

A flexible, modular and extendable framework for CGE analysis in GAMS

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Abstract

We present a GAMS based framework for Computable General Equilibrium analysis which can be flexibly configured to depict different nestings in production and factor supply, while allowing a choice between different functional forms for demand and modeling international trade sectors (Armington, Armington plus CET, Melitz and Krugmann model). Either a regional household approach or separate accounts for government and potentially multiple private household with related closures are available. Supply and factor markets can be dis-aggregated to sub-regions. We compare the layout of different well-known global and single country CGE models and discuss to what extent our flexible framework can replicate these features. In a structural sensitivity analysis, we compare major results of test shocks (multi-lateral trade liberalization and endowment changes in one country) by our framework under different configuration. These reflect important structural differences between the chosen examples as well as additional features such as the Melitz model or endogenous capital stocks driven by investments in a comparative-static setting. We find relative limited differences between models based on the Armington assumption, even if other features differ such as closures, the production function nesting, allowing for substitution on different nodes of the nest, for sluggish factor supply between agricultural and non-agricultural sectors and other elements such as the functional form in demand. A discussion on further joint development of such a framework leads to our summary and conclusions.

Keywords: Computable General Equilibrium analysis, Modularity, Structural sensitivity analysis

JEL classification: C68, C63

1 Background and motivation

Computable General Equilibrium models (CGEs) are perhaps the mostly widely used quantitative tools in economic policy impact analysis. For global CGE analysis, the Global Trade Analysis Project (Hertel 1997) provides since more than two decades the necessary data and parameters. Besides the GTAP Standard model (Hertel 1997) and its many variants, global CGE frameworks such as GLOBE (McDonald and Thierfelder 2014), MIRAGE (Decreu and Valin H. 2007) or ENVISAGE (van der Mensbrugghe 2008) all draw on the GTAP data base. Even earlier, single country framework became popular such as IFPRI standard model (IPFRI-S Lofgren et al. 2002) and STAGE (McDonald 2015), which have been extended in various directions such as multiple households and sub-national detail (cf. Dorosh and Thurlow 2012), dealing with water issues (cf. Luckmann et al. 2014) or migration (Flaig et al. 2013). The GTAP Standard model is open source, which also holds for most of its variants such as GTAP-E (Burniaux and Truong 2002), GTAP-AGR (Keeney and Hertel 2005) or GTAP-AEZ (Lee et al. 2005). While the GTAP family is mostly using the specialized software package for General Equilibrium modeling GEMPACK (Codsí and Pearson 1988), the other examples mentioned above are coded in GAMS (Brooke et al. 1998). Some of them, such as GLOBE, the IFPRI Standard model, STAGE or ENVISAGE are equally open source. Extended versions of these models developed for specific clients might however be copy right protected. Restricted access also holds for MIRAGE. Copy right protected models are not fully transparent as experiments cannot be repeated by outsiders. Furthermore, it is typically impossible to check if published documentation matches the actual code base.

Despite the many CGEs in the market of which we mentioned only a few, both the global and single country CGEs share a common basic structure with features such as representing the technology with nested CES (Constant Elasticity of Substitution) structures. Other building blocks such as modeling bi-lateral import demand based on the Armington assumption, using a CET (Constant Elasticity of Transformation) based approach to complement the Armington

assumption on the supply side or CET nests to model sluggish factor supply are equally common. We will in the following show that this common core is quite large in the examples we analyze. But clearly, there are crucial structural differences in detail which can matter in policy impact analysis, besides differences in parameterization and the chosen regional and sectoral aggregation.

A modeler wishing to apply a combination of specific features in his own analysis faces easily the situation that no model with the desired layout can be accessed or even exists. That implies either extending one of the existing models to cover the desired features or compromising on the model layout. As familiarizing with large-scale models is time-consuming, switching between models or model families for specific applications is unlikely. That renders compromising quite probable. Furthermore and perhaps more important, the community of CGE modelers as a whole does not share effectively costs related to the implementation of new features. Coding efforts are duplicated and potentially useful features not available in specific models. Additionally, the current situation makes it nearly impossible to pinpoint which differences in structure, parameterization, aggregation or shock design provoke deviating impacts found by different models in similar policy experiments.

We therefore propose in here a modeling framework which tries to address these shortcomings at least partly. Firstly, the code is not only open-source, but thought to be further developed based on open source joint development, i.e. a network of developers adds and shares extensions to the code, with the aim to better distribute development costs in the community. Secondly, we aim at “one code base, many models”, i.e. a modular and flexible design which renders extensions or alternative implementations to a large extent mutually compatible. As a consequence, it should become easier both to flexibly adjust the model’s structure for a specific study and to perform sensitivity analysis with structural features. That clearly also improves overall transparency, not at least as experiments can be more simply replicated. Modularity is clearly also necessary to make it inviting to contribute, as it ensures that contributors remain free in deciding rather freely about

the model design they later apply. To our knowledge, there are so far only a few attempts in the direction, mainly the GEMPACK based MAGNET (Modular Applied GeNeral Equilibrium Tool, Woltjer and Kuiper 2013) model which however is not open source and properly less flexible compared to what is discussed in here, but provides other features with a focus on agriculture and food markets and the EU, such as depicting for instance milk and sugar production quotas.¹

The paper is therefore organized as follows. After a brief discussion of the concept of CGEBox, the second section reviews some of the more well-known CGEs with regard to specific features, such as the presentation of technology, firm behavior, trade, final demand, closures and how income distribution and accounts for private households and the government are modelled. We next show in section four, based on a partial multi-lateral trade liberalization experiment, how differences in model layout – all realized with our modular system – impact major results, mimicking in these experiments major elements of well-known models. Section five discusses institutional issues around shared development before we conclude and summarize.

