Model Documentation

BAEGEM – the BAEconomics computable general equilibrium model of the world economy

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Overview

BAEGEM is a recursively dynamic CGE model of the world economy. For each one-year time step, BAEGEM simulates the inter-relationships between economic growth, flows of international trade and investments, constraints on natural resources and production factors, greenhouse gas emissions and climate change policies. The central core of BAEGEM is built on the familar approaches of the GTAP model (Hertel 1997), with the household consumption behaviour and the producer behaviour represented separately by a CDE function and a nesting of Leontief, CES and CRESH functions. The key characteristics of BAEGEM are summarised in Table 1.

BAEGEM is written in GEMPACK (Harrison et al. 2013). The full model code is complemented by four interlinked modules: (i) the government module; (ii) the technology mix module; (iv) the energy module, and (iv) the greenhouse gas emissions module. The model is ideally suited to analysing domestic and international energy-related policies, and impacts of economic shocks.

The BAEGEM database is derived from a number of sources. The global social accounting matrix (SAM) is derived from the GTAP version 8 database (Narayanan et al. 2012) with a base year of 2007. To enhance the capability of modeling individual commodities, the number of commodity groups in BAEGEM has been expanded from 57 in the GTAP version 8 database to 72. The disaggregated commodities include black thermal coal, brown coal, coking coal, iron ore, bauxite, copper ore, gold, uranium, titanium, zirconium, coke, nuclear fuel, alumina, copper, aluminum and LNG.

A suite of models based on the BAEGEM structure have been developed to study developing countries and the impact on those economies of the development of very large mineral projects. These models are known as MINCGEM. Details of MINCGEM-Mongolia, for example, can be found in Fisher et al. (2011).

The emissions database covers all Kyoto gases and is sourced from the International Energy Agency (IEA, 2012a and 2012b), the United National Framework Convention on Climate Change (UNFCCC, 2012) and the US Environmental Protection Agency (EPA, 2012). The data in the government module are sourced from Global Insight while the data in the technology mix and energy modules are sourced from IEA.

The global temperature rise, total radiative forcing and the atmospheric concentration of carbon dioxide can be calculated from BAEGEM results by linking to MAGICC/SCENGEN 5.3 (Wigley 2008), with climate sensitivity set to three degrees Celsius. A schematic diagram outlining the key components of BAEGEM and their interactions is displayed in Figure 1.

Modelling energy commodities

The energy module tracks the production of primary and secondary energy, and the consumption of final energy by government, households and firms. Changes in production volume over the projection period are driven by global demand growth, which in turn is determined by real GDP growth, and changes in prices, consumption preference, market structure, sectoral productivity and market structure.

The government demand for each commodity is derived from a Cobb-Douglas function nested with Armington composites of commodities supplied by domestic and foreign sources. The household demand for each commodity is determined by the demand of a representative household and the growth in population. At the first level, the representative household chooses quantities of non-energy commodities and an energy composite (that is, coal, gas, refined petroleum product, electricity and heat) to maximise a utility function, given a budget constraint. At the next level, the representative household chooses quantities of energy commodities to minimise the cost of consuming the energy composite in the previous level. The purpose of this two-level demand system is to better reflect the substitutability between energy commodities with a more flexible substitution system.

Demands for energy commodities in each production sector are derived from a nesting of Leontief, CES and CRESH functions. At the first level, a Leontief technology links the input of factor-energy composite to the industry output level. At the second level, it is a CES cost minimisation problem searching for an optimal combination of energy and factor composites where energy commodities and primary factors (i.e. capital, labour, land and natural resources) are substitutable, but not perfectly. For land and natural resource-intensive industries (i.e. crops, livestock, coal, oil, and gas), a CES structure with imperfect substitutability ensures that constraints on land and natural resource or more intensive use of capital and labour under finite natural resources can be modelled properly in BAEGEM. At the third level, another cost minimisation problem is specified but here it searches for an optimal combination of energy commodities under a CRESH production function (Hanoch 1971).

Electricity supply from various technologies is modelled inside the technology mix module. The 'technology bundle' approach ensures that electricity output can be produced from a bundle of individually identified generation technologies and that each technology uses a different mix of inputs. The purpose of integrating a bottom-up modelling approach for the electricity sector into BAEGEM is to better represent the technology specific detail of the sector while retaining the benefits of the top-down interactions modelled in BAEGEM. In this application, the electricity output is the sum of 9 technologies: coal; oil; gas; nuclear; hydro; wind; solar; biomass; and others.

The substitution possibilities between electricity technologies in GTEM are governed by a CRESH aggregation function. CRESH is a generalisation of CES and allows elasticity of substitutions to vary between its elements. In other words, certain technologies identified in the framework can be assumed to be more substitutable than others. The use of the family of CRESH aggregation functions allows for the fact that electricity, which is a homogenous output, can be generated in an economy simultaneously from different technologies with different production costs.

