Modularity and flexibility in MANAGE-WB: model structure and the methodological approach

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Abstract

MANAGE-WB is the recursive-dynamic single country model developed and applied by the World Bank. This paper discusses some distinguishing features of MANAGE-WB, including flexible nestings in the production function, in final demand and in factor supply, options for model dynamics and baseline construction, specific mechanism for savings and investment behavior, innovative ways to run different counterfactuals, alternative methods for solving the model, ways of examining post-model results and Monte Carlo type of stochastic simulations. The majority of these options can be configured in the Graphical User Interface (GUI) which also is used to compare and analyze multiple scenarios based on tables, graphs and maps.

Introduction

MANAGE-WB is a recursive-dynamic single country model developed and applied by the World Bank for a wider range of projects. After the development of the MANAGE-WB core model as documented by van der Mensbrugghe (2020), some extensions were added to MANAGE-WB and it underwent rigorous refactoring to render it more modular and flexible. These changes reflect a growing number of quite diverse applications, such as on Climate Change mitigation and adaptation, fiscal reform, or growth and jobs which require their specific model features. Without modularity and flexibility, addressing the different topical foci of the project leads to mushrooming of model variants which have all departed from the same original model but feature their own extensions and improvements in detail. These study specific additions to the model are often useful for parallel or future projects but might be lost or hard to integrate without a code organization supporting modularity.

The refactoring process therefore added features from MANAGE-WB model variants from past projects, but also approaches found in other models deemed relevant for MANAGE-WB. They were integrated in a modular fashion, reflecting approaches, for instance, found in CGEBox (Britz and Van der Mensbrugghe, 2018) or MAGNET (Woltjer et al. 2014). The team gathers that reporting on these features and how they are implemented and steered is of interest to the wider community of CGE analysts. Many teams face the challenge to both maintain and further develop a core model while at the same time need the flexibility to adjust the model to specific projects.

Flexible nestings

To adjust the model structure flexibly for a specific project, a so-called flexible nesting approach is applied for the production function structure, final demand and factor supply. Flexibility means that nesting structures are not hard coded as equations such that any change in the nesting structure for a specific project implies rewriting part of the model code. Instead, the project specific nesting is provided as mapping information in the project specific bridge-file, an EXCEL-Workbook. Generic equations and code for benchmarking generate implement the desired nesting for a specific project. Avoiding the repeated hard-coding of nestings is specifically important for MANAGE-WB where SAMs are mostly built bottom-up for projects and thus differ from country to country in activity, product or factor detail. Without a mapping-based approach, only quite simple nesting structures could be maintained in a common set of equations if the model were applied to SAMs with quite different detail.

The EXCEL-Workbook does not only comprise the nesting information, but hosts all project specific information, such as the SAM, model parameterization and macro-economic projections. Information on each production nest's composition is accompanied by its substitution elasticity and a flag indicating if the volume preserving CES function (van der Mensbrugghe and Peters, 2016) is to be used (see Graphic 1 for a partial example). This form is chosen when the technology suggests physical adding up of the components, such as in case of different energy carriers measured in their energy content. The maps defining the composition enter the generic equations which define intermediate or factor supply composites and related price indices. The model supports assigning shares of observed benchmark demands to such nests. In the example below, this approach is used to assign the skilled labor category *labsk* with 50% to a nest where it can be substituted with capital and to 50% to a nest where it can be substituted with less skilled labor.

The “all” label in front of the shown rows refers to the default nesting used for any production activity. Exemptions can be added for specific activities, for instance, to assign a part of fossil fuel use to energy generation and a part to process use in case of refineries.

		labsk	labus	labsk_labus	cap_labSk	va	cap_labsk_ener	ener
	subsElas	0.5	0.5	0.25	0.2	0.7	0.25	0.5
	additive							1
		labsk	labus	labsk_labus	cap_labSk	va	cap_labsk_ener	ener
all	f-off_mgr_pros	1						
all	f-tech_aspros	1						
all	f-m_skl	1						
all	f-f_skl	1						
all	f-clerks		1					
all	f-service_shop		1					
all	f-ag_othlowsk		1					
all	f-m_nsk		1					
all	f-f_nsk		1					
all	labus			1				
all	labsk			0.5	0.5			
all	f-Capital				1			
all	f-NatlRes					1		
all	labsk_labus					1		
all	cap_labsk_ener					1		
all	wtr_land					1		
all	cap_labSk						1	
all	ener						1	
all	ener_fossil							1
all	ely_tnd							1
all	c-p_c							1

