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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 introduces sector specific productivity changes, endogenous aggregate saving rates, as well as time-varying input-output coefficients. Parameters for these relationships are econometrically estimated or taken from published work. The core of the model is derived from the GTAP standard model and seamlessly incorporated into the modular and flexible CGEBox modelling platform. Accordingly, it can be applied with various other extensions such as GTAP-AEZ, GTAP-Water or a regional breakdown for Europe to 280 NUTS2 regions. G-RDEM maintains the flexible aggregation from the GTAP data base. 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 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

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By Wolfgang Britz[a] and Roberto Roson[b]

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1. 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

2. 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.

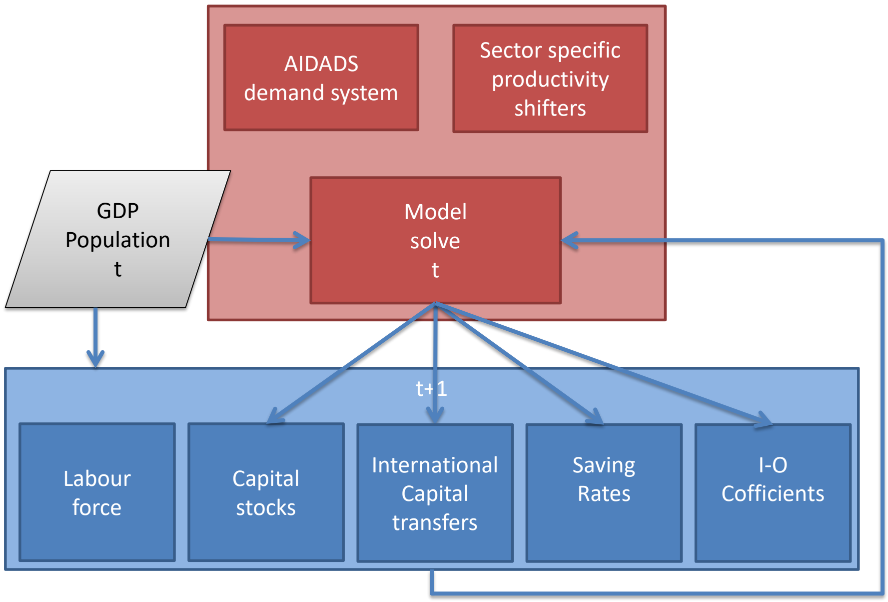

Figure 1: Overview of the recursive-dynamic modelling framework G-RDEM

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

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

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.

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

3.1 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 *a* and *β*, function of the utility level *u*, implicitly defined by (3).

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

$$\delta_i = \frac{\bar{\alpha}_i + \bar{\beta}_i u}{1+u} \tag{2}$$

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

3.2 Estimation and integration into modelling framework

We first econometrically estimated *a, 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. 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 *a* 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 *a, β* and the "corrected" ones, such that all *γ* turn out to be positive.

4. Differentiated productivity growth

4.1 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.

4.2 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.

