EC4MACS
Modelling Methodology

The GEM-E3 Macro-economic Model

European Consortium for Modelling of Air Pollution and Climate Strategies - EC4MACS

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Part 1

Chapter 1

Overview of GEM-E3 Model

An overview of the basic features and the characteristics of the model

Introduction

This presentation describes the basic features and characteristics of the ***GEM-E3*** (***G***eneral ***E***quilibrium ***M***odel for ***E***nergy-***E***conomy-***E***nvironment interactions). The model has been developed as a multinational collaboration project, partly funded by the Commission of the European Communities[1], DG Research, 5th Framework programme and by national authorities, and further developments are continuously under way. Applications of the model have been (or are currently being) carried out for several Directorate Generals of the European Commission (economic affairs, competition, environment, taxation, research) and for national authorities.

The GEM-E3 (World and Europe versions) model is an applied general equilibrium model, simultaneously representing 37 World regions/24 European countries, which provides details on the macro-economy and its interaction with the environment and the energy system. It covers all production sectors (aggregated to 26) and institutional agents of the economy. It is an empirical, large-scale model, written entirely in structural form. The model computes the equilibrium prices of goods, services, labor and capital that simultaneously clear all markets under the Walras law and determines the optimum balance for energy demand/supply and emission/abatement. Therefore, the model follows a computable general equilibrium approach. The main features of the GEM-E3 (World and Europe) model are as follows:

- It 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.

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[1] The GEM-E3 model was built under the auspices of European Commission (DG-Research) by a consortium involving BUES, ERASME, NTUA, KUL, PSI, ZEW and at the beginning of the project CORE, Univ. Strathclyde and CEA.

- It formulates separately the supply or demand behaviour of the economic agents which are considered to optimise individually their objective while market derived prices guarantee global equilibrium, allowing the consistent evaluation of distributional effects of policies.
- It 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
- Although global, the model exhibits a sufficient degree of disaggregation concerning sectors, structural features of energy/environment and policy-oriented instruments (e.g. taxation). The model formulates 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, the choice of production factors can be based on the explicit modelling of 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 backward looking expectations of the participant agents[2].
- The model formulates pollution permits for atmospheric pollutants and flexibility instruments allowing for a variety options, including: allocation (grandfathering, auctioneering, etc.), user-defined bubbles for traders, various systems of exemptions, various systems for revenue recycling, etc.

The GEM-E3 Model includes projections of full Input-Output tables by country/region, national accounts, employment, balance of payments, public finance and revenues, household consumption, energy use and supply, and atmospheric emissions. The computation of equilibrium is simultaneous for all domestic markets of all 37 World Regions/EU-24 countries and their interaction through flexible bilateral trade flows.

The remainder of this manual organized as follows: Chapter 2 describes the conduct of the market participants (consumers, producers, government, the product & factor markets and the bilateral trade flows), Chapter 3 provides mathematical eyeshot to the model and the way the variables, parameters and equations are structured, Chapter 4

[2] The model extensions to represent market imperfections and economies of scale were carried out by the National Technical University of Athens (coordinator), the Catholic University of Leuven and Middlesex University.

provides a micro-economical behaviour analysis of the market acting members in imperfect market conditions, in conjunction with the mathematical approach, Chapter 5 describes some prototype extensions of the GEM-E3 model, including the endogenous presentation of factor productive changes, the endogenous treatment of technology evolution and growth, the engineering representation of energy system, Chapter 6 represents the data sources and the data process manipulation, the construction of the I/O Tables and SAM Matrix., Chapter 7 presents the calibration decisions adopted in GEM-E3 Model and its extensions and the values assigned to elasticities and other exogenous parameters, Chapter 8 describes the model implementation in GAMS. Finally, Chapter 9 includes the appendix with the mathematical model statement in summary form.

Policy Analysis Support

The traditional macro-economic models, due to their temperate structure and function, are not advisable for the planning and the implementation of policy tools[3]. In adverse, the general equilibrium models allow for consistent comparative analysis of policy scenario[4], since they ensure that in all scenarios, the economic system remains in general equilibrium. In addition, the computable general equilibrium models incorporate micro-economic mechanisms and institutional features within a consistent macro-economic framework, and avoid the representation of behaviour in reduced form. This allows analysis of structural change[5]. Particularly valuable are the insights in distributional effects and in longer-term structural mechanisms.

By directly mapping economic theory the GEM-E3 model offers a quantified framework that uniquely characterizes a policy case, through its impact on social welfare. Under reasonable assumptions, this welfare can be measured through the use of model variables such as trade flows, investment, consumption and GDP. In this way, an unobservable construct, such as the welfare function, can be translated into a quantifiable measure of satisfaction.

GEM-E3 is a general-purpose model that aims to cope with the specific orientation of the policy issues that are actually considered at the level of the European Commission. Therefore it is modularly built allowing the user to select among a number of alternative options depending on the issue understudy.

3 For example, Valette P. and Zagame, eds. (1994)

4 See Borges A.M. (1990)

5 See Capros P., Karadeloglou and G. Mentzas (1989) and (1990) for a formal comparison.

Main Applications of the GEM-E3 Model

- The ex-post evaluation of the impact of the Single Market Programme.
- The study of the revision of the minimum excise taxation for energy products for the European Union member states.
- The study of the possibility for a "double dividend" for environment and employment.
- The evaluation of the macroeconomic implications of the European Union's targets for the Kyoto negotiations for greenhouse gas mitigation.
- The examination of the impact of creating a market of tradable pollution permits.

The main types of issues that the model has been designed to study are:

- The analysis of market instruments for energy-related environmental policy, such as taxes, subsidies, regulations, pollution permits etc., at a degree of detail that is sufficient for national, sectoral and Europe-wide policy evaluation
- The evaluation of European Commission programmes that aim at enabling new and sustainable economic growth, for example the technological and infrastructure programmes
- The assessment of distributional consequences of programmes and policies, including social equity, employment and cohesion targets for less developed regions
- The consideration of market interactions across Europe, given he perspective of a unified European internal market, while taking into account the specific conditions and policies prevailing at a national level.
- Public finance, stabilisation policies and their implications on trade, growth and the behaviour of economic agents.
- The standard need of the European Commission to periodically produce detailed economic, energy and environment policy scenarios.

Policies that attempt to address the above issues are analysed as counterfactual dynamic scenarios and are compared against baseline model runs. Policies are then evaluated through their consequences on sectoral growth, finance, income distribution implications and global welfare, both at the single country level and for the EU taken as a whole.

The GEM-E3 model intends to cover the general subject of **sustainable economic growth**, and supports the study of related policy issues. Sustainable economic growth is considered to depend on combined environmental and energy strategies that will ensure stability of economic development.

The model intends, in particular, to analyse the **global climate change** issues (as far as Europe is concerned), a theme that embraces several aspects and interactions within economy, energy and environment systems. To reduce greenhouse gas emissions, CO2 emissions in particular, it is necessary to achieve substantial gains in energy conservation and in efficiency in electricity generation, as well as to perform important fuel substitutions throughout the energy system, in favour of less carbon intensive energy forms.

Moreover, within the context of increasingly competitive markets, new policy issues arise. For example, it is necessary to give priority to market-oriented policy instruments, such as carbon taxes and pollution permits, and to consider market-driven structural changes, in order to maximise effectiveness and alleviate macroeconomic consequences. Re-structuring of economic sectors and re-location of industrial activities may be also induced by climate change policies. This may have further implications on income distribution, employment, public finance and the current account.

The model is designed to support the analysis of **distributional effects** that are considered in two senses: distribution among European countries (Europe Model) and distribution among social and economic groups within each country. The former issues involve changes in the allocation of capital, sectoral activity and trade and have implications on public finance and the current account of member states. The latter issues are important, given the weakness of social cohesion in European member-states, and regard the analysis of effects of policies on consumer groups and employment. The assessment of allocation efficiency of policy is often termed "burden sharing analysis", which refers to the allocation of efforts (for example taxes), over member-states and economic agents. The analysis is important to adequately define and allocate compensating measures aiming at maximizing economic cohesion. Regarding both types of distributional effects, the model can also analyse and compare coordinated versus non coordinated policies in the European Union.

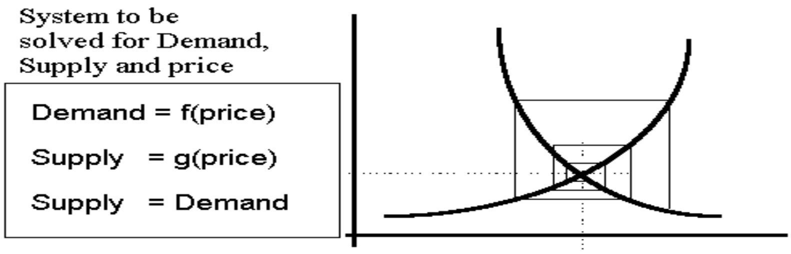
Technical progress and infrastructure can convey factor productivity improvement to overcome the limits towards sustainable development and social welfare. For example, European RTD strategy and the development of pan-European infrastructure are conceived to enable new long-term possibilities of economic growth. The model is designed to support analysis of structural features of economic growth related to technology and evaluate the derived economic implications for competitiveness, employment and the environment.

Model Design

In that section we appose the distinguishing features of the GEM-E3 model including:

The distinguishing features of general equilibrium modelling derive from the Arrow-Debreu[1] economic equilibrium theorem and the constructive proof of existence of the equilibrium based on the Brower-Kakutani theorem[2].

Figure: 1 **Fixed-point and tâtonnement process**



The Arrow-Debreu theorem considers the economy as a set of agents, divided in suppliers and demanders, interacting in several markets for an equal number of commodities. Each agent is a price-taker, in the sense that the market interactions, and not the agent, are setting the prices. Each agent is individually defining his supply or demand behaviour by optimising his own utility, profit or cost objectives.

The theorem states that, under general conditions, there exists a set of prices that bring supply and demand quantities into equilibrium, and all agents are fully (and individually) satisfied. The Brower-Kakutani existence theorem is constructive in the sense of implementing a sort of tâtonnement process around a fixed point where the equilibrium vector of prices stands (see figure 1). Models that follow such a process are called computable general equilibrium models.

It has been demonstrated that the Arrow-Debreu equilibrium can also be obtained from global (economy-wide) optimisation that implements Pareto optimality and uses the equilibrium characterisation introduced by Negishi[3]. Models that follow

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[1] See Arrow K.J. and G.Debreu (1954).

[2] See Kakutani S. (1941).

[3] See Negishi (1962).

this methodology have the form of mathematical programming[4] and are called optimisation equilibrium models[5].

In applied policy analysis, the so-called "closure rule[6]" problem has often been taken as a drawback of general equilibrium models, as the results are depending on the choice of the closure rule. As a matter of fact, a number of earlier approaches have been classified according to the type of closure rules that they were adopting (neoclassical, neokeynesian etc.).

A recent trend in computable general equilibrium modelling consists of incorporating an IS-LM mechanism (termed also macro-micro integration), which has been traditionally used in Keynesian models. The ensuing hybrid models have been, independently, proposed by J. De Melo, Branson and F. Bourguignon, P. Capros and others[7]. The IS-LM closure of computable equilibrium models overcomes the limitation of an arbitrary closure rule which must otherwise be adopted. In addition it provides insight into financial market mechanisms and related structural adjustment, allowing for a variety of choice of a free monetary variable that can then determine the level of inflation. These models have been often used for the evaluation of stabilisation packages. These models often incorporate additional features that enhance their short/medium term analysis features such financial and monetary constraints and dynamically adjusting expectations.

Facilitated by the explicit representation of markets, the computable general equilibrium models have been often extended to model market imperfections in the good or labour market and other economic mechanisms that deviate from the Pareto optimality frontier.

Some authors used the term "generalised equilibrium modelling"[8] to underline the flexibility of the computable equilibrium paradigm, regarding the extensions aforementioned, but also the possibility to represent and even mix different market clearing regimes within a single model. In general, these possibilities enrich the analytical capability of the model regarding structural change and its relation to market distortions, for example price regulations, cost-depending price setting, etc.

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4 for example Dorfman et.al. (1958), Ginsburgh and Waelbroeck (1981).

5 In theory, the computable and the optimisation equilibrium models are equivalent: the former, represented as a system of simultaneous equations, correspond to the first order optimum conditions of the mathematical programming problem. Motivated by the long-term character of the climate change issue, several new optimisation models have been constructed recently. The computable general equilibrium models however, are more common for two reasons: their computer solution is easier; they enable a straightforward representation of policy instruments and market-related institutional characteristics, therefore they enrich policy analysis.

6 See Dewatripont M.and G Michel (1987), and Lysy F.J. (1983).

7 See for example Bourguignon F., Branson, DeMelo (1989), Capros et.al.(1985) and (1990).

8For example Nesbitt D. (1984) on energy system applications.

The extensions that allowed the introduction of alternative market clearing regimes gave the possibility for introducing elements of the new trade economic theory within CGE models[9]. From the simple static open economy models of the 70s, it was now possible to develop sophisticated multi-country models where benefits from the exploitation of the potential for economies of scale and from the intensification of competition due to trade liberalisation are explicitly represented.

Similar methodological approaches have also lead to the incorporation of mechanisms reflecting endogenous technology evolution dynamics[10]. This issue however is at the frontier of current research activities and although the theoretical literature is expanding, few attempts have been made to include endogenous growth in a full-scale applied CGE model. Another area of interest, namely labour market imperfections[11], have also been introduced through the representation of the bargaining power of labour unions[12], while capital mobility regulations are also be taken into account in some models.

The current stream of CGE models, through its modular design, encompasses the whole area of modern economics going much beyond the standard neo-classical economics on which the first generation of CGE models was confined. This new generation of model design is the inspiration behind the development of the ***GEM-E3*** model.

The figure hereafter gives the basic scheme of the model

Main Characteristics of the Model

The design of ***GEM-E3*** 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.

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[9]Helpman and Krugman (1985) decribe the theoretical framework, while Winters and Venables eds. (1992), Baldwin (1992) and Dewatripont and Ginsburgh eds. (1994) give examples of applications. Baldwin and Venables (1995) provide an overview of recent attempts.

[10]The work of Romer P.M. (1990) is one of the first expositions of the new growth theory. Grossman G., Helpman E. (1991) provide the first systematic survey of incorporating endogenous growth mechanisms that is further elucidated by Barro (1995).

[11]The book "The new macroeconomics" Dixon and Rankin eds.(1995) includes an overview of many of the recent attempts.

[12]Recent attempts to introduce wage bargaining processes have been introduced in the WARM (see GRETA (1995)) and the WORLDSCAN models.

- 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 model starts from the same basic structure as the standard World Bank models[13]. Following the tradition of these models, GEM-E3 is built on the basis of a Social Accounting Matrix[14] (SAM) disaggregation of factors, activities, commodities & aggregation and explicitly formulates demand and supply equilibrium. There is no objective function. The equations define the behavior of the different actors. 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 modelled through KLEM (capital, labour, energy and materials) production functions involving many factors (all intermediate products and two primary factors -capital 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 generalised Leontief type of models[15] as initiated in the work of D. Jorgenson.

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' (backward looking) expectations[16].

The model is calibrated to a base year data set that comprises a full Social Accounting Matrices for each EU country that is built by combining Input-Output tables (as published by EUROSTAT) with national accounts data. Bilateral trade

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[14] 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[14]. 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.

[15] The generalised Leontief type of model was first formulated empirically in the work of D. W. Jorgenson[15] 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.

[16]A recent generation of general equilibrium models involves rational expectations where the model is solved inter-temporally i.e. all time-periods together. A recent example of such a model is the G-Cubed model (see McKibbin and Wilcoxen, 1995)

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[17].

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[18]). To cover analysis of European Union's unifying market, the model is simultaneously multinational (for European Union) and specific for each member-state. To this respect the model follows the methodology of the models that are developed to study tax policy and international trade.

GEM-E3 considers explicitly market clearing mechanisms, and related price formation, in the economy, energy and environment markets. Following a micro-economic approach, it formulates the supply or demand behaviour of the economic agents regarding production, consumption, investment, employment and allocation of their financial assets. Prices are computed by the model as a result of supply and demand interactions in the markets. Through its flexible formulation, it also enables the representation of hybrid or regulated situations, as well as perfect and imperfect competition. The current model version for example, incorporates sectors in which only a limited number of firms operate under oligopoly assumptions. Models with imperfect competition are a rather recent addition to the literature of CGE models. They are usually based on the concept of product varieties as this derived from the theory of industrial organisation and the concept of economies of scale which provided an elegant micro-economic framework for including non-linearities in production and consumption[19]. Such models have been developed mainly in Europe to study the impact of European unification. Similar techniques have been utilised to study the labour market imperfections. The concept of product varieties has also been utilised to endogenise technical progress in a number of theoretical models.

Firms in these sectors operate under non-constant returns to scale involving a fixed cost element, endogenously determine their price/cost mark-ups based on Nash-Bertrand or Nash-Cournot assumptions. Firms in these sectors can make profits/losses which will alter the concentration and firm size in the sector demand

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17 Models designed to study trade and fiscal policy do not necessarily represent the full detail of production technologies and consumption patterns, but instead put emphasis on public budgeting and international trade links. They implement a dynamic multi-period structure and they often solve inter-temporally to determine optimal taxation[17]. International trade and multi-country models determine equilibrium as an allocation driven by prices. Shoven, Whalley and others are among the main authors. The equilibrium models for international trade have been applied to policy analysis raised by GATT conventions, by the USA-Mexico trade issues, the USA-Japan trade, the EEC market unification and others.

18 See Armington (1969).

19 Dixit and Stiglitz (1977) for the first exposition of the notion of product varities and J. Tirole (1988) for its use in industrial organisation.

then is also firm-specific in the sense that changes in product varieties directly affect the utility of the consumers.

Institutional regimes, that affect agent behaviour and market clearing, are explicitly represented, including public finance, taxation and social policy. All common policy instruments affecting economy, energy and environment are included. Model closure options mainly investments/savings equality are varied according to capital or labour mobility across sectors/countries, external sector possibility of adjustment.

The model is general and complete, in the sense that it includes all agents, markets and geographic entities that affect European economic equilibrium. The model attempts also to represent goods that are external to the economy[20] as for example damages to the environment.

The internalisation of environmental externalities is conveyed either through taxation or global system constraints, the shadow costs of which affect the decision of the economic agents. The current version of *GEM-E3* links global constraints to environmental emissions, changes in consumption or production patterns, external costs/benefits, taxation, pollution abatement investments and pollution permits. It evaluates the impact of policy changes on the environment by calculating the change in atmospheric emissions and damages and determines costs and benefits through an equivalent variation measurement of global welfare (inclusive environmental impact). The recent awareness about the greenhouse problem motivated the emergence of several empirical models for the analysis of economy-environment interactions. For example, the work of W. Nordhaus, D. Jorgenson and Wilcoxen, A. Manne and Richels, Blitzer and Eckaus, K. Conrad, L. Bergman, S. Proost and Van Regemorter[21] have focused on the economic conditions for obtaining CO_2 reduction by means of a carbon-related tax. Such a policy issue needs to be addressed by ensuring consistent representation of the interactions between the economy, the energy system and the emissions of CO_2.

A counterfactual simulation is characterised through 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 in each member state and for the EU as whole, gives then a measure of the policy's impact and burden sharing implications.

The GEM-E3 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-

[20] On accounting for externalities, see the report of the EXTERNE project, European Commission (1995).

[21] W. Nordhaus (1994), D. Jorgenson and Wilcoxen (1990), A. Manne and Richels (1997), S. Proost and Van Regemorter (1992).

specify or re-calibrate the model. The most important of these options are presented below:

Table 1: **Alternative behavioural/closure options in GEM-E3**

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

Chapter

2

Micro Analysis of the Model

A reference to the conduct of the instiutions, agents, markets, and the macroeconomic and bilateral trade flows

Household Behaviour

Households, as it depicted at the SAM, receive income from the production factors, according to the ownership of them (directly or indirectly from the enterprises), from other institutions and transfers from the rest of the world. At an opposite direction, the household expenditure model includes income payments for taxes, saves, consumes and transfers to other institutions.

The household behaviour is based on an inter-temporal model of the household sector with two stages. In a first stage the households decide each year on the allocation of their expected resources between present and future consumption of goods and leisure, by maximising over their entire life horizon an inter-temporal utility function subject to an inter-temporal budget constraint defining total available resources. It is assumed that at the end of his life they will have no savings left. The utility function has as arguments consumption of goods and leisure. The utility function has as arguments consumption of goods and leisure. The general specification of the first stage problem, with a period separable Stone-Geary utility function, can be written as follows:

$$\max U(q(t)) = \int_{t=0}^{\infty} e^{-\delta t} \cdot u(q(t))dt \text{ , } where \ u(q(t)) = \beta \cdot \log(q(t) - \gamma)$$

Where:

q(t): is a vector of two commodity flows (in our case consumption and leisure) and
δ: is the subjective discount rate of the households.

The maximisation is subject to the following inter-temporal budget constraint, where *w* represents the total wealth the households expect for their lifetime including the value of their total time resources y(t) (leisure and work time).

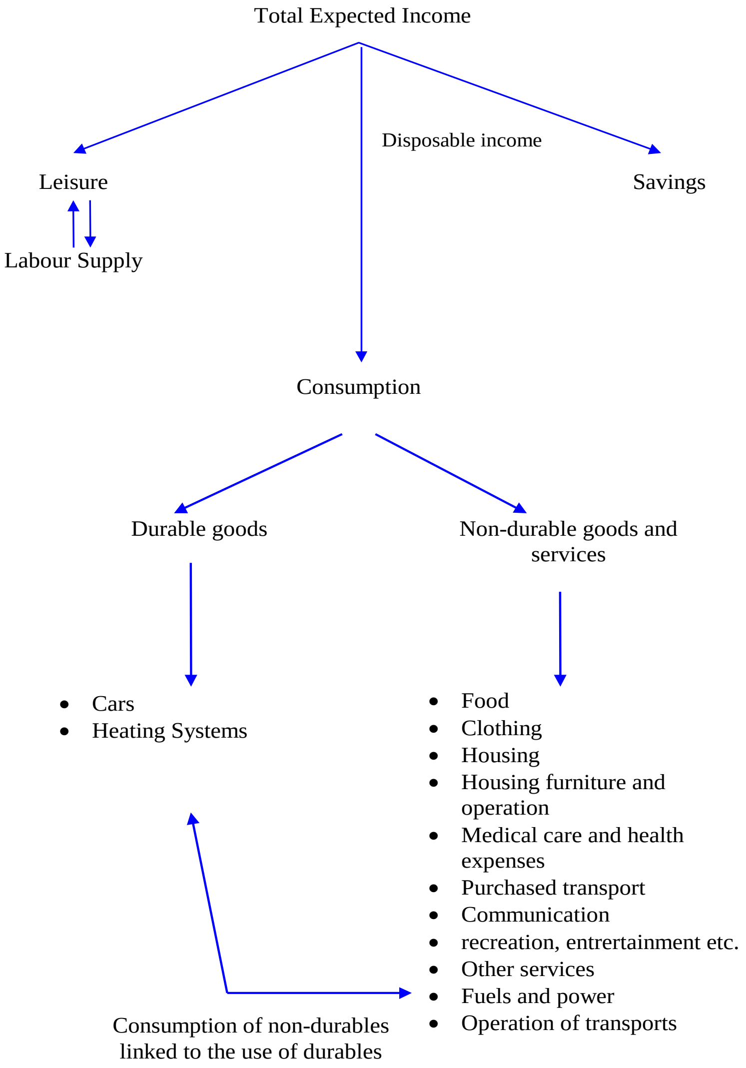
$$\dot{w}(t) = r \cdot w(t) + y(t) - p' \cdot q(t)$$

Although this problem can readily be solved[22] it is often easier to solve its discrete approximation[23].

In the second stage households allocate their total consumption expenditure between expenditure on non-durable consumption categories (food, culture etc.) and services from durable goods (cars, heating systems and electric appliances).

The general form that is described above is being depicted with a nesting scheme as it is appeared below:

Figure 2**: The consumption structure of the GEM-E3 model**



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22 For a detailed presentation of the derivation of the demand functions using optimal control see C. Lluch (1973). The results obtained are identical to the ones presented below.

23 A similar formulation can also be found in Jorgenson et. al (1977).

In each period, households modelled through one representative consumer for each EU country, allocate in the first stage their total expected income between consumption of goods (both durables and non-durables) and services, leisure and savings.

Firms Behaviour – Investment Demand

Each producer (represented by an activity) is assumed to maximize profits, defined as the difference between revenue earned and the cost of factors and intermediate inputs. Profits are maximized subject to a production technology.

Domestic production is defined by branch (for the branches where Perfect Competition (PC) is assumed to prevail) or by firms (for branches with Imperfect Competition[24] (IC)). For the PC branches, it is assumed that each branch produces a single good which is differentiated from any other good in the economy and is supplied to the market for this good.

Production functions in *GEM-E3* exhibit a nested separability scheme, involving capital (K), 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* has been selected to match both available econometric data on KLEM substitution elasticities and to be able to simulate closely industry in the European Union.

The optimal production behaviour can be represented in the primal or dual formulation. Their equivalence, under certain assumptions, can be easily verified with the theory of production behaviour and is illustrated with the following formulations (CES functions are used, but any other form would lead to the same qualitative results).

The primal formulation is given by:

$$XD_i = \sum_j \left[\delta_{i,j}^{\frac{1}{\sigma}} \cdot X_{i,j}^{\frac{\sigma-1}{\sigma}} \cdot e^{-(1-\sigma)\cdot tpj \cdot t} \right]^{\frac{\sigma}{\sigma-1}}$$

$$X_{i,j} = XD_i \cdot \delta_{i,j} \cdot \left(\frac{P_i \cdot e^{-(1-\sigma)\cdot tpj \cdot t}}{PX_{i,j}} \right)^{\sigma}$$

$$P_i \cdot XD_i = \sum_j PX_{i,j} \cdot X_{i,j} \qquad (\textit{zero profit condition})$$

Where:

P_i: is the output price of domestic production, $\delta_{i,j}$ are scale factors for the production factors (intermediate consumption, energy, capital and labour), $PX_{i,j}$ is

24 For IC model, see the section dedicated to the modelling of imperfect competition.

the price of the factor j and σ is the substitution elasticity. The last factor in the equation reflects the technical progress that is embedded in the production factors (tp_j is the rate of technical progress embedded in production factor j).

The dual formulation is given by:

$$P_i = \sum_j \left[\delta_{i,j} \cdot PX_{i,j}^{\;1-\sigma} \cdot e^{-(1-\sigma)\cdot tpj\cdot t} \right]^{\frac{1}{1-\sigma}}$$

$$X_{i,j} = XD_i \cdot \delta_{i,j} \cdot \left(\frac{P_i \cdot e^{-(1-\sigma)\cdot tpj\cdot t}}{PX_{i,j}} \right)^{\sigma}$$

$$P_i \cdot XD_i = \sum_j PX_{i,j} \cdot X_{i,j} \qquad \textit{(zero profit condition)}$$

It can be proved, that under constant returns of scale, the two formulations are exactly the same.

In the *GEM-E3* model, there is an additional constraint, namely that in the short term (i.e. within the period) the amount of available capital is fixed. This breaks the assumption about constant returns of scale, and the supply side of production is reflecting decreasing returns of scale. In both formulations, an equation for the equality between desired and existing capital is added and one of the (j+1) equations (j derived demand functions and the zero profit condition) are redundant:

Either the demand of capital is redundant and the zero profit condition serves to compute the rate of return on capital, the equilibrium on the good market determining the price of the good

Either the zero profit equation is suppressed and the equilibrium on the capital determines the rate of return on capital.

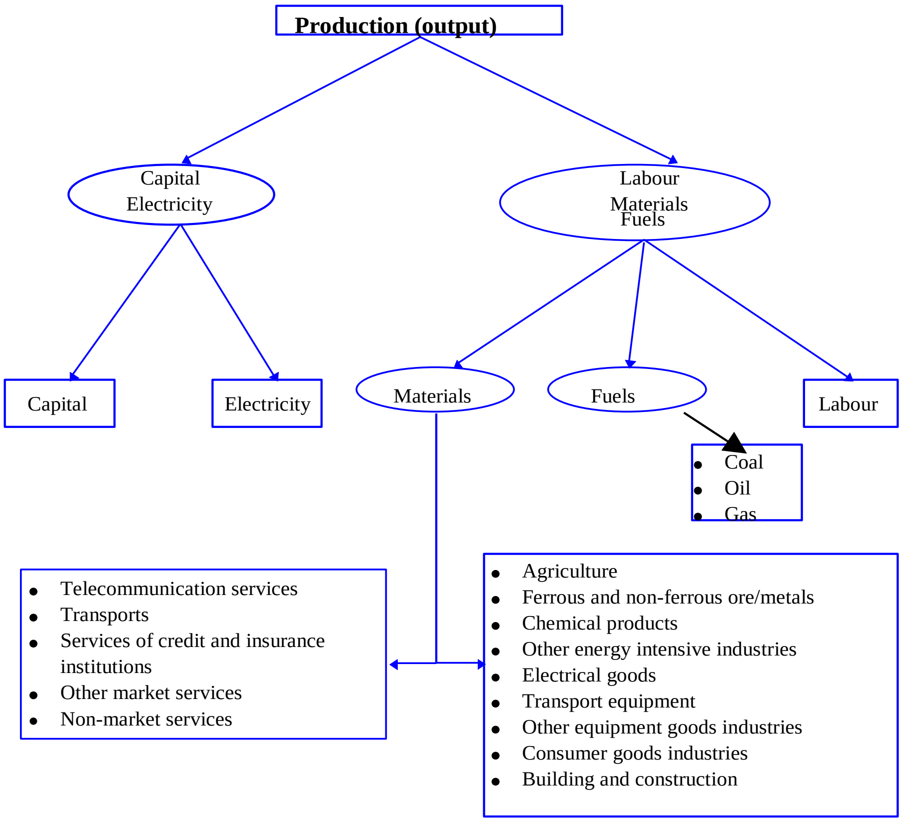
It is easy to prove that the primal and dual formulation will lead here also to the same solution.

At the first level, production splits into two aggregates, one consisting of capital stock and the other of labour, materials, electricity and fuels. At the second level, the latter aggregate is further divided in their component parts.

The dual formulation is used and the long run unit cost function is of the nested CES type with factor-augmenting technical change, i.e. price diminishing technical change.

The firm (at branch level) decides its supply of goods or services given its selling price and the prices of production factors. The production technology exhibits constant return of scale (PC sectors) or increasing returns (IC sectors). The firm supplies its good and selects a production technology so as to maximise its profit within the current year, given the fact that the firm cannot change the stock of productive capital within this period of time. The firm can change its stock of capital the following year, by investing in the current one. Since the stock of capital is fixed within the current year, the supply curve of domestic goods is upwards sloping and exhibits decreasing return to scale[25].

Figure 3: **Production nesting scheme in the GEM-E3 model**[26]



The conduct of firms is influenced substantial from the need of capital investment and replacement.

The demand for capital for the next year, which fixes the investment demand of the firms, is determined through their optimal decision on factor inputs for the next year with the framework described above.

[25] This description applies only to the most rigid of the capital mobility assumptions that are available in the model variants, where capital is assumed immobile across sectors and countries in static terms. When capital is assumed malleable across sectors and/or countries, then the capital stock by sector can adjust even in static terms, but the overall capital resources available to the economy (of the country or the EU as a whole) within each time-period are constant.

[26] Production factors are denoted by bold letters and are in rectangle. Round boxes represent intermediate bundles of goods with no physical relevance.

The desired demand for capital (K_{fut}) (as derived from long run cost minimisation under the production function constraint) is a function of the optimal long run cost of capital and the expected values for the volume of production and the production deflator. The optimal long-run cost of capital derived according to Ando-Modigliani formula[27], is equal to the investment deflator (*PI*), times the real interest rate (*r*) augmented by the depreciation rate (d)

$$PK_{opt} = PINV \cdot (r + d)$$

and the desired capital for the next year (K_{fut}) is

$$\frac{K_{fut}}{Y_{\exp}} = \delta_{k,PR} \cdot \left(\frac{PD_{\exp}}{PK_{opt}}\right)^{\sigma}$$

Government Behaviour

The Government behaviour is exogenous in GEM-E3.

Government final demand (GV) by product is obtained by applying fixed coefficients (t_G) to the exogenous volume of government consumption (G_C):

$$\mathrm{GV} = t_G \cdot G_C$$

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

On the receipt side, the model distinguishes between 9 categories of receipts, which are indirect taxes, environmental taxes, direct taxes, value added taxes, production subsidies, social security contributions, import duties, foreign transfers and government firms.

These receipts are coming from product sales (i.e. from branches) and from sectors (i.e. agents). The receipts from product sales in value (F_G), which include indirect taxes, the VAT, subsidies and duties, are computed from the corresponding receipts in value, given the tax base and the tax rate.

For duties and subsidies, it is:

$$F_{G,Duties} = t_{Duties} * IMPinvalue$$
$$F_{G,Subsidies} = t_{Subsidies} * XD \cdot PD$$

27 See Ando, Modigliani et.al (1974).

Where:

M and D denote the value of imports and domestic production respectively, t_{Duties} is the tariff for imports and $t_{Subsidies}$ is the subsidisation rate by branch.

For indirect taxes and VAT, it is

$$F_{G,Ind.Tax} = \frac{t_{Ind.Tax}}{1+t_{Ind.Tax}} * \left[\frac{C_H + C_G + I_H + I_G}{1+t_{VAT}} + \sum I_C + \sum F_I + S \right]$$

$$F_{G,VAT} = \frac{t_{VAT}}{1+t_{VAT}} * \left(C_H + C_G + I_H + I_G \right)$$

The receipts from agents are computed from the tax base and the tax rate (social security contributions, direct taxation), share of government in total capital income (for government firm's income) or exogenous (transfers from and to the RW)

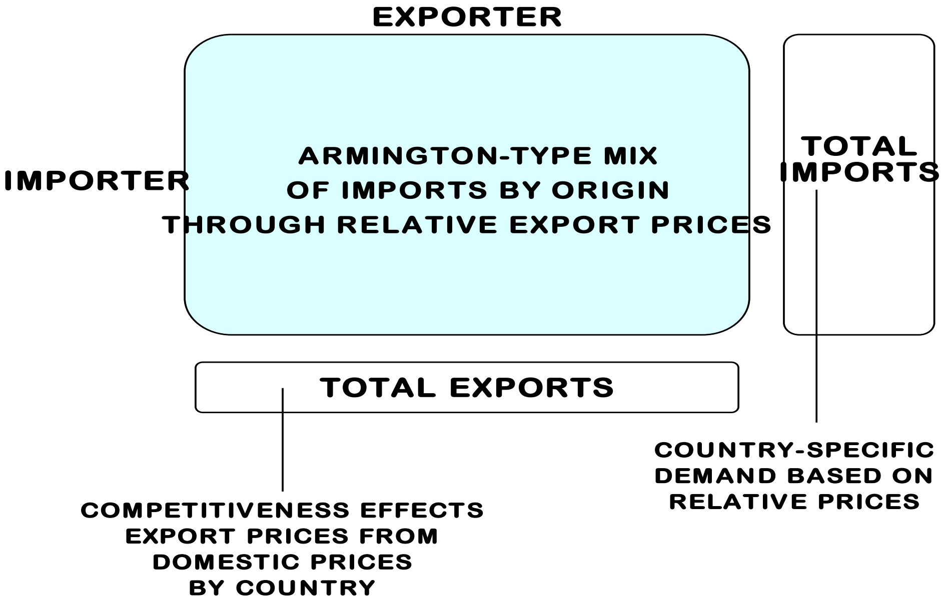
Domestic Demand & Trade Flows

The demand of products by the consumers, the producers (for intermediate consumption and investment) and the public sector constitutes the total domestic demand. This total demand[28] is allocated between domestic products and imported products, following the Armington specification. In this specification, branches and sectors use a composite commodity which combines domestically produced and imported goods, which are considered as imperfect substitutes. Each country buys and imports at the prices set by the supplying countries following their export supply behaviour. The buyer of the composite good (domestic) seeks to minimise his total cost and decides the mix of imported and domestic products so that the marginal rate of substitution equals the ratio of domestic to imported product prices.

The model is not covering the whole planet and thus the behaviour of the rest of the world (RW) is left exogenous: imports demanded by the rest of the world depend on export prices set up by the European Union countries, while exports from the rest of the world to the EU, i.e. demand by the EU, are supplied by the RW flexibly.

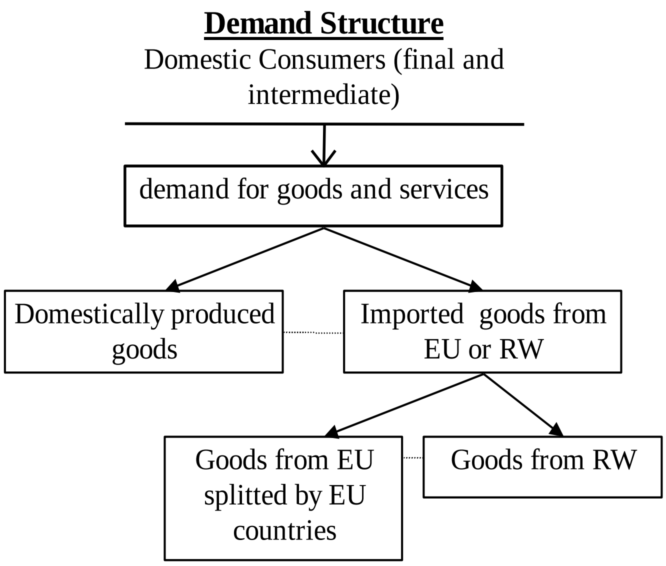
Figure 4: **Trade matrix for EU and the rest of the world**

28 In GEM-E3 we assume that the buyer's decision is uniform throughout the economy, therefore we apply Armington specification at the level of total domestic demand for each sector.



GEM-E3 employs a nested commodity aggregation hierarchy, in which branch's i total demand is modelled as demand for a composite good or quantity index Y_i, which is defined over demand for the domestically produced variant (XXD_i) and the aggregate import good (IMP_i). At a next level, demand for imports is allocated across imported goods by country of origin. Bilateral trade flows are thus treated endogenously in GEM-E3.

Figure 5: **Domestic Demand & Trade Flows Nesting Scheme**



The minimum unit cost of the composite good determines its selling price. This is formulated through a CES unit cost function, involving the selling price of the domestic good, which is determined by goods market equilibrium, and the price of imported goods, which is taken from the second level Armington. By applying Shephard's lemma, we derive total demand for domestically produced goods and for imported goods.

Derived Prices – Firms Pricing

Derived prices are those depending on leading prices, which are derived from market equilibrium. On derived prices appropriate taxation is applied, to form prices as perceived by consumers. The main leading price is that of the composite good. Depending on the destination of a commodity, differentiated taxation may be applied, as for example indirect taxation or VAT.

Firms address their products to three market segments namely to the domestic market, to the other EU countries and to the rest of the world. Prices are derived through demand/supply interactions. In any iteration of the model run and before global equilibrium is achieved, producers face demand for their products. To this demand they respond with a price. For the PC sectors, since these operate under constant returns to scale and the number of firms are very large, this price depends only on their marginal cost of production.

In the core model version a simple specification is followed in which firms do not differentiate their pricing according to the market segment to which they address their products, but rather set a uniform price. Differentiation of prices according to the market segment is formulated in the GEM-E3-IM version of the model.

The producer is assumed not to differentiate his price according to the market to which he sells his products[29]. He therefore sells his products at the same price (equal to his marginal cost reduced by the amount of production subsidies that he receives).

Current Account

One of the model versions allows for a free variation of the balance of payments, while the real interest rate is kept fixed. An alternative approach, implemented in the GEM-E3 model as an option, is to set the current account of the EU with the rest of the world (RW) (as a percentage of total EU imports from the RW) to a pre-specified value, in fact a time-series set of values. This value is the one obtained, as a result, from the baseline scenario. As a shadow price of this

Another model variant incorporates a constant elasticity of transformation (CET) function. In this variant firms try to maximise their profits from selling their commodities, so the prices they address to different markets are different.

