8. APPENDIX A

GEM-E3-CAT MODEL DESCRIPTION

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The GEM-E3-CAT model is a multi-regional, multi-sectoral, recursive dynamic computable general equilibrium (CGE) model. The blueprint to develop the GEM-E3-CAT was the GEM-E3 model[38] which has been used by several Directorate Generals of the European Commission (economic affairs, competition, environment, taxation, research) and by national authorities. GEM-E3-CAT provides details on the macro-economy it is an empirical, large scale model, written entirely in structural form. GEM-E3-CAT is handled, operated and maintained by E3-Modelling.

The GEM-E3-CAT model simultaneously represents 11 countries/regions (Table 38) and 35 economic activities (Table 39) linked through endogenous bilateral trade flows.

Table 38. Regions of the GEM-E3-CAT model

No	Abbreviation	Country/Region
1	ESP	Spain
2	CAT	Catalonia
		Rest of European Union
3	DEU	Germany
4	FRA	France
5	ITA	Italy
6	PRT	Portugal
7	REU	Rest of EU28
		Rest of the world
8	CHN	China
9	FSU	Russia
10	EME	Emerging economies
11	ROW	Rest of the World

The model features perfect competition market regimes, discrete representation of power producing technologies, semi-endogenous learning by doing effects, equilibrium unemployment, option to introduce energy efficiency standards and it formulates emission permits for GHG and atmospheric pollutants.

38. For a detailed model description see Capros et al (2013)

Its scope is general in two terms: it includes all simultaneously interrelated markets and represents the system at the appropriate level with respect to geography, the sub-system (energy, environment, economy) and the dynamic mechanisms of agent's behaviour.

It formulates separately the supply or demand behaviour of the economic agents which are considered to optimize individually their objective while market derived prices guarantee global equilibrium, allowing the consistent evaluation of distributional effects of policies.

The model considers explicitly the market clearing mechanism and the related price formation in the energy, environment and economy markets: prices are computed by the model as a result of supply and demand interactions in the markets and different market clearing mechanisms, in addition to perfect competition, are allowed.

Table 39. Sectoral disaggregation of the GEM-E3-CAT model

No.	Activity	No.	Activity
1	Agriculture		**Power generation sectors**
2	Coal	26	Coal fired
3	Crude Oil	27	Oil fired
4	Oil	28	Gas fired
5	Gas extraction	29	Nuclear
6	Gas	30	Biomass
7	Electricity Supply	31	Hydro electric
8	Food products and beverages; Tobacco	32	Wind
9	Textiles	33	PV
10	Pulp, Paper and Non-metallic minerals	34	CCS coal
11	Basic metals	35	CCS Gas
12	Chemicals		
13	Fabricated metal products, except machinery and equipment		
14	Machinery and equipment goods		
15	Electric goods		
16	Transport equipment goods		
17	Other equipment goods		
18	Construction services		
19	Trade services		
20	Transport services		
21	Financial intermediation services		
22	Other business services		
23	Rest of Market services		
24	Recreational services		
25	Non market services		

The model formulates the production technologies in an endogenous manner allowing for price-driven derivation of all intermediate consumption and the services from capital and labour. In the electricity sector a bottom up approach is adopted for the representation of the different power producing technologies. For the demand-side the model formulates consumer behaviour and distinguishes between durable (equipment) and consumable goods and services.

The model is dynamic, recursive over time, driven by accumulation of capital and equipment. Technology progress is explicitly represented in the production function, either exogenous or endogenous, depending on R&D expenditure by private and public sector and taking into account spillovers effects. Moreover it is based on the myopic expectations of the participant agents.