Graphic 1: Example of flexible nesting information for the production function in the bridge-file

Like for the production function nesting, primary factor allocation to activities or groups thereof is based on flexible nesting structures supporting the additive CET functional form. As in case of the production function, generic equations define the demand for single factor or composite thereof, complemented by code for the benchmarking. The mapping information again stored in the bridge-file, along with transformation and factor supply elasticities and flags to indicate additive nests. Combined, this allows, for instance, to integrate the GTAP-AEZ (Agroecological Zone) data and model structure without changes to the model equations.

	cropLand	grasLand	agrLand	f-land
additive	1	1	1	1
omegaCET	0.75	0.75	0.5	0.25
factSupElas				0.1
	cropLand	grasLand	agrLand	f-land
a-osd	1			
a-c_b	1			
a-pfb	1			
a-ocr	1			
a-ctl		1		
a-oap		1		
a-rmk		1		
a-ctlRais		1		
a-wol		1		
cropLand			1	
grasLand			1	
a-frs				1
agrLand				1

Graphic 2: Partial example of flexible nesting information for factor supply in the bridge-file

Finally, CES final demand composites can be defined in shares from individual products or composites thereof, Graphic 3 below shows a partial example. The resulting nested demand structures enter the top-level CDE (Constant-Difference-in-Elasticities) demand system for households, while other final demand uses a CD or CES specification for the top nest. Again, the demand nesting and related parameters are stored in the project specific EXCEL-Sheet.

Jointly, the flexible nesting gives the necessary flexibility to configure factor demand and supply as well as final demand for different studies, for instance, to allow for capital-energy substitution and substitution between different energy carriers in assessing climate change mitigation options.

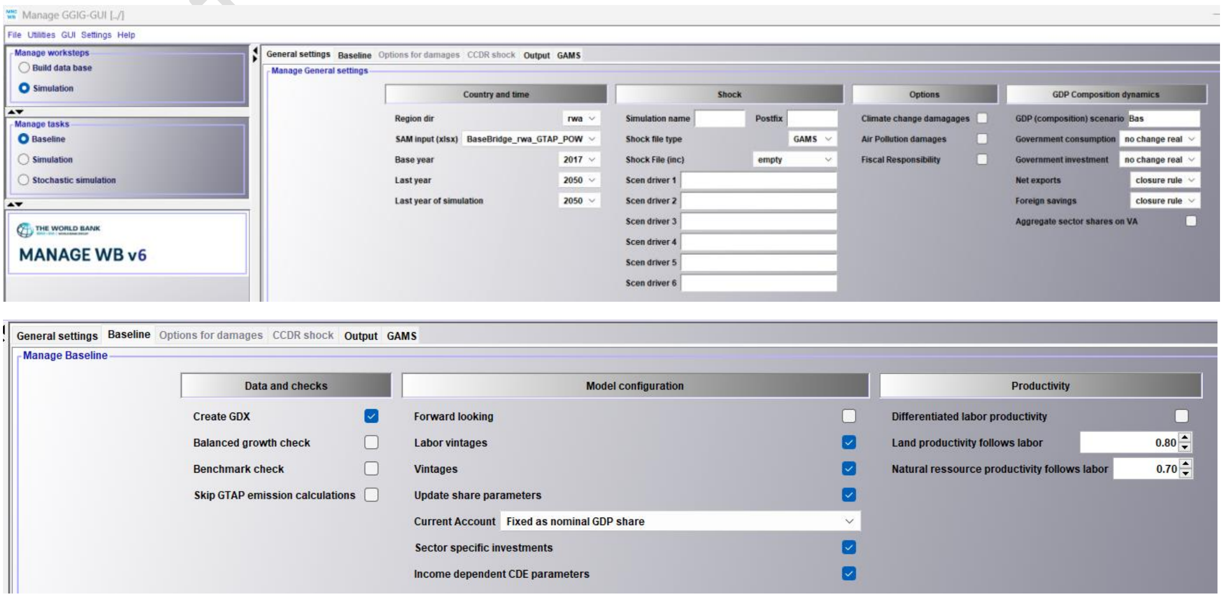
	Crops	MeatDairy	FoodOther	Clothing	Manu	Hot_Trad	Serv	privTrs	privTrsEner	privTrsRest
	0.5	0.25	0.25	0.25	0.25	0.2	0.25	0.1	eps	0.1
	Crops	MeatDairy	FoodOther	Clothing	Manu	Hot_Trad	Serv	privTrs	privTrsEner	privTrsRest
c-pdr	1									
c-wht	1									
c-gro	1									
c-v_f	1									
c-osd	1									
c-c_b	1									
c-ocr	1									
c-ctl		1								
c-ctlRais		1								
c-oap		1								
c-rmk		1								
c-fsh		1								
c-cmt		1								
c-omt		1								
c-mil		1								
c-trd		0.05	0.1	0.1	0.05	0.6				0.1
c-vol			1							
c-pcr			1							
c-sgr			1							
c-ofd			1							
c-b_t			1							

