57 17,56%
GDP, normalized with price index, per cap. [Bio $]	7538,05	7653,68 1,53%	7752,19 2,84%	7852,07 4,17%	7953,58 5,51%	8057,09 6,89%	8163,00 8,29%	8271,47 9,73%
Price index [Index]	1,01	1,01 -0,09%	1,01 0,37%	1,02 1,09%	1,03 1,98%	1,04 3,00%	1,05 4,08%	1,06 5,20%
Consumer price [Index]	1,02	1,02 -0,00%	1,02 0,49%	1,03 1,24%	1,04 2,17%	1,05 3,20%	1,06 4,31%	1,07 5,44%
Government price [Index]	1,00	1,00 0,45%	1,01 0,98%	1,02 1,77%	1,03 2,69%	1,04 3,71%	1,05 4,78%	1,06 5,89%
Savings price [Index]	0,99	1,00 0,54%	1,01 1,54%	1,02 2,82%	1,04 4,28%	1,05 5,87%	1,07 7,54%	1,09 9,24%
Factor income [Bio $]	40419,89	41420,74 2,48%	42554,94 5,28%	43820,08 8,41%	45185,25 11,79%	46632,30 15,37%	48146,78 19,12%	49717,98 23,00%
Factor income, normalized with price index [Bio $]	40003,18	41028,95 2,56%	41961,71 4,90%	42901,09 7,24%	43849,11 9,61%	44808,44 12,01%	45781,84 14,45%	46770,98 16,92%
Current account balance [Bio $]	-0,00		-0,00 0,00%	-0,00 0,00%	-0,00 -100,00%	0,00 300,00%	-0,00 -300,00%	
Tax income [Bio $]	8862,84	9096,80 2,64%	9366,76 5,69%	9670,67 9,11%	10000,95 12,84%	10352,84 16,81%	10722,88 20,99%	11108,39 25,34%
Population size [Mil heads]	6691,97	6763,05 1,06%	6833,37 2,11%	6902,79 3,15%	6971,16 4,17%	7038,42 5,18%	7104,53 6,16%	7169,54 7,14%

The second one focuses on the demand side:



The third one reports production quantities and related input demands:



Computing and data base considerations

Compared to a comparative-static run with the model, constructing a baseline over several decades requires many solves. As indicated above, the time resolution can be chosen by the user. While larger time steps such as five year intervals decrease the number of necessary solves, the resulting shock in each period becomes larger, which implies more time spent by the solver to find a fixed point. For a dataset larger than around 57x24, it is therefore recommended to solve at least in bi-yearly steps, whereas less detailed data sets can still solve quite fast in five year steps. Using the built-in pre-solve mechanism with at least three steps is also recommended for more detailed datasets. Furthermore, we recommend aggregating over the Armington agents, which removes the agent specific differentiation between domestic and imported shares and reduces the model complexity and rigidities in the demand composition.

Some relatively large data sets have been tested, including 33 from all 57 sectors and 80 countries from the 140 available in GTAP 9. One run over 40 years in 2 year steps with such detailed data base might require about two hours. Note that especially debt accumulation from foreign savings might lead to infeasibilities, such that it might be required to manually reduce the accounted share of related debt servings for specific regions. In the same vein, we typically used an ALTERTAX run to construct a benchmark where very high negative macro-economic saving rates are reduced (see gams\scen\user_scenarios\corr_betas.gms). These odd saving rates might point a specific problem in GTAP 9 data, as in the 2011 the global economy was still affected by an economic crisis.

More generally, it should be understood that baseline construction is only partially a process which can be delegated to a ready-to-use code. A close look at some key results, such as the evolution of foreign savings, saving rates and sectoral output per capita is recommended to rule out implausible findings. An ALTERTAX adjustment may be needed to vary the initial benchmark or it might be necessary to add specific shocks on top of the baseline mechanism. We also remind the reader that the SSP1 to 5 storylines comprise elements relating to governance such as policies to abate emissions or control land use change which are not integrated in the model structure discussed here.