2 Concept of CGEBox

GAMS based global CGE which come close to the GTAP Standard model are available for longer such as the well-known GTAPinGAMS implementation (Rutherford and Arbor 2005). However, no truthful replication in GAMS was available which provided the starting point for the joint work on CGEBox by Dominique Van der Mensbrugge at the GTAP center in Purdue and Wolfgang Britz at Bonn University (Britz and Van der Mensbrugge 2016) combined with a

¹ CGEBox discussed in here can be solved as a MCP which allows introducing production or tariff rate quotas without further coding efforts.

Graphical User Interface (GUI). A GUI was deemed useful to allow students to work in classes with the model without requiring a longer targeted course on the specific model implementation. At the same time, the GUI allows an efficient steering of model configuration and shocks while easing result analysis based on table, graphs and maps, which renders it useful also for senior analysts. However, the GAMS code can equally be used without the GUI. That work was presented in a pre-conference event of the GTAP conference 2016.

The original code is largely based on the GAMS code of ENVISAGE (Van der Mensbrugghe 2008) and therefore comprises many features found in ENVISAGE. That rendered it inviting to not only replicate the GTAP Standard model, but to also allow for extensions. Some of these can be realized by changing the parameterization of CGEBox. Introducing non-zero substitution elasticities in the production function nesting, to give an example, allows switching from the Leontief relations found in the GTAP Standard model to a more flexible implementation. Other features are based on exchanging blocks of equations which can be steered by the GUI. Furthermore, the code was set up such that the model can be also used in recursive dynamic mode, supported by the ENVISAGE code base where all variables, equations and most parameters feature a time index. Furthermore, a single country CGE can be derived. Data input combines features from ENVISAGE and GTAPinGAMS, specifically, the latter contributed a filtering algorithm which allows to remove tiny transactions from the global SAM. That algorithm was further improved and a pre-solve algorithm developed which solves single country CGEs before the full global model, a combination which has proven to allow solving large model variants relatively fast (see Britz and van der Mensbrugghe 2016).

Different projects, mostly course work with students since 2014, led to modular implementations of the concepts of GTAP-AEZ (Lee et al. 2005), which depicts land use at the level of Agro-Ecological Zones, GTAP-AGR (Keeney and Hertel 2005) which introducing specific nestings in agricultural production and in factor supply to agricultural and non-agricultural sector, and GTAP-E (Burniaux

and Truong 2002) with its specific nestings for energy demand into the framework. Recently, an implementation of the Melitz model (Britz and Yafari 2016) was added, which can also be turned into a Krugmann model. Equally, support to multiple private households and other features relevant for work with household surveys were integrated (Britz 2016), drawing on myGTAP (Walmsley and Minor 2013), ENVISAGE and GLOBE. The multiple household feature can be used, for instance, to introduce a separate household drawing income from factors employed in agriculture to complement the GTAP-AGR extension. Drawing on earlier work with regionalized single country CGEs, the model can regionalize the production side and the factor markets; currently, SAMs at the NUTS 2 level for most European countries are available to use that feature. Thanks to access to split factors used in the OECD's metro model (OECD 2016), the bi-lateral trade can be modelled differentiated by total intermediate, investment, government and final demand in a MRIO module.

Based on the code base inherited from ENVISAGE, the model supports non-diagonal make matrices which can be combined with a CET nest to allocate production to multiple outputs and a CES nest on the demand side to differentiate between the same product being produced by several sectors. The implementations of GTAP-AGR and GTAP-E draw on a flexible, multi-stage nesting approach which is realized via set-definitions in GAMS. It allows adjusting the nesting in the production functions and in factor allocation across sectors without changing the equation structure of model, even if multi-stage nests are used. A similar concept allows to aggregate commodities in final demand and use CES-nests inside these aggregates to allow for more flexibility in capturing cross-price effects in demand. The final demand system can be either depicted as the Constant Difference Elasticity (CDE) representation found in the GTAP family of models or as LES. The latter can be converted into a CD by removing the commitment terms. A larger set of typical closures for the different accounts are coded. The majority of these choices can be steered by the GUI.

The different features and extensions are integrated in the code in a modular fashion, i.e. they can be switched on and off independently from each other. Given a global SAM with appropriate sectoral detail, it is possible, for instance, to combine the features of GTAP-E, GTAP-AGR, GTAP-AEZ with different household types while some sectors are modeled based on Melitz 2003, using the MRIO split shares. That raises almost naturally the interesting question to what extent the framework can already replicate the structure of some well-known existing models. Furthermore, depending on how easily a kind of “superset” model could be developed, one could imagine moving in the medium term from more isolated coding efforts to a joint initiative where development and thus costs are shared. Before we turn however to question the feasibility of that idea, the next section provides a stocktaking by reviewing structural differences in selected CGE models, before we perform sensitivity analysis with some major differences.

3 Structural differences between some selected CGE modelling frameworks

In the following we have selected a number of CGE modeling frameworks which we consider as well-known examples. Together, they should provide a good overview over major alternative implementations of key modules in existing CGEs. The chosen candidates are five global CGE modeling frameworks, namely the GTAP Standard model and some variants thereof, GTAPinGAMS, GLOBE, MIRAGE and ENVISAGE, and two single country modeling framework, namely the IFPRI standard model and finally STAGE.