Graphic 3: Partial example of flexible nesting information for final demand in the bridge-file

Options for dynamics and baseline construction

MANAGE-WB as a recursive-dynamic model comprises special features to depict dynamics in technological choice. Besides supporting a wide range of productivity shifters (specific to activities, production function nests, combination thereof, group of activities etc.), each sector can be represented optionally by two technologies. They represent old and new vintages, with their own production functions and returns to capital, with identical prices for intermediates and other factors. Each sector's old vintage uses maximally the depreciated capital stock of the two vintages from previous year, while new vintages compete for net investments in the capital market. Old vintages will sell old capital based on an iso-elastic supply schedule if returns to old capital fall below the price for new capital. New vintages have higher substitution elasticities, currently by default in the value-added nests and capital-energy substitution. This assumes higher flexibility for new vintages in choosing a costminimal input mix, reflecting current year's input productivities and prices. Old vintages, in contrast, are subject to a lock-in effect: their technology was largely determined at the time of investment. Resulting dynamics in the average technology of the new and old vintage are reflected by adjusting share parameters of the old vintage to reflect last year's mix of new and old vintage technologies. A similar option allows to split the labor force into new entrants and the existing force. The transformation elasticities for new entrants are then assumed as higher, considering that these can more freely decide on their specific training depending on labor market opportunities.

The default set-up when constructing a baseline fixes real GDP and renders the labor productivity endogenous. Labor productivities for primary and secondary sectors relative to services can be driven by an empirical relation estimated by Roson (2019). The classical Solow-model misses an approach for factors such as land or natural resources neither subject to (direct) accumulation from net savings nor directly driven by population growth. The model therefore allows assigning part of the labor productivity growth to land and natural resources. Parameters of the CDE demand system can be updated based on regression functions estimated from the parameters found in the GTAP Data Base to reflect income dependent elasticities. The GDP composition by the different aggregate final demanders and net-exports can be targeted in real or nominal terms. The same holds for the GDP contribution of sector aggregate. Related time series with such exogenous projections are inputted in the bridge-file, potentially for multiple baseline variants. These options are all steered via the Graphical User Interface (GUI, see Graphic 4). The GUI also allows to turn on a benchmark replication check where some variables in first year need to be redefined and the option to check for a balanced-growth path. It also supports choosing different closure rules for foreign savings and activating a forward-looking mode where price expectations are formed over some future years. These expectations drive stock levels and determine expected returns to capital.



Graphic 4: Part of the MANAGE_WB GUI related to baseline construction

Additional elements in baseline construction, such as targeting a specific power generation mix, can be partly activated directly via the GUI. For these project independent cases, ready-to-use code is available, and the bridge file comprises sheets to enter the necessary projections. Project specific elements in baseline construction can be added in a shock file. The code supports options to remove and add equations to the model which gives additional flexibility, for instance, to implement project specific closure swaps.