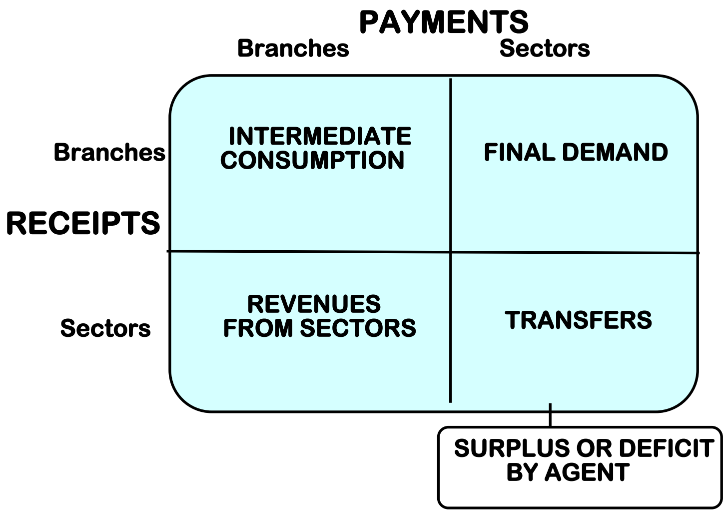
constraint, a shift of the real interest rate at the level of the EU is endogenously computed. This shift is proportionally applied to the real interest rates of each member-state.

Income Accounts, SAM and Agents Surplus

The real sector of the model is grouped within the framework of a Social Accounting Matrix - SAM (figure 5), which ensures consistency and equilibrium of flows from production (branches) to the economic agents (sectors) and back to consumption.

The sources of income for consumers and producers are labour, capital rewarding and transfers. Respectively the sources of income for government are transfers and taxes. The agents use income for consumption or investment. Finally the surplus of deficit by agent equals net savings minus investment.

Figure 6 **: Social Accounting Matrix (SAM)**



The formation of the flows in volume and their closure are fully defined at this stage. It is necessary, then, to formulate the income and transfer flows in value at the level of the Social Accounting Matrix and ensure the closure of the model, by verifying the Walras law.

All elements of demand for products, in value, are computed by multiplying the results in volume with the corresponding deflator. This is derived from the composite good price inflated by the appropriate taxes. As already mentioned, in the description of the government receipts, the indirect taxes are applied to all domestic consumption (intermediate and final), while the VAT tax is only imposed on the consumption and investment of the government and the households. For imports, the deflator equals the export price that the country of origin has set augmented by the import duties rate.

To understand the notation used, consider a more detailed presentation of the SAM framework, in the figure below:

Figure 7: **Detailed SAM Framework with Transfers & Flows**

EXPENDITURES

REVENUES

	Branches	**Factors**	**Sectors**	**Investment & Stocks**	**Total expend.**
Branches	intermediate consumption	0	demand for products by sector and exports	demand for products by sector	total demand
Factors	services in value added	0	income transfers from abroad	0	total factors
Sectors	indirect taxes, VAT, subsidies, duties and imports	factor payments to sectors	income transfers between sectors	0	total sectors
Gross Savings	0	0	total revenues minus investment and stocks	0	
Total Revenues	total supply	total factors	total sectors	0	

Surplus or Deficit	0	0	lending (+ or -) capacity by sector	0

Income flows

The main income transfers and flows derived from the SAM are as follows:

Revenues of sectors from branches ($\boldsymbol{F_{SB}}$), which includes capital and labour income, government receipts (indirect taxes, subsidies and duties) and imports; government receipts are denoted in detail (by category) within the variable $\boldsymbol{F_G}$ (value). The revenues of the rest of the world from the branches, is of course equal to the net value of imports by branch.

Revenues of sectors coming from other sectors ($\boldsymbol{F_{SS}}$), which includes transfers, taxes, social benefits etc.; government receipts are further detailed within the variable $\boldsymbol{F_{GS}}$ (in value);

The most important of these are:

- The dividends the firms pay to the households (F_{HF}), which is proportional to the net revenues of the firms
- The social benefits that the government pays to the households (F_{HG}), which depends on the number of employees by branch (N) and the rate of government payments to the unemployed (U)
- The direct taxes on the firms ($F_{GS,F}$) which is again proportional to the net revenues of the firms (now excluding dividends) and the households($F_{GS,H}$), where the tax is proportional to their disposable income
- The payments of individuals to the government for social security ($F_{GS,SS}$)
- Revenues of sectors coming from factors (F_{SF}), e.g. labour income of households
- Revenues of factors coming from sectors (F_{FS}); this mainly concerns factor income from abroad
- Flows considered as revenues of branches (in fact product demand) coming from sectors are detailed in: final consumption of products by sector in value (F_C), which includes exports, investment by product and sector in value (*I*) and stock variation in value (*S*)
- Flows considered as revenues of factors coming from branches represent the value added, in value
- Flows from branches to branches are the values of intermediate consumption, as computed from the production behaviour of the firms
- Flows from factors to factors and from factors to branches are equal to zero
- The change in stocks, is considered proportional to the volume of production for each branch
- Income transfers and factor payments to or from abroad are set equal to exogenous variables
- Factor payments to sectors are coming from value added and distributed according to an exogenous structure

The disposable income (Y_D) of households (domestic) is evaluated as their net earnings which comprises of their receipts from branches, factors and sectors minus their payments to the sectors and the factors:

$$Y_D = \sum_i F_{HB_i} + \sum_n F_{HF} + \sum_m F_{HS} - \sum_n F_{FH} - \sum_m F_{SH}$$

Firm's disposable income (F_D) is computed as the sum of their income flows coming from branches factors and sectors:

$$F_D = \sum_B F_{FB} + \sum_F F_{FF} + \sum F_{FS}$$

The gross profits (G_P) are then computed by subtracting from the disposable income the payments of the firms to the households and the rest of the world, as follows

$$G_P = F_D - F_{HF} - F_{WF}$$

Public budget results are summarised by computing total government revenues (G_{REV}) and total government expenditures (G_{EXP}) which includes final consumption and investment of the government.

$$G_{REV} = \sum_i F_{GB} + \sum_i F_{GF} + \sum_i F_{GS}$$

$$G_{EXP} = \sum F_C + \sum F_{FS} + \sum F_{SS} + \sum I$$

Gross savings and the closure rule

Gross savings (*SA*) by sector are then computed as the difference between revenues (which consists of the receipts from the branches plus income from factors and sectors) and expenditures (which include final consumption and transfers to factors and sectors):

$$SA_m = Revenues_m - Expenditures_m$$

Where:

m : stands for all the economic agents

The lending capacity or surplus (*SU*) - positive or negative - of the sectors is evaluated by subtracting investment (*I*) and stock variation (*S*) from gross savings:

$$SURPLUS_m = SA_m - I_m - S_m$$

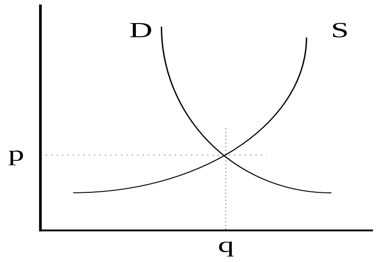
The model is constructed in such a way that the sum of the surpluses is zero, in other words the Walras law is always satisfied. This needs not be an additional model equation, but rather is respected by the construction of the model as it involves full redistribution of profits (or zero profits) and full spending of income available for consumption.

The definition of the set of prices ensures the consistency of the SAM, also in current currency, a fact which is finally reflected in the above condition, which states that the algebraic sum of net savings over the set of agents is, by construction, equal to zero.

Equilibrium of the Real Part

The equilibrium of the real part is achieved simultaneously in the goods market and in the labour market. This equilibrium is represented schematically in Figure 10.

Figure 8**: Equilibrium of the real part**



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, guarantee 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.

The good market

The equilibrium of the goods markets states that production must equal demand at the branch level. In the primal version, this condition serves to compute the unit cost of production (that is of course related to the selling price).

In the case of capital mobility across branches and/or countries the equilibrium condition relates to the total country or EU capital stock: producers demand an amount of capital (as derived from their cost-minimising behaviour), while the total stock of capital available is fixed within the time period either at country or EU level The equilibrium of the market defines then the average uniform rate of return of capital across the area of capital mobility.

The labour market

For the labour market it is postulated that wage flexibility ensures full employment. On the demand side we have the labour demanded by firms (as derived from their production behaviour), while on the supply side we have the total available time resources of the households minus the households' desire for leisure (which is derived from the maximisation of their utility function). The equilibrium condition serves to compute the wage rate. In another version, wage rigidity can be assumed.

Being within a competitive equilibrium regime, the labour market is influenced by the slope of labour supply (as decided by households simultaneously with consumption and leisure). In this sense, the model assumes that the entire unemployment is voluntary. However, as the model assumes that, if the economic conditions are favourable, the households can supply more labour force, a relative high real wage elasticity of labour supply can reflect unemployment that prevails in European countries.

The labour supply is not totally elastic. This elasticity can be thought of, as representing the bargaining power of the already employed people. A high bargaining power would entail that an increase of the labour demand, would lead to an important increase in the wage rate, without any additional employment. The other extreme would be for the wage rate to remain constant and the employment to increase to cover the whole labour demand. The elasticity used in the model, falls between these two extremes.

Another market that can be activated in the model is the pollution permits market, which will be described in the section on the environmental module.

Policy Evaluation

Evaluation of Changes in Consumers' Welfare

Every policy simulation can be uniquely characterised by its effect on the welfare index or through the implied equivalent variation change.

The welfare index is represented by the consumer's utility function completed by an environmental welfare index based on the valuation of the damage generated by the policy.

Besides an evaluation of the welfare impact by country, an overall evaluation in terms of welfare is given through the computation of the change in a Social Welfare function[30], a standard approach in welfare economics.

$$W = \sum_{i=1}^{R} \frac{W_i^{(1-\varepsilon)}}{(1-\varepsilon)}$$

Where:

W_i : represents the country i welfare derived from the consumer's utility function, which includes in a separable way the utility from the consumption of goods and leisure and the environmental utility

[30] Such a function can incorporate two limiting cases: the utilitarian approach (social welfare is the sum of the individual utilities) and the Rawlsian or democratic approach (social welfare = welfare of the worst-off individuals)

ε: represents the degree of inequality aversion

If ε=0, the marginal utility of supplementary unit of welfare is equal for all countries, an equal weight is given to the welfare of the different countries; only efficiency matters and the criteria is the one of the pure utilitarian equality.

When the value of ε increases, the degree of inequality increases and the equity aspect becomes more important in the evaluation of policies. If ε comes near to 1, utility is measured on a logarithmic scale, the marginal utility equals the inverse of the regional welfare and the resulting situation will be one of enhanced Rawlsian democratic equality.

The Social Welfare Function thus incorporates three effects: effects on the total value of private goods, the effect on the environment and the equity effects (which depend on the degree of income inequality aversion).

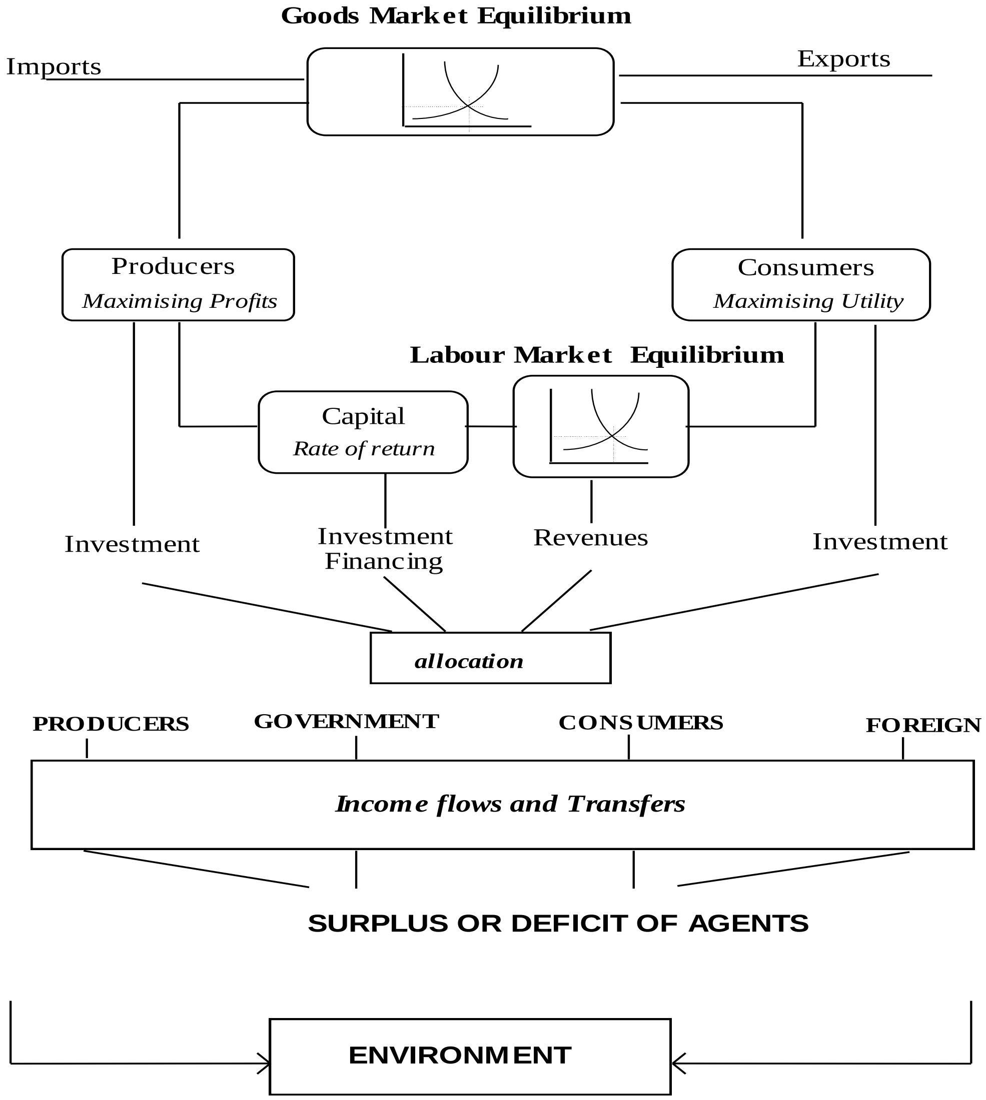
The equivalent variation

The equivalent variation of a scenario, giving the index A in a policy simulation and B in the reference situation, is given as:

$$EV_t\left(U_t^A, U_t^B\right) = C_t^H\left(U_t^A, PCI_t^B, PLJ_t^B\right) - C_t^H\left(U_t^B, PCI_t^B, PLJ_t^B\right)$$

The figure hereafter gives the basic micro-economic scheme of the model

Figure 9: **GEM-E3 Model Design**



Chapter 3

Mathematical Model Statement

A technical presentation of the model is given in this chapter, including the functions, the parameters and the variables of the whole system

Household Mathematical Expressions

The 1st stage:

With a LES (Cobb Douglas) utility function[31] the maximisation problem is written:

$$\text{Max } U = \sum_t (1+stp)^{-t} \cdot \left(BH \ln\left(HCDTOTV_t - CH\right) + BL \ln\left(LJV_t - CL\right)\right)$$

Where:

$HCDTOTV$: represents the consumption of goods (in volume)

LJV : the consumption of leisure

stp : the subjective discount rate of the households, or social time preference

CH : the subsistence quantity of consumption and CL the subsistence quantity of leisure

BH and BL : the respective shares of consumption and leisure in the potential disposable income of the households

The expenditure choice is subject to the following budget constraint, which states that all available disposable income will be spent either now or some time in the future:

---

31 Equations without numbering are not included in the model text, as they are only intermediate steps used for the derivation of other formulas.

$$\sum_t (1+r)^{-t} \cdot \left(HCDTOT_t - PCI_t \cdot CH + PLJ_t \cdot LJV_t - PLJ_t \cdot CL\right)$$
$$= \sum_t (1+r)^{-t} \cdot \left(YTR_t + PLJ_t \cdot LTOT_t - PCI_t \cdot CH - PLJ_t \cdot CL\right)$$

Where:

r : is the nominal discount rate used

YTR : is the total available income of the households from all sources, excluding wages

$PLJ \cdot LTOT$: is the value of their total time resources. The non wage income is income such as interest payments from assets, share in firm's profits, social benefits, and transfers from other countries.

Their behaviour is assumed to be formed as a sequential decision tree: based on myopic assumptions about the future the household decides the amount of leisure that he is wishing to forsake in order to acquire the desired amount of income (thus also defining labour supply behaviour). Assuming in the above equation that, at the aggregate level, the values at the right hand side increase at constant rate *f* (say, according to the wage rate assuming to increase as the inflation rate), then, remembering that for a given year (for example t=0)

$YTR + PLJ \cdot LTOT = YDISP + PLJ \cdot LJV$, the right hand side of the above becomes:

$$\sum_t (1+r)^{-t} (1+f)^t \left(YDISP_0 + PLJ_0 LJV_0 - PCI_0 CH - PLJ_0 CL\right)$$
$$= \left(YDISP_0 + PLJ_0 LJV_0 - PCI_0 CH - PLJ_0 CL\right) \cdot \sum_t \left(\frac{1+r}{1+f}\right)^{-t}$$

Where the last factor in the above equation can be approximated with the inverse of the real discount rate $\frac{1}{rr}$ (for a great T, $\sum_t \left(\frac{1}{1+rr}\right)^t$ converges to $\frac{1}{rr}$).

Computing the Lagrangian of the above problem (maximise utility subject to the budget constraint) the first order conditions are obtained. These consist of the budget constraint, plus the two derived demand functions.

$$(1+stp)^{-t} \cdot BH / \left(HCDTOTV_t - CH\right) - \lambda \cdot (1+r)^{-t} \cdot PCI_t = 0$$

$$(1+stp)^{-t} \cdot BL / \left(LJV_t - CL\right) - \lambda \cdot (1+r)^{-t} \cdot PLJ_t = 0$$

The value of the Lagrangian multiplier λ can be derived by summing up these equations over time, and substituting them into the budget constraint.

Expressing now the above equations for the current time period (t=0) and using the value of the multiplier, the two demand functions to be used in the model are obtained:

$$HCDTOTV = CH + \frac{stp}{rr}\frac{BH}{PCI}\left(YDISP + PLJ \cdot LJV - Obl\right) \quad (1)$$

$$LJV = CL + \frac{stp}{rr}\frac{BL}{PLJ \cdot}\left(YDISP + PLJ \cdot LJV - Obl\right) \quad (2)$$

Where:

$Obl = PCI \cdot CH + PLJ \cdot CL$: is the minimum obliged consumption of goods and leisure.

Given the fact that the model is calibrated to a base year data set in which households have a positive savings rate, the computed STP is less than RR. The savings rate computed from the above is not fixed but rather depends on such factors as the social time preference, the real interest rate and the relative shares of consumption and leisure in total potential disposable income.

The 2nd stage

In the second stage, total consumption is further decomposed into demand for specific consumption goods. For this allocation an integrated model of consumer demand for non durables and durables, developed by Conrad and Schröder (1991) is implemented. The rationale behind the distinction between durables and non durables is the assumption that the households obtain utility from consuming a non-durable good or service and from *using* a durable good. So for the latter the consumer has to decide on the desired stock of the durable based not only on the relative purchase cost of the durable, but also on the cost of those goods that are needed in connection with the durable (as for example fuels for cars or for heating systems).

The consumer problem can be written as

$$Max\, Uc = \prod_{ND}(q_i - \gamma_i)^{\beta_i} \prod_{DG}(SDG_j^{fix} - \gamma_j)^{\beta_j}$$

Under the constraint

$$HCDTOTV \cdot PC = \sum_{ND} p_i q_i + \sum_{DG}(p_j^u SDG_j^{fix} + p_j I_j)$$

Where:

Uc: is the level of utility, *PC* is the consumption price, *SDG* is the stock of durables

γ : is the minimum obliged consumption

β :is the elasticity in private expenditure by category, non-durable goods and services are denoted by the index *ND* while durables by the index *DG*.

Under this specification, one can derive the following expenditure function for non durables (Schröder (1991) :

$$HCNDTOT = E(U, p, SDG) = \sum_{ND} PC_{ND} \cdot \gamma_{ND} + Uc \cdot \prod_{DG} \left(SDG - \gamma_{DG} \right)^{-\beta_{DG}} \cdot \prod_{ND} \left(\frac{PC_{ND}}{\beta_{ND}} \right)^{\beta_{ND}}$$

which gives the (minimum) expenditure on non durables given the stock of durables and the utility level U. From Shephard's lemma, we obtain the derived demand functions for the non-durable goods by differentiating the expenditure function:

$$HCFV_{ND} = \gamma_{ND} + \left(\frac{\beta_{ND}}{PC_{ND}} \right) \cdot \left(HCNDTOT - \sum_{ND} PC_{ND} \cdot \gamma_{ND} \right)$$

Where:

HCNDTOT: is equal to E, the total expenditure on non durables.

To the expenditure on non durables must be added the amount needed to operate the durables to get total expenditure on non durables.

The cost of using a durable is obtained by differentiating the above expenditure function with respect to the stock of each of the durables. This quantity represents the amount of non-durables that the consumer is willing to forsake for one extra unit of the particular durable:

$$\frac{\partial E}{\partial SDG} = - \frac{\beta_{DG} \left(HCNDTOT - \sum_{ND} PC_{ND} \cdot \gamma_{ND} \right)}{SDG - \gamma_{DG}}$$

The cost of operating the durables (e.a. consumption of linked non durables) is included in the user's cost of the durable$(PDUR)$:

$$PDUR_{DG} = PC_{DG}(rr + \delta_{DG}) + TX_{PROP,DG}(1 + rr) + \sum_{LND} \lambda_{LND,DG} PC_{LND,DG} \tag{3}$$

Where:

rr : is the real interest rate

δ_{DG} : is the replacement rate for durable goods

TX : is the property tax for the durables

LND: is the set defining all linked non-durable goods and λ the consumption of non durables per unit of durable (e.g. consumption of gasoline by a car).

The last part of the user cost equation links some non-durable goods to the use of durables. Energy is the main linked non-durable good. Energy complements the use of durables in order for them to provide a positive service flow. Consumption of energy does not affect the expenditure of durables through the change in preferences but rather through the additional burden in the user cost.

To calculate the desired stock levels of the durables, this quantity is set equal to the marginal cost of holding one more unit of durable goods for one period. The desired stock level of the durables is:

$$SDG = \gamma_{DG} + \left(\frac{\beta_{DG}}{PDUR_{DG}} \right) \cdot \left(HCNDTOT - \sum_{ND} PC_{ND} \cdot \gamma_{ND} \right) \qquad (4)$$

The demand for linked non-durable goods, coupled with the use of the durable is then:

$$LLNDC_{ND} = \sum_{DG} \lambda_{DG,ND} \cdot \left(\theta_{ND,DG} SDG \right) \qquad (5)$$

Where:

λ_{DG} : measures the proportion of the consumption of the linked non-durable good that is used along with the durable so as to provide positive service flow

$\theta_{ND,DG}$: represents the minimum consumption of the non-durable that is needed for a positive service flow to be created.

If there is no need for non-durable good the $\theta_{ND,DG}$ in the first equation of the linked non-durables becomes zero Therefore:

$$HCFV_{ND} = CH_{ND} + \left(\frac{\beta_{ND}}{PC_{ND}} \right) \left[HCNDTOT - \sum_{ND} PC_{ND} \cdot \gamma_{ND} \right] \qquad (6)$$
$$+ LLNDC_{ND}$$

Total households' expenditure is then the sum of consumption (for non-linked non-durables) plus investment in durables plus consumption in non-durables used with durables.

$$HCDTOTV = HCNDTOT + \sum_{DG} HCFV + \sum_{ND} LLNDC \qquad (7)$$

Where:

$\sum_{DG} HCFV$: represents the change in stocks of durables or in other words, the net investment that is necessary to move towards the long run equilibrium durable goods levels. Assuming a rate of replacement δ, this investment is equal to:

$$HCFV_{DG} = SDG_{DG} - (1-\delta) \cdot SDG_{DG}\left[-1\right] \qquad (8)$$

The demand for consumption categories is then transformed into demand for products through a consumption transition matrix with fixed technical coefficients:

$$HC_j = \sum_{i=1}^{n+m} THV_{i,j} * HCFV_i$$

This equation determines the final consumption expenditure of the households.

The consumption transition matrix is also used to compute the consumption price by function, as the weighted average of the delivery prices of products to private consumption (PH):

$$PC_i = \sum_{j=1}^{l} THV_{j,i} * PH_j$$

A cost-of-living index can be derived as the ratio between value and volume of consumption, it gives the change in the consumer price relative to the numeraire.

$$PCI = \frac{\sum_{i=1}^{n+m} PC_i * HCFV_i}{\sum_{i=1}^{n+m} HCFV_i}$$

Firms Mathematical Expressions

1. Production Functions

The **primal production function** has the following form (for the1st nest):

$$XD_{PR} = \left[\delta_{KAV,PR}^{\frac{1}{\sigma}} \cdot \left(KAV_{PR} \cdot e^{tgk_{PR} \cdot t} \right)^{\frac{\sigma-1}{\sigma}} + \delta_{LEM,PR}^{\frac{1}{\sigma}} \cdot LEM_{PR}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}$$

Where:

XD_{PR}: is the domestic production

KAV_{PR}: is the fixed capital stock

LEM_{PR}: is the Labour-Energy-Materials bundle in production

σ: is the elasticity of substitution between KAV_{PR} and LEM_{PR}

tgk: is the technical progress of capital

$\delta_{KAV,PR}$ and $\delta_{LEM,PR}$:are scale parameters derived from the base year data set

The scale parameters are calibrated using the observed values and volumes and the substitution elasticities:

$$\delta_{KAV,PR} = \left(VSH_{KAV,XD}\right)^{\sigma} \cdot \left(\frac{KAV_{PR}^{0}}{XD_{PR}^{0}}\right)^{1-\sigma} \text{ and}$$

$$\delta_{LEM,PR} = \left(1-VSH_{LEM,XD}\right)^{\sigma} \cdot \left(\frac{LEM_{PR}^{0}}{XD_{PR}^{0}}\right)^{1-\sigma}$$

Where:

$VSH_{KAV,XD}$ and $VSH_{LEM,XD}$: are the base year value shares of Capital and Labour-Energy-Materials bundle in production respectively.

The **dual function** representing the unit production cost, on the other hand, is expressed with the following way:

$$PD_{PR} = \left[\delta_{KAV,PR}\left(\frac{PK_{PR}}{e^{-tgk_{PR}\cdot t}}\right)^{1-\sigma} + \delta_{LEM,PR} \cdot PLEM_{PR}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

Where:

PD_{PR}: is the deflator in domestic production

PK_{PR} and $PLEM_{PR}$: are the effective capital rate of return for fixed capital and the deflator of Labour-Energy-Materials bundle respectively.

Optimal factor demand is derived from Shephard lemma. We make the assumption that the stocks of capital and labour are proportional to the optimal flows (i.e. the capital and labour services derived through the Shephard lemma) in volume. Notice that the derived demand for capital expresses the desired demand for capital stock.

The derived demand for the Labour-Energy-Materials bundle is:

$$LEM_{PR} = XD_{PR} \cdot \delta_{LEM,PR} \cdot \left(\frac{PD_{PR}}{PLEM_{PR}} \right)^{\sigma} \quad (9)$$

$$KAV_{PR} = XD_{PR} \cdot \delta_{KAV,PR} \cdot \left(\frac{PD_{PR}}{PK_{PR}} \right)^{\sigma} \cdot e^{tgk_{PR} \cdot t \cdot (\sigma - 1)} \quad (10)$$

Equation (10) gives the desired capital demand and will be used in the capital market equilibrium equation which derives the rate of return of capital of capital PK_{PR} as the equilibrium price that equalises demand and supply of capital[32] (either at branch level in the model version with fixed sectoral capital stock or at country or EU level if capital is assumed mobile).

Similar formulas can be derived for the other levels of the nesting scheme of the production function, always linking the demand for a factor at a lower level of the nesting scheme to the bundle to which it belongs, with different substitution elasticities at each level. This gives finally a cost-minimising demand for each production factor

$$ENL_{PR} = f\left(XD_{PR}, \delta_{ENL,PR}, PEL_{PR}, PD_{PR}, e^{tge_{PR} \cdot t \cdot (\sigma_2 - 1)}\right) \quad (11)$$

$$LAV_{PR} = f\left(XD_{PR}, \delta_{LAV,PR}, PL_{PR}, PD_{PR}, e^{tgl \cdot t \cdot (\sigma_2 - 1)}\right) \quad (12)$$

$$IOVE_{BRE,PR} = f\left(XD_{PR}, \delta_{IOVE,PR}, PIO_{BRE}, PD_{PR}, e^{tgi \cdot t \cdot (\sigma_3 - 1)}\right) \quad (13)$$

$$IOVM_{BRM,PR} = f\left(XD_{PR}, \delta_{IOVM,PR}, PIO_{BRM}, PD_{PR}, e^{tgi \cdot t \cdot (\sigma_4 - 1)}\right) \quad (14)$$

Where:

ENL_{PR}: is the demand for electricity

PEL_{PR}: is the corresponding deflator

tge_{PR}: is the technical progress in energy use

LAV_{PR}: is the labour demand

PL_{PR}: is the unit cost of labour and tgl_{PR}: is the technical progress of labour.

[32] The equilibrium of the various markets that are represented in the model are discussed in a later section.

The last two equations represent the demand for intermediate consumption of commodity BR used in the production of sector PR ($IOVE_{BRE,PR}$ for energy and $IOVM_{BRM,PR}$ for material inputs) with PIO_{BR} being the unit cost of the intermediate good.

The unit labour cost is computed through the average wage rate that comes from the equilibrium of the labour market.

$$PL_{PR} = f(WR) \qquad (15)$$

Under the above specification, the zero profit condition is always satisfied (and hence not included in the model text):

$$PD_{PR} \cdot XD_{PR} = PK_{PR} \cdot KAV_{PR} + PLEM_{PR} \cdot LEM_{PR} + \sum_{PR} IOV_{PR} \cdot PIO_{PR}$$

2. Firms Investment Functions

The volume of investment decided by the firms:

$$INVV_{PR} = m \times KAV_{PR} \cdot \left[\left(\frac{PK_{PR}}{PINV_{PR} \cdot (r+d)} \right)^{\sigma} \cdot (1+STGR) \cdot e^{tgk(\sigma-1)} - (1-d) \right] \qquad (16)$$

Where:

$PINV_{PR}$: is the cost of investments

$STGR_{PR}$:is the expected growth rate of the sector.

r :is the real interest rate

d :is the depreciation rate

The next period capital stock is given by the equation:

$$KAVC_{PR} = (1-d)^{T} \cdot KAV_{PR} + \left(\frac{1-(1-d)^{T}}{d} \right) \cdot INVV_{PR} \qquad (17)$$

where :T is the length of the period in the model.

Since the capital is fixed within each period, the investment decision of the firms affects their production frontier only in the next period.

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.

This together with the government investments which are exogenous in ***GEM-E3***, constitute the total demand for investment goods.

3. Firms Pricing Behaviour

$$PXD_{PR} = PD_{PR} \cdot \left(1 + TXSUB_{PR}\right) \qquad (18)$$

$$PWE_{PR} = PD_{PR} \cdot \left(1 + TXSUB_{PR}\right) / EX \qquad (19)$$

Where:

PXD_{PR} : denotes domestic supply price addressed to domestic demand

$\mathrm{PWE}_{\mathrm{PR}}$: is domestic supply price addressed to exports

$TXSUB_{PR}$: is the rate of subsidies.

Domestic Demand Equations

For the mathematical expression of the demand (for the domestic production and aggregate import) it is used the dual formulation of the absorption price of the demand, namely:

Demand is allocated between domestic and imported goods according to the following CES functional form:

$$Y_{PR} = AC_{PR} \left[\delta_{1,PR} \cdot \left(XXD_{PR}\right)^{\frac{\sigma_x - 1}{\sigma_x}} + (1 - \delta_{1,PR}) \cdot \left(IMP_{PR}\right)^{\frac{\sigma_x - 1}{\sigma_x}} \right]^{\frac{\sigma_x}{\sigma_x - 1}}$$

Where:

XXD_i : domestically produced variant

IMP_i : aggregate import good

XXD_{PR} : represents the demand for domestic production

IMP_{PR} : is the demand for imports

$\delta_{1,PR}$: is a scale parameter estimated from the base year data related with the value shares of XXD_{PR} and IMP_{PR} in the demand for composite good Y_{PR} .

σ_x : is the elasticity of substitution between domestic and imported goods.

The corresponding dual formulation is:

$$PY_{PR} = \frac{1}{AC_{PR}}\left[\delta_{1,PR}{}^{\sigma_x} \cdot PXD_{PR}^{(1-\sigma_x)} + (1-\delta_{1,PR})^{\sigma_x} \cdot PIMP_{PR}^{(1-\sigma_x)}\right]^{\frac{1}{1-\sigma_x}} \tag{20}$$

Where:

PY_{PR} : stands for the absorption price of composite good

$PIMP_{PR}$: is the price of imported good PR computed as an average over all trading partners

PXD_{PR} : is the price of the domestically produced good. AC is a scale parameter in the Armington function

The budget constraint is this case, simply states that total expenditures are split between domestic and imported commodities.

$$PY_{PR} \cdot Y_{PR} = PXD_{PR} \cdot XXD_{PR} + PIMP_{PR} \cdot IMP_{PR}$$

The optimal demand for domestic and imported goods is obtained by employing the Shephard's lemma.

$$XXD_{PR} = Y_{PR} \cdot AC_{PR}{}^{(\sigma_x-1)} \cdot \delta_{1,PR}{}^{\sigma_x} \cdot \left(\frac{PY_{PR}}{PXD_{PR}}\right)^{\sigma_x} \tag{21}$$

$$IMP_{PR} = Y_{PR} \cdot AC_{PR}{}^{(\sigma_x-1)} \cdot (1-\delta_{1,PR})^{\sigma_x} \cdot \left(\frac{PY_{PR}}{PIMP_{PR}}\right)^{\sigma_x} \tag{22}$$

The price equation and the two demand equations are incorporated in the model. The demand of the composite good is computed as the sum of the domestic demand categories (i.e. intermediate and final).

At the second level, import demand is allocated across countries of origin using again a CES functional form. In equation below, *EU* and *CO* denote the countries. Index *EU* refers to European Union countries, while index *CO* also includes the rest of the world[33].

$$PIMP_{PR,EU} = \left[\sum_{CO} \beta^{\sigma_{xx}} \cdot PIMPO_{PR,EU,CO}^{(1-\sigma_{xx})}\right]^{\frac{1}{1-\sigma_{xx}}} \tag{23}$$

---

[33] A simplified version of the model is presented. In reality a number of additional factors are also present such as the existence of non tariff barriers and the fact that exporting a unit of a good implies using a number of related banking services and transport costs.

Where:

$PIMP_{PR,EU}$: denotes price of total imports of good *PR* demanded by country *EU*

$PIMPO_{PR,EU,CO}$: denotes import price of good *PR* of country *EU* originating from country *CO*

β : is the share parameter for Armington

σ_{xx} : is the elasticity of substitution

$$\frac{IMPO_{PR,EU,CO}}{IMP_{PR,EU}} = \frac{\partial PIMP_{PR,EU}}{\partial PIMPO_{PR,EU,CO}} \qquad \forall EU \neq RW \tag{24}$$

$computing \;\; IMPO_{PR,EU,CO}$

Where:

$IMPO_{PR,EU,CO}$: denotes imports of good *PR* demanded by country *EU* from country *CO*

$$IMPO_{PR,RW,EU} = \alpha_{RW} \cdot \left(\frac{PWEO_{PR,RW}}{PWEO_{PR,EU} EX_{EU}} \right)^{\varepsilon_{RW}} \tag{25}$$

Where:

$IMPO_{PR,RW,EU}$: denotes imports of good *PR* of the rest of the world originating from country EU

α_{RW} : is a scale parameter for export demand of the rest of the world

$\mathrm{PWEO_{PR,RW}}$: is the exogenous price of good *PR* set by the rest of the world

$PWEO_{PR,EU,RW}$: is the export price of good *PR* set by country *EU* to the rest of the world.

$$EXPO_{PR,CO,EU} = IMPO_{PR,EU,CO} \tag{26}$$

The previous equation is the one that satisfies the Walras law by equating the exports of sector *PR* of country *CO* to country *EU* with the imports of sector *PR* of country *EU* from country *CO*.

$$EXPOT_{PR,EU} = \sum_{CO} EXPO_{PR,EU.CO} \tag{27}$$

Where:

$EXPOT_{PR,EU}$: are the total exports of good *PR* from country *EU*

$EXPO_{PR,EU,CO}$: denote exports of good *PR* from country *EU* to country *CO*.

Import prices are equal to the export prices set by the country of origin (in ECU's), inflated by the appropriate import tariffs rate.

$$PIMPO_j = PWE_{i,j} * EX_j / EX_i * (1 + txduties_{j,i})$$

The model ensures analytically that, under the above assumptions, the balance of trade matrix in value and the global Walras law is verified in all cases. A trade flow from one country to another matches, by construction, the inverse flow. The model ensures this symmetry in volume, value and deflator. It is obvious, then, that the model guarantees (in any scenario run) all balance conditions applied to the world trade matrix, as well as the Walras law at the level of the planet.

Derived Prices Equations

The prices of goods at intermediate consumption are given in (28), while the prices of goods in final consumption are computed through (29) for households and (30) for government. Finally, (31) defines the prices of goods used to build investment.

$$PIO_{PR} = PY_{PR} + \tau_{PR} \qquad (28)$$

$$PHC_{PR} = \left(PY_{PR} + \tau_{PR}\right) \cdot \left(1 + vat_{PR}\right), \qquad (29)$$

Where: vat_{PR} : is a rate of value added tax imposed on good PR .

$$PGC_{PR} = PY_{PR} + \tau_{PR} \qquad (30)$$

$$PINVP_{PR} = PY_{PR} + \tau_{PR} \qquad (31)$$

The unit cost of investment by sector of destination (owner) depends on its composition in investment goods (by sector of origin). This structure is represented by a set of fixed technical coefficients $tcf_{PR,BR}$:

$$PINV_{BR} = \sum_{PR} tcf_{PR,BR} \cdot PINVP_{PR} \; , \qquad (32)$$

Income Accounts, SAM and Agents Surplus Equations

If a monetary/financial sub-model is incorporated in the model, this identity is the starting point of the monetary/financial sub-model which, in fact, expands, the way the identity is satisfied.

$$
\begin{aligned}
& SURPLUS_G = \\
& \quad \sum_{PR} \tau_{PR} \left[\begin{array}{l} \sum_{BR} IOV_{PR,BR} + HC_{PR} \\ \qquad\qquad + \sum_{BR} tcf \cdot INVV_{BR} + INVH_{PR} + INVG_{PR} \end{array} \right] \\
& + \sum_{PR} vat_{PR} \cdot \left[\left(PY_{PR} + \tau_{PR} \right) \cdot HC_{PR} + \left(PINVH_{PR} + \tau_{PR} \right) \cdot INVH_{PR} \right] \\
& + \sum_{EU} TXDUT_{EU,CO} \cdot PIMPO_{PR,EU,CO} \cdot IMPO_{PR,EU} \\
& + \tau s \cdot \sum_{PR} PL_{PR} \cdot LAV_{PR} \quad - HTRA - \sum_{PR} \left(PGC_{PR} \cdot GC_{PR} + PINVP_{PR} \cdot INVG_{PR} \right)
\end{aligned} \tag{33}
$$

Where:

τs : is the rate of social security contribution

HTRA : denotes income transfers from government to households

GC_{PR} : is government consumption

PGC_{PR} : is the price of government consumption

Finally, $SURPLUS_h \quad \forall h = G, H, F, W$ denote surplus or deficit of, respectively, government, households, firms and foreign sector

$$
\begin{aligned}
SURPLUS_H = HTRA + \sum_{PR} PL_{PR} \cdot LAV_{PR} \cdot \left(1 - \tau_i\right) - PC \cdot HCT \\
- \sum_{PR} TINV_{PR} \cdot PINV_{PR} \cdot INVV_{PR}
\end{aligned} \tag{34}
$$

Where:

$TINV$: is part of investments financed by the households (usually investment in dwellings)

HCT: is total household consumption and *INVV* is value of investments

$$SURPLUS_F = \sum_{PR} PK_{PR} \cdot KAV_{PR} - \sum_{PR} PINV_{PR} \cdot INVV_{PR} \qquad (35)$$

$$SURPLUS_W = \sum_{PR} PIMPO_{PR} \cdot IMPO_{PR} - \sum_{PR} PEX_{PR} \cdot EXPOT_{PR} \qquad (36)$$

Real Part Equilibrium Equations

$XD_{PR} = XXD_{PR} + EXPOT_{PR}$ serving to compute PD_{PR} (35)

In the dual version, as GEM-E3, this equation determines the total production, the dual price equation gives the production price and the equilibrium condition on the capital market determines the rate of return of capital.