The design of GEM-E3-CAT model has been developed following four main guidelines:

- Model design around a basic general equilibrium core in a modular way so that different modelling options, market regimes and closure rules are supported by the same model specification
- Fully flexible (endogenous) coefficients in production and in consumer's demand
- Calibration to a base year data set, incorporating detailed Social Accounting Matrices as statistically observed
- Dynamic mechanisms, through the accumulation of capital stock

The GEM-E3-CAT model starts from the same basic structure as the standard World Bank models[39]. Following the tradition of these models, GEM-E3-CAT is built on the basis of a Social Accounting Matrix (SAM). Technical coefficients in production and demand are flexible in the sense that producers can alternate the mix of production not only regarding the primary production factors but also the intermediate goods. Production is modeled through KLEM (capital, labour, energy and materials) production functions involving many factors (all intermediate products and three primary factors –capital, natural resources and labour). At the same time consumers can also endogenously decide the structure of their demand for goods and services. Their consumption mix is decided through a flexible expenditure system involving durable and non-durable goods. The specification of production and consumption follows the generalized Leontief type of models[40] as initiated in the work of Jorgenson (1984).

The GEM-E3-CAT model is built in a modular way around its central CGE core. It supports defining several alternative regimes and closure rules without having to re-specify or re-calibrate the model. The most important of these options are:

- Capital mobility across sectors and/or countries
- Flexible or fixed current account (with respect to the foreign sector)
- Flexible or fixed labour supply
- Market for pollution permits national/international, environmental constraints
- Fixed or flexible public deficit
- Perfect competition or Nash-Cournot[41] competition assumptions for market competition regimes

The model is not limited to comparative static evaluation of policies. The model is dynamic in the sense that projections change over time. Its properties are mainly manifested through stock/flow relationships, technical progress, capital accumulation and agents' (myopic) expectations.

The model is calibrated to a base year data set that comprises a full SAM for each country/region represented in the model. The construction of the SAM is the starting point of the model building work. The SAMs of the world ver-

39. The World Bank type of models constitutes the major bulk of equilibrium modelling experiences. This type of models was usually used for comparative statics exercises. The World Bank and associated Universities and scientists have animated a large number of such modelling projects, usually applied to developing countries. Main authors in this group are J. De Melo, S. Robinson, R. Eckaus, S. Devarajan, R. Decaluwe, R. Taylor, S. Lusy and others. These models however do not use full scale production functions but rather work on value added and their components to which they directly relate final demand

40. The generalised Leontief type of model was first formulated empirically in the work of D. W. Jorgenson who introduced flexibility in the Leontief framework, using production functions such as the translog. The work of D. W. Jorgenson inspired many modelling efforts, in which particular emphasis has been put to energy. For example, such models have been developed in France, by P. Capros, N. Ladoux, in OECD (GREEN and WALRAS), in Sweden by L. Bergman and in Germany by K. Conrad.

41. This option is available only for the EU version of the GEM-E3-CAT model

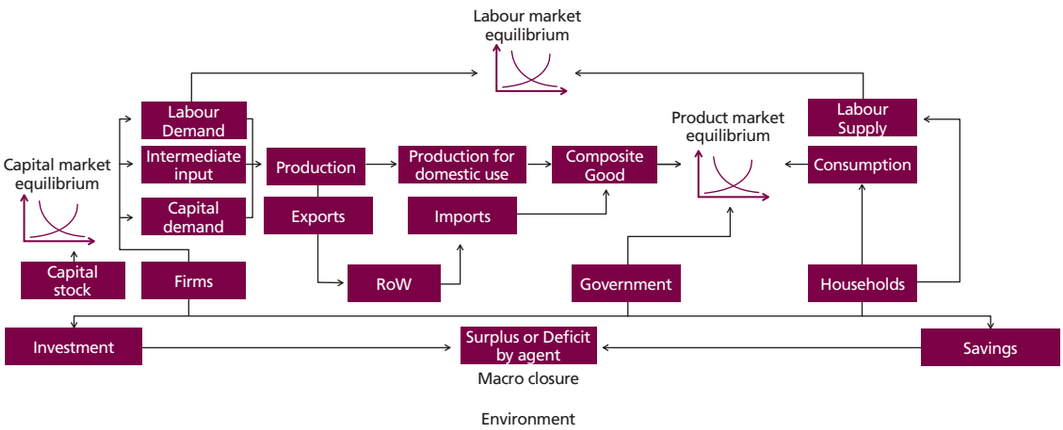
sion of the GEM-E3-CAT model are based on the GTAP database, whereas for the European version, the symmetric input-output tables and national accounts from EUROSTAT are used. The SAM of GEM-E3-CAT represents flows between production sectors, production factors and economic agents. The production sectors produce an equal number of distinct goods (or services), as in an Input-Output table. The SAM distinguishes between intermediate and primary production factors. The economic agents, namely households, firms, government and the foreign sector, are owners of the primary production factors, so they receive income from labour and capital rewarding. All inter-institutional transactions amongst the different agents as recorded in the national accounts are captured by the SAM. The agents use part of their income for consumption and investment, and form final domestic demand. The foreign sector also makes transactions with each other sector. These transactions represent imports (as a row) and exports (as a column) of goods and services. The difference between income and spending (in consumption and investment) by an economic agent determines his surplus or deficit.