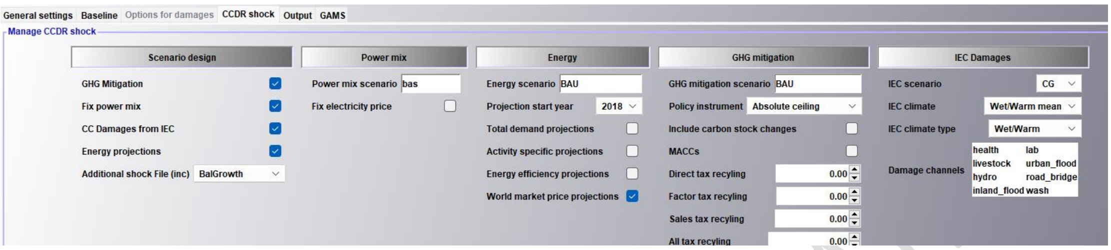
Government account, savings and investments

MANAGE-WB features on demand sector specific depreciation rates and investment vectors which eases the integration of information of engineering studies and detailed sector models, for instance, power system models. The government account is closed by default by issuing bonds with a fixed future interest rate, assuming to be paid back in equal installments. The amount of bonds bought by foreign and domestic lenders depends on the endogenous interest rate offered by the government for bonds issued this year. The amount of bonds bought by foreign lenders depends additionally on a risk premium driven by the public debt to GDP ratio. The portfolio composition between bonds and financing of new investments for all domestic lenders (households, enterprises) is determined by a virtual agent based on an additive CET function which depends on the interest rate offered by government and expected returns to investment. The marginal propensity to save of households is driven by CET function considering the returns to savings – a weighted average of the interest rate on bonds and the expected returns to investments, and the Consumer price index. Government investments are typically assumed to not fully contribute to capital accumulation. A maximum debt-to-GDP can be targeted by a so-called fiscal responsibility mechanism where tax rates and/or government spendings are adjusted to reduce borrowing needs. Related options are set on the user interface.

Counterfactuals

If not defined otherwise in the shock file, counterfactuals take productivity and preference shifters from the baseline as given and fixed, along with exogenous drivers used in the baseline such as changes in population, tax rates, world market prices etc.. An empty shock will therefore recover exactly the baseline, however with GDP being endogenous. This concept eases defining counterfactuals. The shock file will solely comprise changes on top of the baseline.

For typical elements of climate change-related work, ready-to-use sub-shock files can be combined and used during baseline construction as well. These sub-shock files comprise, for instance, climate change damage vectors from Roson and Sartori (2016) or an interface to damages in a format delivered by the IEC consulting group. Damages are introduced as pre-defined productivity, preference or changes in factor stocks to the model. Equally, time series of carbon taxes or emission ceilings can be introduced via the bridge-file for multiple scenarios. Carbon taxes can be recycled to reduce direct taxes, factor taxes, sales taxes or all kinds of taxes. Recycling rates for the categories can be defined in the interface (see Graphic 5). Time series for the power mix or energy demands can be targeted, related closure swaps are part of the core code. The model can endogenously adjust emission coefficients related to activity levels and primary factor use based on a stepwise interpolation between points of sector specific Marginal Abatement Cost Curves from the literature. Related costs refer to the integral under these stepwise curves such that average and marginal abatement costs differ. This mechanism requires a new activity in the SAM which produces abatement technologies as an additional intermediate input.



Graphic 5: Climate change and energy related options on the GUI

Solving the model

Depending on the detail of the SAM and the chosen model layout, a model instance for a single year will comprise a few thousand to ten thousand variables. To ease solving, the code can either use the results of last year's solution or the baseline solution for this year (for counterfactuals, only) as the starting point. Additional code constructs on demand for many endogenous variables start values, considering changes in exogenous variables. The recommended solution method defines the model as a constraint system of equations (CNS) and uses CONOPT4 as the solver, which supports parallel execution of certain operations to benefit from modern multi-processor computers. Variables are mostly free, i.e. don't have lower and upper bounds. The user can define the maximal number of seconds and iterations for a first solve trial of the model. If this first solve fails, the code will switch to Non-Linear Programming (NLP) with a dummy objective. In this mode, CONOPT4 uses more evolved algorithms which usually take longer but can overcome certain numerical difficulties. If this trial fails as well, some bounds are added to exclude math trap errors and feasibility tolerances are slightly relaxed. This can help in some cases, especially for highly non-linear model relations such as related to the vintage mechanism.