If capital is mobile across branches only then:

$$KAV\_Supply = \sum_{PR} KAV_{PR} \qquad (36)$$

Computing an average country-wide rate of return of capital, while if capital is perfectly malleable across countries as well:

$$KAV\_Supply = \sum_{EU} \sum_{PR} KAV_{PR} \qquad (37)$$

KAV_Supply is the total amount of capital stock available, fixed within the time period.The equilibrium condition in the labour market serves to compute the wage rate.

$\sum_{PR} LAV_{PR} = TOTTIME - LJV$ serving to compute WR (38)

Which is the average nominal wage rate used to derive the labour cost PL_{PR}[34].

Policy Evaluation Equations

[34] Other model variants include a Philips curve, fixed labour supply and fixed wages.

The equivalent variation of a scenario, giving the index A in a policy simulation and B in the reference situation, is given as:

$$EV_t\left(U_t^A,U_t^B\right)=C_t^H\left(U_t^A,PCI_t^B,PLJ_t^B\right)-C_t^H\left(U_t^B,PCI_t^B,PLJ_t^B\right)$$

for every time period t, Where:

C_t^H is the expenditure function

$$C_t^H=\left(\frac{rr}{\rho}\right)\left(\frac{PC_t^B}{BH}\right)^{BH}\left(\frac{PLJ_t^B}{BL}\right)^{BL}U_t \tag{39}$$

Putting in base year prices and summing over the whole time period, the present value of the equivalent variation is obtained:

$$EV=\sum_{t=0}^{T}\left[\frac{1}{1+\rho}\cdot\Delta PC_t^B\cdot\Delta PLJ_t^B\left(CH_t^A-CH_T^B\right)\right] \tag{40}$$

Where:

$$\Delta PCI_t^B=\left(\frac{PC_t^B}{PC_0^B}\right)^{\beta_H} \text{ and } \Delta PLJ_t^B=\left(\frac{PLJ_t^B}{PLJ_0^B}\right)^{\beta_L}$$

represent weighted changes in the consumer's price index and the valuation of leisure (equal to net wage rate) between the reference and the counterfactual simulation.

Chapter

4

The Environmental Module

A representation of the environmental frame, that it is been encompassed in the model

Introduction

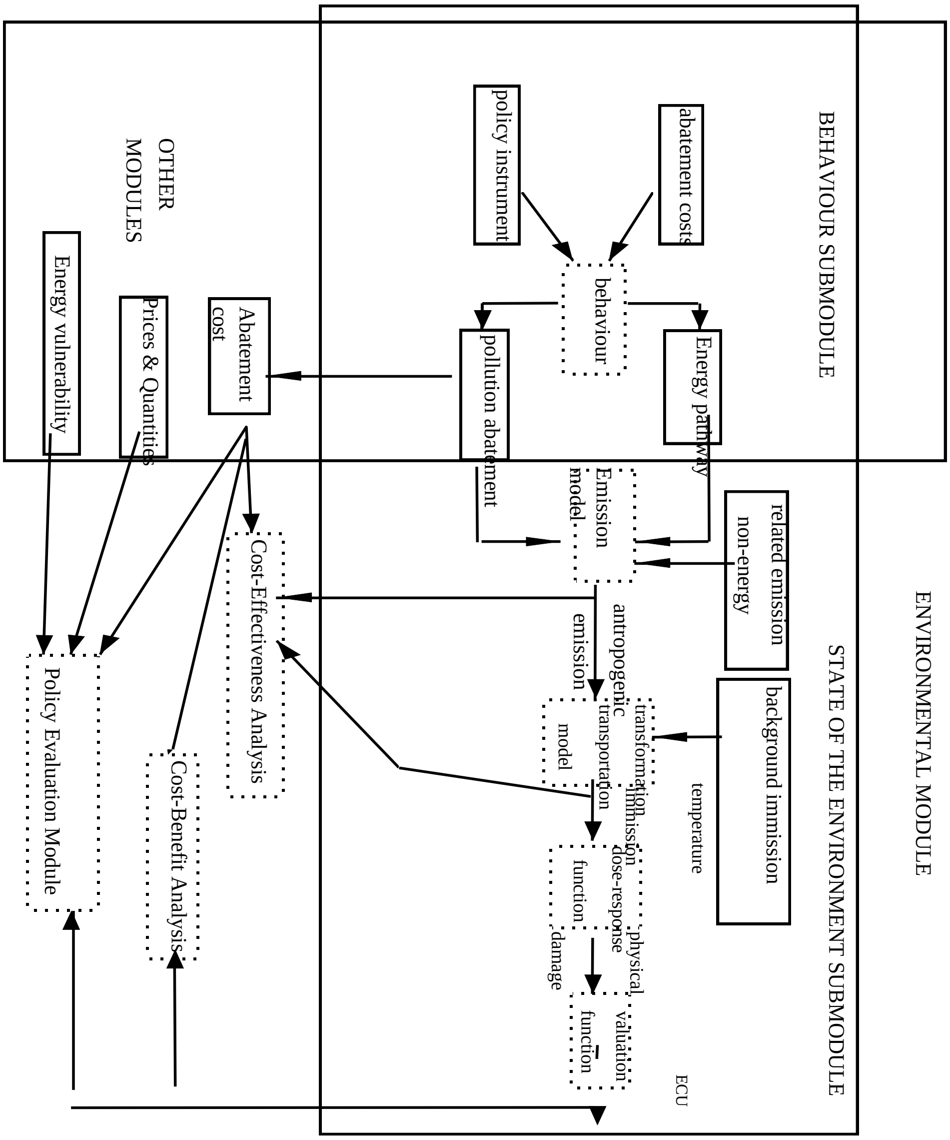
The objective of the environment module is to represent the effect of different environmental policies (i) on the EU economy and (ii) on the state of the environment. Compared to the currently available models, the aim of the introduction of an environment module is to do better in the following four directions:

<u>Aim Points of the Environmental Module</u>

- Integrated analysis of environmental and energy objectives on a European scale, e.g. energy security versus clean air
- Representation of a larger set of environmental policy instruments at different levels: standards, taxes, tradable permits; international, national, and sectoral
- Integrated analysis of different environmental problems: simultaneous analysis of global warming and acid rain policy
- Comparison between a source or a receptor oriented approach: damage valuation versus uniform emission reductions

It concentrates on three important environmental problems: (i) global warming (ii) problems related to the deposition of acidifying emissions and (iii) ambient air quality linked to acidifying emissions and troposheric ozone concentration. Hence, we consider energy-related emissions of CO_2, NO_x, SO_2, VOC and particulates, which are the main source of air pollution. NO_x is almost exclusively generated by combustion process, whereas VOC's are only partly generated by energy using activities (refineries, combustion of motor fuels; other important sources of VOC's are the use of solvents in the metal industry and in different chemical products but are not considered here. For the problem of global warming, CO_2 is responsible for 60% of the radiative forcing (IPCC, 1990). In a later stadium other GHGs (CH_4, CFC, N_2O) will be considered.

Figure 10: **Flow chart of the Environmental module**



The environment module contains two submodules:

a *"behavioural"* module, which represents the effects of different policy instruments on the behaviour of the economic agents (e.g. additive (end-of-pipe) and integrated (substitution) abatement).

a *"state of the environment"* module, which uses all emission information and translates it into deposition, air-concentration and damage data. This submodule was constructed making use of existing information or using results of other EC-projects like the ExternE. Depending on the version of the model, there is a feedback to the behaviour modules.

The emissions of the primary pollutants (CO2, NOx, SO2, VOC and PM) are differentiated by countries, sectors, fuels, and durable goods (e.g. cars, heating systems) that use the fuels and are linked to the use of oil, coal, and gas. This link concerns the energetic use of these inputs only. Non-energetic use like refinery and processing is treated separately. To be able to examine excise taxes on energy, the energy content of fuels and electricity is also considered. For private consumption the major links between energy inputs and consuming durable goods are specified: cars and gasoline, heating systems and oil, coal, gas and electricity and electrical appliances and electricity.

There are three mechanisms of emission reduction are explicitly specified in the model:

- End-of-pipe abatement (where appropriate technologies are available)
- Substitution between fuels and/or between energetic and non-energetic inputs
- Emission reduction due to a decline in production and/or consumption

The dual formulation of the GEM-E3 model eases the incorporation of changes in economic behaviour due to emission or energy based environmental policy instruments. The costs of environmental policy requirements are added to the input (and consumption) prices. Intermediate demand is derived from the unit cost function which takes these extra costs into account. Similarly the demand of households for consumption categories is derived from the expenditure function, which is the dual of the utility function. Hence, the additional policy constraint is easily reflected in prices and volumes.

The model takes into account the transboundary effects of emissions through transport coefficients, relating the emissions in one country to the deposition/ concentration in the other countries. For secondary pollutant as tropospheric ozone, it implies to consider the relation between the emissions of primary pollutants (NO_x emissions and VOC emissions for ozone) and the level of concentration of the secondary pollutants (ozone).

Damage estimates are computed for each country and for the EU-24 as a whole, making the distinction between global warming, health damages and others. The figures for damage per unit of emission, deposition or concentration and per person and their valuation are based on the ExternE project results.

The Behavioural Module

1. Mechanisms of Emission Reduction

There are three mechanisms that affect the level of actual emissions in the model:

Emission Abatement Mechanisms

- End-of-pipe abatement (SO_2, NO_X, VOC and PM): end-of-pipe abatement technologies are formulated explicitly by bottom-up derived abatement cost functions. These cost functions differ between sectors, durable goods, and pollutants but not between countries. It is assumed that these abatement technologies are available all over Europe at the same costs. But, as the marginal costs of abatement are an increasing function of the degree of abatement, these costs differ nevertheless between sectors and countries according to the country- or sector-specific abatement efforts already done.
- Substitution of fuels (all fuels): as the production of the sectors is specified in nested CES-functions, there is (at least for a substitution elasticity greater than 0) some flexibility on the decision of intermediates. The input demand is linked to the relative prices of these inputs. Hence, if there is an extra cost on energy inputs, there will be a shift in the intermediate demand away from 'expensive' energy inputs towards less costly inputs. A politically imposed cost on emissions therefore drives substitution towards less emission intensive inputs, e.g. from coal to gas or from energy to materials, labour or capital.
- Decline in production: in a general system that covers the interdependency of agents decision, imposing an environmental constraint (through standards, taxes or other instruments) causes additional costs to production (which is linked to the costs of substitution or abatement installation). An increasing selling price decreases demand of these goods even if this demand is inelastic to price changes (which is usually not the case) because of budget constraints. This lowers production and accordingly the demand for intermediates. Hence, there is an emission reduction due to a demand driven decline in production.

The abatement activities are modelled such as to increase the user cost of the polluting input (here the price of energy) in the decision process of the firm. When an environmental tax is imposed it is paid to the government by the branch causing the pollution. This has the following implications for the *energy price* modelling:

- The price of energy, inclusive abatement cost and taxes, is used in the decision by the firm on production factors (at the energy level and implicitly at the level of aggregates); it represents the user's cost of energy

- The price of energy, exclusive taxes and abatement cost[40], is used to value the delivery of the energy sectors to the other sectors

- A price for the abatement cost per unit of energy has been defined, because the abatement cost is defined in constant price

In the modelling of the *abatement activities*, installing abatement technologies has been considered as an input for the firms and not as an investment. The major advantage of this formulation is its simplicity, especially as the available abatement cost functions are in terms of annualised cost, and because, with this framework, the abatement costs do not increase directly GDP as it would if modelled as investment. For the latter purpose a depreciation and replacement mechanism would have to be introduced. The user's cost of the abatement equipment would have to be added to the capital income, avoiding however any double counting. The input demand for abatement is modelled in the following way:

the demand for abatement inputs is allocated to the delivery sectors through fixed coefficients;

the total delivery for abatement is added to the intermediate demand and these inputs are valued as the other intermediate deliveries.

The consumer's behaviour

The consumer's side modelling is rather similar to the one used for the firm, with one difference regarding the payment of the environmental taxes to the government. While in case of firms, the environmental taxes are paid by the branch causing the pollution, for the households the tax is paid by the branch delivering the product causing pollution to the household. The environmental tax is therefore treated as the other indirect taxes paid by households. This has the following implications for the modelling of the price equations:

the price of energy in the consumer allocation decision, includes the abatement cost and the tax; it is modelled as a user's cost of energy;

the price of delivery of energy to the household includes the pollution and/or energy tax;

---

[40] i.e. it is the same price as the one in the model without environmental module.

a price for the abatement cost is defined in the same way as for the branches.

The abatement expenditure of households are modelled as in the production sectors (allocation to branches through fixed coefficient and valued as the other deliveries). They are not added to the private consumption and do not enter directly in the allocation of total consumption by categories, only indirectly through the user's cost of durables as they are considered as a 'linked' consumption (to energy) and are added directly to the consumption by goods of production (i.e. the deliveries by branches to the households).

3. The consumer's behaviour

The consumer's side modelling is rather similar to the one used for the firm, with one difference regarding the payment of the environmental taxes to the government. While in case of firms, the environmental taxes are paid by the branch causing the pollution, for the households the tax is paid by the branch delivering the product causing pollution to the household. The environmental tax is therefore treated as the other indirect taxes paid by households. This has the following implications for the modelling of the price equations:

- The price of energy in the consumer allocation decision, includes the abatement cost and the tax; it is modelled as a user's cost of energy

- The price of delivery of energy to the household includes the pollution and/or energy tax

- A price for the abatement cost is defined in the same way as for the branches

The abatement expenditure of households are modelled as in the production sectors (allocation to branches through fixed coefficient and valued as the other deliveries). They are not added to the private consumption and do not enter directly in the allocation of total consumption by categories, only indirectly through the user's cost of durables as they are considered as a 'linked' consumption (to energy) and are added directly to the consumption by goods of production (i.e. the deliveries by branches to the households).

4. Cost and price functions

a) End-of-pipe abatement costs

The average abatement cost reflects annualised costs and the value for the parameters in the equation are based on the estimated technical data.[41] The German database has been extrapolated to the other countries, taking into account the existing abatement levels in these countries relative to the German level.

[41] see Appendix I.

The cost functions that can be derived from this data are represented by the marginal abatement cost function.

$$m\tilde{c}^{ab}_{p,s}(a_{p,s}) = \beta_{p,s} \cdot (1 - a_{p,s})^{\gamma_{p,s}},$$

Where:

$a_{p,s}$: degree of abatement of pollutant p of sector s

$\beta_{p,s}, \gamma_{p,s}$: estimated parameters $\left(\beta_{p,s} \geq 0, \gamma_{p,s} \leq 0\right)$.

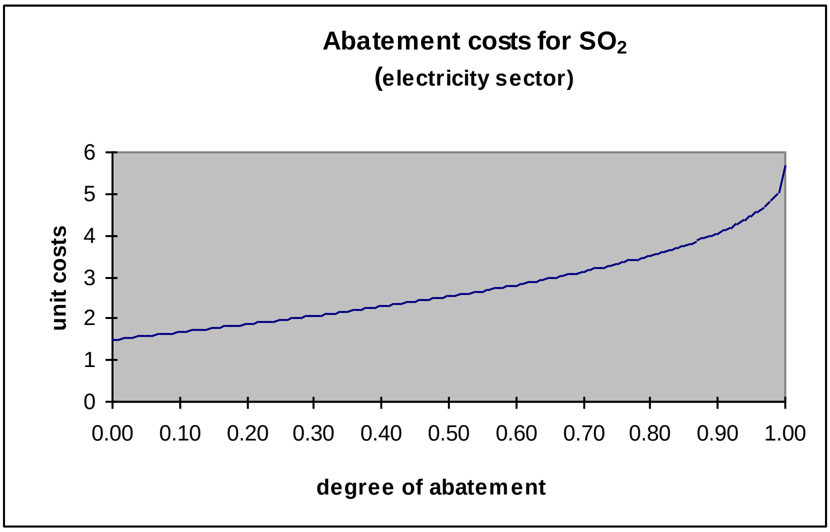
By integrating the above formula and dividing by a one obtains the average cost curve per ton unabated emission $\tilde{c}^{ab}_{p,s}\left(a_{p,s}\right)$.[42]

$$\tilde{c}^{ab}_{p,s}\left(a_{p,s}\right) = \frac{-\beta_{p,s}}{1+\gamma_{p,s}} \cdot \left(1 - a_{p,s}\right)^{\gamma_{p,s}+1} + K_{p,s}$$

The degree of abatement $a_{p,s}$ can be exogenous or determined through the implicit equation, imposing equality between marginal cost of abatement and tax.[43]

The typical slope of the cost curves obtained is depicted by figure 1 (the example shows the unit abatement cost curve of the electricity sector in DM per reduced kilogram of SO_2).

Figure 11: **Unit costs of abatement in DM per reduced kg of SO_2**



[42] This simplification requires the assumption of CRTS.

[43] see below (5)

The abatement cost function of sector s for pollutant p, given the output X_s of this sector and the degree of abatement $a_{p,s}$ is then

$$\tilde{C}^{ab}_{p,s} = \tilde{c}^{ab}_{p,s}\left(a_{p,s}\right) \cdot EM^{pot}_{p,s} = \tilde{c}^{ab}_{p,s}\left(a_{p,s}\right) \cdot \sum_i \left(ef_{p,i,s} \cdot \mu_{i,s} \cdot \alpha_{i,s} \cdot X_s\right),$$

Where:

$ef_{p,i,s}$: emission factor for pollutant p of input i in sector s

$\mu_{i,s}$: share of energetic use of demand of input i

These costs indicate an additional intermediate demand $\tilde{ABI}_{p,i,s}$; the allocation of these costs to the delivering sectors is based on the assumption of fixed coefficients[44]. The main deliveries for abatement technologies are investment goods, energy (due to a decrease in efficiency) and services (maintenance).

$$\tilde{ABI}_{p,i,s} = tab_{p,i,s} \cdot \tilde{C}^{ab}_{p,s},$$

Where:

$tab_{p,i,s}$: share of deliveries of sector i for abatement of pollutant p in sector s $(\sum_i tab_{p,i,s} = 1)$.

The deflator or price of abatement cost per unit of energy by branch is determined by the prices of the required intermediate inputs.

$$PC^{ab}_{p,s} = \sum_i tab_{p,i,s} \cdot \left(1 + t_{i,s}\right) \cdot PY_i,$$

Where:

$t_{i,s}$: indicates the indirect tax rate.

This allows calculating the average abatement cost per unit of energy by branch in value, corresponding to the abatement level:

$$c^{ab}_{p,s} = PC^{ab}_{p,s} \cdot \tilde{c}^{ab}_{p,s}$$

This cost will be used to compute the user cost of energy which the firms and households use in their decision process regarding energy inputs. For the variables

[44] Abatement is therefore not directly increasing the GDP, as it would be the case if one would treat abatement measures as investment demand solely.

$\tilde{C}^{ab}_{p,s}$ and $\tilde{ABI}_{p,i,s}$ the corresponding values $C^{ab}_{p,s}$ and $ABI_{p,i,s}$ are evaluated analogously.

Including the expenditure for abatement in the computation of intermediate demand one obtains the following input-output coefficients $\tilde{\alpha}_{i,s}$:

$$\tilde{\alpha}_{i,s} = \frac{\alpha_{i,s} \cdot X_s + \sum_p \tilde{ABI}_{p,i,s}}{X_s + \sum_{p,i} \tilde{ABI}_{p,i,s}},$$

Where:

$\alpha_{i,s}$: is the I-O coefficient without environmental policy impacts.

If an environmental policy is linked to taxes or permits, there are not only costs for emission reduction but for the actual emission caused as well ($C^{ef}_{p,s}$).

$$C^{ef}_{p,s} = c^{ef}_{p,s}\left(a_{p,s}\right) \cdot (1 - a_{p,s}) \cdot EM^{pot}_{p,s} = c^{ef}_{p,s}\left(a_{p,s}\right) \cdot (1 - a_{p,s}) \cdot \sum_i \left(ef_{p,i,s} \cdot \mu_{i,s} \cdot \alpha_{i,s} \cdot X_s\right)$$

The unit cost of an actual emitted unit of a pollutant $c^{ef}_{p,s}\left(a_{p,s}\right)$ depends on $a_{p,s}$ and the type of policy instrument imposed. While an emission standard gives no extra cost to the remaining emissions ($c^{ef}_{p,s}\left(a_{p,s}\right)$=0), emission taxes and permits lead to a $c^{ef}_{p,s}\left(a_{p,s}\right)$ greater than zero.

The total costs of emission of pollutant *p* emitted by sector *s* are:

$$C^{em}_{p,s} = C^{ab}_{p,s} + C^{ef}_{p,s}$$

The end-of-pipe abatement costs of households are specified rather similar to those of the firms except that emissions and abatement are distinguished by durable goods; i.e. for each durable a separate abatement cost function is specified. The cost prices of the inputs are the prices of the deliveries to household (by consumption categories) instead of the input prices of the firms. Using a bridge matrix that transforms abatement expenditure of households into consumption demand by goods of production closes the loop induced by the modelling of explicit abatement measures.

b) User cost of energy

At this stage of model development emissions are generated by energy consumption only. Hence, the user cost becomes a function of the price of the energy input and of the additional costs per unit of energy linked to emission or the energy content, i.e. the tax a firm has to pay for its actual emissions (and/or the energy) and the costs of abatement depending on the rate of abatement and the baseline emissions (and/or energy) coefficient. Introducing a new variable for the user cost, $PFU_{i,s}$, its equations is, for each branch s and each energy input i

$$PFU_{i,s} = \left(1+t_{i,s}\right)\cdot PY_i + c_s^{en}\cdot ec_i \cdot \chi_{i,s} + \sum_p \left(\left[\left(1-a_{p,s}\right)\cdot c_{p,s}^{ef}\left(a_{p,s}\right) + c_{p,s}^{ab}\left(a_{p,s}\right)\right]\cdot ef_{p,i,s}\cdot \mu_{i,s}\right)$$

Where:

c_s^{en} : tax on energy

ec_i : coefficient for energy content of energy input i (equal across sectors)

$\chi_{i,s}$: share of energy related use of input i in sector s.

This user cost of the energy product influences the choice between the energy products and between aggregate inputs (as it is used in the price-function of the energy aggregate F_s).

The price of the energy aggregate PF_s is then

$$PF_s = \left[\sum_i \delta_{i,s}^{\sigma_F}\cdot \overline{PFU}_{i,s}{}^{1-\sigma_F}\right]^{\frac{1}{1-\sigma_F}},$$

Where:

δ_i : distribution parameter of energy component *l*

σ_F : elasticity of substitution

$\overline{PFU_i} = {PFU_i}\big/{g_i(t)}$: price-diminishing technical progress.

The input price for electricity is affected by an energy tax only (use of electricity causes no emissions).

$$PEL_s = PELU_s = \left(1+t_{El,s}\right)\cdot PY_{El} + c_s^{en}\cdot ec_{El}\cdot \chi_{El,s}$$

Electricity and the fuels aggregate are components of the unit cost function PD_s. Hence, a more restrictive environmental policy which increases $PFU_{i,s}$ and PF_s or PEL_s, will cause an increase in the unit cost and consequently in the deflator of total demand, PY_s.

The price $\left(1+t_{i,s}\right)\cdot PY_i$ remains the delivery price of energy by the energy branches, for the valuation of $F_{i,s}$. This implies that the branch generating emission pays the environmental tax receipts, if there are any, to the government and not the branch delivering the energy product, as is the case for the other production taxes. The environmental taxes are clearly attributed to the branch generating the pollution.

As already mentioned above, the specification of the environmental costs and decisions of household is very similar to those of the firms. In absence of any environmental constraint, the user cost price p_{dur_j} is specified according to the following equation:

$$p_{dur_j} = p_j\left(r + \delta_j + \cdot t_j^{prop} \cdot (1+r)\right) + \sum_l \vartheta_{l,j} \cdot \tilde{p}_{l,j} ,$$

Where:

r : interest rate,

δ_j : depreciation rate of durable good j ,

t_j^{prop} : property taxes for durable j ,

$\vartheta_{l,j}$: minimum consumption of non-durable l that is linked to the use of durable j

$\tilde{p}_{l,j}$: price of linked non-durable good l including value added tax.

If emission costs for households are imposed, the user cost price of durable goods is increased by the costs of abatement as well as by the costs for the actual emissions.

$$\tilde{p}_{l,j} = p_l + c^{en} \cdot ec_l + \sum_p \left(\left[\left(1 - a_{p,j}\right) \cdot c_{p,j}^{ef}\left(a_{p,j}\right) + a_{p,j} \cdot c_{p,j}^{ab}\left(a_{p,j}\right)\right] \cdot ef_{p,l,j} \cdot \mu_{l,j}\right).$$

5. Abatement decision

Based on the above specification, the firms decision whether to abate or to pay taxes can be derived from profit maximisation.

$$\max_{X_s, v_{i,s}, a_{p,s}} G_s ,$$

Where:

$G_s = PX_s \cdot X_s - VC_s$ (with VC_s as variable cost function).

To ease the notation in the following presentation an input price PY_i^{act} is defined that includes emission and/or energy-taxes as well as indirect taxes.[45]

$$PY_i^{act} = (1+t_i)\cdot PY_i + c_s^{en}\cdot ec_i\cdot\chi_{i,s} + \sum_p\left[ef_{p,i,s}\cdot\mu_{i,s}\cdot\left(c_{p,s}^{ab}(a_{p,s}) + c_{p,s}^{ef}(a_{p,s})\cdot(1-a_{p,s})\right)\right]$$

The variable cost function VC_s is then given by

$$VC_s = \sum_{i=1}^{n+2} v_i\cdot PY_i^{act},$$

Where:

$v_{i,s}$: intermediate demand of input i by sector s.

As the indices $n+1$ and $n+2$ denote labour and capital, PY_{n+1}^{act} is equal to PL and PY_{n+2}^{act} is equal to PK_{post}. We suppress the notification of intervals in the following equations.

The first order conditions of the profit maximizing firm serve to determine supply and the degree of abatement. For the description of the environmental module only the latter is of interest.

As the abatement costs are not distinguished by inputs, the formula for the optimal degree of abatement of pollutant p can be reduced to the following expression:

$$\begin{aligned}
&\frac{\partial G_s}{\partial a_{p,s}} \\
&= -\frac{\partial VC_s}{\partial \vec{P}Y^{act}}\cdot\frac{\partial \vec{P}Y^{act}}{\partial a_{p,s}} = -\sum_i v_{i,s}\cdot\frac{\partial\left(\left[\left(c_{p,s}^{ab}(a_{p,s}) + c_{p,s}^{ef}(a_{p,s})\cdot(1-a_{p,s})\right)\right]\cdot\sum_i ef_{p,i,s}\cdot\mu_{i,s}\right)}{\partial a_{p,s}} \\
&\qquad = -\sum_i\left(v_{i,s}\cdot ef_{p,i,s}\cdot\mu_{i,s}\right)\cdot\frac{\partial\left(c_{p,s}^{ab}(a_{p,s}) + c_{p,s}^{ef}(a_{p,s})\cdot(1-a_{p,s})\right)}{\partial a_{p,s}} \\
&\qquad = 0
\end{aligned}$$

45 Assuming linear-homogeneity of the cost function $VC_s\left(X_s, \vec{P}Y^{act}, a_s, \overline{K}_{fix}\right)$ with respect to output (quasi-fixed capital stock) eases the solution of the maximization problem considerably. (see SCHRÖDER, MICHAEL (1991): 'Die volkswirtschaftlichen Kosten von Umweltpolitik: Kosten Wirksamkeitsanalysen mit einem Angewandten Gleichgewichtsmodell', Heidelberg, Physika.).

$$\Rightarrow \frac{\partial\left(c_{p,s}^{ab}\left(a_{p,s}\right)+c_{p,s}^{ef}\left(a_{p,s}\right)\cdot\left(1-a_{p,s}\right)\right)}{\partial a_{p,s}}=0$$

$$\Rightarrow mc_{p,s}^{ab}\left(a_{p,s}\right)+c_{p,s}^{ab}\left(a_{p,s}\right)+mc_{p,s}^{ef}\left(a_{p,s}\right)\cdot\left(1-a_{p,s}\right)-c_{p,s}^{ef}\left(a_{p,s}\right)=0$$

Hence, given an exogenous emission tax rate of $t_{p,s}^{env}$ ($c_{p,s}^{ef}=t_{p,s}^{env}$ and $mc_{p,s}^{ef}=0$) the (cost minimising) degree of abatement $a_{p,s}$ can be derived (numerically) by the following implicit equation:

$$\frac{\partial G_s}{\partial a_{p,s}}=mc_{p,s}^{ab}\left(a_{p,s}\right)+c_{p,s}^{ab}\left(a_{p,s}\right)-t_{p,s}^{env}=0$$

The abatement decision of households can be derived similarly. To reduce the complexity of the analytical solution, it is assumed that only the fixed part of the linked non-durable demand is affected by the end-of-pipe emission reduction measures. Hence, the degree of abatement is independent of the prices and quantities of the linked consumption.

The derivation of the cost minimising degree of abatement can be reduced according to the following expressions:[46]

$$\frac{\partial\tilde{u}}{\partial a_{p,j}}=\frac{\partial\tilde{u}}{\partial z_j}\frac{\partial z_j}{\partial p_{dur_j}}\frac{\partial p_{dur_j}}{\partial a_{p,j}}=0$$

$$\Rightarrow \qquad \frac{\partial p_{dur_j}}{\partial a_{p,j}}=\sum_l \vartheta_{l,j}\cdot ef_{p,l,j}\cdot\mu_{l,j}\cdot\frac{\partial\left(c_{p,j}^{ab}\left(a_{p,j}\right)+c_{p,j}^{ef}\left(a_{p,j}\right)\cdot\left(1-a_{p,j}\right)\right)}{\partial a_{p,j}}=0$$

$$\Rightarrow \qquad mc_{p,j}^{ab}\left(a_{p,j}\right)+c_{p,j}^{ab}\left(a_{p,j}\right)+mc_{p,j}^{ef}\left(a_{p,j}\right)\cdot\left(1-a_{p,j}\right)-c_{p,j}^{ef}\left(a_{p,j}\right)=0$$

Under an exogenous emission tax $t_{p,j}^{env}$ ($c_{p,j}^{ef}=t_{p,j}^{env}$ und $mc_{p,j}^{ef}=0$), the optimal degree of abatement $a_{p,j}$ is given by the following implicit equation:

$$mc_{p,j}^{ab}\left(a_{p,j}\right)=t_{p,j}^{env}$$

The Environment Module

[46] This assumption is not very restrictive as the disposable part of the linked non-durables is typically very small (around 5 to 10 %).

1. General structure

The ‘state of the environment’ module has as main objective the computation of the emissions, their transportation over the different EU countries and the monetary evaluation of the damages caused by the emissions and depositions. The analysis is conducted on a marginal basis, i.e. it assesses the incremental effects and costs compared to a reference situation.

The ‘state of the environment’ module proceeds in three consecutive steps:

- the computation of emissions of air pollutants from the different economic activities, through the use of emission factors specific to these activities

- the determination of pollutants’ transformation and transportation between countries, i.e. the transboundary effect of emissions

- the assessment of the value of the environmental damages caused by the incremental pollution compared to a reference situation in monetary terms

For each step of the environmental module, the equations and the type of data needed will be briefly described, the sources of the data and their manipulation are described in the appendices.

2. Emissions

All emission calculations start from the potential emission $EM^{pot}_{p,s}$ a sector s produces before end-of-pipe measures have been undertaken. These emissions are linked to the endogenous output, the price-dependent (endogenous) input coefficient, the exogenous emission factor and the share of the energetic use of the input demand.

$$EM^{pot}_{p,s} = \sum_i ef_{p,i,s} \cdot \mu_{i,s} \cdot \alpha_{i,s} \cdot X_s \qquad i \in I,$$

Where:

$ef_{p,i,s}$: emission factor for pollutant p using input i in the production of sector s,

$ef_{p,i,s} = 0$ for $i \neq$ emission causing energy input,

$\mu_{i,s}$: share of energetic use of demand of input i in sector s,

$\alpha_{i,s} \cdot X_s$: intermediate demand of input i for output X_s in sector s,

I: set of inputs.

For the households we write analogously:

$$EMH_{p,j}^{pot} = \sum_i ef_{p,i,j}^{\,h} \cdot \mu_{i,j}^{h} \cdot \vartheta_{i,j} \cdot z_j^{fix} \qquad i \in I_j \,,$$

Where:

$ef_{p,i,j}^{\,h}$: emission factor for pollutant p using linked non-durable good i to operate durable good j, $ef_{p,i,j}^{\,h} = 0$ for $i \neq$ emission causing energy input

$\mu_{i,j}^{h}$: share of energetic use of demand of linked non-durable good i to operate durable good j

$\vartheta_{i,j} \cdot z_j^{fix}$: fixed part of the demand for linked non-durable good i induced by use of durable good□.

$i \in I_j$: set of non-durable goods linked to the use of durable good j.

Installing abatement technologies reduces total emissions. With respect to the degree of abatement specified above one obtains the abated emissions $EM_{p,s}^{ab}$ or $EMH_{p,j}^{ab}$.

$$EM_{p,s}^{ab} = a_{p,s} \cdot EM_{p,s}^{pot}$$

and

$$EMH_{p,j}^{ab} = a_{p,j}^{h} \cdot EMH_{p,j}^{pot}$$

The remaining actual emissions ($EM_{p,s}^{ef}$ or $EMH_{p,j}^{ef}$) are then given as residual:

$$EM_{p,s}^{ef} = EM_{p,s}^{pot} - EM_{p,s}^{ab} = \left(1 - a_{p,s}\right) \cdot EM_{p,s}^{pot}$$

and

$$EMH_{p,j}^{ef} = EMH_{p,j}^{pot} - EMH_{p,j}^{ab} = \left(1 - a_{p,j}\right) \cdot EMH_{p,j}^{pot}$$

The actual emissions of primary pollutants are therefore related to the use of energy sources, the rate of abatement, the share of energetic use of the demand of input i and the baseline emission coefficient of a pollutant.

Hence, for every pollutant, sector and fuel, a reference baseline emission factor is needed, relating the baseline emissions before abatement to the energy use. For GEM-E3, the emission coefficient must be related to the energy consumption in monetary value. A conversion factor (from energy unit to monetary unit) is derived from the energy price in the model base year. Moreover, at the aggregation level of GEM-E3, energy consumption by branch includes both energy causing emissions and not causing emissions, therefore a parameter reflecting the fraction of energetic use of the energy consumption (the parameter μ in the equations above) is computed in the data calibration. The abatement level has been assumed to be zero in 1985, the calibration year for the model. The procedure for the computation of the model environmental database is described in the appendices. The data have been completely updated and extended towards the new EU countries and towards the new pollutants considered (VOC, particulates and tropospheric ozone).

3. Transformation and transport of emissions

This step establishes the link between a change in emissions and the resulting change in concentration levels of primary and secondary pollutants. The transboundary nature of pollutants leads to the necessity to account for the transport of SO_2, NO_x, VOC and particulates emissions between countries (or grids). In the case of tropospheric ozone (a secondary pollutant), besides the transboundary aspect, the relation between VOC and NO_x emissions, the two ozone precursors, and the level of ozone concentration has also to be considered.

Theoretically, the concentration/deposition *(IM)* at time t of a pollutant ip in a grid g is a function of the total antropogenic emissions before time t, some background concentration[47] *(BIM)* in every country, and other parameters such as meteorological conditions, as derived in models of atmospheric dispersion and of chemical reactions of pollutants:

$$IM_{ip,g}\ (t) \equiv im_{ip,g}\ (\,EM_{p,c}(t' \leq t),\ BIM_{ip,g}\ (t),..\ \forall\ p,\ c)\ ,$$

For the model, the equations are made static and the problem is linearized through transfer coefficients *TPC.* They reflect the effect the emitted pollutants in the different countries have on the deposition/concentration of a pollutant ip in a specific grid, such as to measure the incremental deposition/concentration, compared to a reference situation:

$$\Delta IM_{ip,g} = \sum_{p}\sum_{c} TPC_{p,ip}\left[g,c\right] \cdot \Delta EM_{p,c}\ ,$$

Where:

TPC[g,c]: is an element of the transport matrix TPC with dimension GxC. In the models the grids considered are the countries and deposition/concentration levels are national averages.

47 Resulting from natural emissions and emissions from geographic parts that are not included in the country set.

The transport/deposition coefficients for SO_2 and NO_x emissions are derived from EMEP budgets for airborne acidifying components which represents the total deposition at a receptor due to a specific source. Basically, the EMEP model is based on a receptor orientated one layer trajectory (Lagrangian) model of acid deposition at 150km resolution. Characteristics of the various pollutants and their transport across countries, as well as atmospheric conditions are taken into account. For particulates, Mike Holland (ETSU, 1997) has estimated country to country transfers of primary particulates. His computations are based on a simple model which accounts for the dispersion of a chemically stable pollutant around a source, including deposition by wet and dry processes. To convert deposition into air concentration, use was made of linear relations estimated by Mike Holland (1997). These data are given in Appendix III.

Tropospheric ozone is a secondary pollutant formed in the atmosphere through photochemical reaction of two primary pollutants, NO_x and VOC. The source-receptor relationship is not as straightforward as for acid deposition. However, it is recognised (EMEP, 1996) that there is a relatively strong linearity between change in ozone concentration and change in its precursors emissions (both VOC and NO_x), allowing an approximation through linear source-receptor relationships. The transformation matrix, established by EMEP, is given in Appendix III.

It would be useful to include the distinction in the source of emission, for instance between emissions from mobile sources and/or low height stationary sources as opposed to high stack sources as it is expected that the deposition of pollutants per unit emitted will be different in each case. However, there is no information available at this moment that allows making such distinction.

For the problem of global warming, the global atmospheric concentration matters and it is only a function of the total antropogenic emission of greenhouse gases:

$$\Delta CC_{ip,g}\ (t) = \Delta CC_{ip}\ (t) = cc_{ip}\ (\Delta TAEM_p\ (t' \le t)..\forall p)\ .$$

and then, the concentration of GHG's (greenhouse gases) must be translated into radiative forcing R and global temperature increase ΔT,

$$R(t) = f_1(\Delta CC_{ip}\ (t)\ \ \forall ip)\ ,$$

$$\Delta T(t) = f_2(R(t))\ .$$

4. Damages and their valuation

a) General structure

The approach followed here is entirely based on the framework and data derived in the ExternE project, though at a much more aggregated level. The damage occurs when primary (e.g. SO_2) or secondary (e.g. $SO_4^{=}$) pollutants are deposited on a receptor (e.g. in the lungs, on a building) and ideally, one should relate this deposition per receptor to a physical damage per receptor. In practice, dose/exposure-response functions are related to (i) ambient concentration to which a receptor is submitted, (ii) wet or dry deposition on a receptor or (iii) 'after deposition' parameters (e.g. the PH of lake due to acid rain). Following the 'damage or dose-response function approach', the incremental physical damage DAM per country is given as a function of the change in deposition/concentration (acidifying components or ozone concentration in the model),

$$\Delta DAM^{c}_{ACID,d}(t) = dam^{c}_{ACID,d}(\Delta IM_{ip,c}(t),.. \ \forall \ ip) \ ,$$

In the case of global warming, damage is a function of the temperature rise,

$$\Delta DAM^{c}_{GLOBWAR,d}(t) = dam^{c}_{GLOBWAR,d}(\Delta T(t),..) \ .$$

The damages categories considered in the model are

1. damage to public health (acute morbidity and mortality, chronic morbidity, but no occupational health effect)

2. global warming

3. damage to the territorial ecosystem (agriculture and forests) and to materials,

4. this last category being treated in a very aggregated way at this stage.