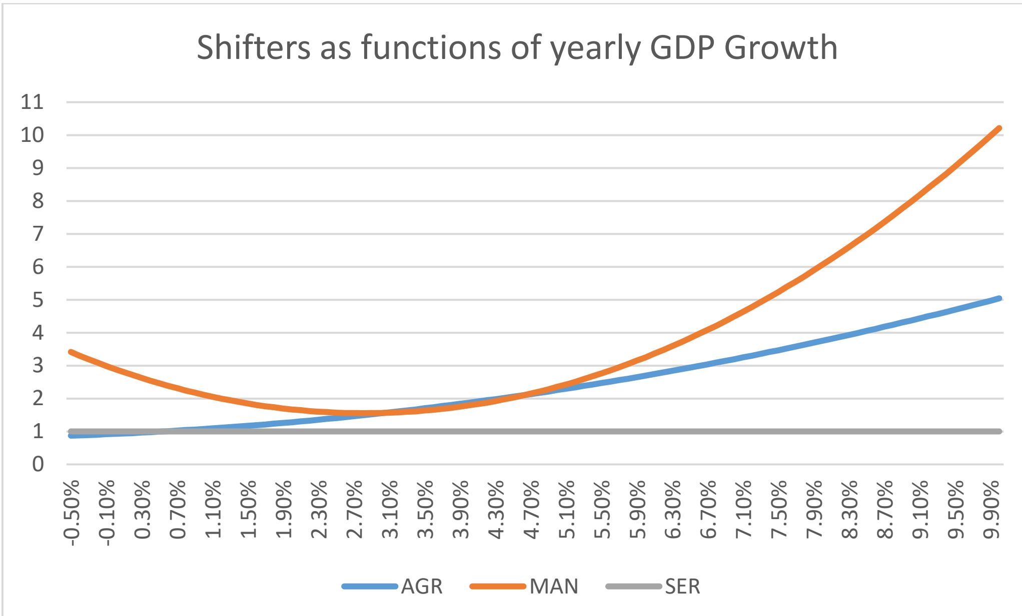

Figure 2 : Productivity growth relative to GDP growth

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:

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

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

5. Endogenous saving rates

5.1 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).

5.2 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.

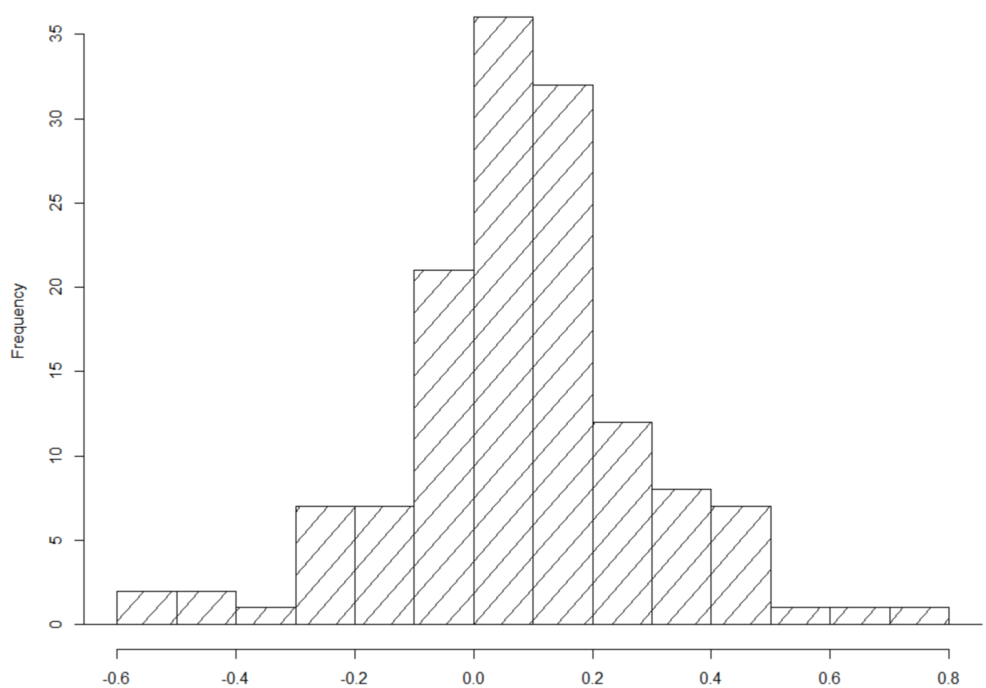

Figure 3 : Distribution of aggregated savings rates in GTAP 9

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.

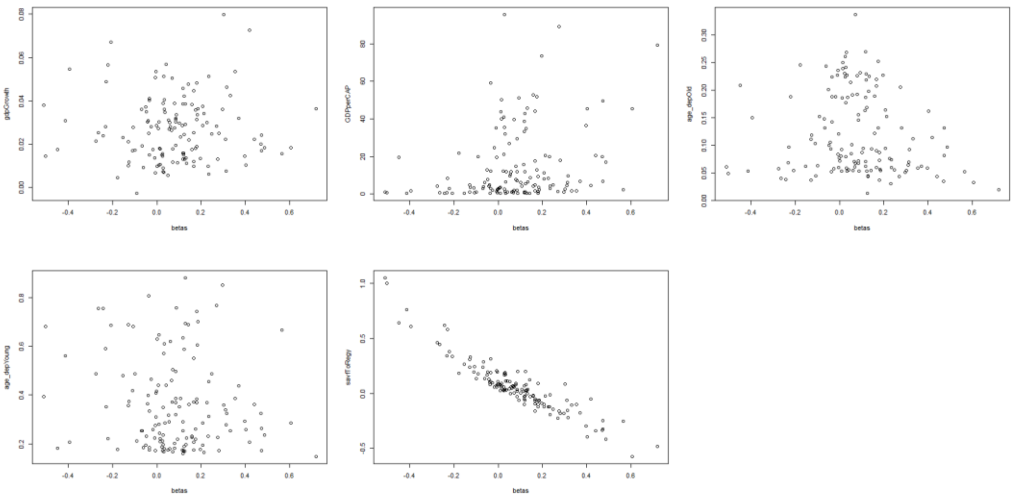

Figure 4 : Scatter plots of explanatory variables against the saving rate

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.