3.1 Data input

All global CGEs reviewed in here draw on the GTAP data base which is released in GEMPACK format. The models can hence either use GEMPACK based utilities distributed with the data base such as GTAPAgg (Horridge 2006) to further transform the data before converting them to GAMS or convert the global SAM in its original format with full regional and sectoral detail and provide their own tools for further processing, for instance, for aggregation over sectors and regions. At

least GLOBE and ENVISAGE are SAM based on the input side which implies that they integrate the different matrices which jointly represent the global GTAP data based into one single global SAM. The single country CGEs draw on country specific SAMs which can be flexible integrated, for instance from spreadsheet or some other software. The SAM based character eases an overview on the model's structure as basically for any transaction in the (global) SAM, matching variables in prices and quantities must be defined. Next, these variables can be either fixed or an equation must be defined which renders them endogenous. The documentation of GLOBE (McDonald and Thierfelder 2014) follows that principle rather stringently. Models such as GLOBE also re-balance the global SAM, for instance in order to overcome rounding errors.

As indicated above, the data driver of CGEBox is closely linked to ENVISAGE and embeds a filtering algorithm to remove small entries from the global SAM. In order to input data into CGEBox, the default solution is to employ the GTAPAGG utility to define a pre-aggregation of the GTAP data base. If only the GTAP Data base without any satellite data is used, the output from GTAPAGG is used directly, otherwise, the GAMS code performs the aggregation to a desired level of sector and regional detail and only uses the aggregate definitions stored by GTAPAGG along with the data base.

3.2 *Production technology*

All CGE frameworks analyzed use nested CES functions to depict technology. While all models assume that the composition of Value Added from different primary factors is price dependent, they might allow or not for price dependent substitution in the input composition at others nodes of these nests. Furthermore, all global models depict intermediate demand for imports and domestic production based on the Armington assumption. However, demand shares might be differentiated by sector or not, or even being identical across all demand agents. In MIRAGE, the Armington model is extended for certain sectors to yield a Krugmann model.

The perhaps most basic layout is found in the Standard GTAP Model and GTAPinGAMS which assume Leontief relations between the value added nest and all intermediates. Each sector features its own Armington nest to source intermediate demand for each commodity from domestic origin and imports. The import composition from different origins is identical across all agents and hence not sector specific. In that regard, the standard layout of GLOBE goes even further by having identical shares for imports and domestic origin for each agent, i.e. including private, government consumption and investments. Variants of the GTAP model such as GTAP-AGR or GTAP-E introduce more complex nesting structures in the production function which might also involve combinations of primary factors and intermediates.

MIRAGE (Decreux and Valin 2007, p. 12) assumes a Leontief relation between the Value Added and intermediate composite whereas the latter allows for substitution between individual intermediate commodities. The value added composite comprises a sub-nest which combines capital and skilled labor. As in the standard GTAP model, each sector splits up intermediate demand for each commodity between domestic origin and imports based on the Armington assumption, while the import shares are driven by a nest which is shared by all sectors and final demand. The production nesting in GLOBE (McDonald and Thierfelder 2014, p. 23) provides a third approach as it assumes by default that the value added nest and the intermediate composite can be substituted while the intermediate composite remains by default a Leontief aggregate as in the standard GTAP model. Inside the value-added nest of the GLOBE, labor is modeled as a CES nest of skilled and unskilled labor, an assumption also found for instance in the GTAP-E extension.

ENVISAGE allows for substitutions between the value and intermediate composite, between intermediate composite and introduces a nesting to differentiate between energy commodities similar to GTAP-E. ENVISAGE support in most cases a choice between a CD-representation and a CES which requires a different expression for dual price aggregators.

Clearly, besides the specific nesting, the substitution elasticities matter. They can in many cases be set region and sector specific and might be adjusted for specific applications. The following table summarizes the major differences discussed above. Generally, the flexible nesting approach in CGEBox allows easily mimicking the different nested CES-structured employed in the models discussed in here. Equally, it inherited from ENVISAGE the possibility to use a CD instead of a CES specification.

Table 1: Overview production function nesting in the different models

Model	Production function nesting		
	Value Added – Intermediate composite	Intermediate composite	Value Added
GTAP Standard	Leontief	Leontief	CES
GTAPinGAMS	Leontief	Leontief	CES
GLOBE	Leontief	CES	CES, with sub-nest for skilled/unskilled labor
MIRAGE	Leontief	CES	CES, with capital-skilled labor sub-nest
ENVISAGE	CES	CES with sub-nests for energy	CES, skilled-unskilled labor nest

3.3 Factor supply and mobility

Most models consider the economy wide stock of primary factors as fixed. Allowing for price dependent factor supply e.g. based on a land supply or wage curve might render the model more realistic. Here ENVISAGE offers a rich choice as different functional forms can be chosen. However, endogenous factor stocks provide a challenge for welfare analysis: extended factor endowments allow for higher overall output and thus welfare gains while at the same time, a down-sloping factor supply curve implies some costs. As these costs are typically not linked to resource use in the sectoral production function, they must relate to utility

losses, such as less leisure or increased negative externalities. Consequently, the downward sloping factor supply should be accounted for by a utility function in welfare analysis.

Furthermore, factors might be considered fully mobile, i.e. assuming homogeneity and the law of one prices, partially (im)mobile based on CET approach, typically termed sluggish factor supply, and fully immobile by rendering them sector specific. Most models allow for a flexible choice between these solutions. The GTAP Standard model renders natural resources such as minerals or fish stocks sector specific and thus immobile, land as sluggish and the other sectors as fully mobile. ENVISAGE and MIRAGE use nested CET functions to split up factor supply for instance between agricultural and non-agricultural sectors. An extension is offered in variants of STAGE where physical units of factors and factor remuneration are distinguished in the data base which allows explicitly considering that moving factors between sectors affects average factor productivity (cf. Flaig et al. 2013).