Modelling greenhouse gas emissions

The greenhouse gas module tracks Kyoto gases emissions (i.e. CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) over the course of production, transformation, consumption and combustion. For each time step, emissions pathways of Kyoto gases are derived from the quantities of these economic activities and changes in emission factors. The projections of radiative forcing agents other than Kyoto gases are selected from emission scenarios in MAGICC/SCENGEN 5.3 according to modelling criteria, assumptions and applications.

BAEGEM assumes constant proportionality of emissions with respect to the quantity of fossil fuel combusted over time. The disaggregated CO_2 emissions for the base year is derived from the GTAP 8.0 database with adjustments to ensure that aggregate combustion emissions at country level are consistent with the IEA combustion emission database (IEA 2012a). The CO_2 combustion emission coefficients for major fuels are shown in Table 2.

Non-combustion emissions, such as fugitive emissions from fossil fuel mining, enteric fermentation in livestock production and chemical transformation in manufacturing processes, are assumed to move proportionally with their production levels adjusted by EMF21 marginal abatement curves (Weyant et al. 2006). The use of marginal abatement curves in the module allows a gradual reduction of non-combustion emissions per unit of output with additional reduction opportunities when carbon price increases. The CH_4 fugitive emission coefficients for major fuels are shown in Table 2. The disaggregated non-CO_2 emissions for the base year is derived from the US EPA database (US EPA 2012) and the GTAP 7.0 database with adjustments to ensure that aggregated non- CO_2 emissions are consistent with the IEA non- CO_2 emissions database (IEA, 2012b). A summary of the data sources used for each greenhouse gas is set out in Table 3.