The impact on biodiversity, noise or water is not considered, either because there are no data available that could be applied in this study or because air pollution is only a minor source of damage for that category.

For the monetary valuation of the physical damage, a valuation function VAL for the physical damage is used:

$$VAL^{c}_{o}(t) = val^{c}_{o}(\Delta DAM^{c}_{o,d}(t),.. \ \forall d) \ .$$

The economic valuation of the damage should be based on the willingness-to-pay or willingness to accept concept. For market-goods, the valuation can be performed using the market price. When impacts occur in non-market goods, three broad approaches have been developed to value the damages. The first one, the contingent valuation approach, involves asking people open- or closed-ended questions for their willingness-to-pay in response to hypothetical scenarios. The second one, the hedonic price method, is an indirect approach, which seeks to uncover values for the non-marketed goods by examining market or other types of behaviour that are related to the environment as substitutes or complements. The last one, the travel cost method, particularly useful for valuing recreational impacts, determine the WTP through the expenditure on e.g. the recreational impacts.

It is clear that measuring environmental costs at the global level as in this model, raises different problems, which are extensively discussed in ExternE:

transferability of the results from specific studies, time and space limits, uncertainty, the choice of the discounting factor, the use of average estimates instead of marginal estimates and aggregation. However, despite all these uncertainties, it is possible, according to ExternE, to give an informative quantified assessment of the environmental costs.

b) Impact on Public Health

The ExternE project retains, as principal source of health damages from air pollution, particulates[48] resulting from direct emission of particulates or due to the formation of sulphates (from SO_2) and of nitrates (from NO_x), and ozone. They retain also a direct effect of SO_2 but no direct impact of NO_x because it is likely to be small. Direct damages from VOC are not yet considered here, because the ExternE figures are still at a preliminary stage. The assessment of health impacts is based on a selection of exposure-response functions from epidemiological studies on the health effects of ambient air pollution (both for Europe and the US). They are reported in the ExternE reports (1997 & 2000) and summarised hereafter. For sulphates, the dose-response functions associated with PM2.5 are taken into account, whereas for nitrates the dose-response functions associated with PM10 are used. ExternE recommends also the use of the E-R functions related to PM2.5 for the particulates with as primary source transport[49]. When chronic mortality impacts are explicitly accounted for, one must exclude the acute mortality impacts because they are already considered in the former (Hurley et al., 1997).

Table 2: **Health impact of pollutants from ExternE (in cases/(yr-1000people-µg/m^3)**

Pollutant	Effect	Rate
PM10	Acute mortality	0.00399
ug/m3	Respiratory hospital admissions	0.00207
	Congestive heart failure	0.00259
	Cerebrovascular hospital admission	0.00504
	RADs	20.00000
	Bronchodilator usage by children for asthma	0.54250
	Bronchodilator usage by adults for asthma	4.56376
	Cough in asthmatic children	0.93100
	Cough in asthmatic adults	4.69284
	Wheeze in asthmatic children	0.72030
	Wheeze in asthmatic adults	1.69681
	Chronic mortality	0.15700
	Chronic bronchitis in adults	0.03920
	Change in prevalence of children with bronchitis	0.32200
	Change in prevalence of children with chronic cough	0.41400

[48] PM10, i.e. particulates of less than 10 µg/m^3 aerodynamic diameter, is taken as the relevant index of ambient particulate concentrations.

[49] This is not yet implemented in GEM-E3, as the emissions/deposition/concentration relations are computed for the aggregate level.

PM2.5	Acute mortality	0.00677
ug/m3	Respiratory hospital admissions	0.00346
	Congestive heart failure	0.00433
	Cerebro-vascular hospital admission	0.00842
	RADs	33.60000
	Bronchodilator usage by children for asthma	0.90440
	Bronchodilator usage by adults for asthma	7.60206
	Cough in asthmatic children	1.56100
	Cough in asthmatic adults	7.82046
	Wheeze in asthmatic children	1.20050
	Wheeze in asthmatic adults	2.82802
	Chronic mortality	0.26000
	Chronic bronchitis in adults	0.06240
	Change in prevalence of children with bronchitis	0.53800
	Change in prevalence of children with chronic cough	0.69200
O3	Acute mortality	0.01168
6hr ppb	Respiratory hospital admissions	0.00709
	Minor RADs	15.61600
	Change in asthma attacks (days)	0.30030
	Symptom days	66.00000
SO_2	Acute mortality	0.00719
ug/m3	Respiratory hospital admissions	0.00204

For the valuation of the different health impacts a distinction is made between morbidity and mortality impacts. The valuation of **morbidity** is based on estimates of WTP to avoid health related symptoms, measured in terms of respiratory hospital admissions, emergency room visit, restricted activity days, symptom days, etc. They are based on an extensive study of the literature on the costs of morbidity, mainly US based. In general the WTP for an illness is composed of three parts: the value of the time lost because of the illness, the value of the lost utility because of the pain and suffering and the expenditure on averting and/or mitigating the effects of the illness. The costs of illness (COI) are measured directly: the actual expenditure associated with the different illnesses plus the cost of lost time (working and leisure time). The other cost components, which are more difficult to evaluate, are measured by CVM methods (for the value of pain and suffering[50]) and models of averting behaviour. When no WTP estimates is available, the COI approach was followed and a ratio of 2 for WTP/COI for adverse health effects other than cancer and 1.5 for non fatal cancer was assumed.

For the valuation of the **mortality** effect, ExternE has changed the approach followed compared to their first report: instead of the 'value of a statistical life' approach (VSL) used in the first report it uses the 'value of life years lost' approach (VLYL), because the E-R functions used are closer to this concept for most health impacts (see Markandya, 1997)[51]. Because of the limited empirical evidence on the

[50] The altruistic cost, i.e. pain and suffering to other people is not included in the ExternE figures

[51] The VSL estimates are based on studies of individuals with normal life expectancies whereas the pollution impacts for some kinds of mortality were on individuals with much shorter life expectancies.

value of VLYL, ExternE estimates it, based on the following relationship between VSL and VLYL:

$$VSL_a = VLYL_r * \sum_{i=a+1}^{T} P_{i,a} \Big/ (1+r)^{i-a}$$

Where:

a: is the age of the person whose VSL is being estimated

$P_{i,a}$:is the conditional probability of survival up to year i, having survived to year *a*

T: is maximum life expectancy and r the discount rate

Starting from a VSL of 3.14 millions ECU 1995 (for males between 35 and 45) and survival probabilities with age 35 and age 45, Markandya (1997) obtains an average value of VLYL ranging from 98000 ECU1995 with a 0% discount rate to 312000 ECU1995 with 10% discount rate. Chronic mortality effects only occur after a certain delay and this is taken into account by computing an average VLYL over the latency period (Markandya, 1997) :

$$VLYL^{r}_{chronic} = \sum_{i=1}^{T} \frac{YOLL_i}{YOLL_{tot}} * \frac{VLYL^{r}}{(1+r)^{i-1}}$$

Where:

$YOLL_i$: is the number of years of life lost in each future year

$YOLL_{tot}$: is the total number of years of life lost in the population.

With a 0% discount rate both values for *VLYL* are the same.

The valuation of a statistical life should take into account the growth per capita when using these figures for evaluation of the damages over time (see Markandya, 1997). The valuation figures used in ExternE are summarised in Table 3: **Valuation of mortality and morbidity impacts from ExternE (ECU 1990)**:

Table 3: **Valuation of mortality and morbidity impacts from ExternE (ECU 1990)**

Mortality	
Statistical life	2600000
Lost life year	81000
Acute Morbidity	
Hospital admission for respiratory or cardiovascular symptoms	6500
Emergency room visit or hospital visit for childhood croup	185
Restricted activity days (RAD)	62
Symptoms of chronic bronchitis or cough	6
Asthma attacks or minor symptoms	31

Chronic Morbidity	
Chronic bronchitis/asthma in adults	87000
Non fatal cancer/malginant neoplasm	372000
Changes in prevalence of cough/bronchitis in children	186

Putting the impact and valuation data together, an estimation of the health damage figure per incremental pollution can be computed for PM10 en PM2.5 (direct and indirect), for SO_2 (direct) and ozone.(Table 4):

Table 4: **Damage from an increase in air pollution (10^6 ECU90 per 1000 persons)**

From an increase of one μg/m^3 of PM10 concentration	0.008322
from an increase of one μg/m^3 of PM 2.5 concentration	0.013631
from an increase of one μg/m^3 of SO_2 concentration	0.000596
from increase of one ppb of ozone concentration	0.001510

c) Impacts on Territorial Ecosystems and Materials

Damage on agriculture and forest is done by foliar uptake or due to acid deposition on the soil. It is often not possible to accredit damage to a specific stress agent and multiple stress hypotheses have been proposed (climate, pests, pathogens). Damage related to chronic exposure is usually different from the acute injury. In some areas plants have been found to grow better in the presence of low levels of fossil fuel related pollution than without any pollution because sulphur and nitrogen are essential nutrients for living organisms (fertilisation). At higher concentrations however pollutants interfere with plant functions and cause damage. A given dose of a pollutant will produce a variable response depending on a wide range of factors: species affected, age of the organism, other pollutants, time of day or season, temperature, water status, light conditions, soil and plant nutrient status, heavy metals in the soil, etc. Moreover, especially in agriculture land, actions are taken to counteract the effect of pollution. These different elements make it very difficult to assess the impact of incremental air pollution.

The ExternE gives the following table for the importance of pollutants for different damage categories.

Table 5: **Importance of pollutants vs damage categories**

	Forests	Crops	Fisheries	Natural
SO_2	XX	XX	0	XX
NO_x	X	X	0	X
NH_3	X	X	0	X
O_3	XXX	XXX	0	XXX
Total acid	XXX	X	XXX	XXX

Total N	XXX	0	XX	XXX

0: not ecologically significant

X: indirect effects

XX: significant effects in some areas

XXX: direct and significant effects in large areas of Europe

Source: ExternE

Agriculture

ExternE has examined in detail the assessment of the direct impact of SO_2 and NO_x on the yield of a limited number of crops (rye, oats, barley, peas, beans and wheat) through the use of exposure-response functions, on the increased liming requirement to compensate for acid deposition and on the reduced nitrogenous fertiliser requirements through deposition of oxidised N. They did not take into account interactions with pathogens, pests or other pollutants. At this stage of the research, the estimated effects on agriculture are small. For the valuation of the damages ExternE used world prices, assuming that the prices are not affected by the effects of emissions.

Forests

As there are no models both widely applicable and well accepted to predict forest response to pollution, ExternE has made tentative estimations of the forest damage, more with a methodological objective than with the objective to give complete results for the assessment of the forest damage. Their approach is based on the critical load/level concept to identify the sensitive areas and on correlation measures between forest damage and critical load/level exceedance. The critical pollutants are SO2, NOx, NH3, O3 and acidity, but the knowledge on their effects is still limited. The valuation should be based on the various components of the value of forests (timber value, recreational value, water management and wildlife habitat, CO2 uptake and storage, etc.).

Impacts on materials

Discoloration, material loss and structural failure are the main impact categories for most materials, which result from interactions with acidifying substances like SO_2 and NO_x, particulates and ozone. The impact is highly dependent on the material in question: buildings, textile, paper, etc. ExternE considers that discoloration and structural failure resulting from pollutant exposure are likely to be small, though there are no specific studies estimating these possible damages. Therefore their analysis has been limited to the effect of acidic deposition on corrosion, the direct effect of SO_2 and the effects of acidity resulting from SO_2 and NO_x. Damage from ozone has not been considered because further research is still needed on ozone formation and on the effects of ozone on materials. The materials for which damage have been considered are calcareous stone, mortar, paint, concrete, aluminium and galvanised steel and the study concentrates on 'utilitarian' buildings (houses, shops, factories, offices and schools), buildings of aesthetic or cultural merit were not considered. Specific dose-response functions for each material were derived from a literature review: 14 dose-response functions were selected, linking the deterioration of materials to SO_2 and O_3 concentration, acidity and meteorological conditions. For non-historic buildings the valuation could be based on the repair cost, for non historic buildings on CVM or travel cost method, but at this stage the results are very preliminary.

Damage to territorial ecosystems and materials in GEM-E3

Because of the great uncertainty around dose response functions, the valuation of the damages and the aggregation level of GEM-E3, it was impossible to derive a damage impact coefficient with a valuation term associated to it for each category of damage. Moreover first results from ExternE showed that they were relatively less important than public health impact: in the first ExternE evaluation they represented approximately 25% of total damage from particulates (direct and indirect). Therefore Mike Holland (ExternE, ETSU) computed an average damage cost per person from ExternE detailed computations to be used in GEM-E3 as an indicative value.

Table 6: **Damage from an increase in air pollution (10^6 ECU per 1000 persons)**

from an increase of one $\mu g/m^3$ of sulphite concentration	0.0028
from an increase of one $\mu g/m^3$ of nitrite concentration	0.0018

Global Warming

For global warming, estimates of the marginal cost of one ton of carbon emitted in the period 2000 to 2010 range between 7$/ton of C (Nordhaus, 1993) to over 150$/ton of C (Cline,1992). This high range results more from differences in the basic assumptions than in the methodology. Important assumptions are the discount rate, the rate of population growth, the rate of technical progress in general and the development of carbon free energy sources in particular. A more complete discussion about global warming damage estimates is presented in ExternE, in the context of the coal fuel cycle. The estimate used in GEME3 is 22.8$/ton of C for the World and 5.38$ for Europe (Fankhauser, 1993).

Chapter

5

Model Extensions

This chapter refers to the GEM-E3 IC Model Extension that has been developed quite recently

Model Extension 1: Imperfect Competition (IC)

1. Model Specifications

The modelling of imperfect competition in a CGE model as GEM-E3 relies on two concept, the 'love of variety' concept and economies of scale.

The 'Love Of Variety' Concept

This concept introduced by Dixit and Stiglitz (1977) expresses the desirability of variety. As they say, this desire of variety is implicitly embodied in the convexity of the indifference curves of a conventional utility function (higher preference for the mix of two commodities when the consumer is indifferent between both commodities). Having less variety (e.g. through scale economies allowing the saving of resources by producing fewer goods but larger quantities of each) will entail a loss in welfare.

This concept can be modelled by considering an additional lower level in the consumption function, representing the choice between different varieties of a same good. Hence the products of different producers/suppliers are imperfect substitutes in demand. It seems reasonable to assume that the different varieties of a good are better substitutes between them than with the other goods.

Considering a CES function for representing the substitution between the different varieties of goods and assuming weak separability relative to the upper levels, the aggregate of the varieties can be given by the following expression when the varieties enter the consumer preferences symmetrically (concave and symmetrical subutility function):

$$D_g = \left(\sum_{i=1}^{n} (d_i)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$$

Where:

D_g : is the aggregated good g demand

d_i : is the demand for a variety of the good considered

σ: is the substitution elasticity between varieties[52] and n the number of varieties (or firms if each firm produces one variety).

If an equivalent symmetry assumption is also made on the firm's cost function, total output per variety is equal at equilibrium.

This concept can also be applied on the production side: the benefit of input variety is translated into a productivity effect, i.e. more efficient options in the production process because more differentiated inputs.

This specification of consumer choice is incompatible with a constant return to scale technology where the number of suppliers is indeterminate, so it necessitates the simultaneous introduction of economies of scale which put then an upper bound on the number of varieties supplied at equilibrium.

Economies of Scale

The presence of economies of scale in production or increasing returns is another reason to model imperfect competition, as they are inconsistent with perfect competition (except in special cases): marginal cost pricing implies losses. Therefore their presence necessitates defining a market structure which implies prices above marginal costs.

Scale economies are modelled by assuming a fixed cost element, which generates then decreasing unit cost functions. For instance, certain fixed output-independent amounts of labour and capital are required per firm to maintain the capacity to produce any output, the variable output-dependent input requirement being determined by a 'classic' production function.

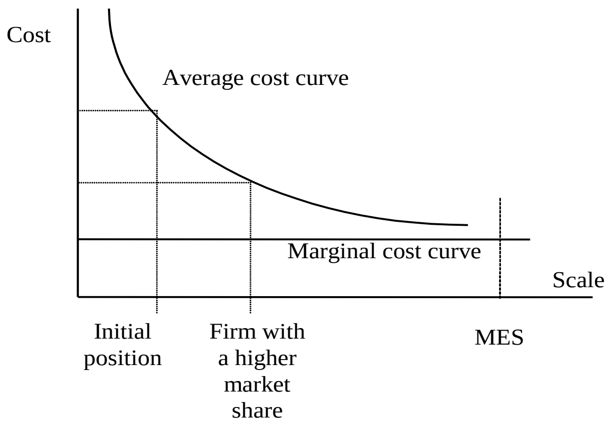
Empirical cost studies based on the engineering approach as surveyed by Pratten (1988), report estimates of the MES, minimum efficient scale, beyond which long run unit cost function reductions become negligible, as represented in the figure below. These studies report also an estimate of the unit cost gradient at ½MES.

The figure below illustrates the assumed average and marginal cost curves. If production scale by firm increases, the share of fixed costs in total costs decreases

52 The substitution elasticity has to be larger than one, otherwise marginal revenue in monopolistic competition is negative.

resulting in efficiency gains. The curve in the figure shows that costs are steeply declining when production is low, and almost flat when it is high. The lowest level of the curve, assumed never to be achievable, corresponds to the Minimum Efficiency Scale (MES). The concept is based on engineering considerations. The horizontal marginal cost curve, is tangent to the average cost curve at the MES point. Firms mainly operate at a point that stands at the left of the MES. The degree at which they are, initially, within the deeply declining region of the average cost curve, largely determines the degree of positive gains resulting from market enlargement.

Figure 12 : **Love of variety and the demand addressed to firms**



Consumers (i.e. firms, in intermediate consumption and investment, private consumers and the government) all may benefit from product variety expansion and can achieve efficiency gains, in the volume and costs of their consumption. In this sense, technical progress due to increasing specialization, is endogenously modeled, as an indirect consequence of the expansion of product variety. While in production a decrease in industrial concentration (increase of the number of firms) will incur proportional increases in the demand for production factors, the effect on demand is non-linear: households are assumed to be attracted by product variety (they prefer two units of consumption coming from two varieties to the same amount coming from one variety), while use of new varieties in intermediate consumption and investment generates gains similar to factor productivity gains. An increase in the number of varieties available in the market, means that same volume of demand (or the same level of utility) can be satisfied by a lower volume of goods. This will have an additional positive effect on the economy, since it entails that capacity constraints are relaxed and economic growth can ensue.

In the model, according to Dixit and Stiglitz approach, demand for the domestically produced variant (XXD_{PR}) and imports distinguished by country of origin $IMPO_{PR,EU,CO}$ are further disaggregated into demand for firm-specific varieties[53]. Each firm within an IC branch, produces a variety of the sectoral

[53] Note that that in all equations apart from the trade equations, the country suffix is omitted.

commodity. The varieties are not perfect substitutes within the demand addressing sector's supply.

So for the IC branches, XXD_{PR} and $IMPO_{PR,EU,CO}$ become themselves aggregators defined over sector's PR demand for the output of each individual firm. Correspondingly, the prices PXD_{PR} and $PIMPO_{PR,EU,CO}$, associated with XXD_{PR} and $IMPO_{PR,EU,CO}$, become also aggregate prices.

Firms in the same country and branch are symmetric in the sense that they utilise the same technology, so that in the equilibrium, for any two given firms *k* and *λ* located in sector PR of country *EU:*

$$xxd^{k}_{PR,EU} = xxd^{\lambda}_{PR,EU} \text{ and } exot^{k}_{PR,EU} = exot^{\lambda}_{PR,EU} \qquad (1)$$

Where:

$exot^{k}_{PR,EU}$: denotes the firm-specific exports of the firm

$xxd^{k}_{PR,EU}$: the production oriented to the domestic market.

Given a sector's total demand for aggregate domestically produced goods, the following equation further allocates it across firms:

$$XXD_{PR} = \left[\sum_{k}^{n_{PR}} (xxdf_{PR})^{\frac{s_{PR}-1}{s_{PR}}} \right]^{\frac{s_{PR}}{s_{PR}-1}} = n_{PR}^{\frac{s_{PR}}{s_{PR}-1}} \cdot xxdf_{PR}$$

PXD_{PR} is then the dual associated price index

$$PXD_{PR} = \left[\sum_{k}^{n_{PR}} (pxdf_{PR})^{1-s_{PR}} \right]^{\frac{1}{1-s_{PR}}} = n_{PR}^{\frac{1}{1-s_{PR}}} \cdot pxdf_{PR} \qquad (2)$$

Where:

n_{PR}: is the number of firms

s_{PR} : is the elasticity of substitution between firm-specific product varieties.

These are assumed close but not perfect substitutes[54] so $s_{PR} >> 1$. The derived demand function for individual firm-specific products is derived by applying Shephard's lemma to the unit cost function:

[54] See Willenbockel (1994) for a survey of numerical values for this elasticity.

$$xxdf_{PR} = XXD_{PR}^{k} \cdot \left(\frac{PXD}{pxdf} \right)^{s_k} \quad (3)$$

The bottom level nesting for bilateral imports $IMPO_{PR}^{EU,CO}$ is:

$$IMPO_{PR,EU,CO} = \left[\sum^{n_{CO}} (impof_{PR,EU,CO})^{\frac{s_{CO}-1}{s_{CO}}} \right]^{\frac{s_{CO}}{\sigma_{CO}-1}}$$

$$= n^{\frac{s_{CO}}{s_{CO}-1}} \cdot impof_{PR,EU,CO}$$

and the associated price indices:

$$PIMPO_{PR,EU,CO} = \left[\sum^{n_{CO}} (pimpof_{PR,EU,CO})^{1-s_{CO}} \right]^{\frac{1}{1-s_{CO}}}$$

$$= n^{\frac{1}{1-s_{CO}}} \cdot pimpof_{PR,EU,CO} \quad (4)$$

Where:

s_{CO} : is the elasticity of substitution between firm-specific product varieties.

Again the firm-specific volume of imports is derived from Shephard's lemma applied to the previous equation:

$$impof_{PR,EU,CO} = IMPO_{PR,EU,CO} \cdot \left(\frac{PIMPO_{PR,EU,CO}}{pimpof_{PR,EU,CO}} \right)^{s_{CO}} \quad (5)$$

The specification chosen in GEM-E3 imposes a constant (and equal) elasticity of substitution between any pair of varieties within the same branch, i.e. s_{CO} and s are equal.

The equations above exemplify the discussion about efficiency gains from increasing variety. While for example, a doubling in the number of domestic firms will cause, ceteris paribus, each firm to produce half the amount it was producing before. Demand for domestic goods on the other hand, can now be satisfied using less than half from each of the firms:

$$xxf^{new} = \left(\frac{1}{2} \right)^{s/_{s-1}} \cdot xxdf^{old} < \left(\frac{1}{2} \right) \cdot xxdf^{old}$$

This effect unleashes productive resources and leads to economic growth in the context of general equilibrium with constraints on primary factor supply.

2. The firms behaviour

Firms' supply technologies

Firm-internal economies of scale in the sense of decreasing unit costs are introduced by incorporation of a recurrent annual fixed-cost element. Before the first unit of output can be produced using the production technology, fixed amounts of output-independent production factors must be hired in addition to variable, output-dependent input requirements just to maintain a firm's capacity to produce and sell its output variant. A firm's total cost function then takes the form:

$$Costf_{PR} = \{marginal\,cost\ \ function\} \cdot xdf_{PR} + \{\ fixed\,cost\}\ F_{PR} \qquad (6)$$

where the marginal cost function is identical to the one that corresponds to the PC sectors, only now at the individual firm level, depending only on the prices of the production factors, F is the total fixed cost and depends on $L^f_{i,m}$, $K^f_{i,m}$, $XI^f_{i,m}$ respectively fixed amounts of labour services, capital services and intermediate inputs, which are constant parameters numerically calibrated in accordance with the existing extraneous evidence on cost-scale relationships by industry. The volume of production of the individual firm is denoted by xdf .

It is assumed that firms in oligopolistic industries do not perceive to have monopsony power in input markets, therefore firms act as price takers in input markets. Thus, variable, output-dependent input demand per firm is derived in standard fashion from the CES production functions. Each of the individual firms chooses the optimal mix of production factors so as to minimise its variable cost.

$$\begin{cases} Min \quad PD_{PR} \cdot xdf_{PR} = \sum\limits_{BR} PIO_{PR,BR} iovf^{\text{var}}_{PR,BR} \\ \qquad\qquad\qquad\qquad + PL_{PR} \cdot lavf^{\text{var}}_{PR} + PK_{PR} \cdot kavf^{\text{var}}_{PR} \\ s.t. \quad xdf_{PR} = CES\left(iovf^{\text{var}}_{PR,BR}, kavf^{\text{var}}_{PR,t}, lavf^{\text{var}}_{PR}\right) \end{cases}$$

Where:

PD_{PR} : is the marginal cost of production

xdf_{PR} : is the volume of production of the firm

$kavf^{\text{var}}_{PR}$, $lavf^{\text{var}}_{PR}$, $iovf^{\text{var}}_{PR}$: is the variable part of the firm-specific demand for production factors (capital, labour, intermediate inputs respectively).

Following the same methodology as in the PC sectors (see previous section, equations 11-15), demand for production factors is derived.

Total demand by firm for production factors is then the sum of the variable part as derived from the cost-minimising production schedule of the producer and the fixed part which is calibrated using engineering evidence[55]:

$$KAVf_{PR} = kavf_{PR}^{\mathrm{var}} + kavf_{PR}^{fix} \qquad (7)$$

$$IOVf_{PR} = iovf_{PR}^{\mathrm{var}} + iovf_{PR}^{fix} \qquad (8)$$

$$LAVf_{PR} = lavf_{PR}^{\mathrm{var}} + lavf_{PR}^{fix} \qquad (9)$$

As all firms in the same location and industrial branch are assumed symmetric, industry-level input requirements are simply the n-fold of the respective firm-level requirements. Industry level totals for output and output-depended factors are:

$$XD_{PR} = n_{PR} \cdot xdf_{PR} \qquad (10)$$

$$IOV_{PR,BR} = n_{PR} \cdot IOVf_{PR,BR} \qquad (11)$$

$$LAV_{PR} = n_{PR} \cdot LAVf_{PR} \qquad (12)$$

Total fixed cost by sector is:

$$Fixed\ Cost_{PR} = n_{PR} \cdot \left(KAVf_{PR}^{fix} + LAVf_{PR}^{fix} + \sum_{BR} IOVf_{PR,BR}^{fix} \right) \qquad (13)$$

The firms can make positive profits or losses:

$$\begin{aligned} profitf_{PR} = {} & PS_{PR} xd_{PR} - \sum_{BR} PI_{PR,BR} \cdot xif_{PR,BR} + PL_{PR} \cdot lf_{PR} \\ & + PK_{PR} kf_{PR,t} - fixed\cos tf_{PR} \end{aligned} \qquad (14)$$

The total profit (or loss) of the branch is then added to (subtracted from) the capital value added of that branch and distributed to the rest of the economy according to the SAM.

Firm's oligopolistic behaviour

Firms in the IC branches are assumed to exert a price-setting behaviour. Their behaviour, seeking profit maximisation, depends on their perception about the adjustment ability of the demand and the reaction of their rival firms. The firms in IC branches, as indicated by the Lerner formula, set optimal profit-maximising price mark-ups on marginal cost for each market segment, based on their conjectures of their rivals' reactions to their own actions and on the demand price elasticities. Among the various oligopolistic market operation models, we adopt the

[55] The fixed part of production is different for each branch and does not necessarily includes the use of all production factors.

Cournot assumption[56]. The Bertrand assumption has been tested but is not used because its results are too close to the perfect competition case when the number of firms is above 2 to 3[57]. We only adopt the Nash variety of these assumptions involving zero and invariant conjectures[58].

The firm's optimal mark-ups depend on the perceived price elasticities of demand for its output. For two market segments, the domestic and the export market, the Lerner-type first order conditions for a profit maximum describing the optimal relationships between price and marginal cost in each market segment are:

$$PXD_{PR} \cdot \left(1 - \frac{1}{\psi do_{PR}}\right) = PD_{PR} \quad (15)$$

$$PEX_{PR} \cdot \left(1 - \frac{1}{\psi \, \mathrm{ex}_{PR}}\right) = PD_{PR} \quad (16)$$

Where:

PD_{PR} (The marginal (unit) cost of production) : is used throughout, because the products oriented to all markets are supposed to be produced using identical technology

ψdo_{PR}, and ψex_{PR}, respectively: are the perceived elasticities of demand with respect to domestic and international markets.

To compute the perceived price elasticities, it is reasonably assumed that individual firms do not have full information about the complex determination of the volume of the composite good *Y*, or that the cost of gathering this information coupled with the complexity of finding their "true" demand functions, precludes them from making use of all available information. Instead firms are characterised by bounded rationality at this stage and make simplifying working assumptions when they decide their optimal supply strategy. Specifically firms are taken to assume that top level composite demand at any sector, is governed by a constant elasticity demand function.

$$Y_{PR} = \alpha_{PR} \cdot \left(PY_{PR}\right)^{\Omega_{PR}} \quad (17)$$

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56 In the Cournot model a firm operates under the assumption that its rivals do not alter their supply quantities as a result to changes in the firm's supply. On the other hand, the firm conjectures that its rivals prices will change. This expected price change, called "conjectural variation" is assumed zero in the Bertrand case.

57 For an exploration of the alternative approaches for firm conduct, see Willenbockel (2002)

58 Other models in the literature assume conjectural variation. We avoided such an assumption because of the implied arbitrariness of the applied analysis.

Setting Ω to zero that firms ignore the effects of changes in their prices on top-level demand, while Ω=1 is equivalent to assuming that firms perceive total expenditure values to be unaffected by their actions.

Given this assumption, the elasticities are derived from the firm-level demand functions, involving the demand for the composite good[59]. The composite good includes demand by households, demand for intermediate production inputs, demand by government etc.

Considering segmented markets, the inverse perceived elasticity in the domestic market is:

$$(41)\ \frac{1}{\psi do_{PR,EU}} = -\frac{1}{s} + \frac{1}{s}\frac{1}{n} - \frac{1}{\kappa}\frac{1}{n}(1 - share_{Y}^{XXD}) + \frac{1}{\Omega}\frac{1}{n} share_{Y}^{XXD} \quad (18)$$

Where:

$share_{Y}^{XXD} = \frac{PXD_{EU} XXD_{EU}}{PY_{EU} Y_{EU}}$: is the share in value of all domestic firms in the domestic market, κ is the Armington elasticity of substitution at the top level, n is the total number of firms, s the love of variety and Ω the upper level price elasticity. The other parameters in the above are defined as follows:

For the export market, the price elasticity perceived by an individual firm is computed as the weighted average of the perceived elasticities of the demand functions of the various countries[60].

$$\psi \exp_{PR,EU} = \sum_{CO} \frac{IMPO_{PR,CO,EU}}{EXPOT_{PR,EU}} \cdot \phi_{CO,EU} \quad (19)$$

Where:

$$\frac{1}{\phi_{CO,EU}} = -\frac{1}{s} + \frac{1}{s}\frac{1}{n} - \frac{1}{\pi}\frac{1}{n} + \frac{1}{\kappa}\frac{1}{n} share_{Y}^{IMP} + \frac{1}{\Omega}\frac{1}{n} share_{Y}^{IMP}$$
$$+ (\frac{1}{\pi} - \frac{1}{\kappa})\frac{1}{n} share_{IMP_{CO}}^{IMPO_{CO,EU}}$$

Perceived price elasticities can change endogenously as they depend on a number of factors:

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[59] A more detailed explanation of the derivation of mark-up pricing rules in the context of general equilibrium models can be found in D. Willenbockel (1994).

[60] This is a simplifying assumption

- changes of the competitive environment through changes in the number of firms

- changes in the share of domestic and imported goods in final demand, or across imported goods

Number of firms

The number of firms within IC branches can endogenously vary to represent entry and exit/merging of firms. Due to its explicit dynamic character and the associated endogenisation of investment, the incorporation of entry and exit processes in GEM-E3 is an intricate problem to which the existing literature provides no guidance, since most of the existing models apart from GEM-E3 perform comparative static analyses.

In GEM-E3 the number of identical firms in a branch varies endogenously in the model. If profits are positive, then new firms may decide to enter into the market while negative profits will induce a higher industrial concentration to exploit economies of scale potential and reduce fixed costs. Two ways for this adjustment of the number of firms are supported in the model:

Instantaneous adjustment: in this model variant, the number of firms adjusts within the year/period so that net profits (inclusive of fixed costs) are always zero. In that case equation 24, is used to evaluate the industrial concentration consistent with zero profits.

Partial dynamic adjustment: the number of firms is assumed constant within each time period, but profits/losses will affect the number of firms in the next. Firm numbers change according to a dynamic adaptation mechanism

$$n_{i,t+1} = n_{i,t} + g \cdot \left(n^{\otimes}{}_{i,t} - n_{i,t} \right) \quad (20)$$

where $n^{\otimes}{}_{i,t}$ is the number of firms consistent with zero profits in the industry, and the parameter g controls the speed of adjustment. For g=1, option (b) would be equivalent to the first option. The extraneous determination of g might be broadly based on the actual evolution of concentration levels over the simulation period, but would nevertheless be somewhat arbitrary. In this modelling option firms are allowed to make profits/losses according to equation 24.

For the capital of disappearing firms, it is assumed that their capital stock is reemployed by existing firms, through instantaneous adjustment.

Calibration of Imperfect Competition Sectors with Fixed Costs

Numerical calibration of imperfect markets under economies of scale requires additional information at a more micro-level. It has not been possible to update the data from the IM study, so these data were used to evaluate the new model specification. Engineering information about sectoral technology economics, has been based on Pratten (1988). This study provides estimation of the minimum efficient scale per sector and the cost increase gradient.

The number of symmetric firms, by country and sector, has been approximated by computing Herfindahl indices for 1985 and 1992, from EUROSTAT data; these have been cross-checked with those by Bruce Lyons (East Anglia University) who provided such an index for the whole European Union in 1988; statistical rank correlation analysis showed for example that the UK numbers were close to those of the whole EU.

The calibration procedure for IC sectors starts from the computation of the fixed cost per firm. Assuming that the firm operates at zero profit in the base year, the sectoral value of mark-up can be determined, as it exactly covers the fixed cost, under a zero profit assumption for the base year. Also given the number of firms in the sector, the elasticity of substitution among varieties within each commodity category, is uniquely defined[61].

Model Extension 2: Depletable Resources Module

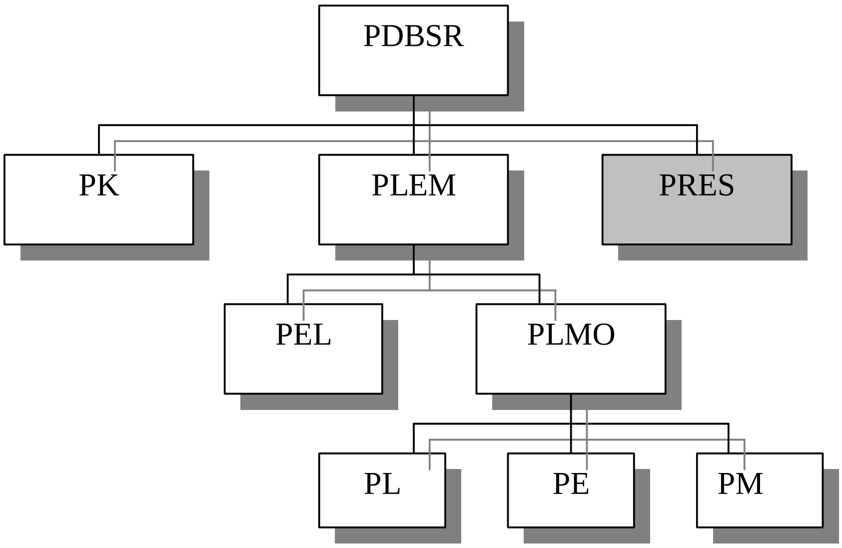
Up until now the energy supply sectors in GEM E3 were modeled in a way that was identical to any other industrial sector, without taking into account certain particular features such as the finite nature of fossil fuel resource base and without taking into consideration a mechanism for depletion. In an attempt to create a more complete and realistic representation of the supply behavior of these sectors an energy sub model was developed. Coal reserves are assumed to be sufficiently abundant in the horizon to 2030 so as to obviate the need to represent restrictive mechanisms constraining them. Therefore only the supply of crude oil and natural gas are derived from the specific sub model.

The Resource Depletion Mechanism in GEM E3

In this version of GEM E3 reserves are considered as an additional factor of production. Thus reserves of each fuel along with the capital, labour, energy and material bundle constitute the top level of the CES production function (Figure1). As indicated above this scheme applies only to the sectors of crude oil and primary gas production.

Figure 13: **Nesting Scheme of the Dual Production Function in GEM E3**

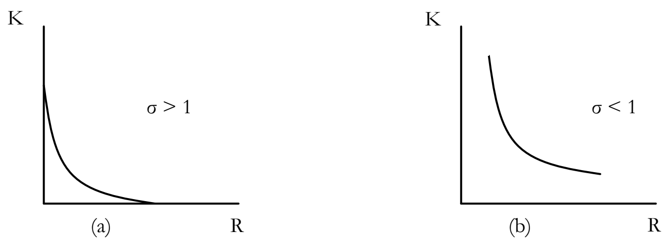
[61] See Willenbockel (1994) or Capros, Georgakopoulos et. al. (1997a) for a detailed explanation of the above process including numerical examples.



Substitution Elasticity between Production Factors

One crucial issue emerging from this modification is the determination of the substitution elasticity, among the production factors. Assuming two production factors a typical isoquant for output Q is indicated in part (a) of Figure 2. In such a case resources are not essential in the sense that they are not indispensable for output production: as the input of resources declines and approaches zero the marginal and average product of capital tend to a positive limit and do not decline to zero.

Figure 14: **Isoquants and Substitution Elasticity**

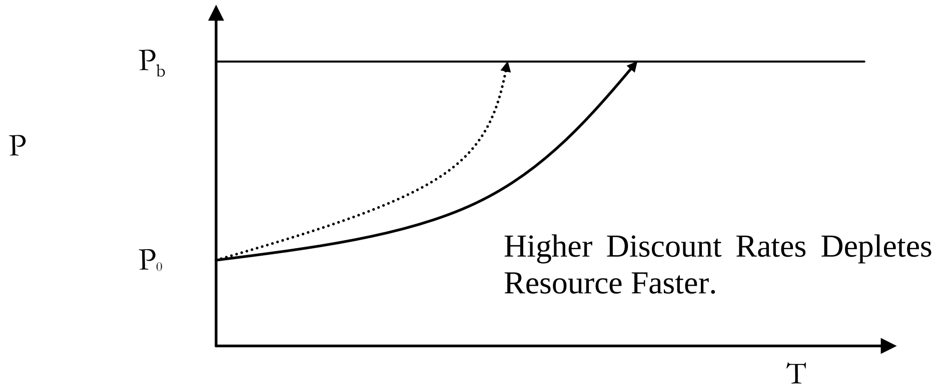


In the case where $\sigma < 1$ for each value of Q there is some minimum quantum of R which is required to make production possible, even with the assistance of an indefinitely large amount of capital (the typical isoquant is shown in figure 2 part (b)). Evidently with the substitution possibilities available in this second case ultimately production possibilities are limited. Even with an infinite capital stock there is a limit on the amount of output which can be produced with a given quantum of reserves. In these circumstances it is evident that consumption must eventually decline over time as with declining resources, the marginal product of capital falls to zero.

The Price Path and Resource Depletion

As the resource is depleted, the price rises and as the price rises the demand, and hence the consumed quantity, falls.