Many models allow fixing factor prices instead of factor stocks, an approach typically used for unskilled labour to endogenize the (un)employment rate. If the model is solved as a MCP, a reserve wage rate can be modelled depicted by a lower price floor. In conjunction with a maximal stock for labor, a regime switch between unemployment at the fixed lower wage and flexible wages at full employment can be modelled. The model documentation suggests that only MIRAGE uses that mechanism as a default for unskilled labor in some developing countries, while it is supported by several others. Our own tests suggest that solving large-scale models as a MCP can slow down solution compared of solving a simple constrained system of equations. MCP solution time increases further if a shock requires a larger set of redefinitions where variables are at their bounds and the equations become slack, a case where a constrained system of equations is declared infeasible.

Generally, the possibility to solve the model as a MCP combined with the flexible nesting approach allows CGEBox to host the different variants depicted

above. The GTAP-AGR extension makes already use of that approach and seems to at least close to the solutions in ENVISAGE and MIRAGE, However, updating factor productivity when factors move between sectors is not yet supported.

3.4 *Income distribution*

The GTAP Standard Model and GTAPinGAMS use the concept of the regional household which collects factor and tax income and distributes it to private and government consumption and savings based on a modified Cobb-Douglas utility function where the share parameters depend on the utility of consumption expenditure with regard to income. MIRAGE simplifies that structure further by lumping final and government consumption together. The regional household approach with its single income collection and distribution node in the framework does not allow reflecting relations between earned and spent of the different agents.

GLOBE therefore refrains from a regional household approach. Rather, one or several representative private households receive a share of factor income net of factor taxes from which direct taxes are deducted based on ad valorem rates. The after tax income of these households is distributed to savings and consumption with different closures for the saving rate available. The STAGE model adds intra-household transfers, transfers from enterprises and from government as additional income sources. That is rather similar to IFPRI-S which also considers enterprises as an intermediate layer between factor cost paid by sectors and factor income received by households (Lofgren et al. 2002, p. 19). ENVISAGE uses one representative private household while considering remittances which are collected and distributed from a global trust. All models depict tax income by a central government agent in quite some detail.

CGEBox uses either the regional household approach of the GTAP Standard Model or an approach drawing mostly on myGTAP (Walmsley and Minor 2013), with elements added found in STAGE and ENVISAGE; i.e. it can consider remittances and international capital transfers as well as transfers between households in the same region. The enterprise approach from STAGE and IFPRI-S

can be depicted by CGEBox as well as the factor income shares for the different private households are sector and factor specific. That allows defining for instance an agricultural household which owns the factors employed in agriculture plus some factor shares in other sectors.

3.5 *Final demand and related account closures*

3.5.1 *Private consumption*

The GTAP Standard model uses a Constant Difference in Elasticities (CDE) demand system for private consumption which hence is also found in the default layout of CGEBox. GLOBE (McDonald and Thierfelder 2014, p. 53), STAGE and IFPRI-S employ LES demand systems for final private demand. The LES demand system is less flexible compared to the CDE system which has three vector of parameters compared to two in the LES system. MIRAGE uses a CES system with commitment terms. ENVISAGE can translate produced outputs into commodities demanded by the household based on a transition matrix. Furthermore, savings can be added as a further argument in the LES demand function which can also be replaced by an AIDADS system. CGEBox can alternatively use a LES or CD system for private households and additionally introduce CES-Nests under aggregated product commodities which can depict the transition matrix from ENV-LINK. Such sub-nests are found in ENV-LINK and GTAP-E to model detail in energy demand.

3.5.2 *Government demand*

Government demand is lumped together with private demand in MIRAGE. GLOBE and STAGE use either fixed shares of government income in real terms or volumes to depict government demand. Government consumption is fixed in real terms in IFPRI-S. The GTAP Standard model uses a CD-utility function, i.e. fixed value shares. Based on the code of ENVISAGE, CGEBox can accommodate either a CD or CES demand system for the government, the latter hence also allows

capturing the fixed in real terms representation found optionally in GLOBE and STAGE by setting the substitution elasticities to zero. Fixing government consumption for each commodity as in IFPRI-S is equally possible in CGEBox as a pre-compiled closure rule.

3.5.3 *Savings and investments*

All models hence implicitly consider in their standard layout government saving as residual. GLOBE and STAGE comprises a well-developed system to render different tax rate endogenous which allows fixing government saving. CGEBox allows the same type of closure; however, the choice of which tax rates are endogenously adjusted is more restricted. ENVISAGE drives government expenditures as a share of GDP, similar to the GTAP Standard model, and fixes government savings. The government account is then closed by an endogenous shift of direct tax rates. With the exemption of integrating savings into the LES demand system, CGEBox seems to be able to depict all variants to model final demand and the different closures for the final, government and savings account found in the discussed models.

MIRAGE as a dynamic model assumes in any one year that the existing capital stock is immobile. Allocation of regional and foreign savings to sector and regions in MIRAGE is driven by differences between capital returns exponent an elasticity. It also let capital revenue from foreign savings flow back to the source country. The FDI implementation shows thus some similarity to the global bank mechanism in the GTAP standard model, but tracks additionally the bilateral allocation of capital.

ENVISAGE uses a vintages concept where existing (depreciated) capital stock is immobile or sluggish, and new capital stock is fully mobile. Furthermore, production sectors are split up in activities which old and new capital. That complex mechanism is not fully supported by the so-called capital vintage module of CGEBox, rather depreciated capital stock is considered immobile in CGEBox and investments define an endogenous stock of fully mobile new capital. That

implies that the capital accumulation process depicted in a recursive-dynamic framework can be integrated in a comparative-static one in CGEBox by indicating over how many years the capital stock is depreciated in a comparative-static experiment.