Figure 1: A schematic illustration of BAEGEM

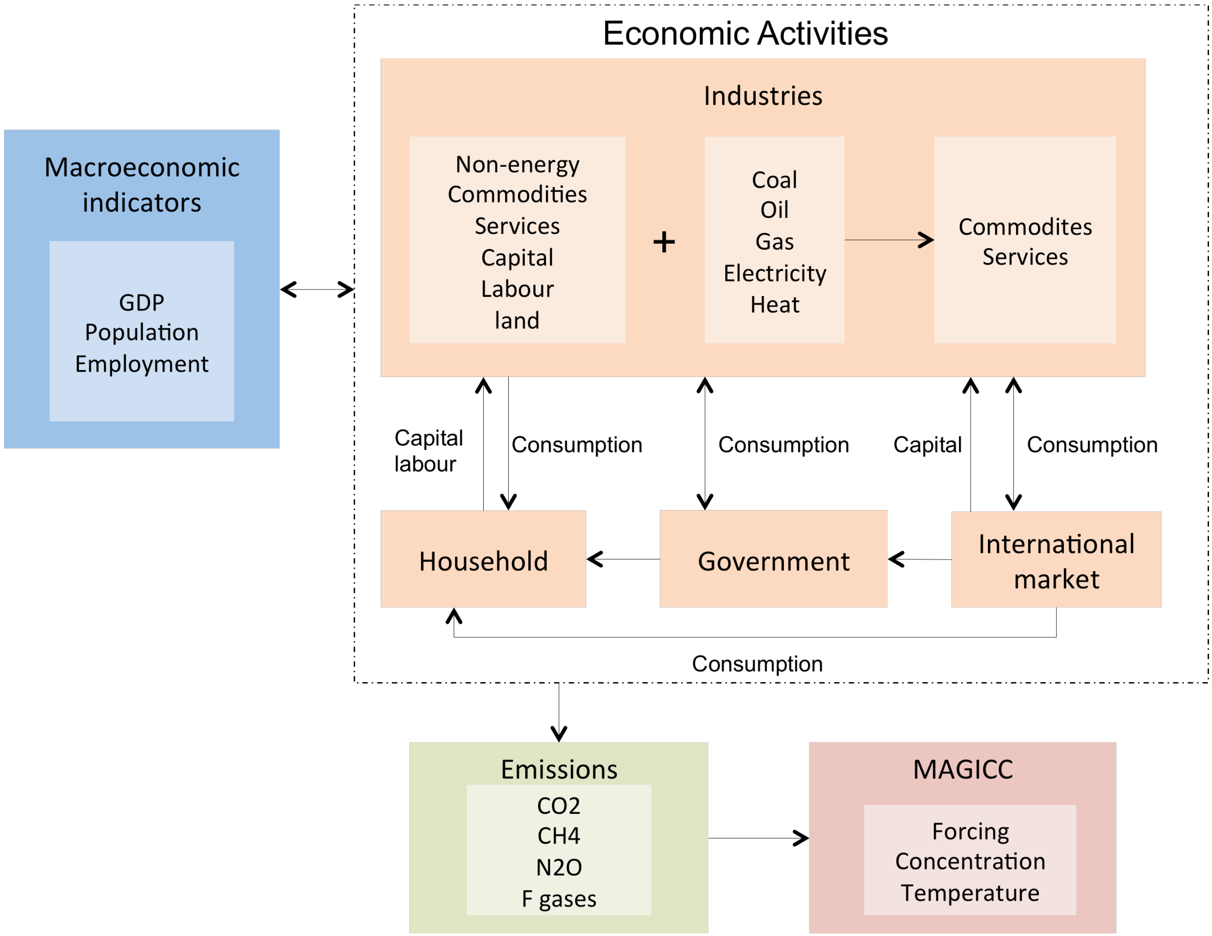

Table 1

Overview of the key characteristics of BAEGEM

Distinguishing Feature	**BAEGEM**
Solution Concept	Market Equilibrium driven by supply and demand
Expectations/Foresight	Recursive dynamics
Macroeconomic assumptions	GDP growth rates are based on IMF (up to 2018) and Global Insights' (after 2018) projections. Population growth rates are based on the UN medium variant projections. Employment growth rates are determined exogenously by assumptions on work-age population, labour-force participation and unemployment rates.
Macroeconomic assumptions across scenarios	GDP growth rates are treated exogenously only in the GT2010 scenario. GDP growth rates for GT1990 and NA2010 scenarios are derived from the model using the new production growth rates of these scenarios plus the productivity data calculated from the GT2010 scenario. BAEGEM does not assume fixed GDP growth rates across scenarios.
Sectoral coverage	25 aggregated production sectors, including coal, oil, gas, nuclear fuel, electricity, heat, oil refining and processing, iron ore, other mining, non-metallic mineral, iron and steel, non-ferrous metal, other manufacturing, land transport, water and air transport.
Link between energy system and macro-economy	GDP sets the scale of economic activity in the model, which in turn drives the demand for each commodity in each segment of the world economy.
Production function in non-electricity sectors/substitution possibilities	Demand for energy commodities in non-electricity sector are governed by a nested CES and CRESH production function. In each sector, the use of primary factor aggregate and energy aggregate are substitutable through a CES production function. Within the energy aggregate, a CRESH production function allows substitution between energy commodities over the projection period.
Production function of the electricity sector/substitution possibilities	Production is the sum of output of a technology bundle, specifically a suite of electricity technologies including coal, oil, gas, nuclear, hydro, wind, solar, biomass and others. Substitutions between technologies are governed by a CRESH aggregation function, subject to differentials in productivity gains and prices.
International macro-economic linkages/Trade	Global market for all commodities. All commodity markets clear at each time-step.
Implementation of climate policy targets	Carbon taxes, cap-and-trade, indirect taxes, regulatory targets, and combinations of the above.
Technological Change/Learning	Learning-by-doing gradually reduces the average production costs of wind and solar technologies, compared with conventional electricity technologies.
Representation of end-use sectors	Apart from 25 aggregated production sectors, there is one representative household and one government for each country/region and one global investor.
Investment dynamics	Investment is driven by GDP growth rates and investment return differentials between regions.

Table 2

Emission coefficients for fossil fuels in BAEGEM

		2010	2050	units
CO_2	Coal	101.0	101.0	$kgCO_2/GJ$
	Oil	78.7	78.7	$kgCO_2/GJ$
	Gas	58.8	58.8	$kgCO_2/GJ$
CH_4	Coal	0.31	0.21	$kgCH_4/GJ$
	Oil	0.15	0.11	$kgCH_4/GJ$
	Gas	0.46	0.32	$kgCH_4/GJ$

Table 3

Greenhouse Gas emission source data

Name	Total emission data	Sectoral disaggregation data
CO_2	IEA, UNFCCC	GTAP
CH_4	IEA, UNFCCC	US EPA, GTAP
N_2O	IEA, UNFCCC	US EPA, GTAP
HFC125	IEA	GTAP
HFC134a	IEA	GTAP
HFC245fa	IEA	GTAP
C_2F_6	IEA	GTAP
CF_4	IEA	GTAP
SF_6	IEA	GTAP
NO_X	RCP	--
CO	RCP	--
SO_2	RCP	--
NMVOC	RCP	--
NH_3	RCP	--
BC	RCP	--
OC	RCP	--

IEA: International Energy Agency
GTAP: GTAP 8.0 database
UNFCCC: Australian Data in the 2012 Annex I Party GHG Inventory Submissions
US EPA: Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990-2030
RCP: Representative Concentration Pathway (RCP) data (MAGICC v5.3 WRE650 scenario)

Note: Only Kyoto gases are modelled directly in BAEGEM

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