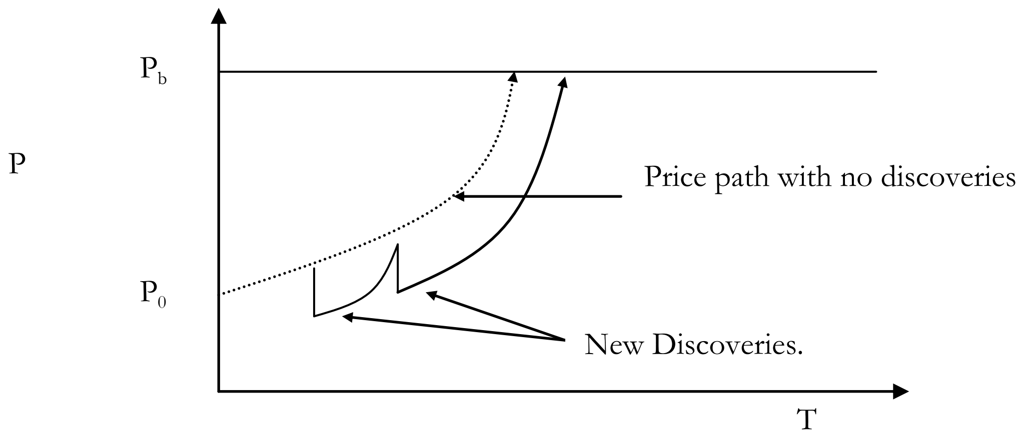
Figure 15: **Resource Depletion and Price Path**



This continues until a price is reached where an alternative technology or a substitute for the resource becomes economically viable. This is known as a backstop price. The backstop resource is on the flat part of its exploitation curve, so that the price of the resource is blocked and production ceases. At this point, the resource is said to be economically exhausted, even though there is very likely a considerable amount of the resource remaining in the ground. Figure 3 shows the consequence of a change in the discount rate, the higher the discount rate, the quicker the resource will be depleted.

Finally, the discovery of new deposits, new technologies, new strategies of conservation will introduce downward pressure on prices and extend the lifetime of the resource. If this happens at discrete times, the price path can take on a saw tooth pattern, but always displaying downward convexity.

Figure 16: **Price Path (impact of new discoveries)**



Thus the sub model makes production of each energy good to be a function of the respective reserves the latter being in turn a function of unproven reserves (yet to find reserves). Prices and quantities are derived through the optimization behavior of the economic agents.

Reserves and Yet To Find Resources.

The USGS defines **reserves** as resources that are currently identified and economical to extract. The magnitude of the overall resource base is unknown (fuzzy boundaries). As production reduces reserves, the price of the resource increases, converting some sub-economic resources into reserves by definition. The price increase also motivates increased exploration and beyond a given level substitution of alternative/non conventional resources.

For the needs of GEM E3 data related to reserves and oil in place were acquired from the most recent publication of the U.S. National Geological Survey. Table 7 and Table 8 depicts the level of reserves and yet to find reserves for oil and gas, in the 14 EU countries.

Table 7: **Production, reserves and yet to find reserves of OIL for EU (1996)**

Region	**Cumulative Production (Mbl)**	**Reserves (Mbl)**	**Undiscovered (Mbl)**	**URR (Mbl)**
United Kingdom	14.5967	4.5169	6.4920	25.6056
Germany	1.8259	0.4105	0.2069	2.4433
Italy	0.7216	0.6843	0.7428	2.1487
Denmark	0.6464	1.0000	0.1230	1.7694
France	0.6535	0.1488	0.8798	1.6821
Netherlands	0.6580	0.1198	0.4320	1.2098
Spain	0.2797	0.0270	0.6486	0.9553
Austria	0.3133	0.0705	0.0005	0.3843
Greece	0.1038	0.0120	0.0000	0.1158
Ireland	0.0000	0.0010	0.0000	0.0010

Portugal.	0.0000	0.0010	0.0000	0.0010
Belgium.	0.0000	0.0010	0.0000	0.0010
Finland.	0.0000	0.0010	0.0000	0.0010
Sweden	0.0001	0.0010	0.0000	0.0011

Table 8: **Production, reserves and yet to find reserves of GAS for EU (1996)**

Region	**Cumulative Production (Mbl)**	**Reserves (Mbl)**	**Undiscovered (Mbl)**	**URR (Mbl)**
United Kingdom	1.2032	0.7600	0.5989	2.5622
Germany	0.5201	0.2110	0.3506	1.0817
Italy	0.5125	0.2780	0.6840	1.4745
Denmark	0.0294	0.1790	0.0201	0.2285
France	0.1524	0.0140	0.4772	0.6436
Netherlands	0.5243	1.7560	0.2222	2.5026
Spain	0.0098	0.0160	0.4111	0.4369
Austria	0.0474	0.0220	0.0018	0.0712
Greece	0.0016	0.0090	0.0000	0.0106
Ireland	0.0371	0.0220	0.0000	0.0591
Portugal.	0.0027	0.0200	0.0000	0.0227
Belgium.	0.0000	0.0010	0.0000	0.0010
Finland.	0.0000	0.0010	0.0000	0.0010
Sweden	0.0000	0.0010	0.0000	0.0010

Within the model, the supply of reserves is derived from the following motion equation:

$$RES_{t,i} = RES_{t-1,i} + NRES_{t-1,i} - XD_{t-1,i}$$

where:

$RES_{t,i}$ = Reserves of fuel i at time t.

$NRES_{t,i}$ = New Reserves (discoveries) of fuel i at time t.

$XD_{t,i}$ = Production of fuel i at time t.

Moreover New Reserves (*NRES*) are a function of the Yet To Find Reserves (*YTFR*) and the rate of discovery (*d*):

$$NRES_{t,i} = (1-d_i) * YTFR_{t-1,i}.$$

Since a price signal might induce the producer to reduce or intensify exploration/drilling activity, the rate of discovery *d* has been modeled to be a function of the price of the respective fuel:

$$d(\tilde{p}_i) = \bar{d}_i \cdot \tilde{p}_i^{\,w}$$

GEM E3 modifications

The sector OIL of GEM E3 consists of both the crude oil production and refineries while the sector GAS consists of primary gas production and distribution of gaseous fuels respectively. These sectors were split up to their components and the following sectors were separately identified:

(03) Crude Oil Production.

(04) Primary Gas Production.

(19) Petroleum Refineries and Production of misc. Products.

(20) Distribution of Gaseous Fuels.

Supply and Demand

The supply of the crude oil and natural gas sector is now a function of the capital, labor, energy, materials bundle and reserves. In this section the reasoning and the general methodology applied in the GEM E3 is described.

Specifically let us consider that the energy commodity e is produced using a CES technology from resources R and a mixture of other inputs X. The unit cost function derived from a CES type production function is:

$$P_e = \left(\Theta RES_e \cdot PRES_e^{\ 1-S_e} + \Theta X_e \cdot PX_e^{\ 1-S_e} \right)^{\frac{1}{1-Se}}$$

Where:

P_e is the output price of fossil fuel e

$PRES_e$ is the price of the resource input

PX_e is an aggregate price of the unit bundle of other inputs

ΘRES and ΘX are the values shares

S_e is the elasticity of substitution.

The unit demand function for Reserves RD_e can be found by differentiating the unit cost function with respect to the price inputs:

$$R_e^D = \Theta RES \cdot \left(\frac{PRES_e}{P_e} \right)^{-s_e}$$

The technical coefficient on the resources is related to the assumed value of the resource R_e in the benchmark economic accounts by:

$$\overline{R}_e = \Theta RES \cdot \overline{Q}_e$$

At the initial equilibrium point this benchmark value must be consistent with the demand for the resource specified above, so that

$$Q_e \cdot R_e^D = Q_e \cdot \Theta RES \cdot \left(\frac{PRES_e}{P_e} \right)^{-s_e}$$

For the benchmark output $y_e = \bar{y}_e$ in a new equilibrium where prices and quantities depart from their benchmark values this expression may be inverted to obtain the unobservable price of the resource.

$$PRES_e = P_e \left(\frac{Q_e \cdot \Theta RES_e}{\overline{R}_e} \right)^{\frac{1}{s_e}}$$

Through this procedure supply and demand are specified as well as the price of reserves. In GEM E3 a calibrated share form of the production function is adopted and the corresponding unit cost function and derived demand are:

$$P = \frac{1}{TFP} \left[\left(\Theta RES^{S1} \cdot PRES^{1-S_1} \cdot \frac{RESB}{XDB} \right)^{1-S_1} + \left(\Theta KAV^{S_1} \cdot \frac{PK}{TPK} \right)^{1-S_1} \cdot \left(\frac{KAVB}{TPKB} \cdot \frac{e^{-TGK \cdot t}}{XDB} \right)^{1-S_1} + \left(\Theta LEM^{S_1} \cdot PLEM^{1-S_1} \cdot \frac{LE}{XD} \right.\right.$$

$$RES = \left(P \cdot \frac{\Theta RES}{PRES} \right)^{S_1} \cdot \left(\frac{XDB \cdot TFP}{RESB} \right)^{S_1 - 1} \cdot \frac{XD}{XXNUM}.$$

Data

The Data related to the reserves and yet to find reserves of oil and gas were obtained from the latest (preliminary) issue of the U.S. National Geological Survey. While data related to the final demand and to the capital stock, wages, imports and taxes were acquired from the GTAP v.4 database[62].

In order to make GEM-E3 results comparable with Poles results GEM-E3 regional specification changed in the following respect:

Regions/ Countries	GEM-E3 Depletable Sources Aggregation
AUZ	Australia/New Zealand
JAP	Japan
EAS	Korea/Indonesia/Malaysia/Philippines/Singapore/Thailand/ Vietnam/Taiwan
CHI	China/Hong Kong
IND	India
RAS	Rest of Asia/Sri Lanka
USA	U.S.A
CAN	Canada
LAM	Argentina/Chile/Uruguay/Central America and Caribbean/Rest of South America/Venezuela/Rest of Andean Pact
LAO	Mexico/Brazil
NEU	Denmark/Sweden/Finland
GEU	Germany
BEU	UK
REU	Rest of European Union
OEU	Iceland/Norway/Switzerland
CEA	Central European Associates
FSU	Former Soviet Union
MED	Morocco/Rest of North Africa/Turkey
MEA	Middle East
AFR	South Africa/Rest of Southern Africa/Rest of Sub Saharan Africa
ROW	Rest of World

[62] GTAP v.4 distinguishes the following EU countries: United Kingdom, Germany, Denmark, Sweden, Finland.

PART 2

Chapter

6

GEM-E3 EU Model

Which are the specific characteristics of the EU model and which are the data that are calibrated here? This chapter analyzes that frame

Data Sources for the Model

The main sources of the GEM-E3 data are:

- The Input-Output tables in producer's prices, per member-state, compiled by **Eurostat** from national sources.
- Consumption matrix, investment matrix and employment by sector, also compiled by **Eurostat**.
- The **Eurostat Energy Balances**.
- National accounts by sector and by branch from **New Cronos** of Eurostat, that (after aggregation) have been used to complete the
- Income distribution part of the Social Accounting Matrix (**SAM**) by country.
- The Trade Data of bilateral trade flows as in **COMEXT**.

The model incorporates data for 22 EU members' countries and furthermore depicts more extensively the Rest of the World by separating it into OECD non-Europe, the energy producing countries and rest of the world in order to enhance the simulation properties of the model. The following Table 9 illustrates the aggregation of the regions that included in the model:

Table 9: **GEM-E3 Regions Aggregation for EU**

Countries/ Regions	GEM-E3 Regions Aggregation

FRA	France
ITA	Italy
GBR	United Kingdom
DEU	Germany
ESP	Spain
REU15	Austria/ Belgium/Denmark/Finland/Greece/Ireland/Luxembourg/ The Netherlands/Portugal/Sweden
HUN	Hungary
SVN	Slovenia
CZE	Czech Republic
SVK	Slovakia
POL	Poland
EST	Estonia
LTU	Lithuania
LVA	Latvia

There does exist a complete data set for each of the 22 EU countries for base year 1995 (the calibration year of GEM-E3 after update of the GEM-E3 database with the latest IO tables from EUROSTAT year 1995) and values expressed in millions of ECU 1995.

The information value from GEM-E3 Model is in constant interdependence with the quality of the data, which have been used. Recent studies demonstrate evidently that even if ideally performed CGE model, can lead the research to erroneous conclusions because of inconsistency of data[63]. For the European version of the GEM E3 model we set as calibration base year the 1995.

Data requirements of the GEM-E3 EU Model related to: a) Final demand, b) Intermediate consumption, c) Government revenues, d) Bilateral trade matrices, e) Investment matrices, f) Consumption matrices, g) Transfer payments among institutional agents, h) Interest rates, i) Inflation rates, Employment. These data had to be adjusted in order to be consistent with the model nomenclature. Specifically GEM E3 distinguishes the following products/sectors:

These sectors are disaggregated based on the **G**lobal **T**rade **A**ssistance and Protection (**GTAP**) v.4[64] dataset, issued by Purdue University. The further disaggregation of the branches is illustrated below:

[63] For more analytical projections on this subject see. Mercenier *et al.* (1999)

[64] A list of applications based on the GTAP v4 framework can be found at the GTAP home page:

http://www.agecon.purde.edu/gtap/apps/

The classification of the consumption of households by purpose is as in the following table (ND stands for non durables and D for durables):

Table 10: **Classification of Consumption in GEM-E3 EU Model**

No	Purpose Name	Status
1	Food, Beverages and Tobacco	ND
2	Clothing and Footwear	ND
3	Housing and Water Charges	ND
4	Fuels and Power	ND
5	Household Equipment and Operation (excl. heating & cooking appliances)	D
6	Heating and Cooking Appliances	D
7	Medical Care and Health Expenses	ND
8	Transport Equipment	D
9	Operation of Transport Equipment	ND
10	Purchased Transport	ND
11	Communication	ND
12	Recreational Services	ND
13	Miscellaneous Goods and Services	ND

D=Durable Goods
ND=Non Durable Goods

Complete data sets for all countries were not always available and data from different sources were obtained. These data were combined in a consistent way in order to arrive at a Social Accounting Matrix for each country, with the disaggregation level required in GEM-E3. The data sources used for the implementation of this task were: EUROSTAT, New CRONOS Database, European Central Bank and in certain cases the respective statistical offices of each country. In particular the information that could not be supplied by the statistical offices was obtained from the following sources:

- Projected IO tables (Source: EUROSTAT).

- Data on National Accounts 1995 (Source: EUROSTAT)
- Bilateral trade for the product categories. (Source: COMEXT)
- Consumption by purpose and Investment by Product (Source: New CRONOS Database)
- Transfers between institutional agents (Source: New CRONOS Database)
- Capital Transfers (Source: New CRONOS Database)
- Employment (Source: New CRONOS and EUROSTAT National Accounts)
- Interest rates (Source: New CRONOS and European Central Bank)

At this point it should be noted that completed data sets were available for Greece and Denmark[65]. Moreover the statistical offices of Belgium, Germany and Ireland provided the full sequence of national accounts.

General Procedure – SAM Construction

The main sources for the data, that are in use in GEM-E3 are derived from the Social Accounting Matrix.. SAM is a quadratic matrix of monetary flows, depicting all the transactions of the economical agents during an explicit period. The number of transactional parts-agents implies explicitly the dimensions of the matrix. .

The construction of the SAM (Social Accounting Matrices) is the starting point of the model building work. In the base year, by definition the balance of flows in the SAM is satisfied in both constant and current currency. Figure 17 illustrates a comprehensive frame of the GEM E3 EU SAM.

Figure 17: **GEM E3 EU SAM (according to ESA 95 methodology)**

	Industries	**Total**	**Labour**	**Capital**	**Consumption**	**Firms**	**Investment.**	**Ch. in Stocks**	**Exports (F.O.B)**	**Total**
	1………18				Hous. Gov.		H. G. F.			
Products 1 .	Intermediate Consumption at Producers Prices.		0	0	Demand of Hous. and Gov. consumption.	0	Demand for goods for investment		Demand for Exports	**Total Demand for Goods**

[65] Since recently the complete data sets (Input Output tables, Consumption Matrices, Investment Matrices, Full sets of National Accounts) were obtained from the statistical offices of the United Kingdom and Germany, the data of these countries are expected to be slightly modified.

. 18					(+ NPIHS)					
Total	Σ(1)									
Wages and Salaries										
Social Security Contribution	Rewarding of factors from value added by sector.								Income Transfers from foreign.	**Total Factor Revenues**
Operating Surplus										
Total	Value added by Branch at basic Prices.									
Households	0									
Firms	0									
Government	Indirect Taxes									
	Direct Taxes									
	Social Security		Factor Payments to Agents According Ownership.		Income Transfers between Agents.				Income Transfers from to abroad.	
	Subsidies									
	VAT taxes									
	Duties									
	Gov. Foreign									
	Gov. firms									
G. Transfers										
Imports										
Savings	0									
Total	**Total Supply of goods**		**Total Payments of factors**		**Total Spending of Agents**					

The balance is conceived as the equality between the sum by row and the sum by column. In addition, a SAM ensures the fulfilment of the Walras law in the base year, since by construction the algebraic sum of surplus or deficits of agents is equal to zero. To understand the notation used, see Figure 19 which gives a more detailed presentation of the SAM framework, as used in GEM-E3 EU.

The SAM of GEM-E3 EU 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. Production factors include, in the SAM, only primary factors, namely labour and capital. The economic agents, namely households, firms, government and the foreign sector, are owners of primary factors, so they receive income from labour and capital rewarding. In addition, there exist transactions between the agents, in the form of taxes, subsidies and transfers. The agents distribute their income between 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 (on consumption and investment) by an economic agent determines his surplus or deficit.

Combining the Input-Output data, adapted to market prices and to national concept (instead of domestic concept), and the data of the National Accounts by sector allows building the Social Accounting Matrix for each country. The allocation of the adapted Input-Output totals to the different sectors, household, government, firms and rest of the world is rather straightforward using National Accounts data, and can be summarised as follows:

- The total labour value added is allocated to the households except for the part going to the Rest of the World

- The capital income is distributed between household, firms and government as in the National Accounts

- The social security contributions are paid by households to the government and to the firms

- Households and firms pay the direct taxes to the government.

- In the SAM it is assumed by construction that all subsidies are paid by the government to the branches. In fact a part of the subsidies is paid by the foreign sector. In order to take into account this issue we created in the "transfers part" of the SAM an imputed flow that represents the difference between the subsidies received by the branches and the actual subsidies paid by the government (this difference is attributed to the foreign sector).

- Since government does not receive the sum of the taxes on product paid by the branches (a part goes to the foreign sector) a similar treatment with subsidies has been established.

ESA 95 Methodology

The main consideration throughout the data collection exercise was to ensure the data compatibility with ESA 95 methodology. This has been achieved for all main aggregates and partly for the rest of the transactions. Moreover all values in the Social Accounting Matrices are expressed in millions of ECU 1995.

Before proceeding with the analysis of the SAM construction it should be noted that the 1995 ESA distinguishes two main valuation concepts of the flows of goods and services: purchasers' prices and basic prices:

The purchasers' price is the amount paid by the purchaser, excluding any deductible VAT, in order to take delivery of a unit of a good or service at the time and place required by the purchaser. The purchasers' price of a good includes any transport charges paid separately by the purchaser to take delivery at the required time and place.

The basic price is the price receivable by the producer from the purchaser for a unit of a good or service produced as output minus any tax payable on that unit as a consequence of its production or sale (i.e. taxes on products), plus any subsidy receivable on that unit as a consequence of its production or sale (i.e. subsidies on products). It excludes any transport charges invoiced separately by the producer. It includes any transport margins charged by the producer on the same invoice, even when they are included as a separate item on the invoice.

The difference between these two basic valuation concepts relates therefore to trade[66] and transport[67] margins on the one hand, and taxes less subsidies on products on the other. If we introduce also the concept of producers' prices (which was the main valuation concept in the former system), the difference between these two valuation concepts can be attributed to the two factors. Thus the producer price is the amount receivable by the producer from the purchaser for a unit of a good or service produced as output minus any VAT, invoiced to the purchaser. It excludes any transport charges invoiced separately by the producer.

Figure 18: **Main Steps for the GEM E3 data construction**

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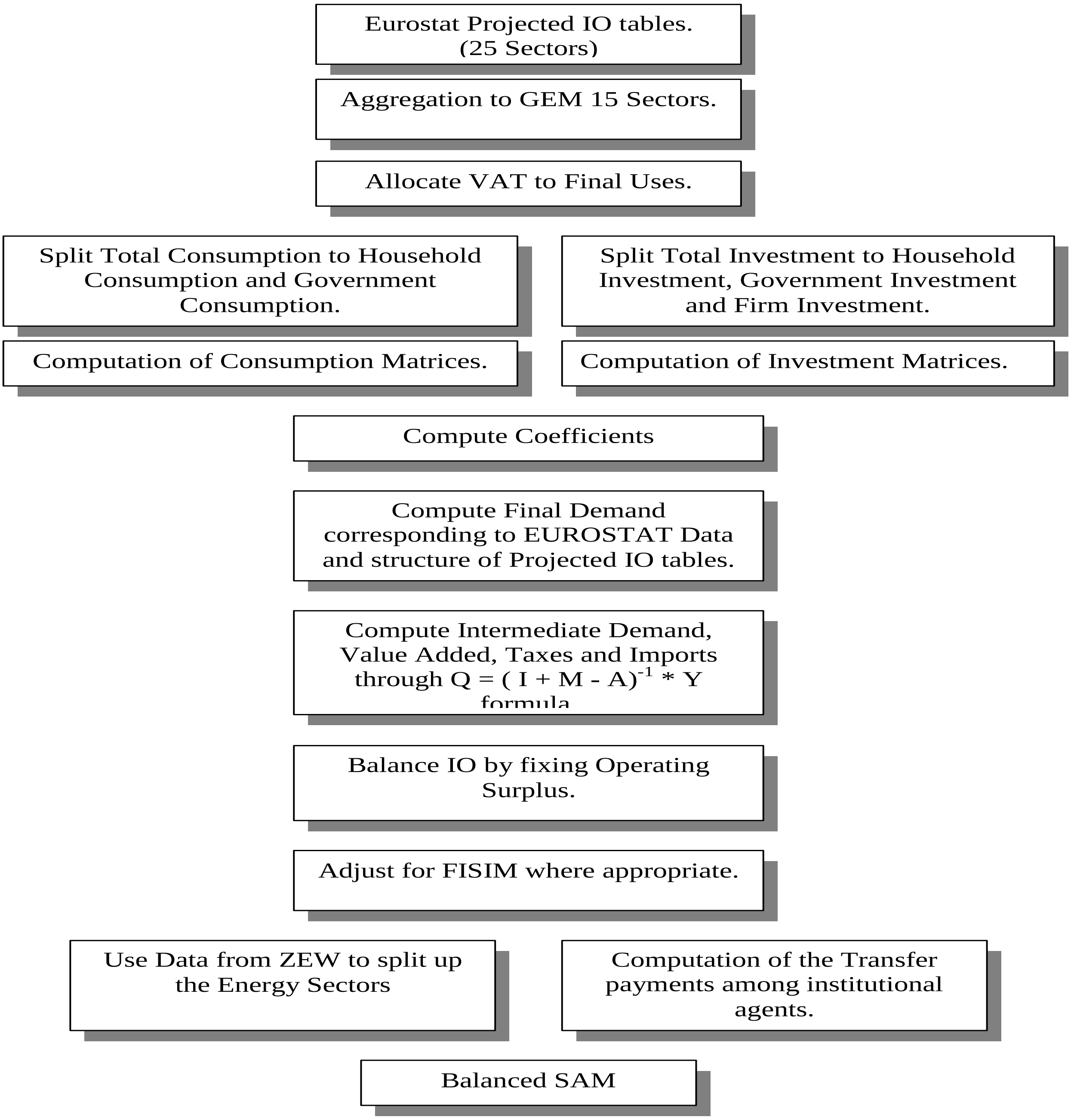
[66] The 1995 ESA defines a trade margin as the difference between the actual or imputed price realized on a good purchased for resale and the price that would have to be paid by the distributor to replace the good at the time it is sold or otherwise disposed of. By convention, holding gains and losses are not included in the trade margin. However, in practice, data sources may not allow to separate out all the holding gains and losses. Trade margins are valued at basic prices.

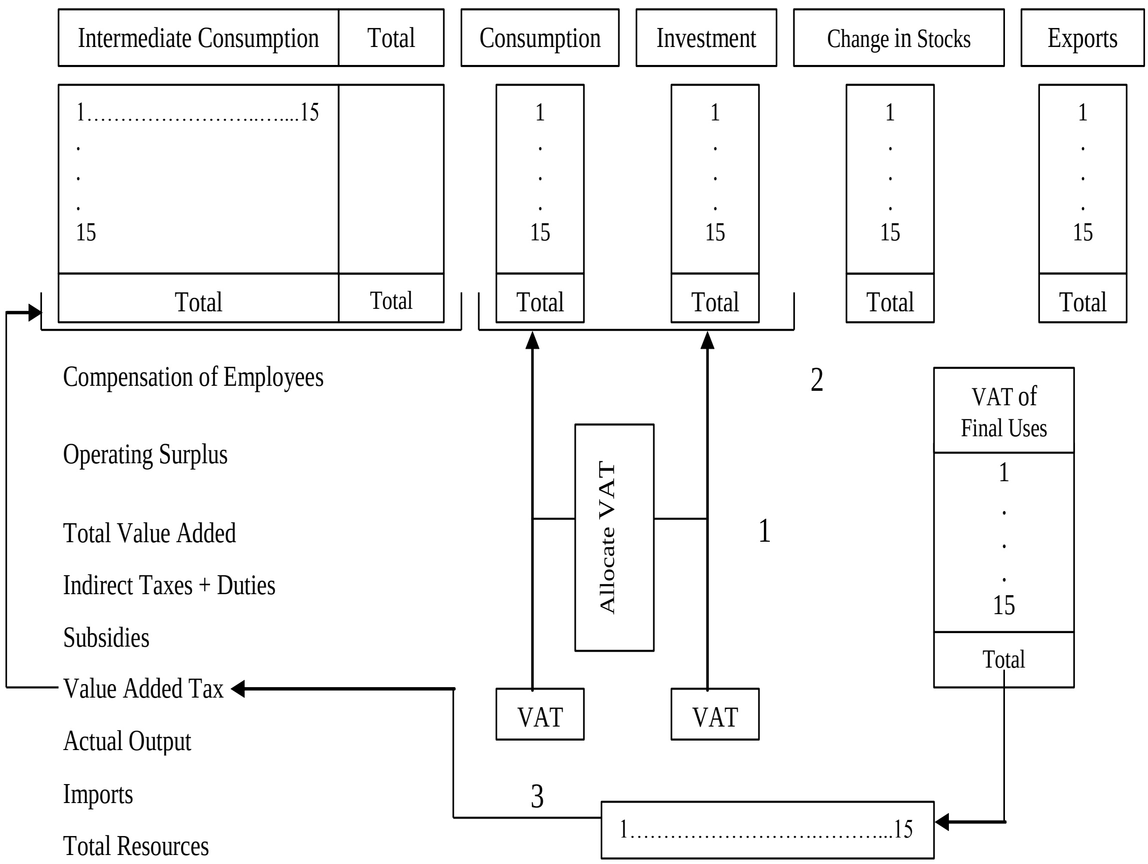
[67] The 1995 ESA defines transport margins as the transport costs for transportation of products paid separately by the purchaser and included in the use of products at purchasers' prices but not in the basic price of a manufacturers output or in the trade margins of wholesalers or retail traders.



The main steps followed during the construction of the GEM E3 data set are depicted in

Figure 18 above. For the construction of the Social Accounting Matrices the Projected IO tables had to be aggregated from 25 to 18 sectors in order to be compatible with GEM E3 data requirements. Since these tables were evaluated at producers' prices excluding VAT, a first step was to allocate the non-deductible VAT to the final uses and intermediate consumption (this action resulted an IO tables expressed at producer prices including VAT).

Figure 19: **Allocation of VAT to the Eurostats' Input Output Table (Producers' Price)**



The allocation was made by applying the VAT rates to each use. Finally in order to equilibrate the sum of the derived amount of VAT with the amount presented at the corresponding row of the projected IO tables a normalization procedure was adopted. In this way the VAT row in the projected table was replaced by the estimated non-deductible VAT by product on final uses (the procedure is depicted in figure 3).

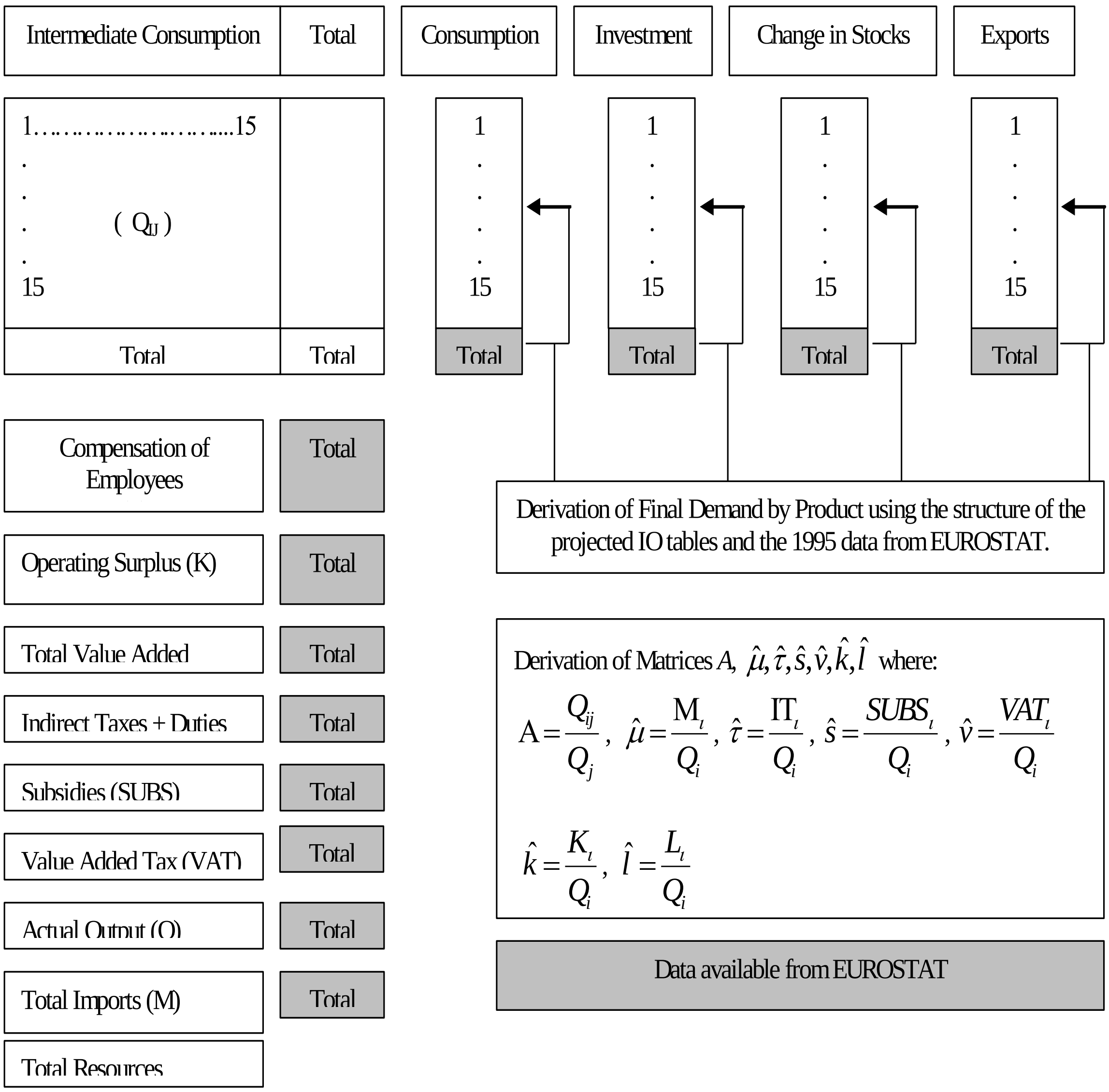
Final Demand

For the Final Demand the following official data were available:

- Total Household Consumption
- Final consumption of NPISH'S
- Total Government Consumption
- Total Exports of goods

- Total Exports of Services
- Total Changes in inventories and acquisition less disp. of valuables
- Gross fixed capital formation of: products of agriculture – forestry - fisheries and aquaculture, metal products and machinery, transport equipment, housing, other construction and other products

Figure 20: **Computation of the Final Demand**



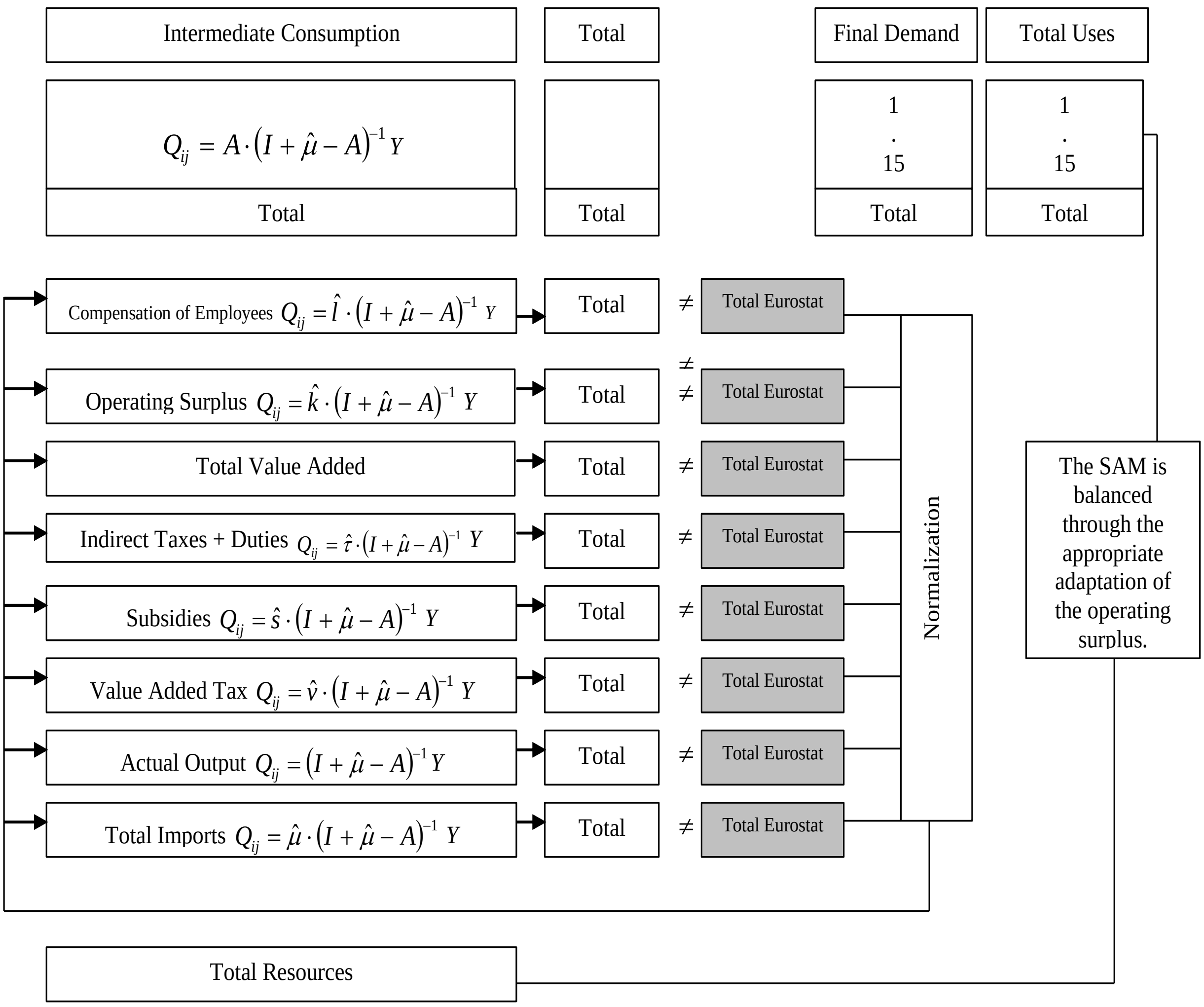
In general in order to achieve the GEM E3 15 sector aggregation level (the energy sector is aggregated at this stage), the coefficients of each use of final demand from the projected IO tables were applied to the total amount of the corresponding uses received from EUROSTAT.

In particular for the investment computation the more detailed information were exploited. The distinction of investments between the institutional sectors (Households, Firm, and Government) was made by incorporating the information realised from the investment matrices as well as from the respective structure of Greece, and Denmark. In the case of consumption this distinction was based on the information provided by the projected tables. Finally the NPISH'S account was included in the household consumption.

Intermediate Demand, Value added, Taxes, Imports

Having computed the Final Demand by product a version of an open Leontief model can by adopted in order to derive the Intermediate Demand matrix, the Value Added components (Compensation of Employees, Operating Surplus), the taxes on production (VAT, Subsidies, Indirect Tax, Duties) and Imports by product (Figure 21)

Figure 21: **Computation of Value Added, Intermediate Consumption, Taxes and Imports**



In particular from the projected tables (as modified during the previous stages) the following coefficients were calculated:

$A_{ij} = \dfrac{Q_{ij}}{Q_j}$, where A_{ij} is the intermediate demand coefficient.

$\hat{\mu}_i = \dfrac{M_\iota}{Q_i}$, where $\hat{\mu}_i$ is the imports coefficient.

$\hat{\tau}_i = \dfrac{IT_\iota}{Q_i}$, where $\hat{\tau}_i$ is the indirect tax coefficient.

$\hat{s}_i = \dfrac{SUBS_\iota}{Q_i}$, where $\hat{s}_i$ is the subsidies coefficient.

$\hat{v}_i = \dfrac{VAT_\iota}{Q_i}$, where $\hat{v}_i$ is the VAT coefficient.

$\hat{k}_i = \dfrac{K_\iota}{Q_i}$, where $\hat{k}_i$ is the operating surplus coefficient.

$\hat{l}_i = \dfrac{L_\iota}{Q_i}$, where $\hat{l}_i$ is the compensation of employees coefficient

Then by applying the formula $Q_{ij} = A \cdot (I + \hat{\mu} - A)^{-1}$ Y, to the corresponding final demand Y as estimated above, actual output Q was estimated. Once the actual output was obtained the rest of the variables were computed by applying the aforementioned formulas. The sum by product of each derived variable is then different from the actual numbers provided by EUROSTAT. For that reason a normalization procedure has been applied. Finally the total resources by product derived in this ay in some cases were found to differ from the corresponding total uses. In such cases by making the appropriate adjustment to the operating surplus of each branch the Input Output table was equilibrated.

Transfer Payments to Institutional Agents

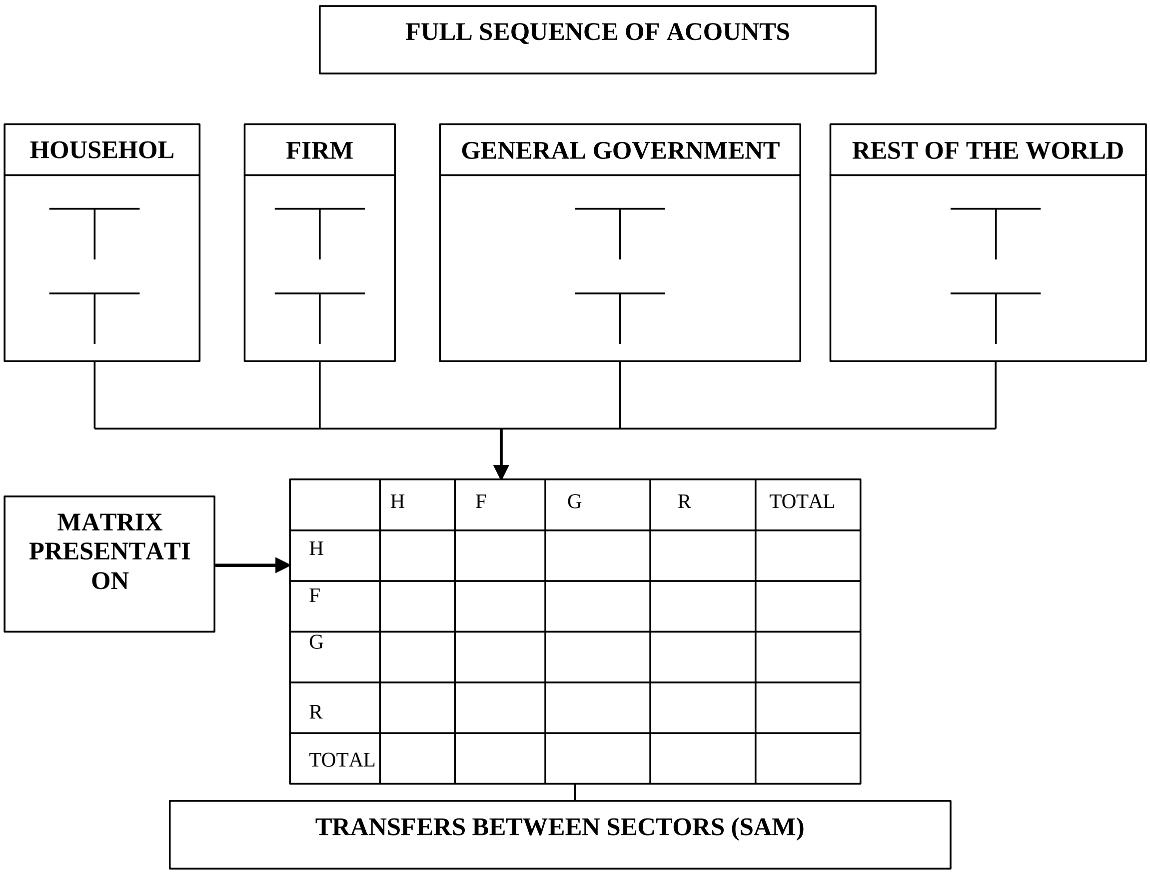
In order to build the table "transfers between sectors" we have used two sets of tables:

- The tables for the full sequence of Accounts of each institutional sector (Households, Firms, General Government, Rest of the World, total Economy). These tables were not available in the same format for each country. The full set of tables according to ESA 95 methodology was available only for Greece, the United Kingdom, Belgium, Germany and Denmark. The full sequence of accounts of General Government and of Total Economy according to ESA 95 methodology was available for all the countries (New CRONOS Database). For France, Spain, the Netherlands and Italy the full sequence of Accounts of all sectors was also available but it followed the ESA 79 methodology (New CRONOS Database).