3.6 *Trade and imperfect competition*

3.6.1 *Armington specification and CET*

All global models are based on the Armington assumption and their specific layouts can be seen as variants of the two-stage CES specification found in the GTAP standard model where the upper nest differentiates between domestic origin and imports and the lower nest between imported origins. GLOBE adds a third nest on demand which splits up imports into two nests with bi-lateral trade flows which are large and small in shares. The small share nest is a Leontief aggregate; it is up to the user set the related cut-off (McDonald and Thierfelder 2014, p. 21). That nest with the small shares is aggregated with the more standard large scale nest in Leontief fashion. That solution does hence not relate to the “small shares stay small problem” often discussed as a dis-advantage of the Armington specification (cf. Himics and Britz 2016), but rather helps to avoid numerical problems related to small trade shares. A mirroring implementation is used on the supply side based on three-stage CET nests.

GLOBE and MIRAGE deviate from the other global model as the different sectors and final demand share the top level Armington nest, i.e. all agents have equal shares of domestic and imported goods in their consumption. CGEBox allows on demand both the GLOBE solution where all Armington agents share both nests and an intermediate solution where all intermediate demand shares are equal. Equally, CGEBox features the third level based on small import and export shares found in GLOBE. MIRAGE features potentially also a third nest, however here, it is introduced in some sectors to distinguish between imports from developed and

developing economies under the assumptions that qualities imported inside each of that group are more similar (Decreux and Vilan 2007, p. 10).

The single country CGEs do usually not differentiate between importers. STAGE (McDonald 2015, p. 28) uses the Armington assumption to model domestic produce and imports as imperfect substitutes. The world market prices for imports and exports can be either fixed or in case of the export price can be based on downward sloping demand curves (Mc Donald 2015, p. 54). A similar solution is used in IFPRI-S (Lofgren et al. 2002).

ENVISAGE can alternatively depict goods as homogenous to derive a net-trade specification with homogenous world market prices. That however requires re-constructing the SAM in order to level out e.g. differences in bi-lateral tax rates. The description also implies that the trade margins are absent for homogenous commodities. It is hence not clear if that extension is widely used. It is not supported by CGEBox. High substitutions elasticities in the Armington nests as used in the GTAP Standard model for instance for natural gas will probably yield similar results.

3.6.2 Imperfect competition

A recent extension of the GTAP model family is GTAP-HET (Agkul et al 2016) which introduces heterogeneous firms based on Melitz 2003 into the GTAP structure, considering vertical differentiation inside sectors under monopolistic competition. A similar implementation is available for CGEBox (Britz and Jafari 2016). MIRAGE considers imperfect competition for some sectors, however based on the more restricted model by Harrison et al. 1997 drawing on Krugman 1979 where fixed costs occur only at sector level and are not differentiated by trade link. However, MIRAGE employs the imperfect competition framework in a multi-level CES framework where the lowest level differentiate the different varieties, while GTAP-HET and CGEBox use one nest only such that no differentiation of the substitution elasticities such as in MIRAGE is possible. CGEBox can simplify the Melitz model to yield the Harrison et al. 1997 implementation by setting the fix

costs on each trade link to zero which also implies that the number of varieties is not differentiated by trade link.

Another aspect of modeling international trade relates to international transport services. The Standard GTAP model introduces a global transport sector which allocates total global transport demand to the different regions based on a CD function, while the per unit demand for the transport margin on each trade link is a fixed Leontief coefficient. That structure is employed by GTAPinGAMS, MIRAGE and ENVISAGE as well. GLOBE uses a somewhat more complex system (McDonald and Thierfelder 2014, p. 27) which requires allocating bi-lateral transport sector demands to the regions exporting the transport services. As a consequence, GLOBE has fully specified bi-lateral trade balances.

Summarizing, all models are based on the Armington assumption and, besides MIRAGE, assume perfect competition. Only GLOBE and ENVISAGE apply a CET on the export side. CGEBox is currently not able to perfectly replicate MIRAGE as different substitution elasticities in import flows for one commodity are not supported. Furthermore, CGEBox can so far not implement the more complex transport service sector implementation of GLOBE. The MIRAGE solution for imperfect competition cannot be fully implemented; however, an implementation of the more powerful Melitz model is available or alternatively, the Krugmann model with however only one CES nest.

When used as a single region model, CGEBox can either fix international prices, use iso-elastic function to render them endogenous depending on export or import quantities or use the lower CES and CET nests at export and import destinations to render bilateral imports and exports and related prices endogenous.

3.7 *Macro-Economic closures and numeraires*

3.7.1 *Numeraires*

The behavioral functions of these neo-classical models are homogenous of degree zero in prices which requires fixing one price at regional level and additionally,

according to Walras law, an additional one at international level. The choice of these numeraires should hence not affect the simulated quantity changes, but needs to be reflected when simulated price and value changes are analyzed, especially when comparing different regions. The Standard GTAP model uses the exchange rate as the (fixed) regional numeraire and a global factor price index as the international numeraire. That implies that prices can be directly compared across regions. GLOBE, STAGE and IFPRI-S use either the regional consumer price or domestic producer price index as regional numeraires. CGEBox can use the exchange rate, consumer, and producer or factor price indices as regional numeraires.

3.7.2 Balance of payment and trade balance

The GTAP standard model features a so-called global bank which distributes foreign savings according to expected return to investments which are derived from returns to the given, fixed capital stock in each region. In GLOBE, STAGE and IFPRI, the capital account balance can be maintained by either fixing the foreign savings and solving for the exchange rate or fixing the exchange rates and solving for foreign savings. ENVISAGE uses fixed foreign savings in real terms. Similar to the GTAP model, it does not comprise exchange rates.

CGEBox can use the global bank mechanism, fix foreign savings in international currency, use fixed allocation shares of global foreign saving in international currency or derive the foreign savings based on the regional capital account balance, by fixing beside the factor price or consumer price index additionally the exchange rate.