Bilateral trade flows are also calibrated for each sector represented in the model, taking into account trade margins and transport costs. Consumption and investment is built around transition matrices linking consumption by purpose to demand for goods and investment by origin to investment by destination. The initial starting point of the model therefore, includes a very detailed treatment of taxation and trade.

Total demand (final and intermediate) in each country is optimally allocated between domestic and imported goods, under the hypothesis that these are considered as imperfect substitutes (the "Armington" assumption[42]). Figure 5 illustrates the overall structure of the GEM-E3-CAT model.

42. See Armington (1969).

Figure 5. GEM-E3-CAT economic circuit



Source: Capros et al (2013)

Institutional regimes, that affect agent behaviour and market clearing, are explicitly represented, including public finance, taxation and social policy. The model represents goods that are external to the economy as for example damages to the environment. The internalization of externalities is achieved either through taxation or global system constraints, the shadow costs of which affect the decision of the economic agents.

In the GEM-E3-CAT firms are modelled to maximize their profits, constrained by the physical capital stock (fixed within the current period) and the available technology. Producers can change their physical capital stock over time through investment. Capital stock data by sector of production are not available either from GTAP or from EUROSTAT databases (it is computed in the calibration phase of the model).

Each producer (represented by an activity) is assumed to maximize profits, defined as the difference between the revenue earned and the cost of factors and intermediate inputs. Profits are maximized subject to its production technology. Domestic production is defined by branch. It is assumed that each branch produces a single good which is differentiated from any other good in the economy. Production functions in GEM-E3-CAT exhibit a nested separability scheme, involving capital (K), skilled and unskilled labour (L), energy (E) and materials (M) and are based on a CES neo-classical type of production function. The exact nesting scheme of production in GEM-E3-CAT has been selected to match available econometric data on KLEM substitution elasticities and the specific features of each activity. The optimal production behaviour can be represented in the primal or the dual formulation.

Households in the GEM-E3-CAT SAM are identified as a single social group (a single representative household is modeled). Households maximize their inter-temporal utility under an inter-temporal budget constraint. The demand functions are derived by solving the maximization problem, under general assumptions regarding expectations and steady state conditions. These demand functions allocate the expected income of the household, depending on the formulation of the problem, between consumption goods and future consumption (savings). This is the default formulation of households' behaviour. Alternatively household behavior is modelled so that the consumer allocates its expected income between present, future consumption and leisure. For household consumption, the model considers an allocation mechanism. The allocation mechanism considers durable and non-durable goods. Durable goods include cars, heating systems and electric appliances, and their use involves demand for non-durable goods, mainly energy (fuels and electricity).

Households receive income from their ownership of production factors, from other institutions and transfers from the rest of the world. Household expenditure is allocated between consumption, tax payment and savings. The representative household firstly decides on the allocation of its income between present and future consumption of goods. At a 2nd stage the household allocates its total consumption expenditure between the different consumption categories available. The consumption categories are split in non-durable consumption categories (food, culture etc.) and services from durable goods (cars, heating systems and electric appliances).