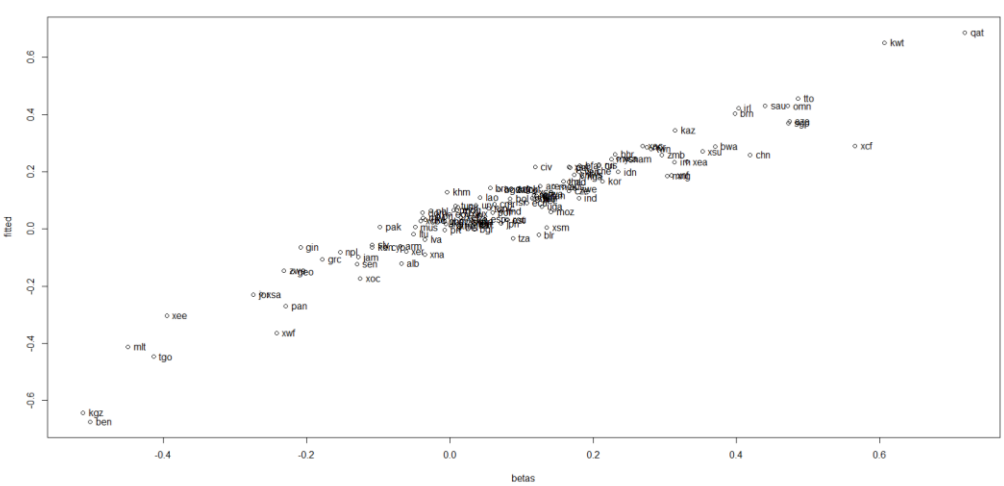

Figure 5 : Fitted against observed saving rates, GTAP region codes as labels

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.

6. 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:

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

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:

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

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:

$$rore_r\ \overline{risk_r} = rorg \tag{7}$$

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):

$$\sum_r fsav_r rorg \equiv 0 \tag{8}$$

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:

$$captrans_{r,t} = \sum_{tt<t} fsav_{r,tt} rorg_{tt} \tag{9}$$

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,*:

$$regy_{r,t} = factY_{r,t} + yTaxInd_{r,t} - captrans_{r,t} \tag{10}$$

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).

7. Cost-share adjustment

7.1 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.

7.2 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.