3.8 Software aspects

We restricted ourselves mostly to GAMS based system while only mentioning the GEMPACK based realization of the GTAP Standard model and some widely used variants thereof. That implies that most models reviewed are realized in GAMS. GLOBE and STAGE use a very similar coding style and are linked to some

Graphical User Interface (GUI). MIRAGE uses an EXCEL interface in combination with macros for model steering and result exploitation, the latter based on pivot tables which allow combined analysis of several experiments.

CGEBox uses clearly the most complex GAMS code implementation of the reviewed models in order to allow for a modular design. That implies GAMS pre-processor command for conditional compilation to include certain blocks of equations and related code for data transformations and parameter calibration on demand. Equally, macros are used to substitute out variables and partly as well to support the modular design. That certainly renders the code less self-explaining compared to the other models with a more straightforward and less flexible implementation. A specific feature of CGEBox is a quite extended post-model processing part which feeds into an exploration system which is shared with some other economic models (Britz et al. 2015). CGEBox adds a GUI which allows selecting shock files, closures and model features. The GUI is realized by a package which can generate GUIs for GAMS and R projects (Britz 2014) from a simple XML test file. It also supports post-model analysis with tables, graphs and maps (Britz et al. 2015).

4 To what extent does structural CGE layout matter?

4.1 Setting up structural experiments close to the different models

In that section, we provide a comparison of simulated impacts on the same data base and shock, using configurations of CGEBox which come as close as currently possible with its current modular design to the layout of the global models discussed above. As we are clearly in most cases neither able to fully replicate the structure of these models nor aim at meeting their specific parameterization, we will name these structural sensitivity experiments after the models they are derived from, but put these names in quotes.

The “GTAPinGAMS” experiment comes rather close that the actual model layout. The Armington structure is identical to the GTAP Standard model. Private

demand is depicted by a CES function, total government demand is fixed in real terms. Both government and investment demand are distributed to the different commodities based on a Leontief relation.

In our “GLOBE” experiment, we aggregate all Armington agents, use a two-stage CET on the supply side to distribute output to domestic sales and exports in the upper and to trade flows in the second nest. Demand for the private household is depicted by LES function. Separate accounts for the representative private household and the government are introduced, and the regional household consequently removed. The production function does not allow for substitution between the value added and intermediate composite, but inside both nests, non-zero substitution is used. The consumer price index is used as the regional numeraire, foreign savings in international currency are fixed and the capital account is closed by flexible exchange rates. While CGEBox can introduce the third level in the Armington and CET to depict small shares via Leontief, we refrain from that in here. What is clearly missing in our “GLOBE” experiments is the GLOBE approach to model international transport demand. We would also remind the reader again that we are not aiming at replicating the specific parameterization found in the model of which we try to capture the major structural differences to the GTAP Standard model.

The differences for the “MIRAGE” experiment against the MIRAGE model itself are more pronounced. As in the “GLOBE” experiment, we aggregate the Armington agent. We use a Krugman model to model monopolistic competition under vertical differentiation into varieties, but our implementation is much simpler compared the one in MIRAGE. It lumps the Armington structure into one nest with common substitution elasticities, whereas MIRAGE features CES nests to differentiate between domestic and imports, in imports between developed and developing, in these two import bundles the different trade flows and finally varieties. MIRAGE also uses a different allocation model of foreign saving; we consider the global bank mechanism as most similar. MIRAGE uses a CES system with constant terms at the top level which combines government and private

household demand. We try to mimic that by fixing total government demand in real terms and using a Leontief relation to distribute that total, which means that in final demand net of investment, we now have constant terms as well. Furthermore, we introduce sluggish factor mobility between agricultural and non-agricultural sectors.

For “ENVISAGE”, we introduce a CET on the export side, and, as in “MIRAGE”, we model sluggish factor supply between agricultural and non-agricultural sectors. Additionally, we use the production nesting of GTAP-E while also considering a specific sub-nest under the LES demand function which substitutes between different types of energies. Government and investment demand uses a CD utility function. Government savings and real government consumption are fixed; the government account is closed by updating direct taxes. Foreign savings are fixed as well.

Finally, we add two configurations which make use of modules already available in CGEBox. Firstly, we use the GTAP-AEZ module to dis-aggregate land-use, which also adds factor price dependent land supply to agriculture and forestry in each AEZ. Moreover, depreciated capital is sector specific, i.e. immobile, considering twenty years, while net investments define the final capital stock in use. That implies endogenous capital stocks in a comparative static setting. The configuration uses a CET to distribute output to domestic sales and exports. The CGEBox+ as the final configuration replaces the CET for manufacturing sector by the Melitz model with monopolistic competition, industry and trade-link specific fix costs and endogenous number of varieties on each trade link.

Solving each single configuration on the experiments discussed below including full model post-processing take less than half a minute; the predefined configurations can be chosen from the GUI and in conjunction with a batch facility, they can be quickly run on a type of shock. That underlines that structural sensitivity analysis with the flexible and modular approach in CGEBox is quite straightforward. The framework additionally supports sensitivity analysis for major parameters.

4.2 Results from a partial, multi-lateral trade liberalization

In order to compare the model configuration, we use the equivalent variation approach and, additionally, GDP corrected for the overall demand price index.