The model is fully paired, i.e. for each equation, a matching variable is defined, to allow solution as a Mixed Complementarity Problem (MCP). Solution as a MCP is generally slower and the standard model does not comprise regime switch equations, such as referring to production or trade quotas, which require a MCP solver. Having the model fully paired is, however, useful during model development if coding errors provoke non-square models where the number of equations differs from the number of variables. The MCP algorithm in GAMS will report the offending variables and equations which usually allows to quickly locate the erroneous code.

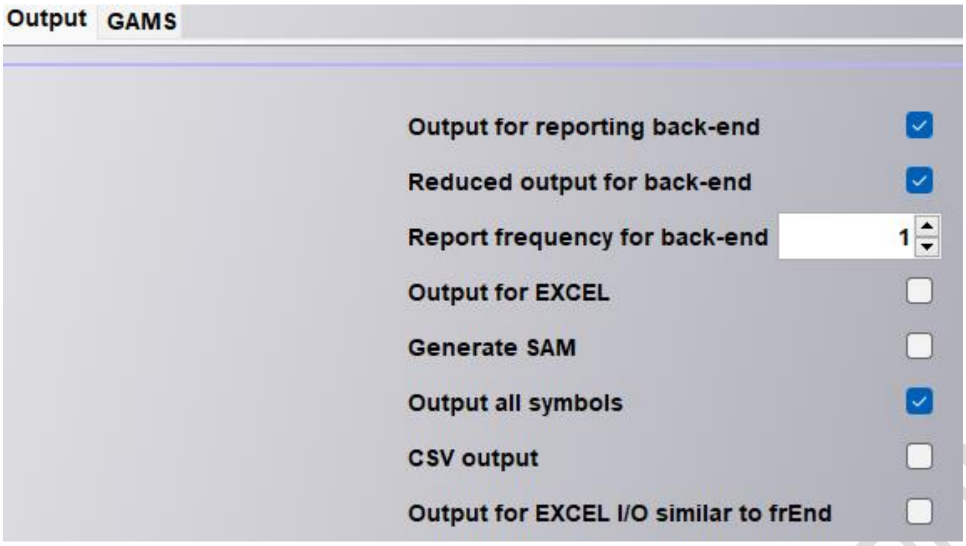
To ease the numerical stability of solving the model, most equations can be scaled on demand with the previous year's solution of the variable it defines, subject to a cut-off value. Exemptions are mostly equations defining prices which are unity at the benchmark such that related equations remain nicely scaled during simulations as well. On demand, the SAM can be scaled such that the GDP at the benchmark is equal to a given value, usually 1E+5. This has shown to improve numerical stability and solution speed, especially in cases of countries where due to the size of the economy and the currency used there are many extremely large or small transactions reported in the SAM. The SAM scaling has however the dis-advantage that variable levels differ from the related SAM entries, which must be reflected in shock files targeting transactions in absolute terms.

Post-model reporting

The reporting back-end based on Britz et al. 2015 offers a larger set of pre-defined reports as tables, graphs or maps for analysis of a single run over time or across multiple scenarios. Each report shows a block of information helping to analyze specific aspects of the model solution. This implies typically looking simultaneously at different model variables, say quantities, pre- and post-tax prices or values which is cumbersome with the model listing or GAMS Studio. The back-end therefore removes the technical dis-aggregation of the model's solution space into GAMS symbols (variables, parameters and equations) by constructing a multi-dimensional matrix, organized like a time series of SAMs. It comprises for each time point and cell in the SAM besides the value also the volume, pre- and after-tax price, value and tax revenue. This core matrix is complemented by other results, such as on emissions, land use and carbon stocks. Besides results at the level of individual products, activities and factors, the code also calculates results for user defined product and activity aggregates and economy wide totals.