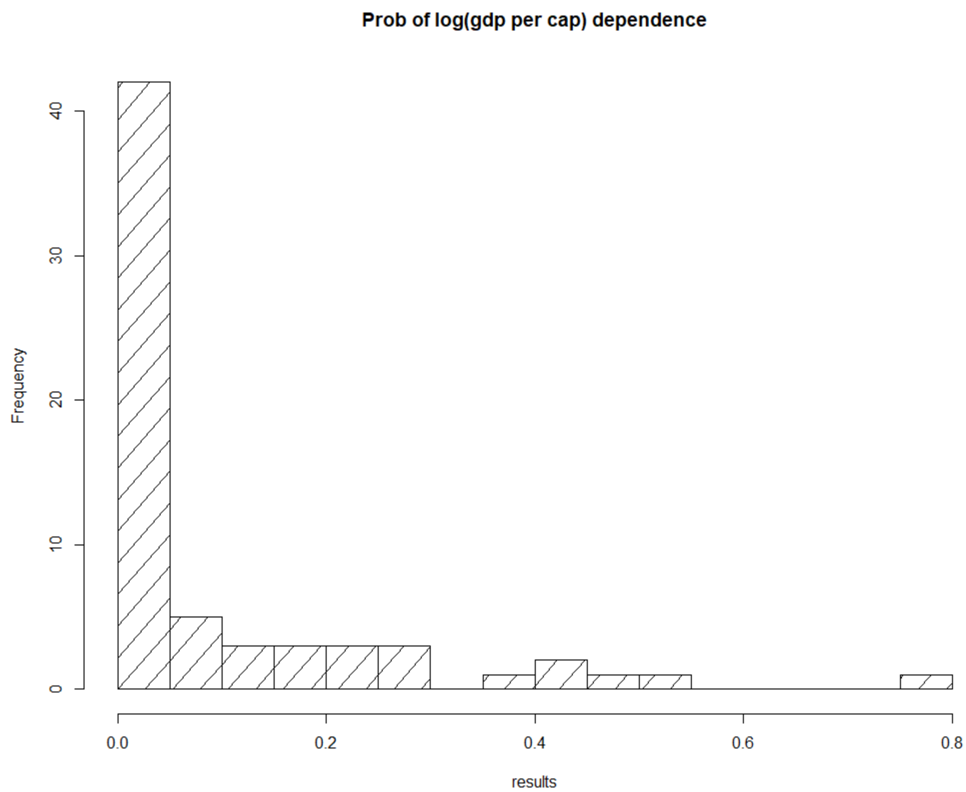

Figure 6: Distribution of significance levels of the regression coefficient between the IO-coefficients and GDP per capita being zero

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.

8. 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

8.1 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.

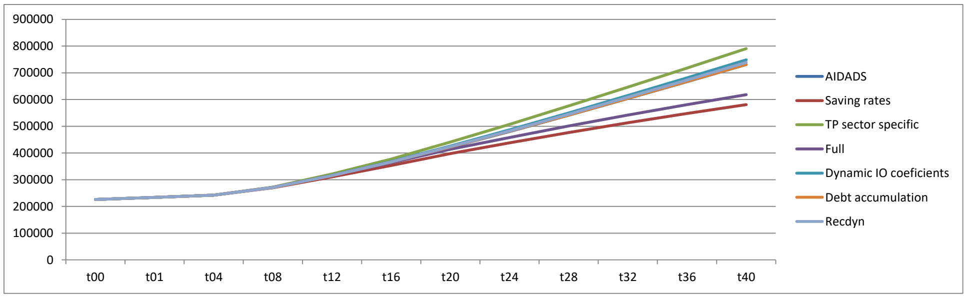

Figure 7 : Global capital stock projection

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.

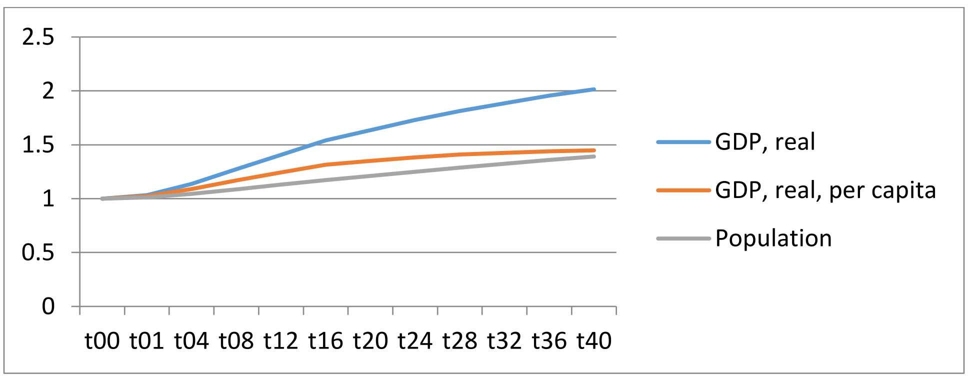

Figure 8 : GDP, Population and GDP per capita projections from SSP3

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.

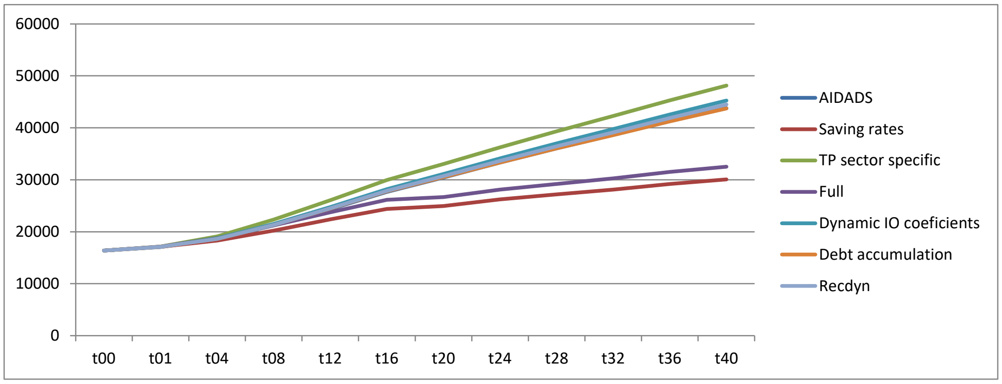

Figure 9: Aggregate gross investments

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.