Table 1: variation globally and per region [const. US\$ per capita] under the same multi-lateral trade experiment with different model configurations

	GTAP Standard	GTAPinGAMS	GLOBE	ENVISAGE	CGEBOX	MIRAGE	CGEBOX_plus
World	8	8	13	7	8	23	34
Australia, New Zealand	51	50	56	60	64	89	130
East Asia	19	19	15	20	13	40	53
Southeast Asia	6	6	11	7	6	22	24
South Asia	2	2	5	-1	-2	34	7
North America	-6	0	10	-1	11	-80	58
Latin America	2	1	8	1	4	-10	18
European Union 25	13	17	20	14	25	102	93
Middle East and North Africa	4	2	18	-2	3	-6	14
Sub-Saharan Africa	1	1	10	0	2	-1	6
Rest of World	13	12	34	8	17	21	47

The global welfare changes are most pronounced under the Melitz model (CGEBox+), followed by “MIRAGE” based on the Krugmann model, expected outcomes consistently shown in literature where these so-called “new trade theory” based models are compared to an Armington specification. The differences between the other, Armington based, configurations are quite limited. That might come as a surprise given the larger structural differences. Still, there are larger differences between GLOBE and ENVISAGE which both use a CET transformation on the supply side and a LES demand system. Compared with the impact of changes the regional dis-aggregation (see Britz and van der Mensbrugge 2016), structural changes while using overall the same or very similar parameterization seem to have at least in that of type of experiment little overall welfare impacts. Note also the level of the welfare gains are at the lower limit of what was reported in Britz and van der Mensbrugge 2016 as the regional aggregation with ten world regions in our experiments is quite high.

We also tested differences under a 50% reduction of all consumer taxes and again found similar limited differences. Depending on the configuration, no region (“GTAPinGAMS”, “GLOBE”, CGEBox+) or one region loses out from multi-lateral trade liberalization, in the latter case, there is no agreement who loses.

However, consistently, the “East Asia” region is depicted as benefiting most in relative terms.

Table 2: Change in GDP [%], normalized with overall price index, under the same multi-lateral trade experiment with different model configurations

	GTAP Standard	GTAPinGAMS	GLOBE	ENVISAGE	CGEBOX	MIRAGE	CGEBOX_plus
World	0,10%	0,11%	0,07%	0,09%	0,10%	0,13%	0,44%
Australia, New Zealand	0,19%	0,18%	0,16%	0,20%	0,24%	0,29%	0,49%
East Asia	0,35%	0,36%	0,18%	0,30%	0,24%	0,56%	0,98%
Southeast Asia	0,30%	0,31%	0,19%	0,25%	0,27%	0,60%	1,17%
South Asia	0,19%	0,21%	-0,19%	-0,02%	-0,18%	0,83%	0,73%
North America	-0,02%	0,00%	0,02%	0,00%	0,03%	-0,24%	0,17%
Latin America	0,04%	0,02%	-0,04%	0,05%	0,07%	-0,29%	0,33%
European Union 25	0,04%	0,06%	0,06%	0,04%	0,08%	0,31%	0,31%
Middle East and North Africa	0,18%	0,11%	0,08%	0,02%	0,16%	-1,03%	0,66%
Sub-Saharan Africa	0,13%	0,09%	0,04%	0,08%	0,16%	-0,51%	0,60%
Rest of World	0,15%	0,14%	0,13%	0,10%	0,19%	0,00%	0,55%

4.3 Results from a regional tfp shock

Assuming that differences between configurations might be greater if the shock only roots in one region, we increase the total factor productivity in all sectors in our “North American” region by 20%. Given its weight in the global economy, that generates a welfare impact per capita globally between around 500 and 650 USD, see table 3 below. The largest boost stems from using a monopolistic competition model (“MIRAGE”, “CGEBOX+”). Interestingly here, using a LES demand system in CGEBox+ instead of the CDE system, not shown below, leads to welfare gains almost identical to the “MIRAGE” configuration.

Differences between individual countries are here more pronounced, depending on the configuration, EU citizens are simulated to lose 50 USD or win 225 USD from a tfp boost in North America.

Table 3: Equivalent variation globally and per region [const. US\$ per capita], under a 20% tfp boost in North America with different model configurations

	GTAP Standard	GTAPinGAMS	GLOBE	ENVISAGE	CGEBOX	MIRAGE	CGEBOX_plus
World	498	494	576	566	562	700	653
Australia, New Zealand	-55	7	67	73	220	101	238
East Asia	-8	-2	18	4	53	-2	66
Southeast Asia	1	1	12	2	26	14	33
South Asia	-3	0	2	3	8	-2	9
North America	7503	7342	8374	8271	7613	10468	8812
Latin America	0	12	35	29	69	9	75
European Union 25	-49	-3	49	53	271	-50	327
Middle East and North Africa	23	22	29	38	43	21	49
Sub-Saharan Africa	7	7	13	15	16	8	19
Rest of World	65	58	67	77	131	68	154

Interesting here are difference in simulated GDP changes normalized with the price index (see table 3) for “North America” between the “ENVISAGE” (+19.5%, the lowest value in any configuration) and “CGEBOX (+23,1%) configuration which both use the “capital vintage” mechanism where the stock of new capital, considered fully mobile, is investment driven. A helper simulation revealed that this difference roots almost entirely in the fixed foreign saving closure in “ENVISAGE” compared to the global bank mechanism in “CGEBOX”. The global bank mechanism used in the “CGEBOX” configuration seems to re-inforce that impact.

It is interesting to see that (almost) all countries are winners based on the new trade theory based configurations, and even all in the “CGEBOX” configuration with endogenous capital stocks plus the global bank mechanism.