- A matrix presentation of the most important transactions of the system

A matrix presentation permits each transaction to be represented by a single entry and the nature of transaction to be inferred from its position. Each transaction between two institutional sectors is represented with a column and a row pair. The convention followed is that resources are shown in the rows and uses are shown in the columns. For instance, taxes on income (D5) are payable by the Households and received by the government (Figure 22).

Figure 22: **Transfer Payment Computation Methodology**



For the construction of the table "transfers between sectors we generally have followed the recommendations of Denise Van Regemorter in "GEM-E3 DATA AND CALIBRATION". Nevertheless some problems exist with the treatment of some transactions such as the D4-Property Income, or the D6-D8 "Other current transfers". As it can be seen, in the corresponding matrices there are some entries which represent a kind of income received by Government and is payable from all other sectors (for example penalties, rents from public mines etc.). But in the Government section of the SAM there is no specific row to introduce such a transaction. Temporarily such transactions have been placed in the row with heading "General transfers".

Figure 23: **Matrix presentation of Institutional Sector Accounts (Denmark)**

Allocation of primary income of Households

Uses		Resources	
Property Income	81547	Property Income	74018
- Interest	80470	- Interest	32406

Allocation of primary income of Firms

Uses		Resources	
Property Income	236575	Property Income	245002
- Interest	169492	- Interest	226430

Allocation of primary income of Government

Uses		Resources	
Property Income	64692	Property Income	37979
- Interest	64692	- Interest	32952

Current Accounts with the Rest of the World.

Uses		Resources	
Property Income	108456	Property Income	134271
- Interest	99388	- Interest	122255

Property Income

	H	F	G	W	Resources
H	33483	40534	0	0	**74018**
F	48064	183438	8874	4627	**245002**
G	0	5027	32952	0	**37979**
W	0	7575	22867	103829	**134271**
Uses	**81547**	**236575**	**64692**	**108456**	

Interest

	H	F	G	W	Resources
H	32406				**32406**
F	48064	169492	8874		**226430**
G			32952		**32952**
W	0		22867	99388	**122255**
Uses	**80470**	**169492**	**64692**	**99388**	

The investment matrix translates the demand of investment goods by the branches into deliveries by branches. The matrix, which has been constructed to portray the investment transactions between sectors of the United Kingdom Economy, is showed in Table 11.

Table 11 : **United Kingdom Investment Matrix.**

U.K	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	T
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0

5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0**
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0**
7	2.3	2.5	1.0	6.6	0.7	5.2	3.3	5.9	3.8	3.7	2.1	1.6	2.1	5.9	1.1	0.9	2.1	4.5	**5**
8	52.8	27.8	31.5	377.6	280.8	306.8	689.1	2111.5	537.7	625.6	455.9	703.5	73.4	155.1	176.9	92.0	1069.8	418.0	**81**
9	0.0	21.4	24.3	290.8	216.2	234.3	327.4	596.4	216.2	144.1	155.5	131.0	21.0	4034.9	83.8	74.6	1168.6	1202.5	**89**
10	276.6	17.7	20.1	240.8	179.0	58.0	429.9	1274.4	310.9	80.4	199.7	770.7	760.6	1011.4	2984.3	593.0	4619.6	1536.2	**153**
11	1535.8	69.8	79.1	947.4	704.3	981.7	2017.8	4463.2	1557.0	1033.7	1126.1	1604.4	458.2	1051.0	289.9	1563.1	6071.7	1056.2	**266**
12	0.0	2.4	2.7	32.8	24.4	20.7	38.7	74.3	22.3	46.8	17.6	28.8	5.7	72.6	3.1	37.0	143.0	520.7	**10**
13	408.5	158.3	179.2	2147.3	1596.4	159.3	606.7	1121.3	326.5	1064.3	244.3	556.1	212.2	3953.2	846.6	3411.7	30380.2	16692.2	**640**
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0**
15	15.7	2.4	2.7	32.5	24.1	13.1	29.1	67.4	20.7	23.6	15.6	25.2	8.1	91.9	21.7	44.5	377.5	180.5	**99**
16	0.7	0.7	0.3	1.9	0.2	1.5	1.0	1.7	1.1	1.1	0.6	0.5	0.6	1.7	0.3	0.3	0.6	1.3	**1**
17	250.5	-9.4	1.7	61.7	76.1	28.2	113.9	209.8	81.8	-14.2	52.6	102.3	72.0	449.2	232.3	588.0	12659.9	113.0	**150**
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0**
Total	**2543.0**	**293.7**	**342.6**	**4139.4**	**3102.2**	**1809.0**	**4257.0**	**9926.0**	**3078.0**	**3009.0**	**2270.0**	**3924.0**	**1614.0**	**10826.9**	**4640.1**	**6405.0**	**56492.9**	**21724.9**	**140**

This example depicts that the deliveries were basically made by the branch of other energy intensive industries (number 08), the branch of Electrical Goods (number 09), the Transport Equipment branch (number 10), the Other Equipment Goods Industries branch (number 11), the Building & Construction (number 13) among industrial sectors and to a lesser extent the branch which represents the market related services (number 17).

Investment matrices were available only for Greece[68]. For the computation of the rest of the matrices the information available was the investment by branch and by product. Since there were insufficient information on the transformation matrix a RAS procedure was adopted. The initial tables for the RAS procedure were based on the Greek investment matrix modified appropriately in order to serve the specific investment structure of each country.

Consumption Matrix

The final demand of the households includes also the presumed house rent, the real unit income and the consumption privately produced goods. In the GEM-E3 EU Model, there is a fusion of the Non Profit Institutions Serving Households (NPISH) with the household sector. The household consumption can be approached from two different aspects. Firstly, the disaggregation of goods in reference to the type of them (consumption by product). Secondly, the disaggregation according to the purpose of the expenditure (consumption by purpose). That differentiation is based on an international standard (COICOP) that categorize goods in correspondence to the purpose of their use.

[68] Recently the Investment Matrices of United Kingdom and Germany were obtained and they will be used to make a refinement to the rest of the matrices.

The consumption matrix translates the demand per consumer category into deliveries by branch. The example of the consumption matrix of Greece is given below:

Table 12: **Consumption Matrix of Greece (1999 in million €)**

Products \ Cons. Categories	01	02	03	04	05	06	07	08	09	10	11	12	13	Tota
01	2116.4	0.0	0.0	58.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**2174.**
02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
03	0.0	0.0	0.0	537.0	0.0	0.0	0.0	0.0	1156.3	0.0	0.0	0.0	0.0	**1693.**
04	0.0	0.0	0.0	48.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**48.2**
05	0.0	0.0	181.8	821.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**1003.**
06	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
07	0.0	0.0	34.4	0.0	310.7	0.0	308.0	0.0	0.0	0.0	0.0	157.6	557.8	**1368.**
08	0.0	0.0	0.0	0.0	496.8	29.8	0.0	0.0	0.0	0.0	0.0	490.0	220.0	**1236.**
09	0.0	0.0	2.6	0.0	8.3	62.5	0.0	0.0	0.0	0.0	0.0	157.3	0.0	**230.**
10	0.0	0.0	0.0	0.0	0.0	0.0	2.6	708.2	0.0	0.0	0.0	14.1	0.0	**724.**
11	0.0	0.0	0.0	0.0	1.9	240.7	26.9	0.0	0.0	0.0	0.0	75.0	0.0	**344.**
12	8489.2	3954.6	38.3	0.0	1308.1	0.0	0.0	0.0	35.4	0.0	0.0	145.8	299.6	**14271**
13	0.0	0.0	381.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**381.**
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	834.8	0.0	0.0	**834.**
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1754.9	0.0	0.0	108.6	**1863.**
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	188.3	0.0	0.0	0.0	519.9	**708.**
17	0.0	0.0	9795.7	0.0	344.4	192.7	3579.0	0.0	1124.6	98.5	0.0	3019.7	16839.8	**34994**
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	335.4	**335.**
Total	**10605.6**	**3954.6**	**10434.3**	**1465.0**	**2470.2**	**525.7**	**3916.6**	**708.2**	**2504.6**	**1853.4**	**834.8**	**4059.7**	**18881.1**	**62213**

The previous table represent the demand of every one of the 18 branches divided into 13 consumption categories. For the countries where no such matrix exists, the matrix was computed using the following procedure:

- The consumption per consumer category is taken from the National-Accounts
- Given VAT rates for the different consumer categories, the total per category without VAT is computed
- The total deliveries are taken from the Input-Output tables and appropriate assumptions were made to allocate the total per categories to the delivery branch.

Concluding the Consumption matrices were computed based on information regarding the consumption by purpose and the consumption by product. Once again since there was lack of information on the transformation matrices the matrix of Greece was used after certain modifications. These modifications were based on information obtained from the energy balances of each country.

Computation of Trade

The Comext data have been used to compute a bilateral trade matrix for the GEM-E3 branches for 1995. The export values has been appraised, using the f.o.b (free on board) prices, while for the import prices, they have been used c.i.f. (cost-insurance-freight) prices. During the computation process, different problems have been encountered:

- Quality of the data: Exports as given in Comext in certain cases are very different from those reported in the NEW CRONOS database.

- The Comext data only concern trade of goods and there are no other sources for the disaggregation by country of the external trade in services of a particular country. On the other hand the NEWCRONOS database contains aggregate data on service trade. We had to assume the allocation of services trade by country.

Time Series for Dynamic Calibration

In the absence of SAMs for years other than 1985, we were obliged to only use sectoral time-series as provided by Cronos database of Eurostat. We have collected the following time-series, which have been aggregated to model's classification:

- value added per sector (volume, value), factor prices (gaps exist) and market prices

- exports and imports per sector (volume and value)

- actual output (available for a few countries)

- investment by ownership branch (gaps exist)

- consumption of households by purpose (volume and value)

- employment per sector (gaps exist)

- National Accounts per sector

It was however not possible to build a complete benchmark data set for 1993 or 1994, as a complete set of data for each country and with the sectoral disaggregation needed, only exist up to 1991. The available data have therefore been used to ensure an evolution in the dynamic simulations with GEM-E3 which is compatible with this statistical information. They have served as targets for the dynamic calibration. Practically, the time-series concern some of the margins of the Input-Output tables and the income distribution structure.

Social Accounting Matrix for the post-1985 years Eurostat does not provide new observed Input-Output tables for after 1985. For a few countries post 1985 I-O tables, following the national methodology are available, but it was not possible, with the resources within this project, to make them compatible with Eurostat 1985 tables. We had access only to a time-series of French Input-Output table that were used to compute technical progress. The Input-Output tables of 1991, as prepared by J.Beutel and al., were evaluated, but were found inappropriate to serve as database for the model for two main reasons:

1. The structure of the intermediate consumption is created artificially (i.e. not through real data), using a type of advanced RAS method.

2. The I-O tables are in current prices, and the appropriate deflators are not available. Thus, it is very difficult to assess volume changes.

The Incorporation the Greenhouse Gases on the GEM-E3 Model

In many studies that work on the assessment of policies that confront climate change phenomenon, they are included only CO_2 emissions, which are emanated from the combustion of fossil fuel. The present edition of GEM-E3 incorporates all the greenhouse emissions that derived from energy & non energy use activities, as long as the marginal abatement cost curves.

The encompass of all the greenhouse emissions in the model necessitates the construction and estimation of the marginal abatement cost curves, the definition of anticipations for the future evolution of these emissions, the re-planning of enterprise & household conducts and the integration of the existing emissions trading permits mechanism with new emissions.

The data in reference to emissions that are used in the model stemmed from the database EDGAR v3.3, using as base year the year 1995. Information on abatement technologies come from the "EU Sectoral Objective Study" ECOFYS-NTUA. Backing from all available data, there was an attempt to construct the marginal abatement cost curves for all the regions and the sectors that are being covered from the model. In regions or countries where data were inefficient, these curves have been constructed with implicit methods, in consistency with the special characteristics of the sector/country (where that was feasible).

The methodological procedure that has been followed in the GEM-E3 EU Model for the incorporation of the greenhouse gazes is as follows:

$Y_i = CES(K_i, L_i, E_i, M_i)$

Where:

Y_i = the production of sector i

K_i = inflows of capital in sector i

L_i =inflows of labour in sector i

E_i =inflows of energy in sector i

M_i =material inflows in sector i

The basic assumptions under the construction of that function are:

- Emissions of sector i, are a constant ratio of the production quantity $e_{s,i}$, where s are the emissions
- Sector i, apart from the quantity M_i that utilizes should consume, during the production process, over above quantities of material M_i, in order to reduce emissions.

The additional quantity of M_i that should be used during the production is given by the equation:

$$I_i = Y_i \cdot \sum_S C(a_{S,i}) \cdot a_{S,i} \cdot e_{S,i}$$

Where:

I_i= the quantity of materials be in need for the abatement of emissions in sector i

$a_{s,i}$ =the reduction rate of emission S in sector i

$C(a_{sa,i})$ = average abatement cost, that emanates from the integration of the marginal cost equation

If PM is the price of the input materials, then the cost of the abatement in monetary terms is $PM \times I$. If it's assumed that every unit of emissions, the firm pays a price PP (price of permits), then the cost-minimization problem of producer I, described by the following optimization problem:

$$TC(Y, PK, PL, PE, PM, A) = \min(PK \cdot K + PL \cdot L + PM \cdot M + PE \cdot E + PM \cdot I_i + T_i)$$

s.t: $Y_i = f(K_i, L_i, E_i, M_i)$

$$I_i = Y_i \cdot \sum_S C(a_{S,i}) \cdot a_{S,i} \cdot e_{S,i}$$

$$T_i = Y_i \cdot \sum_S PP_{S,i}(1 - a_{S,i}) \cdot e_{S,i}$$

Where:

PK = Rate of capital return

PL = Marginal/unit cost of labour

PE = Price of energy input

PM = Price of material input

T_i = Expenditure of sector i for environmental taxes or emission permission purchases

Consequently, a representative firm confronts the dilemma: to reduce its emissions and to pay the accessory cost PMI , or on the other hand to pay the price for an extra emission unit that it produces T_i . In equilibrium the relationship between these two costs come up from the first order conditions (FOC) of the above mentioned minimization problem.

$$\frac{\partial \mathrm{TC}}{\partial \mathrm{a}_{S,i}} = \mathrm{PM}[\mathrm{C}'(\mathrm{a}_{S,i}) \cdot \mathrm{a}_{S,i} + \mathrm{C}(\mathrm{a}_{S,i})] - \mathrm{PP} = 0$$

Taking into account the hypotheses mentioned above, the total "demand" for emissions of firms is provided by the following equation:

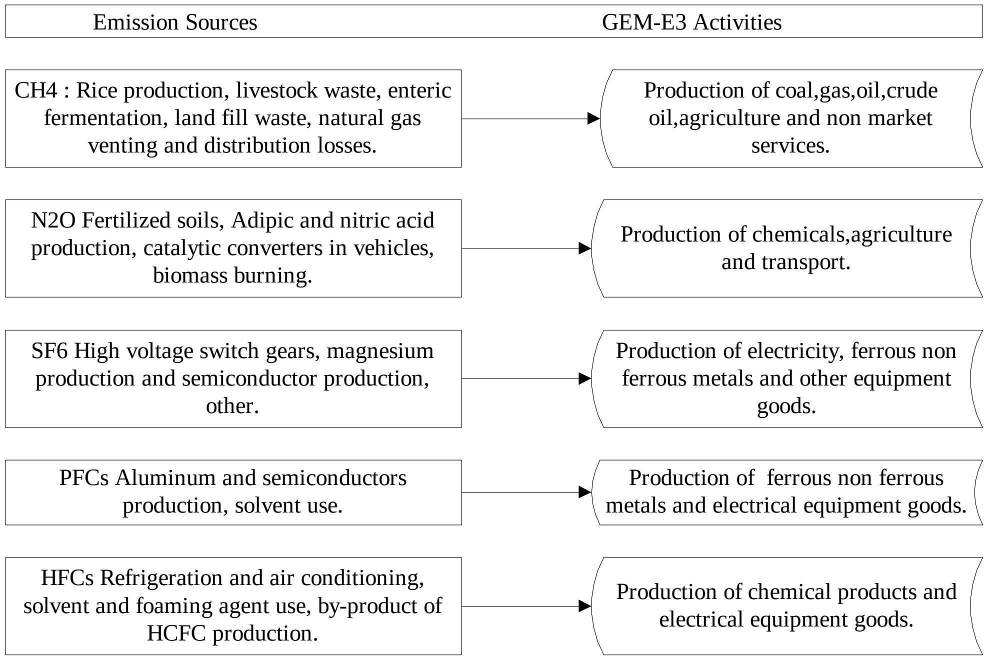
$$EB_i = Y_i \cdot \sum_S a_{S,i} \cdot e_{S,i}$$

Therefore, the total "demand" for emissions of firms and households is:

$$EMD_t = \sum_i EB_{i,t} + \sum_S EH_S$$

This equation depicts the firms demand curve for emissions. The intersection point of the demand curve with that of supply curve, defines the price of tradable emission permits. The interconnection between emissions and economic activities is showed up in the following figure:

Figure 24: **Correspondence of emission sources and activities**


Emission Sources
GEM-E3 Activities
CH4 : Rice production, livestock waste, enteric fermentation, land fill waste, natural gas venting and distribution losses.
Production of coal,gas,oil,crude oil,agriculture and non market services.
N2O Fertilized soils, Adipic and nitric acid production, catalytic converters in vehicles, biomass burning.
Production of chemicals,agriculture and transport.
SF6 High voltage switch gears, magnesium production and semiconductor production, other.
Production of electricity, ferrous non ferrous metals and other equipment goods.
PFCs Aluminum and semiconductors production, solvent use.
Production of ferrous non ferrous metals and electrical equipment goods.
HFCs Refrigeration and air conditioning, solvent and foaming agent use, by-product of HCFC production.
Production of chemical products and electrical equipment goods.

Chapter

7

GEM-E3 EU Model Calibration

We appose the calibration decisions adopted in GEM-E3 EU Model, in relation the values assigned to elasticities and other exogenous parameters. Simultaneously, we exhibit the data requirements and the modifications for the calibration of the environmental module

Calibration Structure and Data

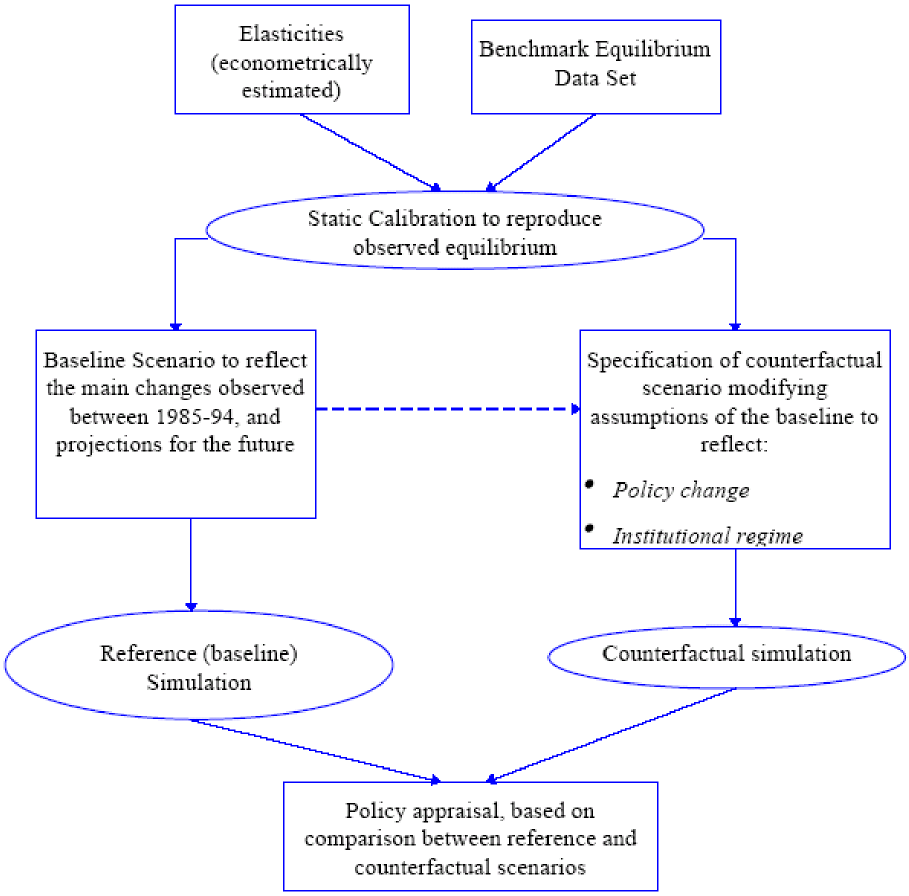
The first step for running the calibration procedure of the GEM-E3 model, is to guess-estimate values for the elasticities that determine all coefficients that do not correspond to directly observable variables and then to run the calibration procedure.

This is written as a separate model and has a recursive structure (except for the IC sectors). The base-year data, used for calibration, correspond to monetary terms, therefore appropriate price indices are chosen to compute the corresponding volumes (quantities).

Once the model is calibrated, the next step is to define a baseline scenario that starts from 1995, tries to reproduce as accurately as possible the last year for which observations are available (1994) and then gives some projections up to a future year which is the final year of the model simulation (usually 2010 or beyond). This simulation defines the model baseline projection against which the policy simulations can be evaluated.

The "counterfactual" equilibria can be computed by running the model under assumptions that diverge from those of the baseline. 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 in the baseline scenario thereby modifying it. To perform a counterfactual simulation it is not necessary to recalibrate the model. The exact process of calibrating and running GEM-E3 is illustrated in the following Figure 25:

Figure 25: **The calibration procedure of GEM E3 Model**



Static calibration of the CGE model follows a standard procedure, as in most CGE models. The starting data set includes the following:

Values of production, consumption, investment, imports and exports per sector, which are available from the Social Accounting Matrix tables that include the Input-Output tables and the National Accounts

Bilateral sectoral trade tables for the EU member states and the rest of-the-world.

The calibration procedure is a model run that assumes unit values for the export price and the price of absorption and a complete set of elasticity parameters. The calibration computes volumes, effective fiscal policy rates and a number of share parameters in production and consumption functions.

Values of Elasticities and other Exogenous Model Parameters

Three main sets of elasticities are used in the GEM-E3 model:

- Demand function elasticities following the Armington assumption adopted in the model (substitutability of domestic/imported goods and across imported goods, by country of origin)

- Elasticities of substitution in production (substitution among production factors)

- Consumer preferences (price or income elasticities in households demand for commodities)

Literature survey on empirical studies for the Armington elasticities

Despite of the popularity of the Armington concept, only few studies on direct econometric estimates of substitution elasticities have been published. Elasticities of upper-level substitution between imported and domestic goods have been estimated, for example, by Reinert and Roland-Holst (1992), Shiells et al. (1986) and Lächler (1985). Shiells and Reinert (1993) have estimated lower-level elasticities and non-nested elasticities, as well as Sobarzo (1994), and Roland-Holst et al (1994). Unfortunately, the estimated values from the literature are difficult to compare, as the sectoral aggregation levels differ according to the statistical data base used.

A study for Germany was conducted by Lächler (1985). Lächler estimated disaggregated elasticities of substitution between demand for imports and domestic substitutes in Germany. He found that the primary goods industry which consists of relatively homogeneous and easily replaceable goods and which is under high pressure in terms of international competitiveness is the one with the highest elasticity ranking: Apart from two exceptions, elasticity values range from 0.233 to 2.251. In contrast, in the case of the investment goods sector, and particularly in the case of capital goods in the short run, technological rigidities restrict the substitutability; thus, elasticity values are rather low and between the range of -2.283 to 1.209. Finally, the sectors that are classified as belonging to the consumption goods industry differ with respect to the degree of international competitive pressure, reflected by wide differences in measured substitution elasticities (-0.697 to 1.092).

Likewise, Reinert and Roland-Holst (1992) have estimated elasticities of substitution between imported and domestic goods for 163 U.S. mining and manufacturing sectors, based on U.S. trade data time series of both prices of domestic and imported goods, and real values of domestic sales of domestic goods and imports. In about two-thirds of the cases Reinert and Roland-Holst obtained positive and statistically significant estimates ranging from 0.14 to 3.49. Their results allow the conclusion that at the level of aggregation chosen imports and U.S. domestic products are far away from being perfect substitutes.

Furthermore, Shiells et al. (1986) have published estimations on disaggregated own-price elasticities of import demand for 122 3-digit SIC U.S. industries (covering mainly mining and manufacturing sectors) which serve as a basis for inferring upper-level substitution elasticities. The estimations are based on annual data for period 1962-1978. In 48 cases positive and statistically significant elasticities of substitution were obtained, ranging from 0.454 for SIC 208 (beverages) to 32.132 for SIC 373 (yachts).

Shiells and Reinert (1993) estimated both lower-level nested and non-nested elasticities of substitution among U.S. imports from Mexico, Canada, RoW, and competing domestic production, for 22 mining and manufacturing sectors, based on quarterly data for 1980-88. In the non-nested specification, U.S. imports from Mexico, Canada, and RoW as well as domestic substitutes enter a single CES function. The estimates of the non-nested elasticities of substitution range from 0.101 (sector primary lead, zink, and non-ferrous metals, n.e.c.) to 1.49 (sector primary aluminium). The nested specification is composed of an upper-level CES aggregation function for U.S. imports as a whole and a lower-level CES aggregate function for the various import sources, i.e. lower-level substitution elasticities are among U.S. imports from Mexico, Canada, and RoW. Estimates range from 0.04 (sector clay, ceramic, and non-metallic minerals) to 2.97 (sector iron, and ferroalloy ores mining).

A comparison of estimates for non-nested, lower-level and upper-level elasticities for selected sectors taken from Shiells and Reinert (1993) and Reinert and Roland-Holst (1992) show that values differ. While the non-nested estimates lie mainly above the upper-level estimates, they are in half of the cases lower and in half of the cases higher than the lower-level estimates. As already mentioned in Section 8.1.2, lower-level elasticities are not generally higher than upper-level elasticities, but only in about two thirds of the sectoral cases considered in the table. However, lower-level estimates show that the range of positive values (0.04 - 2.97) is larger, as in the case of the non-nested specification (0.1 - 1.49) and in the case of upper-tier estimates (0.02 - 1.22).

All in all, the sectoral values used in the GEM-E3 model are close to the typical values found in the literature. In most cases the estimates arise from U.S. data whereas for EU countries no estimates are available in the literature.

Table 13 contains upper- and lower-level Armington elasticity values actually used in the GEM-E3 model in EU and RoW import demand. Elasticities differ among sectors, but values for each sector are identical for all EU countries.

For EU countries upper-level elasticity values are greater than 1 for sectors with a relatively high degree of international competition, such as energy-intensive or consumer goods industry, while values of service sectors or sectors with relatively homogeneous goods (e.g. sector crude oil and oil products) are set below 1. Basically, lower-level elasticity values are set higher than upper-level elasticities. As Shiells and Reinert (1993) - with reference to Brown (1987) - have noted, the two-level nested Armington approach may imply large terms-of-trade effects that are the greater the larger the upper-level elasticities are relative to the lower-level elasticities. Thus, in order to avoid large terms-of-trade effects, lower-level elasticities take often higher values than upper-level elasticities in empirical trade models. However, as empirical studies indicate, this pattern is not absolutely evident. For instance, a comparison of U.S. upper-level elasticities estimated by Reinert and Roland-Holst (1992), with U.S. lower-level elasticities estimated by Shiells and Reinert (1993) shows that for some sectors lower-level elasticities are higher than upper-level elasticities[69].

The last column of Table 12 presents values of substitution elasticities used in RoW's import demand. Lower-level elasticity values are set equal to upper-level elasticity values. With regard to relative sectoral degrees of substitutability RoW's

Table 13: **Armington elasticity values in the standard version of the GEM-E3 model**

		EU-14		RoW
		σ_x	σ_m	$\sigma_x^{row} = \sigma_m^{row}$
1	**Agriculture**	1.2	1.6	1.4
2	**Coal**	-	-	0.6
3	**Crude oil and oil products**	0.6	0.8	0.6
4	**Natural gas**	-	-	0.6
5	**Electricity**	-	-	0.6
6	**Ferrous, non-ferrous ore and metals**	1.5	2.4	2.2
7	**Chemical products**	1.5	2.4	2.2
8	**Other energy intensive industries**	1.5	2.4	2.2
9	**Electrical goods**	1.5	2.4	2.2
10	**Transport equipment**	1.5	2.4	2.2
11	**Other equipment goods industries**	1.5	2.4	2.2
12	**Consumer goods industries**	1.7	2.8	2.5
13	**Building and construction**	-	-	1.4
14	**Telecommunication services**	0.6	1.6	1.4
15	**Transports**	1.2	2.4	2.2
16	**Credit and insurance**	0.6	1.6	1.4
17	**Other market services**	0.6	1.6	1.4
18	**Non-market services**	-	-	0.6

No econometric estimates of sector- and country-specific substitution elasticities for EU countries are available in the literature. Thus, in this section the required set of Armington elasticities for the 14 EU countries is generated following a procedure proposed by Harrison et al. (1991, p. 100). The procedure takes place in three steps:

Starting point are sector-specific 'best guess' upper-level Armington elasticities for the U.S. presented in Shiells et al. (1986). Using country-specific import weights

[69] Whalley (1985, p. 109), for example, in his seven region model uses upper-level elasticity values, that are based on literature values of import-price elasticities. The lower-level elasticity values are set for all sectors and regions on a common value of 1.5, which roughly approximate literature estimates of export price elasticities

(drawn from 1993 data[70]) for each country an *average Armington elasticity of substitution* σ_x^{av} is calculated. The country-specific import weighted elasticities σ_x^{av} are reported in Table 16.

The country-specific elasticities σ_x^{av} are then compared with country-specific Armington elasticities ($\sigma_x^{\inf}$) that are inferred from country-specific import price elasticities (ε) and from import shares. Whereas the national import price elasticities are taken from the empirical trade literature (Stern et al. 1976), the import shares are calculated from the equilibrium benchmark data set.

Finally, we re-scale for each country the sector-specific elasticities so that the aggregated, import-weighted elasticity σ_x^{av} is equal to the country-specific elasticity $\sigma_x^{\inf}$ which is derived from the national import price elasticity. The results of the sectorally and nationally disaggregated substitution elasticities are reported in Table 17.

Table 14: **Sectoral values of upper-level Armington elasticities in RoW's import demand**

	Case 0: Standard version of GEM-E3	**Case 1:** Halved values	**Case 2:** Doubled values	**Case 3:** U.S. 'best guess' estimates
Agriculture	1.2	0.60	2.40	
Crude oil and oil products	0.6	0.30	1.20	Country- and sector-
Ferrous, non-ferrous ore and metals	1.5	0.75	3.00	specific values
Chemical products	1.5	0.75	3.00	
Other energy intensive industries	1.5	0.75	3.00	(for sector 3, 7- 10:
Electrical goods	1.5	0.75	3.00	values as calculated from
Transport equipment	1.5	0.75	3.00	'best guess' estimates
Other equipment goods industries	1.5	0.75	3.00	presented in Shiells et al. (198
Consumer goods industries	1.7	0.85	3.40	for sector 1, 6, 11-17:
Telecommunication services	0.6	0.30	1.20	values as in standard versio
Transports	1.2	0.60	2.40	
Credit and insurance	0.6	0.30	1.20	
Other market services	0.6	0.30	1.20	

While step 1 and step 3 are more or less self-evident, some comments should be made on the derivation of the national Armington elasticities from literature-based import price elasticities (step 2).

Obviously, the procedure proposed is faced with some problems which arise from the existence of non-tradable sectors and non-competitive imports. Both import demand of non-traded and non-competitive commodities are excluded from the Armington assumption. It is assumed that they are determined not by price relations but by the domestic production level and institutional settings, such as supply contracts. As national import price elasticities, taken from the literature, normally refer to the national aggregate of import demand (aggregating all sectors), they may provide a distorted picture of Armington elasticities. However, this problem is less important here. Fortunately, in the GEM-E3 model the national

[70] 1993 International Trade Statistics Yearbook. Vol. 1. Trade by Country. United Nations. New York

shares of imports of non-tradable goods in total imports are low and by a majority below 5% (see Table 14). Thus, the literature-based import price elasticity values are reasonable approximates for the price elasticity of import demand of tradable goods in the GEM-E3 model.

Table 15: **Import shares of non-tradable commodities in the GEM-E3 model**

	Share of imports of non-tradeables goods in all imports (base year)
Austria	4.14%
Belgium	4.02%
Germany	5.70%
Denmark	3.48%
Finland	10.34%
France	5.36%
Greece	0.44%
Ireland	2.29%
Italy	4.87%
Netherlands	1.90%
Portugal	0.41%
Spain	2.92%
Sweden	1.00%
Un. Kingdom	3.26%

More importance should be attached to the problem arising from non-competitive imports. Given the same import price elasticity value, the share of non-competitive imports assumed influences the inferred Armington elasticity values $\sigma_x^{\inf}$ decisively. This can be demonstrated by using equation (27) and equation (28) alternatively for the derivation of the Armington elasticities. As can be shown easily, in the GEM-E3 model the price elasticity of the aggregate import demand ε in terms of upper-level Armington elasticity σ_x and empirically measurable parameters (import shares) is given by:

(1) $$\varepsilon^c = \sigma_x \cdot (\omega \; - 1),$$

When all imports are competitive, and by:

(2) $$\varepsilon^{nc} = \sigma_x \cdot \left[\frac{IMC}{IM} \cdot (\omega - 1) + \frac{IMNC}{IM} \cdot (\omega - \omega^{nc}) \right]$$

When non-competitive imports exist[71]

[71] The own-price elasticity of the import aggregate demand is defined as $\varepsilon = (\partial IM/\partial PIM) * (PIM/IM)$, whereas domestic supply Y is kept constant. If all imports of tradable goods are competitive (i.e. $IM=IMC$) the import price elasticity ε^c is derived from equation (12) which expresses the upper-level import demand for tradable goods. If a positive share of total imports of tradable goods is non-competitive (i.e. $IM=IMC+IMNC$) the derivation of ε^{nc} must consider that the specification of non-

. IM are total imports of tradable goods

IMC: represent the competitive and $IMNC$ the non-competitive part

ω: denotes the share of expenditure on imports in expenditure on domestically supplied goods

ω^{nc}: denotes the ratio of expenditure on non-competitive imports to expenditure on domestically produced and demanded goods, i.e.

$$\omega = \frac{PIM \cdot IM}{PY \cdot Y} \quad \text{and}\, \omega^{nc} = \frac{PIM \cdot IMNC}{PXD \cdot XXD}.$$

When $IMC = IM$ and $IMNC = 0$, then equation (1) is the same as equation (2).

Table 16: **Sector- and country specific upper-level Armington elasticities for EU-14**

Sector	Austria	Belgium	Germany	Denmark	Finland	France	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	Un.
3 Crude oil and oil products	5.1	5.6	3.2	3.1	3.0	3.4	2.3	3.2	7.5	3.9	3.8	3.1	1.6	
6 Ferrous, non-ferrous ore and metals	3.1	3.4	2.0	1.9	1.8	2.1	1.4	2.0	4.6	2.4	2.3	1.9	1.0	
7 Chemical products	5.6	6.2	3.6	3.4	3.3	3.8	2.5	3.5	8.3	4.3	4.2	3.4	1.7	
8 Other energy intensive industries	6.2	6.5	3.7	3.3	3.5	3.8	2.4	3.5	8.3	4.2	3.8	3.4	1.9	
9 Electrical goods	4.5	5.0	2.9	2.8	2.6	3.1	2.1	2.9	6.7	3.5	3.4	2.7	1.4	
10 Transport equipment	7.7	8.5	4.9	4.7	4.5	5.2	3.5	4.9	11.4	5.9	5.7	4.6	2.4	
11 Other equipment goods industries	2.3	2.5	1.4	1.4	1.6	1.5	1.0	1.4	3.4	1.7	1.7	1.4	0.7	
12 Consumer goods industries	5.2	4.9	3.2	2.6	2.7	2.0	1.9	2.8	5.9	3.4	2.5	2.5	1.5	

As Table 16 shows, a variation of the share of non-competitive imports in total imports of tradable goods leads to different values of Armington elasticities. In summary, one can say that the higher the share of non-competitive imports, the higher the Armington elasticity which corresponds to a given import price elasticity. In the GEM-E3 model the shares of non-competitive imports are set equal to 0.5 for all countries and all sectors. Thus, the country-specific upper-level Armington elasticities $\sigma_x^{\inf}$ depicted in the fourth column of Table 16 are applied. Keeping in mind that values of own import price elasticities vary widely between alternative import demand specifications (see Kohli 1982), the Armington elasticities derived from the import price elasticities must be interpreted as crude approximations. However, Whalley (1985, p. 103) states that import price elasticity values in the neighbourhood of unity still reflect the current consensus on import price elasticities.

competitive imports in the GEM-E3 model includes two further equations: *PXD=PD+RTNC*PIM* and *IMNC=XXD*RTNC*, where *RTNC* is calibrated. Thus, the price for domestically produced and demanded goods, *PXD*, entering the unit cost function of domestic supply (equation (11)), is no longer independent from *PIM*

Finally, re-scaling the average Armington elasticity values σ_x^{av} according to step 3 leads to the final values which are reported in Table 17.

Table 17: **Country-specific price and substitution elasticities of import demand for different shares of non-competitive imports**

	ε *	σ_x^{av} **		σ_x^{inf} ***	
			(IMNC/IM=0)	*(IMNC/IM=0.5)*	*(IMNC/IM=0.8)*
Austria	-1.32	2.13	1.88	4.57	10.48
Belgium	-0.83	2.13	1.67	5.03	6.53
Germany	-0.88	2.12	1.09	2.90	6.09
Denmark	-1.05	1.99	1.53	2.61	-10.31
Finland	-0.50	2.37	0.62	2.97	3.46
France	-1.08	1.63	1.31	2.36	7.31
Greece	-1.03	2.15	1.04	2.10	5.24
Ireland	-1.37	1.95	1.62	2.65	8.94
Italy	-1.03	2.01	1.77	6.39	8.57
Netherlands	-0.68	2.03	1.20	3.32	5.63
Portugal	-1.03	1.92	1.33	3.05	7.52
Spain	-1.03	2.03	1.21	2.63	6.68
Sweden	-0.79	2.06	0.80	1.38	1.99
Un. Kingdom	-0.65	1.93	0.66	1.17	1.83

* 'Best guess' estimates of uncompensated import price elasticities suggested by Stern et al. (1976, p. 20), constructed as point estimates for several countries according to the three-digit International Standard Industrial Classification (ISIC). As for Greece, Spain and Portugal no data were available, we used Italian data.