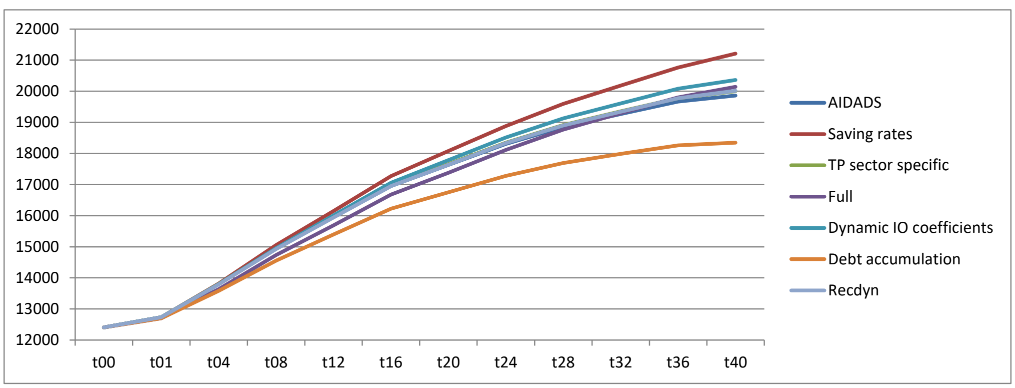

Figure 10: Aggregate demand by private household

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.

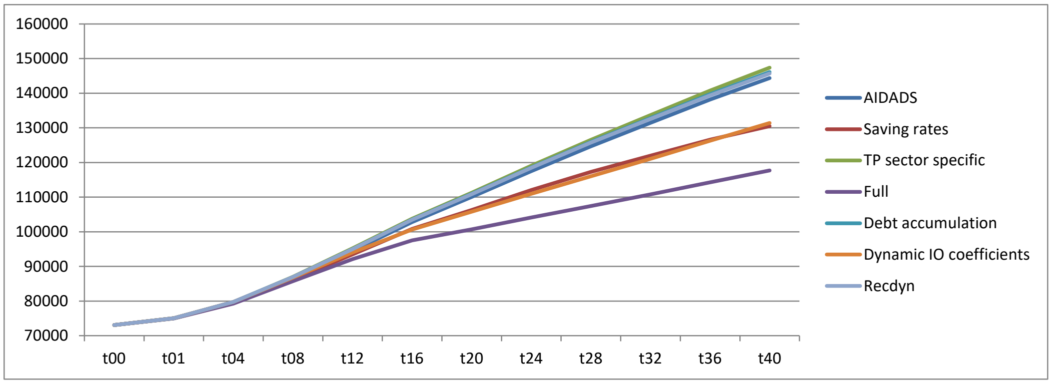

Figure 11: Aggregate intermediate demand

8.2 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.

Table 6 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

	AIDADS	Full	Recdyn
Total	**287662**	**259533**	**289301**
Grains and Crops	4419	4329	5121
Livestock and Meat Products	3491	3736	4289
Mining and Extraction	10644	8724	10655
Processed Food	8638	10176	9543
Textiles and Clothing	5152	5788	4764
Light Manufacturing	27598	24170	27461
Heavy Manufacturing	61824	48908	63203
Utilities and Construction	33425	28675	33306
Transport and Communication	45207	41338	47344
Other Services	87265	83689	83615

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 1500%.