Table 4: Change in GDP, normalized with price index prices [%]

	GTAP Standard	GTAPinGAMS	GLOBE	ENVISAGE	CGEBOX	MIRAGE	CGEBOX_plus
World	6,63%	6,42%	6,45%	6,68%	7,25%	8,19%	8,61%
Australia, New Zealand	-0,21%	0,03%	0,24%	0,31%	0,83%	0,37%	0,90%
East Asia	-0,15%	-0,04%	0,29%	0,09%	0,98%	-0,11%	1,21%
Southeast Asia	0,05%	0,05%	0,46%	0,15%	1,29%	0,53%	1,63%
South Asia	-0,34%	0,01%	0,18%	0,27%	0,88%	-0,06%	1,03%
North America	22,01%	21,52%	21,14%	21,84%	22,32%	26,59%	25,80%
Latin America	-0,01%	0,22%	0,48%	0,45%	1,26%	0,15%	1,36%
European Union 25	-0,17%	-0,01%	0,16%	0,19%	0,90%	-0,16%	1,09%
Middle East and North Africa	1,13%	1,07%	0,99%	1,33%	2,10%	0,79%	2,42%
Sub-Saharan Africa	0,72%	0,77%	0,79%	1,02%	1,66%	0,63%	2,00%
Rest of World	0,77%	0,69%	0,61%	0,80%	1,55%	0,60%	1,82%

The comparisons reveal that it is often far from obvious how a combination of certain features influences simulation behaviour which underlines the usefulness of a modular approach where different configuration can be easily tested.

5 Institutional issues around a jointly maintained modular and flexible CGE framework

The sections above underline that CGEBox already at current state is already able to reproduce many features found in some well-known CGE modelling frameworks. Additionally, it adds extensions so far presumably only available in GEMPACK based models such as a dis-aggregation of land use to Agro-Eological zones (GTAP-AEZ, Lee et al. 2005) or a Melitz model implementation (Britz and

Jafari 2016). One could hence imagine a joint effort of several teams to maintain and further develop the modeling framework. Each team would add the not yet available features to the code base of CGEBox which it considers essential for its own CGE applications. Code and documentation of these new extensions are shared. The teams would hence benefit from features implemented by others which would become available on the common modeling platform. Each team could probably access a more powerful modeling system compared to stand-alone development, at potentially lower development cost. Additionally, it would be easier for the teams to support each other. Common courses could be realized to introduce new staff to the modeling platform.

Such as development process however poses clearly a number of challenges. The first one relates to quality management. So far, the different models feature a rather stringent layout with limited flexibility. That implies that testing of newly added features is rather straightforward. Comparing different versions of model documentations seems to suggest that adding features is not a very frequent exercise. Rather, the default case seems that one major development step is done to set-up the framework once, and afterwards, only moderate extensions are added. In a highly modular framework, new features must be tested under potentially all possible combinations of already existing ones. Accounting for sparsity and other more unusual data constellations in the global SAMs also implies that the testing cannot be restricted to some highly aggregated SAMs by region and sector/commodity, but must encompass differently detailed SAMs to avoid that users are confronted later with run time errors such as zero divisions. That requires a well-developed Quality Management system, for instance, comprising a larger test suite of shocks which can be applied for differently detailed data bases. The current developers are probably not trained and used to that vigorous type of testing.

Equally, keeping their model documentation up-to-date is already today often a challenge for the teams. For joint model development and maintenance, common standards of documentation must be developed and also successfully implemented.

The same holds for coding style. In order to allow for a critical review of newly added features and continued code maintenance, all contributors must strictly adhere to common coding and documentation guidelines. These guidelines might deviate from the personal style preferred by individual coders or teams and thus provoke additional costs compared to a stand-alone implementation. Joint efforts will also demand technical solutions such as a Software Version System which are not yet used by all teams. However, the development of whole Operation Systems such as LINUX based on open access underlines that these more technically impediments to a common development process can be overcome.

The perhaps most critical points are hence questions around trademarks and Intellectual Property Rights. All the models discussed above have been successfully marketed over more than a decade under their specific name which leads to reputation and opportunities to raise funds, attract staff or eases peer reviewed publication of work based on the models. Considerable efforts have been invested to generate that reputation. A strategy towards a common platform will most probably fail if it does not allow the teams to keep the reputation which requires continued marketing of applications with “their model” under its established trademark. A potential solution consists in trademarks such as “ENVISAGE, realized in CGEBox”. One might imagine that once the trademark of the common platform becomes more widely known along with the efforts with regard to Quality Management and transparency of code and documentation, the reputation of the individual trademarks would even benefit.

A related key question is how to generate incentives to contribute to model development and quality management when the code is fully open source. Only some coders might be intrinsically motivated to contribute, but even these might need to defend their efforts towards their management and need proof of some cost saving effect. That implies that some returns for contributors must be generated which are differentiated from benefits for users of the open source model. A common license model should hence forbid any publication with a newly contributed module during a grace period which the contributor can use for its own

publication. Equally, one could imagine a peer-reviewed publication process for new developed modules similar to R-packages which hence can be cited. The GTAP center already goes in that direction with their technical paper series and the newly established journal.

6 Summary and conclusions

We have shown that some well-known global and single country CGE framework (GTAP Standard model, GTAPinGAMS, GLOBE, ENVISAGE, MIRAGE, STAGE, IFPRI-S), all realized in GAMS, share a large common structural basis, but clearly differ in detail. Some interesting features found in some models are not available in others. We therefore developed a modular and extendable CGE framework titled CGEBox which is able to replicate to a large extent the layout of these different models. That implies CGEBox can be solved as a single country or global model, in comparative-static or dynamic model. Using a partial multi-lateral trade liberalization and tfp shock in a global, comparative-static setting as show cases, we highlight how major structural differences between the different models impact core results in our experiments.

We conclude that it is by now technically relatively straightforward to set-up a modular and extendable code basis for CGE modeling in GAMS. That renders it inviting to jointly further develop such a modular and extendable system where individuals and teams contribute new modules and share them with the others. Impediments to such a solution are clearly the required common coding and documentation standards, the more complex quality management to ensure that modules are interoperable and perhaps most important questions around IPR and trademarks.

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