Reports are defined in an XML dialect which requires for each report at least the following information: (1) Which dimension (for instance, SAM row or column) from the result matrix to show in columns and rows, (where applicable column or row groups) of the user's viewport, and which ones to move to drop down lists. This information is called the pivot. (2) The selection of labels from each dimension in the result matrix, and (3) the view type (table, graph, map). Further information can be added, such as the number of digits, if percentages changes should be additionally shown, if empty rows and columns should be hidden etc. The user can change the pivot, view type, digits, comparisons interactively, sort or select etc. The reporting back-end can combine result sets from multiple scenarios for analysis. The user has the option to output only each nth year and to remove certain elements from the report matrix if many scenarios are to be analyzed to save disk space and memory (see Graphic 6 below).

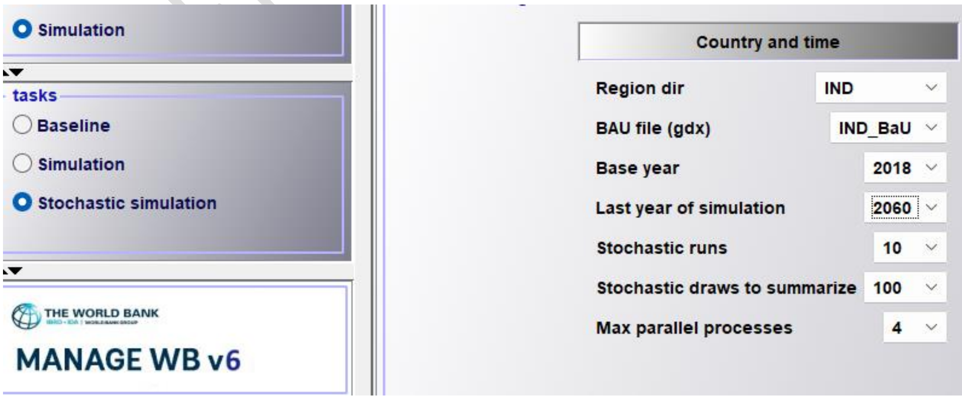
Besides the interactive reporting tools, additional reporting options are available, for instance to generate CSV files, as seen from the screenshot below. They are not discussed here but detailed in the model documentation.



Graphic 6: Options for reporting

Stochastics

MANAGE-WB employs a scenario reduction tool to condense a large set of time series of scenarios to a representative set of scenarios, not necessarily equally likely. This option is mainly used to assess Climate Change related changes in the probability and severity of disasters such as flooding or tropical storms with high damages. Information is typically provided by damage estimates for multiple return periods, such as 100 Mio $ damages to capital stock for a 10-year event, 2 Bio $ for 100-year event etc. Using the so-called trapezoidal rule to interpolate between given probabilities and applying random generators, random time series of damages are generated. In the example depicted in Graphic 7 below, each time series comprises 43 years with randomly drawn damage estimates, and for each of the 10 runs to conduct, 100 such time series are generated. The scenario reduction tool by Dupačová et al. 2003 available as a tool in GAMS will condense this total of 43.000 random observations into 10 representative runs.



Graphic 7: Options on the GUI to steer stochastics

These representative runs are then automatically distributed to a grid for solving and combined in one set of results afterwards. The reporting tool allows presenting these results as scatter graphs, and to add statistics such as mean, median, variance, standard deviation.

Summary

MANAGE-WB is the recursive-dynamic single country model developed and applied by the World Bank. As detailed above, MANAGE-WB allows for a quite flexible configuration of model features for a specific study. This includes changes to the nesting in the production function, final demand and factor supply. Different model features, such as the vintages, can be activated on demand. Closure swaps repeatedly used in past projects, such as for targeting the power generation mix or the GDP composition, are now made available as features on the GUI to guarantee harmonized solutions across multiple projects. Combined with a powerful reporting back-end which supports in analyzing its results, MANAGE-WB is a key tool in projects to analyze macro-impacts in a wider range of World Bank projects.

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