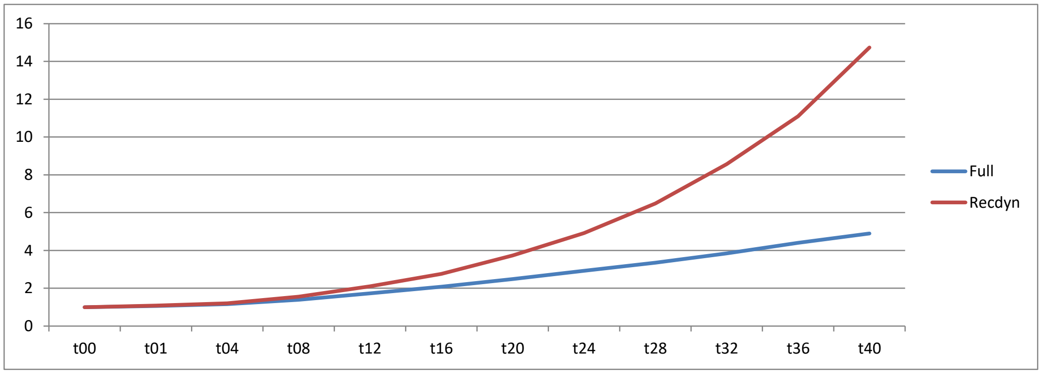

Figure 12: Land price development in Sub-Saharian Africa

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.

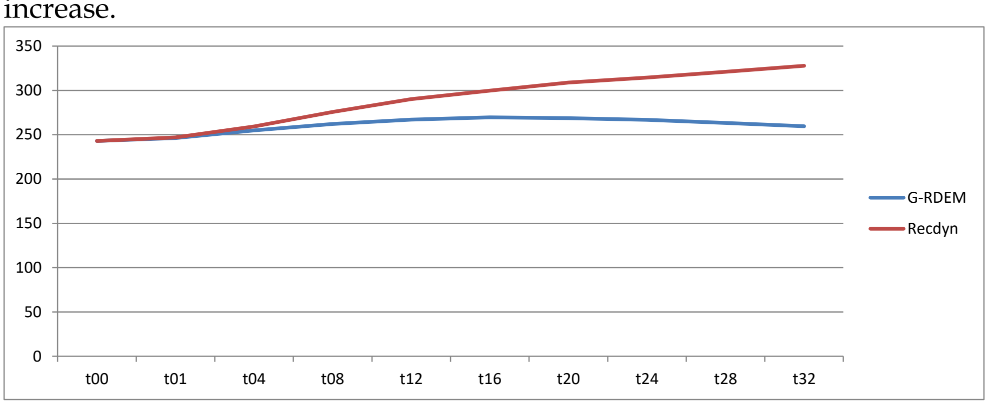

Figure 13: Per capita demand for grains and crops in Sub-Saharan Africa

9. 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.

References

Alexandratos, N., & Bruinsma, J. (2012). World agriculture towards 2030/2050: the 2012 revision (Vol. 12, No. 3). FAO, Rome: ESA Working paper.

Arrow, K. J. (1959). A time series analysis of interindustry demands (Vol. 17). North-Holland.

Baumol, W. J. (1986). Productivity Growth, Convergence and Welfare: What the Long-Run Data Show. *The American Economic Review* 76 (5), 1072-1085.

Caron, J., Markusen, J. R., (2014). International Trade Puzzles: a Solution Linking Production and Preferences. *The Quarterly Journal of Economics*, 1501-1552.

Chenery, H. B., Robinson, S., & Syrquin, M. (1986). Industrialization and growth (p. 45). The World Bank, Washington.

Corong, E., Hertel, T., McDougall, R., Tsigas, M., & van der Mensbrugghe, D. (2017). The Standard GTAP Model, Version 7. Journal of Global Economic Analysis, 2(1), 1-119. doi:http://dx.doi.org/10.21642/JGEA.020101AF.

Cranfield, J. A., Preckel, P. V., Eales, J. S., & Hertel, T. W. (2000). On the estimation of'an implicitly additive demand system'. *Applied Economics*, *32*(15), 1907-1915

Dellink, R., Chateau, J., Lanzi, E., & Magné, B. (2017). Long-term economic growth projections in the Shared Socioeconomic Pathways. *Global Environmental Change*, *42*, 200-214

Doshi, K. (1994). Determinants of the saving rate: an international comparison. *Contemporary Economic Policy*, *12*(1), 37-45.

Duarte, M., Restuccia, D., (2010). The role of the structural transformation in aggregate productivity. *The Quarterly Journal of Economics* 125, 129-173.

Harberger, A. C., (1998). A Vision of the Growth Process. *The American Economic Review* 88 (1), 1-32.