** Based on Shiells et al. (1986).

*** Elasticities are inferred from equation (1) for *IMNC/IM=0* and from equation (2) for *IMNC/IM*>0. Import shares ω and ω^{nc} are based on observed data of the benchmark equilibrium.

Table 18 reports the values of the upper-level Armington elasticity for which sensitivity analysis is performed. As in the previous section, the case of doubled and halved elasticity values is tested. Additionally, the calculated sector- and country-specific values from Table 6 are applied.

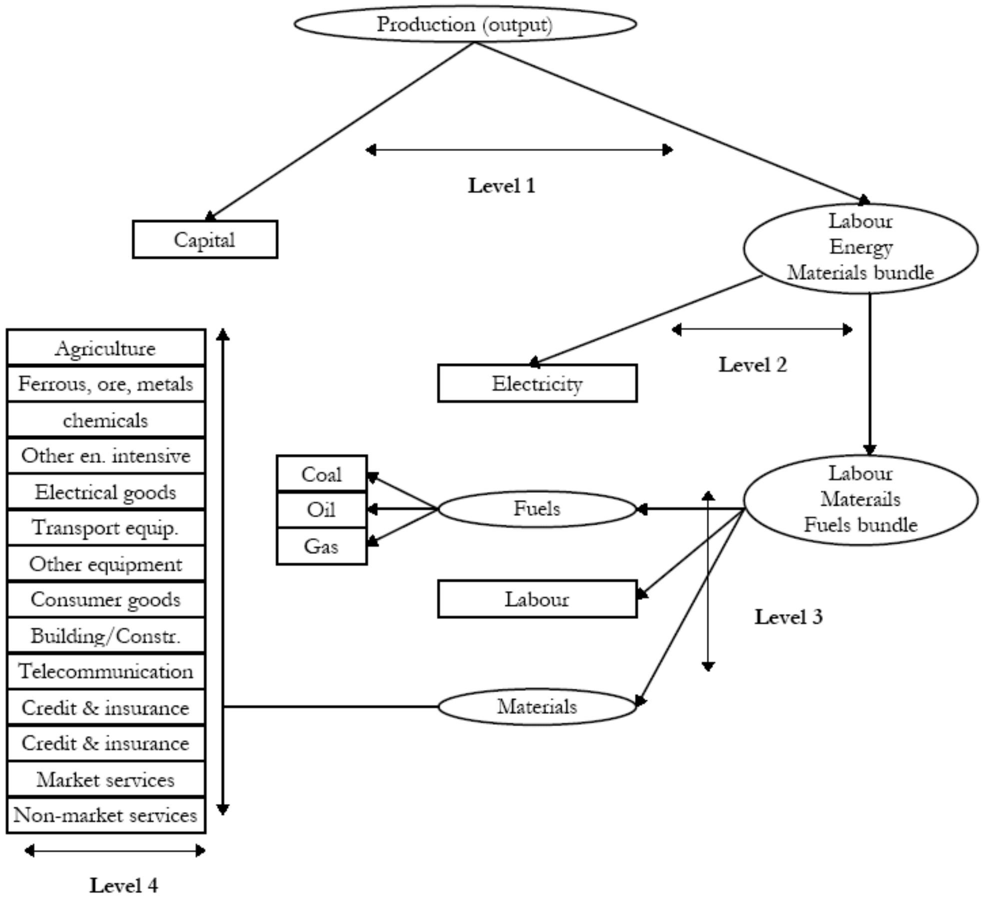
Elasticities of Substitution in Production

In the derived factor demand of the industrial sectors, the assumptions regarding the substitution elasticities are crucial parameters for the results obtained. Many econometric studies have tried to evaluate the substitution possibilities between the production factors within an integrated production model. They point out to the importance of the number of productions factors specified and of the specification of technical progress. The distinction between electricity and other fuels is necessary because the substitution mechanism and possibilities between these energy factors and the other production factors are different. The specification of the technical progress has a clear impact on the estimated substitution elasticities.

The nested CES structure and the substitution elasticities in GEM-E3 are based on the econometric study by CES and the Belgian Planning Office on the substitution possibilities in 10 Belgian industrial sectors, as this study was available and took into account the main findings on the specification needed for the modelling of factor demand. Production factors demand equations derived from CRESH production function have been jointly estimated for 10 industrial sectors in Belgium and 5 factors (capital, labour, electricity, fuels and other intermediate inputs) over the period 1966-1986, taking into account the within and across equation constraints imposed on the parameters by the CRESH production function and with factor specific technical progress. The CRESH function imposes substitutability between factors, but estimation results with other functional forms allowing for both complementarity and substitutability were worse. The long run substitution elasticities are rather low for all factors (i.e. below 1) and especially between capital and the other factors. Electricity is also a rather poor substitute. The highest substitution possibilities are between labour, materials and fuels.

Based on these results, the following nesting structure and substitution elasticities were applied in GEM-E3. The nesting structure is the same for all branches in GEM-E3 as shown in the following figure (repeated here from previous chapter):

Figure 26: **The production nesting scheme in GEM-E3**



The substitution elasticities can vary between sectors and is reproduced below:

Table 18: **Elasticities of substitution in GEM-E3**

	level 1	level 2	level 3	level 4
Energy Intensive sectors	0.4	0.5	0.5	0.9
Equipment goods sectors	0.4	0.5	0.3	0.6
Consumer Good	0.4	0.5	0.1	0.4
Services	0.3	0.5	0.3	0.6

Calibration of Sectors with Imperfect Competition

The choice of imperfectly competitive sectors is based on the results by Pratten (1988) who identified the sectors with significant unexploited potential of economies of scale and the ex-ante evaluations of the Single Market Programme, as surveyed in the literature.

The table below shows the sectors of the model in which oligopolistic competition is assumed to prevail:

The above statistics have been complemented with specific information to calibrate the imperfect market formulations. We have been based on:

The Pratten (1988) study regarding the engineering estimation of the Minimum Efficient Scales per sector and the cost increase gradient (related to the number of firms)

Herfindahl indices computed for 1985 and 1992; these have been compared to similar information available by Bruce Lyons (East Anglia University) who provided such an index for the whole European Union and 1988; statistical rank correlation analysis showed for example that the UK numbers were close to those of the whole EU

The starting data set includes the following:

- Values of production, absorption, imports and exports per sector, which are available from the SAM tables

- The Minimum Efficiency Scale (MES) per unit of domestic production, computed from the engineering data of Pratten

- The cost gradient, that is the percent increase of average cost of the firm when it produces 1/3 of the Minimum Efficiency Scale; (available from Pratten)

- The number of firms per sector, computed as the inverse of a sectoral Herfindahl index

The calibration procedure starts from the computation of the fixed cost per firm. This computation assumes that the firm operates at zero profit in the base year. The formula is derived as follows. The cost gradient is defined as the increase in average cost AC when production of a firm is reduced from the MES to 1/3 of:

$$Cost\_Gradient = \frac{AC(1/3 \cdot MES) - AC(MES)}{AC(MES)} =$$

$$\frac{MC + {}^{3Fixed\_Cost}/_{MES} - MC - {}^{Fixed\_Cost}/_{MES}}{MC + {}^{Fixed\_Cost}/_{MES}}$$, the MES.

Or

$$Cost\_Gradient = \frac{2 \cdot {}^{Fixed\_Cost}/_{MES}}{MC + {}^{Fixed\_Cost}/_{MES}} \quad (3),$$ where MC is the marginal cost.

Assuming now zero-profits $AC = MC + \frac{Fixed\_Cost}{XD_{firm}}$ (4)

$$Cost\_Gradient = \frac{2 \cdot {}^{Fixed\_Cost}/_{MES}}{AC - \frac{Fixed\_Cost}{XD_{firm}} + \frac{Fixed\_Cost}{MES}} =$$

$$\frac{2 \cdot {}^{Fixed\_Cost}/_{MES}}{AC - \frac{Fixed\_Cost}{XD_{Value}} + \frac{Fixed\_Cost}{MES}}$$

Combining the two above equations and letting N be the number of firms.

$$Cost\_Gradient = \frac{\dfrac{2 \cdot Fixed\_Cost}{MES / XD_{Branch}}}{XD_{Branch} + \dfrac{Fixed\_Cost}{MES / XD_{Branch}} - N \cdot Fixed\_Cost}$$

From which the fixed cost can be derived:

$$Fixed\_Cost = \frac{\left(MES / XD_{Branch} \right) \cdot (Cost\_gradient) \cdot XD_{Branch}}{2 - (Cost\_Gradient) \cdot \left[N \cdot \left(MES / XD_{Branch} \right) - 1 \right]}$$

The calibration procedure runs, then, a simultaneous system of equations per sector involving:

- Unit price assumption for the export price and the price of absorption

- The relationship between marginal costs and selling prices to domestic, exports to EU and exports to the rest-of-the-world (RW), involving the mark-ups under a segmentation hypothesis

- The analytical formulas of the mark-ups, including the elasticities of substitution in the love of variety of domestic, EU and RW consumption, the number of firms and the value shares (known from the SAM)

- A zero profit condition per sector
- A domestic production equilibrium condition for volumes.

This system is iteratively solved for the elasticities of substitution in the love of variety of domestic consumption, the mark-ups, the selling prices and the volumes of production and exports. Once this completed, a set of recursive equations compute the rest of the calibration as in any CGE model (there we use the code from the original GEM-E3 model).

Information on the firm size distribution in all three-digit industries:
- No of firms in each firm size class
- Total output value in each size class

The computation of model firm numbers proceeds as follows:

- Compute Herfindahl index H_i for each three digit industry (as explained below)

- Compute the implied number of symmetric firms n_i in each three digit industry simply by taking the reciprocal value of: $H_i : n_i = \frac{1}{H_1}$

- Compute the firms number used in the model as output-weighted average of the three digit level *ni* figures: $n = \sum_i W_i \cdot n_i$

Where:

i : Index over three-digit industries in a model sector

n: Firm no used in the model

Wi: Output (gross production value) of sub-industry i divided by the Output of model industry

The Herfindahl index *Hi* in step 1 is computed as follows.

In general, the Herfindahl index is defined as:

$$H = \sum_J MS_J^2$$

i.e. sum of the squared market shares of each firm, where j index over all firms in an industry and *MSj* is the market share (output share) of firm j.

In practice, Census of Production data provide numbers of firms by size class and one has to assume for the computation that all firms within a discrete size class are equal sized.

A practical example for the UK 1985 may be helpful.

Size class k	**Enterprise size by number of employees (1)**	**No of enterprise n_k (2)**	**Gross Output per size class (million) X_k (3)**
1	1-99	935	1065
2	100-199	34	600
3	200-499	35	1523
4	500-999	12	1184
5	1000-1499	7	1299
6	1500 and over	8	6767
			$\sum_{k=1}^{6} X_k$ **=12439**

Let us take "Chemicals" (model sector 4). According to the UK SIC classification, the sector consists of 7 three digit industries (251, 255, 256, 257, 258, 259, 260). Let us take sector 251 (basic industrial chemicals) as example. The UK 1985 Census of Production gives the information presented in the table.

The output share of a typical firm is size class k is then:

$$\frac{\left(X_k / n_k\right)}{\sum_k X} = MS_k$$

Eg. $MS_1 = {(1065/935)}\big/{12439}$, and

$$H_i = \sum_{k=1}^{6} n_k \cdot (MS_k)^2 = 0.039822 \Rightarrow n_i = \frac{1}{H_i} = 25.1$$

The same procedure is then repeated for the other six sub-industries and the *n* for model sector 4 is computed as an output-weighted average over the 7 sub-industries.

Data Requirements and Objectives for Calibrating the Environmental Module

Since there are no end-of-pipe-technologies for reducing greenhouse gases at reasonable costs, the end-of-pipe abatement technologies considered in GEM-E3 are limited to the primary pollutants SO_2, NO_x, VOC and particulates. The purpose of this Chapter is the parameterization of abatement cost function for SO_2 and NO_x.

The estimation of these cost functions is based on data of a survey undertaken by the Institute for Energy Economics and the Rational Use of Energy (IER, Stuttgart) in 1985 for the German state Baden-Württemberg.[72] Its objective was to calculate the minimal costs of abatement in the year 2000 under varying technical, political and economic assumptions. Therefore the emission structure of 1985 was projected up to the year 2000 without any additional environmental regulations (i.e. no change in the rate of abatement in this matter up to the year 2000).

For this projection several assumptions have been made[73]:

1. Population decrease: 0.7 percent (1985-2000)
2. Annual GNP growth: 2.2 percent
3. Decrease in the energy-intensity of the manufacturing sector: 17.5 %

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[72] There are a few other assumption of minor importance. For more detail see Friedrich, R., Umweltpolitische Instrumente zur Luftreinhaltung - Analyse und Bewertung, 1993.

[73] see footnote 62

4. Increase of transportation services: cars 20.7 percent

   Trucks 26.7 percent

5. Increase of specific fuel use for petrol-driven cars from 9.8 to 7.91 liter per km and for diesel-driven cars from 8.9 to 6.61 liter per km

For the consideration of the abatement cost functions these assumptions are not very restrictive.

- A growth in GNP or in the transport sector will influence the emission structure. The affected industries may vary their rate of abatement and therefore the industry-specific costs of abatement could rise or fall. But the basis of their abatement behaviour, the marginal cost function, won't alter.

- A decrease in energy-intensity (see assumption 2) and 5)) will reduce the energy input per unit of output. Hence there will be an emission reduction which is related to the saving of energy: The emissions will fall in the same way as energy is saved. The emission intensity per unit of energy input is not influenced.

- It is the technical progress which will induce a change in the marginal cost function and subsequently in the abatement behaviour.

Based on the projection up to the year 2000, the author of the study computed the costs and the abatement rates of present abatement measures in a bottom-up analysis. Five aggregated groups of emittants were taken into consideration, i.e. (1) power stations, (2) combustion systems requiring official approval (without refineries), (3) refineries, (4) combustion systems that do not require official approval and (5) traffic. The licence requirement for a plant depends on type and size of the inherent combustion process[74]. Roughly we can say that huge combustion plants do require a licence while the smaller heating systems of small and middle scale industries do not.

The abatement data of these five groups of emittants do not fit exactly in type and size to the classification of the sectors of GEM-E3. In GEM-E3 we distinct twenty emission relevant sectors (firms) or uses (households): agriculture/fishery/forestry, coal, crude oil/oil products, natural gas, electricity, ferrous/non-ferrous/metal products, chemical products, other energy intensive industries, electrical goods, transport equipment, other equipment goods, consumer goods, building/construction, telecommunication services, transport services, services of credit and insurance institutions, other market services, non-market services, heating systems of households and private traffic. As already mentioned, the available data is collected under the criterias "type" and "size" of the combustion systems. If we aggregate some GEM-E3 industries, we can keep the consistency of the data.

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[74] see 'Verordnung über genehmigungsbedürftige Anlagen', 4. Bundesimmissionsschutzverordnung (BImSchV)

Table 19: **The industry grouping along the GEM-E3, according to the type and size of the relevant sector**

Group of Emittants	GEM-E3 Industries
1	electric power
2a	ferrous/non-ferrous/metal products, chemical products, other energy intensive industries
2b	coal, electrical goods, transport equipment, other equipment goods
3	crude oil/oil products (refineries)
4a	natural gas, consumer goods, building and construction, agriculture/fishery/forestry
4b	telecommunication services, services of credit and insurance institutions, other market services, non market services, heating systems of households
5	transport and private traffic (households)

Using these cost functions for all countries implies the following assumptions:

- Availability of the considered abatement technology all over EU-24
- The installation of this technology is feasible in all countries
- Equal installation costs for all countries
- Abatement before 1985 is not considered. Hence, for this year the degree of abatement is zero for all countries.

As an example,

Figure 27 & Figure 28 shows the study's outcome for the group of "electric power":

Figure 27: **Marginal abatement costs of group 1 of emittants (SO_2 emittant)**

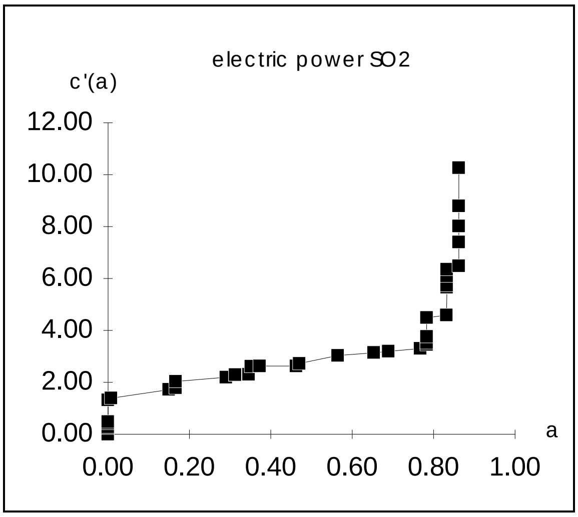
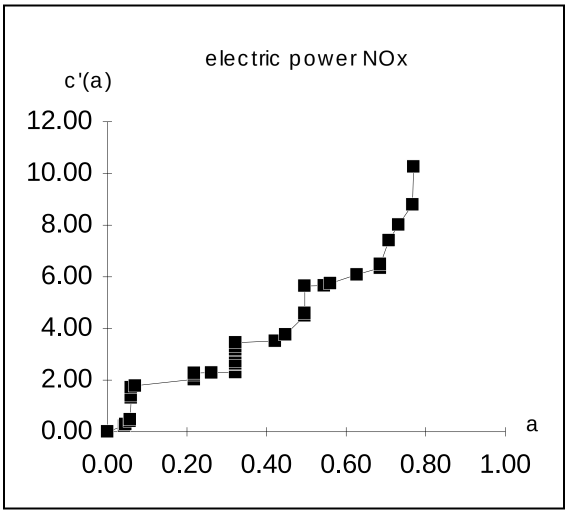


Figure 28: **Marginal abatement costs of group 1 of emittants (NO_X emittant)**



Based on this data a uniform specification of a marginal cost function was estimated for each group of emittants. This specification assumes CRTS in abatement emissions for a firm's aggregated abatement technology but the costs per unit of abated emissions are convex in the degree of abated emissions.

Marginal cost function $c'(a) = \beta(1-a)^{\gamma}$

We derive the unit cost function from the integration of the marginal cost function.

Unit cost function $c(a) = \delta(1-a)^{\lambda} + \kappa$

Where: $\delta = \dfrac{-\beta}{\gamma + 1}$ & $\lambda = \gamma + 1$

Econometric estimation yields the following parameterization for NO_x and SO_2.

Table 20: **Unit abatement costs for NO_x in ECU per reduced kg of NO_x**

	group 1	group 2a	group 2b	group 3	group 4a	group 4b	group 5
δ	4.240	5.39E-03	5.39E-03	2.01E-10	1.35E-03	1.35E-03	2.017
λ	-0.294	-7.473	-7.474	-29.000	-14.300	-14.300	-0.734
ϰ	-3.189	0.943	0.741	7.55E-09	0.741	0.334	-0.194

Table 21: **Unit abatement costs for SO_2 in ECU per reduced kg of SO_2**

	group 1	group 2a	group 2b	group 3	group 4a	group 4b	group 5
δ	-1.890	0.387	0.265	7.35E-07	0.078	0.078	0.105
λ	0.408	-0.586	-0.612	-14.000	-2.668	-2.668	-4.380
ϰ	2.560	0.539	0.539	1.11E-05	0.134	0.134	0.578

Based on some further information for group 2, the following deliveries of abatement expenditures are used throughout all sectors and pollutants.

Table 22: **Break down of deliveries of abatement technologies (in % of total costs)**

cost type	%	assignment to GEM-E3 classification
investment costs	77	equipment goods industries
labour costs	3	labour
waste costs and other variable costs	12	services
fuel costs	8	main energetic input of the sector

Emission Coefficients and Related Parameters for GEM-E3

The following exogenous data were used:

1. EUROSTAT energy balance sheets
2. baseline emission coefficients, from COHERENCE, EUROSTAT and CORINAIR
3. some ratio's needed for the calculation of the input-output table (own calculations).

The Energy Data

Energy consumption, by country, sector and fuel, are taken from the Eurostat energy balances in TOE. The procedure to construct the country excel-workbook is the following. The energy balance 1985 for each country is copied in the first worksheet of the general template, it has to be corrected for the fuels and the energy sectors not available in that country compared to the general template and then the energy balance is converted into PJ in the 2[nd] worksheet. In a third worksheet, a synthetic balance sheet is constructed, aggregating the EUROSTAT balance sheet and considering only the data needed for the computations of the data for GEM-E3 (i.e not import, exports and primary production). The fuel disaggregation has been kept as in the original energy balance with the exception of other solid fuels, which aggregates total lignite and tar and with biomass as the only renewable. The disaggregation takes into account the distinction to be made between relevant energy input, which causes emissions, and non-relevant energy input, which does not cause emissions. The following categories are for relevant energy use:

ELE: energy use in conventional thermal power stations

ENE: own consumption of the energy sector

IND: industrial use for combustion

TRA: energy use for transportation

HEA: energy use by households, commerce, agriculture, fishery

The non-relevant energy use is non-energetic final consumption, transformation input (except power) and bunkering.

In terms of the energy balance categories, the following table illustrates the disaggregation has been used, with the non relevant at the right rows and the relevant at the right:

Table 23: **The disaggregation of energy balance categories in GEM-E3**

Relevant Energy Input	Non-Relevant Energy Input

ELE: electricity sector consumption and district heating **ENE: energy sector consumption with emission, each sector consuming its own type of fuel** ENE-SOL ENE-LIG ENE-GAS ENE-ELEC **IND: industry energy consumption** I&S non-ferro chemical building-mat food, drink & tobacco textile paper engineering other industry **TRA: transport energy consumption** rail road air inland navigation **HEA: energy use for heating** household agriculture/fisheries tertiary	**NENE: energy sector consumption, which does not give emissions** *CKO*, coke-ovens *BFG*, blast furnace *GAS*, gas sector *REF*, refinery **NON ENER, non energy consumption of energy** c*hemical* Other

For the GEM-E3 model, several assumptions have been made to allocate the EUROSTAT energy balance sheet values to the branches and products of the IO table:

Energy consumption by energy branches: combustion of solid fuels is allocated to branch '2'. Combustion of liquid fuels is allocated to branch '3'. Combustion of natural gas is allocated to branch '4'.

Energy consumption by tertiary sector: the total energy inputs are allocated to the tertiary branches on the basis of ratios derived from the IO tables.

Transportation: only LPG, gasoline and diesel oil are used for road transport. The total road transportation input figures are allocated to the different branches and households on the basis of 1980 ratios for Belgium which were extrapolated to 1985. For the computation of the emission coefficient, product '3' is explicitly specified into a fraction used for road transport purposes and a fraction used for other purposes. The energy inputs for non-road transport are allocated to the branch transportation services.

Manufactured gases: since the GEM-E3 IO-table does not include transfers between branches, the manufactured gases have to be handled as a delivery of solid fuels '2'. Total blast furnace gas consumption is allocated as a delivery of product '2' to branch iron and steel. A correction is made for the demand of electricity of this branch (efficiency=0.4). Coke oven gas used for 'power generation' and 'own consumption' is allocated as a delivery of product '2' to branch '2'. A correction is made for the demand for electricity '5' of the branch '2' (efficiency=0.4). Coke oven gas used by 'I&S' is allocated as a delivery of product '2' to branch iron and steel.

Non energy use: the bunkers are allocated as a delivery of product '3' to branch transportation services. The transformation input are allocated to their respective branch, with the exception of blast furnace gas which is already handled as relevant energy use. For the non-energetic final input, the chem goes to branch chemical and the other is allocated to the other branches on the basis of 1980 ratios which are extrapolated to 1985.

With these computations, one obtains, for GEM-E3, one sheet with the relevant deliveries of the energy branches to all branches and one sheet with total deliveries. This allows computing the relevant fraction of total input, i.e. the μ parameter in GEM-E3, which is needed to compute emissions in GEM-E3.

The Baseline Emission Coefficients

1. CO_2 Coefficients

The CO2 emission coefficients are those used by EUROSTAT, in 'Environment Statistics', if no country specific information available.

2. NOx and SO2 emission coefficients

The SO2 emission coefficients are computed taking into account the sulphur content in the fuel, the fraction of sulphur retained and the net heating value of the fuel. The NOx emission coefficients are those computed by Coherence in the HECTOR model (1993). The NOx coefficients are fixed on the basis of technological assumptions as the NOx emissions are dependent on the combustion technology. Some corrections were made when more complete information was available.

3. Voc Emission Coefficients

Emission coefficients for VOC were added to the database and were considered equal across countries. The basic data, with their sources, are given in Table 24 and in Table 25 .

Table 24: **VOC emission factors for stationary sources**

	NMVOC emission factor (g/GJ)	nomenclature in GEM-E3
Large Boilers		
Hard coal or brown coal		
P>50MW	1.5	ELE
P<50MW	15	IND
Peat	15	IND
Residual oil	3	IND
Gas oil	1.5	IND
Natural gas P>50MW	2.5	ELE
P<50MW	4	IND
Oil refinery gas	2.5	IND
Coke oven gas	2,5	IND
Petrocoke	1.5	IND
Wood	48	IND
Residential space heating		HEA
Anthracite	10	HEA
Briquettes	200	HEA
Bituminous coal	200	HEA
Brown Coal	200	HEA
Peat	200	HEA
Gas coke	5	HEA
Wood	600	HEA
Gas Oil	3	HEA
Kerosene	3	HEA
LPG	2	HEA
Natural gas	5	HEA
Manufactured gas	5	HEA
Oil refinery (1)	0.23	ENE

Note: Figures in italic were included in the models.
(1) kg/t of material input in the refinery (crude oil as well as heavy residual products to be
Source: CORINAIR Inventory, July

Table 25: **VOC emission factors for mobile sources**

Road Transport	**g VOC/GJ**
Gasoline vehicles <2.5t conventional (1)	290.2
Diesel vehicles <2.5t (2)	35.3
LPG vehicles <2.5t (3)	335.4
Gasoline Light Duty vehicles<3.5t	
Urban	682.5
Rural	573.0
Highway	356.9
Diesel Light Duty vehicles<3.5t	
Urban	89.0
Rural	87.0
Highway	48.2
Gasoline Heavy Duty vehicles>3.5t	

Urban	707.8
Rural	834.2
Highway	482.6
Diesel Heavy Duty vehicles 3.5-16t	
Urban	283.8
Rural	94.6
Highway	94.6
Diesel Heavy Duty vehicles >16t	
Urban	378.4
Rural	189.2
Highway	189.2
Motor cycles	
<50 cc	7583.9
>50 cc 2 stroke	11375.8
>50 cc 4 stroke	1796.2

Source: Part 3, Default Emission Factors Handbook, CORINAIR Inventory, 1992
1.999-0.034*V+0.000214*V^2;
(2) 4.61*V^(-0.973); (3)26.3*V^(-0.865) with V=60km/h

The VOC emission coefficients for mobile sources used in the model are given in Figure 29. The average between the two diesel truck categories was computed (141.9g/GJ) and then between diesel cars and trucks with as weight for diesel cars the share of household in total diesel consumption, used for the computation of the energy I-O table.

Figure 29: **Model VOC emission coefficients**

Category	**Coefficient (g/GJ)**		
Gasoline vehicles	290	290	290
Diesel cars	35.3	35.3	
Diesel trucks	94.6	141.9	132.8
Diesel big trucks	189.2		

4. Particulate Emission Coefficients

Particulate matter, and in particular **PM10**, is considered in several studies as responsible for important impacts on human health. Its emissions are mainly related to energy use in the transport sector, electricity generation and refineries. Information about the contribution of each sector to the emission of PM10 is coming from ExternE project (stationary sources), VIA, RWTH (1995) and TRENEN project (mobile sources). Data from ExternE are presented in.

ExternE distinguishes the main sources of particulate for each activity within the fuel cycle (mining, transport, electricity generation, etc.), however given the structure of GEM-E3, only the data for electricity generation (coal, lignite, oil and gas) was considered. We assumed the same emission coefficient for the industry sector. For the conversion from g/MWh to ton/PJ (stationary sources), we used the efficiency of the power plant considered and the conversion factor

3600KJ/kWh. As for VOC, the emission coefficients are assumed to be equal across countries.

Figure 30: **Particulate emission coefficients for stationary sources**

	PM10 (g/MWh_{el})	**PM10 (g/GJ)**
Coal power plant in Lauffen (efficiency = 37.6%)	200	20.9
Lignite power plant (efficiency = 36.2%)	167	16.8
Oil peak load plant (efficiency = 31%)	18	1.6
Oil combined cycle base load plant (efficiency=47.5%)	12	1.6

Source: ExternE

Emission coefficients for mobile sources are given in Figure 31. An average speed of 60km/h, a diesel density of 0.842 kg/l[75] and a net heating value of 42.3 MJ/kg were assumed.

Figure 31: **Particulate emissions from vehicles**

Category	**Emission** (g/Veh km)	**Energy consumption** (ton diesel/km)	**Emission** (g/ton diesel)
Normal diesel car	0.0284	4.73574E-05	600.2
Normal diesel bus	0.2324	0.000209005	1111.9
Small lorry (4.37t, diesel)	0.1950	0.000102771	1897.4
Diesel car improved engine with particule filter	0.0043	4.09845E-05	105.3
Diesel car improved engine without particule filter	0.0072	4.05346E-05	177.5
Lorry (diesel)*	0.24	0.000238286	1007.2
Lorry + payload (diesel)*	0.46	0.000358692	1282.4

Source: VIA, RWTH (1995), Emission Calculations for TRENEN

*Assumptions for lorry and lorry + trailer: Utilisation rate: 80%

Lorry, payload 9.86t, diesel engine for lorries overcharged, intercooler, 16 speed gear box, 28.3l/100km, 0.24gPM10/km

Lorry + trailer, payload 25.8t, diesel engine for lorries overcharged, intercooler, 16 speed gear box, 42.6l/100km, 0.46gPM10/km

The final figures to be used in the model and derived from the table above are given in Figure 32.

Figure 32: **Particulate Emissions from vehicles**

Category		**Emission(ton/PJ)**	
Normal diesel car	14.2	16.6	
Normal diesel bus	26.3		26

[75] Statistisch Vademecum. Simulatie Transport. Christian Cuijpers, KUL, Werkdocument, April 1992)

Lorry (diesel)	23.8	27
Lorry +payload (diesel)	30.3	

A weighted average was done to calculate the emission coefficients for cars and buses (80% and 20% respectively). The emission coefficient for diesel vehicles was computed considering the share of fuel use in each category and the average value is 26 ton/PJ.

The different emission coefficients are put all in an excel file emiss&share.xls, which is referred to in the excel file for the computation of GEM-E3 data. Default coefficients are used when no national data are available.

5. General Data Framework

All the data are assembled in an excel file, which structure is given in Figure 33

Figure 33: **Content of the country file with energy and emission data**

Worksheet	**Notes**
eurostat-toe	EUROSTAT energy balance in toe, to insert in B4 with copy/paste special to be adjusted for all columns and lines not present for one country
eurostat-pj	Eurostat-toe*0.04186, copy B5 to all cells again
Synthesis-pj	Energy balance sheet, aggregated to some main sectors + correction of adjustment. It's a simplified version of the previous table, useful for further computations.
relevant-io-gem-pj-95	Input-output table in PJ, with the relevant energy consumption Contains energy consumption that contributes to emissions. Contains information regarding road transport and service branch disaggregation. Coming from the file emiss&share.xls
Total-io-gem-pj-95	Relevant + non-relevant energy consumption from synthesis-pj
Total-io table-pj-gem-e3	Relevant + non-relevant energy consumption in GEM-E3 format, country indices to change
%relev-io-gem-pj-95	Fraction of relevant energy consumption.
%relev.table—gem-e3	Fraction of relevant energy consumption in GEM-E3 format, country indices to change
bec-baseline	Baseline emission factors (SO2, NOx, CO2, VOC, PM10), country name to change in kton/PJ
bem-primes	bec*synthesis in kton
bem-SO2-gem-95	Baseline emission calculation on the basis of the relevant input-output table and
bem-NOx-gem-95	The Hector baseline emission coefficients.
bem-CO2-gem-95	As the file 'relevant-io-gem-pj-85' has total values, we used the figures from
bem-VOC-gem-95	
bem-PM10-gem-95	The file 'synthesis-PJ' that contribute to relevant emissions.

bec-SO2-gem-95	Calculation of the GEM-E3 baseline emission coefficients through a division
bec-NOx-gem-95	of the baseline emissions by the relevant input-output table
bec-CO2-gem-95	in kton/PJ
bec-VOC-gem-95	
bec-PM10-gem-95	
bec-gem-E3	Information from three previous worksheets, in GEM-E3 format, country indices to change

A GAMS calibration file has been built to generate the data for the model, starting from the energy balance and emission coefficients by branch and by country. This program will after some further check replace the Excel sheet presented above.

PART 3

Chapter
8

The GEM-E3 World Model

In that chapter are referred the special characteristics of the GEM E-3 World Model

Data Sources

That extension of the baseline model includes 21 regions, aggregating countries under more general regional schemes. The table below is refereed to the regions aggregation that has been followed in GEM-E3 World Model, according to the GTAP procedure:

Table 26: **GEM-E3 World Aggregation of Regions**

Countries / Regions	GEM-E3 World Regions Aggregations
FRA	France
ITA	Italy
GBR	United Kingdom
DEU	Germany
ESP	Spain
REU15	Austria/Belgium/Denmark/Finland/Greece/Ireland/Luxembourg /Netherlands/Portugal/Sweden
POL	Poland
RCC	Bulgaria/Croatia/Cyprus/Czech Republic/Hungary/Malta/Poland/Romania/Slovakia/Slovenia/Estonia/Latvia/Lithuania
USA	United States of America
CANIN	Canada/Australia/New Zealand/Switzerland/Rest of EFTA
LA	Mexico/Venezuela
RLA	Colombia/Peru/Rest of Andean Pact/Argentina/Chile/Uruguay/Rest of South America/Central America/Rest of Free Trade Area of the Americas/Rest of the Caribbean
BRA	Brazil
JPN	Japan
CHN	China/Hong Kong

RSEA	Korea/Taiwan/Rest of East Asia/Indonesia/Malaysia/Philippines/Singapore/Thailand/Viet Nam/Rest of Southeast Asia/Bangladesh
SAS	India/Sri Lanka/Rest of South Asia
RUS	Russian Federation
XSU	Rest of Former Soviet Union
MENAF	Rest of Middle East/Morocco/Tunisia/Rest of North Africa

The data requirements for the GEM-E3 EU model are referred to the below apposed elements: a) Final demand, b) Intermediate consumption, c) Government revenues, d) Bilateral trade matrices, e)Investment matrices, f) Consumption matrices, g) Transfer payments among institutional agents, h) Interest rates, i) Inflation rates, Employment. The GEM-E3 World Model distinguishes the below mentioned productive sectors in the economy (as already has been depicted at **Error! Reference source not found.**):

Table 27: **The categorization of productive sectors at GEM-E3 World Model**

No	Sector Name	No	Sector Name
1	Agriculture	10	Transport equipment
2	Coal	11	Other Equipment Goods
3	Oil	12	Other Manufacturing Products
4	Gas	13	Construction
5	Electricity	14	Food Industry
6	Ferrous & Non-Ferrous Metals	15	Trade & Transports
7	Chemical Products	16	Textile Industry
8	Other Energy-Intensive Industries	17	Other Market Services
9	Electronic Equipment	18	Non-Market Services

The disaggregation of the productive sectors in the GEM-E3 World Model follows the (**GTAP**) v.4[76] dataset (see. Table 28). The whole process remains the same in reference to the classification of the consumption of households by purpose (see Table 10).

Table 28: **Disaggregation of Sectors according to GTAP v.4 Dataset**

01	**Agriculture**.
□	Agriculture and livestock production (paddy rice only).
□	Agriculture Services (servicing paddy rice production only),
□	Wheat
□	Servicing wheat production only.
□	Grains except wheat and rice.
□	Servicing production of grains.
□	Vegetables fruits and nuts.
□	Oil seeds.
□	Plant based fibers.
□	Crops n.e.c.
□	Bovine cattle, sheep and goats, horses.
□	Animal products n.e.c.
□	Raw milk.
□	Wool, silk-worm cocoons.
□	Forestry.
□	Fishing.
02	**Coal**.
□	Coal mining.
□	Manufacture of miscellaneous products of petroleum and coal (briquettes only).
03	**Oil**.
□	Crude Petroleum & natural gas production (oil only).
□	Petroleum refineries (except LPG).
□	Manufacture of miscellaneous products of petroleum and coal (except briquettes).
04	**Gas**.
□	Crude petroleum and natural gas production (gas only).
□	Petroleum refineries (LPG only).
□	Manufacture of Gas, distribution of gaseous fuels through mains.
□	Steam and hot water supply.
05	**Electricity**.
□	Production, collection and distribution of electricity.
06	**Ferrous and non ferrous metals**.
□	Manufacture of basic iron and steel.

[76] A list of applications based on the GTAP v4 framework can be found at the GTAP home page:

http://www.agecon.purde.edu/gtap/apps/

- Casting of iron and steel.
- Manufacture of basic precious and non ferrous metals.
- Casting of non ferrous metals.

07 Chemical Products.

- Processing of nuclear fuel.
- Manufacture of basic chemicals.
- Manufacture of other chemical products.
- Manufacture of rubber and plastic products.

08 Other energy intensive.

- Iron ore mining.
- Non-ferrous ore mining.
- Stone quarrying, clay and pits.
- Chemical and fertilizer mineral mining.
- Salt mining.
- Mining and quarrying n.e.c.
- Manufacture of pottery, china and earth ware.
- Manufacture of glass and glass products.
- Manufacture of structural clay compounds.
- Manufacture of cement, lime and paster.
- Manufacture of non metallic mineral products.
- Manufacture of pulp, paper and paperboard.
- Manufacture of containers and boxes of paper and paperboard.
- Manufacture of pulp, paper and paperboard articles n.e.c.
- Printing publishing and allied industries.

09 Electronic Equipment.

- Manufacture of office, accounting and computing machinery.
- Manufacture of radio, TV and communication equipment and apparatus.

10 Transport equipment.

- Manufacture of motor vehicles, trailers and semi trailers.
- Manufacture of other transport equipment.

11 Other Equipment Goods.

- Manufacture of engines and turbines.
- Manufacture of agricultural machinery and equipment.
- Manufacture of metal and wood working machinery.
- Manufacture of special industrial machinery and equipment except metal and wood working machinery.
- Manufacture of office, computing and accounting machinery.
- Machinery and equipment except electrical n.e.c.
- Manufacture of electrical and industrial machinery and apparatus.
- Manufacture of radio, TV and communication equipment and apparatus.
- Manufacture of electrical appliances and housewares.
- Manufacture of electrical apparatus and supplies n.e.c.

- Manufacture of professional and scientific and measuring and controlling equipment n.e.c.
- Manufacture of photographic and optical goods.
- Manufacture of watches and clocks.
- Manufacture of cutlery, hand tools and general hardware.
- Manufacture of furniture and fixtures primarily of metal.
- Manufacture of structural metal products.
- Manufacture of fabricated metal products except machinery and equipment n.e.c.

12 Other Manufacturing products.

- Sawmills, planing and other wood mills.
- Manufacture of wooden and cane containers and small cane ware.
- Manufacture of wood and cork products n.e.c.
- Manufacture of furnitutre and fixtures except primarili of metal.
- Manufacture of jewlery and related articles.
- Manufacture of musical instruments.
- Manufacture of sporting and athletic goods.
- Manufacture of industries n.e.c.

13 Construction.

14 Food Industry.

- Distilling, rectifying & blending spirits.
- Wine industries.
- Malt liquors and malt.
- Soft drinks & carbonated waters industries.
- Tobacco manufacturers.
- Canning and preserving of fruits and vegetables.
- Canning, preserving & processing of fish, crustceans and similar foods. Manufacture of vegetable and animal oils and fats.
- Grain mill products (except processed rice).
- Manufacture of bakery products.
- Sugar factories and refineries.
- Manufacture of cocoa, chocolate and sugar confectionery.
- Manufacture of food products n.e.c.
- Manufacture of prepared animal feeds.
- Sugar.
- Grain mill products (processed rice only).
- Manufacture of dairy products.
- Vegetable oils and fats.
- Meat products.
- Bovine cattle, sheep and goat, horse meat prods.