The following data are essential for the modeling of GEM-E3-CAT labor market: i) Skilled and unskilled labor force (total and by category) and ii) Unemployment rate for skilled and unskilled labour force. The GEM-E3-CAT model adopts the EUROSTAT definition of the labour force and thus it is computed by multiplying the participation rate to total active population. The databases mainly used to extract these data are the EUROSTAT, ILO and WorldBank.

Regarding foreign trade data, the GEM-E3-CAT model requires detailed bilateral trade matrices for all regions and commodities included in the model. GTAP database provides such matrices together with bilateral duties and transportation costs. For countries that are not identified separately in GTAP the UN Comtrade database is used in order to extract the relevant data.

GEM-E3-CAT is a recursive dynamic model (solved sequential over time). The sequential equilibria are linked through a motion equation regarding the update of the capital stock. According to the standard neoclassical approach agents investment decision depends on the rental cost of capital in the presence of adjustment costs and on its replacement cost. In GEM-E3-CAT agents have myopic expectations. Their future planning is based on current prices. It is assumed that investment that takes place in time t increases the production capacity at time t+1.

The investment demand of each branch is transformed into a demand by product, through fixed technical coefficients, derived from an investment matrix by product and ownership branch. The investment matrix is computed using the intermediate goods used in the production of capital goods and data provided in the literature on the inputs delivered by the sectors of the economy to the investments undertaken by each sector of production. The standard approach when no additional data are available is to use the same coefficient structure for each branch. This approach can be extended when additional information is available on investment by branch and on the structure of capital formation. In order to make changes in the investment matrix a simple procedure is followed. The initial investment matrix (with the same coefficients in each branch) is updated with the new investment shares. Then a RAS procedure is followed in order to ensure that the total of each row and column of the investment matrix remains constant and that the model remains balanced.

Government consumption is exogenous to the model. Public investment, assumed exogenous in the model, is performed by the branch of non-market services. Transfers to the households are computed as an exogenous rate per head times the population.

The equilibrium of the real part is achieved simultaneously in the goods market and in the labour market. In the goods market a distinction is made between tradable and non tradable goods. For the tradable goods the equilibrium condition refers to the equality between the supply of the composite good, related to the Armington equation, and the domestic demand for the composite good. This equilibrium combined with the sales identity, guarantees that total resource and total use in value for each good are identical. For the non tradable, there is no Armington assumption and the good is homogeneous. The equilibrium condition serves then to determine domestic production.

Once the model is calibrated, the next step is to define a reference case scenario. The reference case scenario includes all already decided policies. The key drivers of economic growth n the model are labour force, total factor productivity and the expectations on sectoral growth. The "counterfactual" equilibria can be computed by running the model under assumptions that diverge from those of the reference scenario. This corresponds to scenario building. In this case, a scenario is defined as a set

of changes of exogenous variables, for example a change in the tax rates. Changes of institutional regimes, that are expected to occur in the future, may be reflected by changing values of the appropriate elasticities and other model parameters that allow structural shifts (e.g. market regime). These changes are imposed on top of the assumptions of the reference scenario thereby modifying it. To perform a counterfactual simulation it is not necessary to re-calibrate the model.

A counterfactual simulation is characterized by its impact on consumer's welfare or through the equivalent variation of his welfare function. The equivalent variation can be, under reasonable assumptions, directly mapped to some of the endogenous variables of the model such as consumption, employment and price levels. The sign of the change of the equivalent variation gives then a measure of the policy's impact and burden sharing implications. The most important results, provided by GEM-E3-CAT, are:

- Dynamic annual projections in volume, value and deflators of national accounts by country
- Full Input-Output tables for each country/region identified in the model
- Distribution of income and transfers in the form of a social accounting matrix by country
- Employment, capital, investment by country and sector
- Greenhouse gasses, atmospheric emissions, pollution abatement capital, purchase of pollution permits and damages
- Consumption matrix by product and investment matrix by ownership branch
- Public finance, tax incidence and revenues by country
- Full bilateral trade matrices