Hertel, T.W. & Tsigas, M.E. (1997) "Structure of GTAP", in: T.W. Hertel (ed.), Global Trade Analysis: Modeling and Applications, Cambridge University Press.

ICP (2015). Purchasing Power Parities and Real Expenditures of World Economics: A Comprehensive Report of the 2011 International Comparison Program. World Bank, Washington, D.C.

Kirsanova, T., & Sefton, J. (2007). A comparison of national saving rates in the UK , US and Italy. European Economic Review, 51(8), 1998-2028.

Loayza, N., Schmidt-Hebbel, K., & Servén, L. (2000). What drives private saving across the world?. *Review of Economics and Statistics*, *82*(2), 165-181.

Lutz, W., Butz, W. P., & Samir, K. E. (Eds.). (2017). World Population & Human Capital in the Twenty-First Century: An Overview. Oxford University Press

Masson, P. R., Bayoumi, T., & Samiei, H. (1998). International evidence on the determinants of private saving. *The World Bank Economic Review*, *12*(3), 483-501.

Matsuyama, K. (2008). Structural change. In S. Durlauf, & L. E. Blume (Eds.), *The New Palgrave Dictionary of Economics (2 ed.)*. Palgrave-Macmillan.

McMillan, M., Rodrik, D., (2011). Globalization, Structural Change and Productivity Growth. NBER Working Paper w17143.

Muhammad, A., Seale, J. L., Meade, B., & Regmi, A. (2011). International evidence on food consumption patterns: an update using 2005 international comparison program data. (March 1, 2011). USDA-ERS Technical Bulletin No. 1929. Available at SSRN: https://ssrn.com/abstract=2114337 or http://dx.doi.org/10.2139/ssrn.2114337

Riahi, K., Van Vuuren, D. P., Kriegler, E., Edmonds, J., O'neill, B. C., Fujimori, S.,. & Lutz, W. (2017). The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview. *Global Environmental Change*, 42, 153-168.

Rimmer, M. T., & Powell, A. A. (1996). An implicitly additive demand system. *Applied Economics*, *28*(12), 1613-1622.

Rodrik, D., (2016). Premature deindustrialization. *Journal of Economic Growth* 21, 1-33.

Roson R, & van der Mensbrugghe D. (2018), Demand-Driven Structural Change in Applied General Equilibrium Models, in F. Perali and P. L. Scandizzo (eds.), The New Generation of Computable General Equilibrium Models, Springer International, doi: /10.1007/978-3-319-58533-8_2.

Roson R. (2018), Understanding the Global Dynamics of Sectoral Labor Productivity, *International Economics Letters*, forthcoming.

Sato, R., & Ramachandran, R. (1980). Measuring the impact of technical progress on the demand for intermediate goods: A survey. *Journal of Economic Literature*, *18*(3), 1003-1024.

Skolka, J. (1989). Input-output structural decomposition analysis for Austria. *Journal of Policy Modeling*, 11(1), 45-66.

Swiecki, T. (2017) Determinants of structural change. *Review of Economic Dynamics* 24, 95-131.

Triplett, J. E., Bosworth, B. P., (2003). Productivity Measurement Issues in Services Industries: Baumol's Disease Has Been Cured. *Economic Policy* (September), 23-33.

Üngör, M., (2013). De-agriculturalization as a result of productivity growth in agriculture. *Economics Letters* 119, 141-145.

de Vries, G., Timmer, M., de Vries, K., (2015). Patterns of structural change in develop-ing countries. In: Weiss, J., Tribe, M. (Eds.), Routledge Handbook of Industry and Development. Routledge, pp. 65-83.

van Meijl, H., Havlik, P., Lotze-Campen, H., Stehfest, E., Witzke, P., Dominguez, I.P., Bodirsky, B.,van Dijk, M., Doelman, J., Fellmann, T. and Humpenoeder, F., 2017. Challenges of Global Agriculture in a Climate Change Context by 2050 (AgCLIM50). JRC Science for Policy Report, EUR 28649 EN, doi:10.2760/7724

Woltjer, G. B., Kuiper, M., Kavallari, A., van Meijl, H., Powell, J. P., Rutten, M. M., ... & Tabeau, A. A. (2014). The MAGNET model: Module description (No. 14-57). LEI Wageningen UR.

Young, A., (2014). Structural transformation, the mismeasurement of productivity growth, and the cost disease of services. *American Economic Review* 104 (11), 3635-3667.