15 Trade and Transport.

- Wholesale trade.
- Retail trade.

- Restaurants, cafes and other eating and drinking places.
- Hotels, rooming houses, camps and other lodging places.
- Railway transport.
- Urban, suburban and interurban highway passenger transport.
- Other passenger land transport.
- Freight transport by road.
- Pipeline transport.
- Supporting services to land transport.
- Ocean and Coastal transport.
- Inland water transport.
- Supporting services to water transport.
- Air transport carriers.
- Supporting services to air transport
- Services incidental to transport.
- Storage and warehousing.
- Communication.

16 Textile Industry.

- Manufacture of textiles.
- Manufacture of man-made fibers.
- Manufacture of wearing apparel, dressing and dyeing of fur.
- Tanning and dressing of leather, manufacture of luggage, handbags, saddlery, harness and footwear.

17 Other Market Services.

- Monetary Institutions.
- Other financial institutions.
- Financial Services.
- Insurance.
- Real estate.
- Legal services.
- Accounting, auditing and bookkeeping services.
- Data processing and tabulating services.
- Engineering, architectural and technical services.
- Advertising services.
- Business services, except machinery and equipment rental and leasing.
- Machinery and equipment rental and leasing.
- Motion picture production.
- Motion picture distribution and production.
- Radio and television broadcasting.
- Theatrical producers and entertainment services.
- Authors music composers and zoological gardens, and other cultural services.
- Amusement and recreational services.
- Repair of footwear and other leather goods.

- Electrical repair shops.
- Repair of motor vehicles and motorcycles.
- Watch, clock and jewellery repair.
- Other repair shops.
- Laundries, laundry services and cleaning and dyeing plants.
- Domestic services.
- Barber and beauty shops.
- Photographic studios, including commercial photography.
- Personal services.
- Collection, purification and distribution of water.
- Dwellings.

18 Non Market Services.

- Public administration and defence.
- Sanitary and similar services.
- Education services.
- Medical, dental and other health services.
- Veterinary services.
- Welfare institutions
- Business, professional and labour associations.
- Religious organizations.
- Social and related community services n.e.c.
- International and other extra territorial bodies.

Chapter

9

The GEM-E3 World Model Calibration

We are referring to calibration of the GEM-E3 World Model

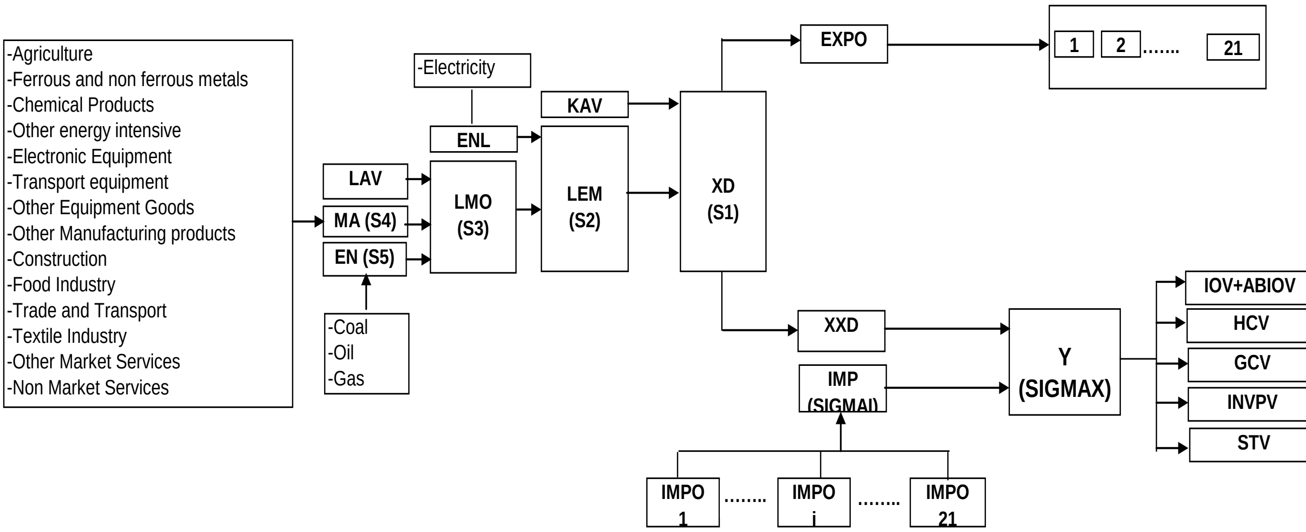
Calibration Structure and Data

Values of elasticities and other exogenous model parameters

Elasticities of substitution in production

Having in concern the preceding analysis at Chapter 7: (Elasticities of Substitution in Production) and the nested CES structure scheme, production factors demand elasticities are constructed with the same notion, as in the GEM E3 EU Model. In the scheme below is illustrated the commodity circuit in GEM E3 World Model, in an explanatory form, so as the substitution elasticities to be defined in a bottom-up approach:

Figure 34: **Commodities Circuit in GEM-E3 World Model**



Where:

S_1 = elasticity of substitution between KAV (capital) and LEM (Labour-Material-Fuels Bundle)

S_2 = elasticity of substitution between ENL (electricity) and LAV (Labour), IOV (Intermediate products)

S_3 = elasticity of substitution between LAV (Labour), MA (Materials) and EN (Fuels)

S_4 = elasticity of substitution between Coal, oil and Gas

The substitution elasticities for each sector and in disaggregated form are showed up at the table below:

Table 29: **Substitution Elasticities in GEM-E3 World Model**

	Elasticities / Sectors	S1			S3			S4			S5		
		RCO	MCO	PCO	RCO	MCO	PCO	RCO	MCO	PCO	RCO	MCO	PCO
1	**Agriculture**	0.4	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.6	0.6	0.6
2	**Coal**	0.4	0.2	0.2	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
3	**Oil**	0.5	0.3	0.3	0.4	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1
4	**Gas**	0.5	0.3	0.3	0.4	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1
5	**Electricity**	0.5	0.3	0.3	0.4	0.3	0.3	0.1	0.1	0.1	0.9	0.9	0.9
6	**Ferrous and non ferrous metals**	0.5	0.3	0.3	0.4	0.3	0.3	0.5	0.5	0.5	0.9	0.9	0.9
7	**Chemical Products**	0.5	0.3	0.3	0.4	0.3	0.3	0.5	0.5	0.5	0.9	0.9	0.9
8	**Other energy intensive**	0.5	0.3	0.3	0.4	0.3	0.3	0.5	0.5	0.5	0.9	0.9	0.9
9	**Electronic Equipment**	0.5	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.6	0.6	0.6
10	**Transport equipment**	0.5	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.6	0.6	0.6
11	**Other Equipment Goods**	0.4	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.6	0.6	0.6
12	**Other Manufacturing products**	0.4	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.6	0.6	0.6
13	**Construction**	0.4	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.6	0.6	0.6
14	**Food Industry**	0.4	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.6	0.6	0.6
15	**Trade and Transport**	0.4	0.2	0.2	0.3	0.2	0.2	0.1	0.1	0.1	0.4	0.4	0.4
16	**Textile Industry**	0.4	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.6	0.6	0.6
17	**Other Market Services**	0.4	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.6	0.6	0.6
18	**Non Market Services**	0.4	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.6	0.6	0.6

Calibration of sectors with imperfect competition

Chapter

10

Appendixes

Appendix 1: I/O Matrixes & Trade Matrixes

Appendix II Table 1: **An example of consumption Matrix of Germany**

	01	02	03	04	05	06	07	08	09	10	11	12	13
01	15893	0	0	261	0	0	0	0	0	0	0	6054	164
02	0	0	0	1588	0	0	0	0	0	0	0	0	0
03	0	0	0	19369	0	0	0	0	30126	0	0	0	0
04	163	77	0	11805	65	12	15	19	24	0	0	62	24
05	0	0	0	25123	0	0	0	0	0	0	0	0	0
06	0	0	0	0	0	0	0	4	10	3	0	344	0
07	40	0	0	5	3002	548	6394	24	58	15	0	1899	3253
08	126	50	0	3	8442	1540	47	19	46	12	0	14397	4332
09	0	0	0	0	6405	1168	42	97	239	61	0	9976	265
10	0	0	0	0	124	23	7	26646	13411	0	0	822	0
11	0	0	0	0	330	60	1494	0	0	0	0	2432	1879
12	125120	61042	0	229	28793	5253	225	0	2031	0	0	9234	6160
13	0	0	0	0	2481	453	0	0	0	0	0	0	0
14	455	214	0	45	180	33	42	53	68	0	18670	173	67
15	1374	648	0	136	545	99	126	160	2194	16362	0	522	1831
16	839	395	0	83	333	61	77	98	125	1	0	319	33453
17	52899	24923	159062	5248	24152	4406	17567	6160	37300	49	0	45377	63888
18	4479	2110	278	444	3097	565	6842	776	1295	164	0	7369	132895
Total	201390	89460	159340	64340	77950	14220	32880	34056	86929	16665	18670	98980	248210

Appendix II Table 2: **An example of the investment Matrix from the French Economy**

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
01	2584	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33
02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
08	983	156	414	778	5648	2975	2965	7428	3360	3871	3958	10630	2023	467	3847	391	11434	2887
09	0	136	362	681	4940	2581	1600	2383	1535	1013	1533	2250	659	13791	2071	360	14188	9434
10	1646	32	84	159	1152	180	592	1434	621	159	555	3725	6707	973	20761	805	15792	3393
11	16619	227	604	1135	8239	5536	5048	9129	5657	3719	5684	14098	7346	1839	3667	3858	37735	4242
12	0	14	38	71	512	210	174	273	146	302	159	454	164	228	71	164	1595	3753
13	6901	803	2136	4016	29152	1403	2370	3581	1852	5978	1926	7629	5311	10798	16716	13147	294770	104654
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	2042	38	101	190	1379	423	408	701	442	288	425	1214	1133	952	2445	1110	48457	2577
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	30775	1405	3738	7029	51022	13307	13157	24929	13613	15331	14240	40000	23342	29047	49579	19834	423971	130972

Appendix II Table 3: **The Intermediate Consumption Matrix-the 1ST division of SAM**

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
01	81327	91	0	0	27	11	802	1480	0	4	82	210625	0	1	0	0	8330	3055
02	0	7051	0	0	6201	8391	453	1597	3	80	10	427	12	10	40	26	279	430
03	10783	259	145277	70	3763	1439	23888	7581	816	1681	1081	8696	8994	674	34861	802	21477	10944
04	254	570	1528	31345	1299	2963	7444	4751	412	991	300	3168	114	109	169	150	4498	3140
05	1743	733	1022	276	44821	5339	5429	7845	1343	2447	1398	9967	1837	728	4235	824	17336	11208
06	525	95	271	0	1317	67907	3253	35126	10971	13975	12201	4876	11307	0	441	0	50	10
07	30828	343	6492	0	436	3399	75804	14139	2482	4176	1986	40075	5316	0	227	0	7641	12163
08	2396	449	2223	146	1612	2905	18455	113773	17947	34867	23750	28831	75858	893	1676	5881	69662	14682
09	67	91	1269	73	2575	1089	769	8160	21262	19960	8415	324	18590	2529	572	0	10008	12688
10	461	0	40	11	83	49	142	1071	111	61754	151	648	506	216	7458	0	5829	25633
11	6310	591	616	125	870	1340	1440	10481	2300	8455	24348	5213	12937	18	624	108	15782	2037
12	41222	481	780	0	129	388	17081	9869	12656	20767	5745	188772	28386	719	2782	387	45741	25654
13	1095	218	2877	1296	3718	203	462	607	261	631	326	599	245	166	540	10310	6429	26254
14	73	47	258	195	940	784	1996	4582	1270	1424	1953	3634	2278	3063	1661	7429	35609	9310
15	2689	335	4360	1529	1888	4400	10394	27129	5807	4555	4697	10693	15554	1780	34521	1460	70650	7933
16	3821	4	841	21	674	1029	3282	5133	2304	2743	2533	6745	13859	0	6534	24032	19073	1814
17	27210	1734	11408	2189	11173	12875	29532	51852	24512	38696	33467	84522	90824	5974	26237	54607	277027	66129
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	210803	13094	179261	37274	81527	114510	200625	305175	104457	217205	122440	607815	286619	16880	122579	106015	615421	233084

Appendix II Table 4: **The final Demand Matrix – the 2nd division of SAM**

	Labour	Capital	Total	Consumption			FIRMS	Total	Investments				Change
				Househ.	Govern.	Banks		Exports	Househ.	Private	Govern.	Total	in Stocks
01	0	0	0	76221	0	0	0	65419	0	2584	33	2616	1610
02	0	0	0	2860	0	0	0	1570	0	0	0	0	-652
03	0	0	0	138610	0	0	0	33378	0	0	0	0	-6677
04	0	0	0	29931	0	0	0	1119	0	0	0	0	504
05	0	0	0	68767	0	0	0	20740	0	0	0	0	-2378
06	0	0	0	620	0	0	0	66223	0	0	0	0	-2105
07	0	0	0	68343	0	0	0	116845	0	0	0	0	192
08	0	0	0	53757	0	0	0	76235	6951	54375	2887	64213	-5322
09	0	0	0	36205	0	0	0	67230	8626	41456	9434	59515	375
10	0	0	0	102172	0	0	0	160008	9601	45777	3393	58771	-2942
11	0	0	0	15606	0	0	0	100047	22941	107200	4242	134383	1015
12	0	0	0	550290	0	0	0	190622	969	3604	3753	8326	4070
13	0	0	0	27173	0	0	0	677	179202	229285	104654	513142	-5549
14	0	0	0	53880	0	0	0	2649	0	0	0	0	0
15	0	0	0	78774	0	0	0	56478	0	0	0	0	0
16	0	0	0	63242	0	192340	0	8705	0	0	0	0	0
17	0	0	0	1408200	0	0	0	153584	29459	32290	2577	64326	0
18	0	0	0	96446	910323	0	0	2402	0	0	0	0	0
Total	0	0	0	2871097	910323	192340	0	1123930	257749	516570	130972	905291	-17859

Appendix II Table 5: **The revenues of Sectors-the 3rd division of SAM**

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
Wages+SSC	30038	9384	11306	8511	31317	33397	56660	157191	71473	92796	70420	194243	168612	54611	126058	118147	696477	6518
Capital	154346	1521	3940	14180	61842	11816	25802	52592	22393	9884	27176	103042	71352	50252	74076	91734	869670	645
Tot Val. Add.	184384	10905	15246	22691	93159	45213	82462	209783	93866	102681	97596	297285	239965	104862	200133	209881	1566147	7163
Act. Output	395187	23999	194507	59965	174686	159723	283087	514958	198323	319886	220036	905100	526584	121742	322712	315896	2181568	9494
HHS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
FIRMS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Indir. Taxes	8501	391	62378	751	10282	2391	5297	10505	3975	7424	4089	28217	10456	4055	11255	53559	139768	491
Direct Taxes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Soc. Security	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Subsidies	-8440	-7123	-20	-12	-482	-474	-405	-2883	-1606	-7828	-1541	-17565	-3010	-18	-23178	-24665	-43339	
VAT taxes	3579	279	13538	2923	6716	61	6654	6866	6765	12602	7257	37023	57258	5149	7629	6037	131768	91
Duties	1175	1	51	1	1	156	599	384	1464	996	1442	2470	0	0	0	0	1	
Gov. Foreign	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Gov. firms	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total Taxes	4815	-6452	75947	3663	16517	2134	12145	14872	10598	13194	11247	50145	64704	9186	-4294	34931	228198	583
Distr. Output	400002	17547	270454	63628	191203	161857	295232	529830	208921	333080	231283	955245	591288	130928	318418	350827	2409766	10077
EC	14026	4159	46550	9063	6128	36199	65776	45876	29857	47096	60775	116581	0	568	12090	2799	19330	
NON-EC	36575	7041	129395	21635	7337	28997	28893	28407	32465	40521	52361	75101	0	761	13979	4190	26667	
Total Imports	51701	11241	177945	31130	14457	65205	95655	75059	62844	89091	113361	199621	392	2106	27205	7901	66313	13
Savings	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total Resour.	451703	28789	448399	94758	205661	227062	390887	604889	271766	422171	344644	1154866	591680	133034	345624	358728	2476079	10091

Appendix II Table 6: **The transfers between sectors-the 4rth division of SA**M

				Consumption			FIRMS	Total	Investments				Change	
	Labour	Capital	Total	Househ.	Govern.	Banks		Exports	Househ.	Private	Govern.	Total	in Stocks	
Wages+SSC	0	0	0	0	0	0	0	10350	0	0	0	0	0	2
Capital	0	0	0	0	0	-192340	0	0	0	0	0	0	0	1
Tot. Val. Added	0	0	0	0	0	-192340	0	10350	0	0	0	0	0	4
Actual Output	0	0	0	0	0	0	0	0	0	0	0	0	0	7
HHS	2573107	838188	3411295	0	1149998	0	171798	-13955	0	0	0	0	0	4
FIRMS		600203	600203	76979				0	0	0	0	0	0	
Indirect Taxes	0	0	0					0	0	0	0	0	0	
Direct Taxes	0	0	0	311356	0		113703	1416	0	0	0	0	0	
Social Security	0	0	0	985492				7441	0	0	0	0	0	
Subsidies	0	0	0		109854			32898	0	0	0	0	0	
VAT taxes	0	0	0					0	0	0	0	0	0	
Duties	0	0	0					0	0	0	0	0	0	
Gov. Foreign	0	0	0					0	0	0	0	0	0	
Gov. firms	0	79410	79410					0	0	0	0	0	0	
Total Taxes	0	79410	79410	1296848	109854	0	113703	41755	0	0	0	0	0	2
Distr. Output	0	0	0					0	0	0	0	0	0	8
Total Imports	19689	0	19689	0	47459	0	0	0	0	0	0	0	0	1
SAVINGS	0	0	0	474212	23852	0	391681	-2313	0	0	0	0	0	1
Total Resources	2592796	1517801	4110597	4719136	2241486	0	677182	1159767	257749	516570	130972	905291	-17859	23

Appendix II Table 7: **A bilateral Trade Matrix based on Comext Data**

	Importer													
Exporter	AU	BE	DE	DK	FI	FR	GR	IR	IT	NL	PL	SP	SV	
AU	0	16018	258019	20634	106	38363	10600	145	155061	176896	572	28447	5098	3
BE	15562	0	158246	42115	1398	1342552	10348	4700	89138	508526	8082	71935	24027	110
DE	131446	611269	0	426624	18116	1515941	129519	30840	1126883	2900127	10271	500749	69137	158
DK	893	16061	73091	0	2641	104209	2104	1298	31900	83340	6243	27738	96507	21
FI	467	6209	20214	16052	0	15274	233	562	8385	37000	538	10111	35719	2
FR	6157	527120	225794	197106	791	0	23897	75367	424962	717132	23627	490015	96329	499
GR	6067	5413	30025	24542	2323	148562	0	214	57952	42217	1598	9547	2302	38
IR	28	7180	8569	5901	998	64050	2103	0	7060	45672	662	6394	1015	313
IT	437344	116011	243965	160981	7710	1870800	275038	29422	0	378165	15007	232470	27828	278
NL	9487	449075	399482	75928	700	823116	22088	8255	84378	0	9237	150733	24390	154
PL	198	6436	6649	24913	0	168312	5965	595	14801	33810	0	124900	3269	50
SP	1492	20737	71885	37718	175	447933	32352	25001	75326	92038	48386	0	11654	216
SV	8428	10570	67789	101730	9418	41603	2743	1835	36286	135065	3144	39610	0	14
UK	3921	129023	163166	66028	5275	950112	30357	187490	200537	528430	23104	210477	20575	
RW	282434	120622	941164	340826	117054	2096702	219401	140643	663589	1067905	68787	311397	219094	576

Appendix II Table 8: **The CPC/ISIC correspondence to the GEM-E3 EU Data calibration**

CPC/ ISIC Classification	Branch Description
0113	Rice, not husked
0114	Husked Rice
0111	Wheat and meslin
0112	Maize (corn)
0115	Barley
0116	Rye, oats
0119	other cereals
012	Vegetables
013	Fruit and Nuts
014	Oil seeds and oleaginous fruit
018	Plants used for sugar manufacturing
0192	Raw Vegetable Materials used in Textiles
015	Live Plants, cut flowers
016	Beverage and spice crops
017	Unmanufactured tobacco
0191	Cereal Straw and husks, unprepared, whether or not chopped, ground, pressed or in the form of pellets; swedes, mangolds, fodder roots, hay, lucerne (alfaalfa), clover, sainfoin, forage kale, lupines, vetches and similar forage products, whether or not in ythe form of pellets
0193	Plants and parts of plants used primarily in perfumery, in pharmacery, in pharmacy, or for insecticidal, fungicidal or similar purpose
0194	Sugar beet seed and seeds of forage plants
0199	Other raw vegetable materials
0211	Bovine attle, sheep and goats, horses, asses, mules and hinnies, live
0299	Bovine semen
0212	Swine, poultry and other animals, live
0292	Eggs, in shell, fresh, preserved or cooked
0293	Natural honey
0294	Snails, live, fresh, chilled, frozen, dried, salted or in brine, except sea snails; frogs' legs, fresh, chilled or frozen
0295	Edible products of animal origin n.e.c.
0297	Hides, skins and furskins, raw
0298	Insect waxes and spermaceti, whether or not refined or coloured
0291	Raw milk
0296	Raw animal materials used in textile
03	Forestry, logging and related service activities
015	Hunting, trapping and game propagation including related service activities
05	Fishing, operation of fish hatcheries and fish farms; service activities incidental to fishing
101	Mining and agglomeration of hard coal
102	Mining and agglomeration of lignite
111	Extraction of crude petroleum and natural gas (part)
112	Service activities incidental to oil and gas extraction excluding surveying (part)
231	Manufacture of coke oven products

232	Manufacture of refined petroleum products
233	Processing of nuclear fuel
111	Extraction of crude petroleum and natural gas (part)
112	Service activities incidental to oil and gas extraction excluding surveying (part)
231	Manufacture of coke oven products
232	Manufacture of refined petroleum products
232	Processing of nuclear fuel
111	Extraction of crude petroleum and natural gas (part)
112	Service activities incidental to oil and gas extraction excluding surveying (part)
402	Manufacture of gas; distribution of gaseous fuels through mains
403	Steam and hot water supply
401	Production, collection and distribution of electricity
271	Manufacture of basic iron and steel
2731	Casting of iron and steel
272	Manufacture of basic precious and non-ferrous metals
2732	Casting of non-ferrous metals
241	Manufacture of basic chemicals
242	Manufacture of other chemical products
25	Manufacture of rubber and plastics products
12	Mining of uranium and thorium ores
13	Mining of metal ores
14	Other mining and quarrying
21	Manufacture of paper and paper products
2211	Publishing of Books, brochures, musical books and other Publications
2212	Publishing of newspapers, journals and periodicals
2213	Publishing of recorded media
2219	Other Publishing (photos, engravings, postcards, timetables, forms, posters, art reproductions, etc.)
222	Printing and service activities related to printing
223	Reproduction of recorded media
26	Manufacture of other non-metallic mineral products
30	Manufacture of office, accounting and computing machinery
32	Manufacture of radio, television and communication equipment and apparatus
34	Manufacture of motor vehicles, trailers and semitrailers
35	Manufacture of other transport equipment
28	Manufacture of fabricated metal products, except machinery and equipment
29	Manufacture of machinery and equipment n.e.c.
31	Manufacture of electrical machinery and apparatus n.e.c.
33	Manufacture of medical, precision and optical instruments, watches and clocks
36	Manufacturing n.e.c.
37	Recycling
20	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials

45	Construction
24	Beverages
25	Tobacco products
212	Prepared and preserved fish
213	Prepared and preserved vegetables
214	Fruit juices and vegetable juices
215	Prepared and preserved fruit and nuts
2311	Wheat or meslin flour
2312	Cereal flours other than of wheat or meslin
2313	Groats, meal and pellets of wheat
2314	Cereal groats, meal and pellets n.e.c.
2315	Other cereal grain products (including corn flakes)
2317	Other vegetable flours and meals
2318	Mixes and doughs for the preparation of bakers' wares
232	Starches and starch products; sugars and sugar syrups n.e.c.
233	Preparations used in animal feeding
234	Bakery products
236	Cocoa, chocolate and sugar confectionery
237	Macaroni, noodles, couscous and similar farinaceous products
239	Food products n.e.c.
235	Sugar
2316	Rice, semi- or wholly milled
22	Dairy products
2168	Margarine and similar preparations
2169	Animal or vegetable fats and oils and their fractions, partly or wholly hydrogenated, interesterified,re-esterified or elaidinised, whether or not refined, but not further prepared
217	Cotton linters
218	Oil-cake and other solid residues resulting from the extraction of vegetable fats or oils; flour sand meals of oil seeds or oleaginous fruits, except those of mustard; vegetable waxes, except triglycerides; degras; residues resulting from the treatment of fatty substances or animal or vegetable waxes
2163	Soya-bean, ground-nut, olive, sunflower-seed, safflower, cotton-seed rape, colza and mustard oil, crude
2164	Palm, coconut, palm kernel, babassu and linseed oil, crude
2165	Soya-bean, ground-nut, olive, sunflower-seed, safflower, cotton-seed, rape, colza and mustard oil and their fractions, refined but not from olives and sesame oil, and their fractions, whether or not refined, but not chemically modified
2166	Maize (corn) oil and its fractions, not chemically modified
2167	Palm, coconut, palm kernel, babassu and linseed oil and their fractions, refined but not chemically modified; castor, tung and jojoba oil and fixed vegetable fats and oils (except maize oil) and their fractions n.e.c., whether or not refined, but not chemically modified
21113	Meat of swine, fresh or chilled
21114	Meat of swine, frozen
2112	Meat and edible offal, fresh, chilled or frozen, n.e.c.

2113	Preserves and preparations of meat, meat offal or blood
2114	Flours, meals and pellets of meat or meat offal, inedible; greaves
2162	Animal oils and fats, crude and refined, except fats of bovine animals, sheep, goats, pigs and poultry
21111	Meat of bovine animals, fresh or chilled
21112	Meat of bovine animals, frozen
21115	Meat of sheep, fresh or chilled
21116	Meat of sheep, frozen
21117	Meat of goats, fresh, chilled or frozen
21118	Meat of horses, asses, mules or hinnies, fresh, chilled or frozen
21119	Edible offal of bovine animals, swine, sheep, goats, horses, asses, mules or hinnies, fresh, chilled or frozen
2161	Fats of bovine animals, sheep, goats, pigs and poultry, raw or rendered; wool grease
50	Sales, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel
51	Wholesale trade and commission trade, except of motor vehicles and motorcycles
521	Non-specialized retail trade in stores
522	Retail sale of food, beverages and tobacco in specialized stores
523	Other retail trade of new goods in specialized stores
524	Retail sale of second-hand goods in stores
525	Retail trade not in stores
526	Repair of personal and household goods
55	Hotels and restaurants
60	Land transport; transport via pipelines
63	Supporting and auxiliary transport activities; activities of travel agencies
61	Water transport
62	Air transport
17	Manufacture of textiles
243	Manufacture of man-made fibres
18	Manufacture of wearing apparel; dressing and dyeing of fur
19	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear
41	Collection, purification and distribution of water
65	Financial intermediation, except insurance and pension funding
67	Activities auxiliary to financial intermediation
66	Insurance and pension funding, except compulsory social security
70	Real estate activities
711	Renting of transport equipment
712	Renting of other machinery and Equipment
713	Renting of personal and household goods n.e.c
72	Computer and related activities
73	Research and Development activities
74	Other business activities
92	Recreational, cultural and sporting activities
93	Other service activities
95	Private households with employed persons

75	Public Administration and Defence; compulsory social security
80	Education
85	Health and Social work
90	Sawage and refuse disposal, sanitation and similar activities
91	Activities of membership organizations n.e.c
99	Extra-territorial organizations and bodies

Appendix 2: Transport & Transformation Coefficients

EMEP Transport Coefficients

(NOx and SO2)

Units: % of total emissions

Columns: Emitters

Rows: Receivers

Appendix III Table 1: **EMEP Transport Coefficient for NO_X across EU Countries**

	AU	BE	DE	DK	FI	FR	GR	IR	IT	LX	NL	PL	SV	S
NOX.AU	0.044	0.022	0.024	0.003	0.000	0.016	0.001	0.004	0.014	0.035	0.013	0.000	0.002	0.
NOX.BE	0.000	0.026	0.006	0.002	0.000	0.008	0.000	0.004	0.000	0.017	0.013	0.000	0.001	0.
NOX.DE	0.023	0.144	0.133	0.044	0.004	0.071	0.001	0.032	0.009	0.173	0.126	0.003	0.015	0.
NOX.DK	0.000	0.007	0.006	0.028	0.001	0.002	0.000	0.004	0.000	0.000	0.011	0.000	0.006	0.
NOX.FI	0.001	0.005	0.007	0.025	0.107	0.002	0.000	0.004	0.000	0.000	0.008	0.000	0.046	0.
NOX.FR	0.013	0.088	0.045	0.013	0.001	0.152	0.001	0.036	0.026	0.121	0.050	0.027	0.005	0.
NOX.GR	0.003	0.001	0.002	0.001	0.000	0.002	0.043	0.000	0.005	0.000	0.001	0.000	0.001	0.
NOX.IR	0.000	0.003	0.002	0.001	0.000	0.002	0.000	0.043	0.000	0.000	0.003	0.000	0.001	0.
NOX.IT	0.031	0.014	0.017	0.003	0.001	0.032	0.012	0.004	0.113	0.017	0.009	0.003	0.002	0.
NOX.LX	0.000	0.002	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.
NOX.NL	0.000	0.017	0.006	0.003	0.000	0.005	0.000	0.007	0.000	0.000	0.026	0.000	0.001	0.
NOX.PL	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.068	0.000	0.
NOX.SV	0.003	0.022	0.020	0.070	0.068	0.007	0.000	0.011	0.000	0.017	0.026	0.000	0.120	0.
NOX.SP	0.003	0.007	0.006	0.002	0.000	0.022	0.000	0.004	0.005	0.017	0.006	0.099	0.001	0.
NOX.UK	0.003	0.019	0.011	0.012	0.003	0.011	0.000	0.072	0.001	0.017	0.025	0.003	0.006	0.

Appendix III Table 2: **EMEP Transport Coefficient for SO_2 across EU Countries**

	AU	BE	DE	DK	FI	FR	GR	IR	IT	LX	NL	PL	SV	S
SO2.AU	0.125	0.014	0.018	0.002	0.001	0.012	0.001	0.003	0.008	0.025	0.008	0.000	0.001	0
SO2.BE	0.000	0.107	0.007	0.002	0.000	0.016	0.000	0.003	0.000	0.025	0.033	0.000	0.001	0
SO2.DE	0.031	0.155	0.220	0.055	0.003	0.073	0.000	0.019	0.005	0.213	0.136	0.002	0.012	0
SO2.DK	0.001	0.006	0.005	0.086	0.001	0.002	0.000	0.003	0.000	0.000	0.008	0.000	0.009	0
SO2.FI	0.001	0.003	0.006	0.014	0.216	0.001	0.000	0.001	0.000	0.000	0.004	0.000	0.040	0

SO2.FR	0.012	0.111	0.030	0.009	0.001	0.244	0.001	0.024	0.017	0.163	0.057	0.014	0.003
SO2.GR	0.002	0.001	0.001	0.001	0.000	0.001	0.074	0.000	0.006	0.000	0.001	0.000	0.000
SO2.IR	0.000	0.003	0.001	0.001	0.000	0.002	0.000	0.123	0.000	0.000	0.002	0.000	0.000
SO2.IT	0.035	0.008	0.012	0.002	0.001	0.025	0.009	0.001	0.148	0.013	0.005	0.001	0.001
SO2.LX	0.000	0.002	0.001	0.000	0.000	0.002	0.000	0.000	0.000	0.038	0.001	0.000	0.000
SO2.NL	0.001	0.041	0.009	0.004	0.001	0.008	0.000	0.004	0.000	0.000	0.113	0.001	0.001
SO2.PL	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.121	0.000
SO2.SV	0.002	0.014	0.015	0.089	0.065	0.005	0.000	0.007	0.000	0.013	0.015	0.001	0.231
SO2.SP	0.002	0.006	0.003	0.001	0.000	0.019	0.000	0.003	0.003	0.013	0.004	0.083	0.000
SO2.UK	0.001	0.026	0.009	0.009	0.001	0.013	0.000	0.074	0.000	0.013	0.032	0.001	0.004

EMEP Transport Coefficients

(NOx, VOC and Ozone)

Appendix III Table 3: **EMEP Transport Coefficients for VOC, O_3**

change in yearly
average change in ozone concentrations (ppb)
if 1000kt VOC is increased in the country in the column :

TPCC (VOC,O3)

	AU	BE	DE	DK	FI	FR	GR	IR	IT	LU	NL	PL	SP	SV
AU	0.260	0.136	0.288	0.080	0.011	0.104	0.000	0.038	0.193	0.219	0.142	0.000	0.007	0.02
BE	0.023	1.105	0.503	0.080	0.006	0.197	0.000	0.188	0.005	0.563	1.049	0.002	0.010	0.03
DE	0.063	0.444	0.475	0.154	0.011	0.158	0.000	0.119	0.018	0.507	0.451	0.000	0.009	0.03
DK	0.014	0.145	0.118	0.350	0.021	0.057	0.000	0.093	0.001	0.102	0.150	0.001	0.001	0.06
FI	0.001	0.016	0.012	0.054	0.048	0.004	0.000	0.010	0.001	0.009	0.015	0.000	0.000	0.02
FR	0.041	0.462	0.281	0.037	0.002	0.265	0.000	0.070	0.039	0.457	0.420	0.014	0.064	0.01
GR	0.020	0.011	0.020	0.008	0.002	0.008	0.547	0.001	0.075	0.010	0.005	0.002	0.003	0.00
IR	0.003	0.194	0.084	0.032	0.000	0.043	0.000	0.445	0.002	0.040	0.214	0.003	0.002	0.00
IT	0.124	0.085	0.099	0.022	0.005	0.145	0.007	0.016	0.418	0.114	0.069	0.006	0.024	0.00
LU	0.052	0.842	0.713	0.147	0.017	0.218	0.000	0.134	0.015	1.405	0.904	0.003	0.018	0.05
NL	0.008	0.786	0.359	0.101	0.004	0.146	0.000	0.227	0.002	0.281	0.944	0.002	0.006	0.02
PL	0.000	0.011	0.003	0.005	0.000	0.015	0.000	0.005	0.002	0.010	0.009	1.739	0.341	0.00
SP	0.004	0.036	0.017	0.005	0.000	0.049	0.000	0.007	0.007	0.041	0.031	0.409	0.296	0.00
SV	0.003	0.038	0.037	0.105	0.033	0.011	0.000	0.022	0.001	0.025	0.047	0.000	0.000	0.04
UK	0.002	0.197	0.100	0.046	0.002	0.045	0.000	0.266	0.002	0.068	0.097	0.003	0.001	0.01
RW	0.079	0.086	0.148	0.066	0.013	0.050	0.050	0.023	0.075	0.108	0.088	0.000	0.004	0.02

Appendix III Table 4: **EMEP Transport Coefficients for NOX, O_3**

change in yearly
average change in ozone concentrations (ppb) if
1000kt NOx is increased in in the country in the column :

TPCC(NOX,O3)

	AU	BE	DE	DK	FI	FR	GR	IR	IT	LU	NL	PL	SP	SV
AU	1.173	0.142	-0.085	0.046	0.035	0.076	0.000	0.024	0.077	-0.096	-0.155	0.001	0.008	0.05
BE	0.017	-1.916	-0.699	0.027	0.012	0.192	0.000	0.296	0.001	-0.322	-1.353	0.000	0.014	0.04
DE	0.147	-0.479	-0.353	0.162	0.029	0.130	0.000	0.142	-0.004	-0.096	-0.453	0.000	0.011	0.10
DK	0.002	-0.044	0.021	0.951	0.093	0.019	0.000	0.135	0.001	0.020	-0.010	0.000	0.001	0.47
FI	0.001	-0.009	0.001	0.130	1.779	0.000	0.000	0.015	0.000	-0.004	0.003	0.000	0.000	0.63
FR	0.030	-0.409	-0.207	0.008	0.002	0.682	0.000	0.187	0.034	-0.352	-0.318	0.018	0.164	0.01
GR	0.038	-0.001	0.002	0.001	0.007	0.019	0.874	0.002	0.122	0.000	0.000	0.003	0.012	0.00
IR	-0.002	-0.206	-0.095	-0.002	0.003	0.010	0.000	2.287	-0.002	-0.031	-0.200	0.006	0.003	0.02
IT	0.172	-0.035	-0.034	0.011	0.011	0.305	0.020	0.020	0.266	-0.044	-0.038	0.013	0.069	0.01
LU	0.003	-1.070	-0.920	-0.029	0.009	0.373	0.000	0.178	-0.002	-1.703	-0.909	0.000	0.031	0.03
NL	0.001	-0.969	-0.466	0.074	0.014	0.097	0.000	0.343	0.001	0.040	-1.336	0.001	0.005	0.06
PL	0.000	0.000	0.000	0.006	0.000	0.029	0.000	0.020	0.008	-0.001	0.002	2.023	0.465	0.00
SP	0.005	0.004	-0.004	0.008	0.000	0.154	0.000	0.027	0.022	0.010	0.001	1.051	1.279	0.00
SV	0.005	-0.010	0.006	0.302	0.702	0.002	0.000	0.042	0.000	-0.003	0.003	0.000	0.000	1.28
UK	0.000	-0.193	-0.081	0.092	0.007	0.017	0.000	1.091	-0.001	-0.020	-0.229	0.002	0.004	0.05
RW	0.238	-0.066	-0.042	0.081	0.094	0.053	0.096	0.027	0.044	-0.063	-0.062	0.001	0.007	0.15

Appendix III Table 5: **ETSU Transport Coefficients for Particulates**

(Change in yearly particulate concentration in μg m^{-3} from 1000t/y of emission in country in column)

TPCC (PM10	**AU**	**BE**	**DE**	**DK**	**FI**	**FR**	**GR**	**IR**	**IT**	**NL**	**PL**	**SV**	**S**
PM10.AU	1.66E-02	8.92E-04	1.52E-03	7.29E-04	3.36E-04	7.77E-04	6.10E-04	3.49E-04	1.70E-03	8.31E-04	2.69E-04	4.31E-04	3
PM10.BE	8.92E-04	2.79E-02	2.24E-03	1.13E-03	3.11E-04	1.94E-03	3.11E-04	7.77E-04	7.77E-04	5.44E-03	3.79E-04	5.21E-04	4
PM10.DE	1.52E-03	2.24E-03	5.44E-03	1.37E-03	3.63E-04	1.13E-03	3.79E-04	5.21E-04	9.62E-04	2.64E-03	3.11E-04	5.78E-04	4
PM10.DK	7.29E-04	1.13E-03	1.37E-03	8.24E-03	5.78E-04	6.10E-04	2.79E-04	5.48E-04	4.96E-04	1.70E-03	2.52E-04	1.24E-03	2
PM10.FI	3.36E-04	3.11E-04	3.63E-04	5.78E-04	5.44E-03	2.52E-04	1.96E-04	2.52E-04	2.44E-04	3.49E-04	1.26E-04	1.24E-03	1
PM10.FR	7.77E-04	1.94E-03	1.13E-03	6.10E-04	2.52E-04	5.44E-03	3.23E-04	6.46E-04	9.62E-04	1.24E-03	5.78E-04	3.49E-04	8
PM10.GR	6.10E-04	3.11E-04	3.79E-04	2.79E-04	1.96E-04	3.23E-04	5.44E-03	3.49E-04	6.46E-04	3.00E-04	1.96E-04	2.14E-04	2
PM10.IR	3.49E-04	7.77E-04	5.21E-04	5.48E-04	2.52E-04	6.46E-04	3.49E-04	1.66E-02	3.36E-04	7.77E-04	4.12E-04	3.79E-04	4
PM10.IT	1.70E-03	7.77E-04	9.62E-04	4.96E-04	2.44E-04	9.62E-04	6.46E-04	3.36E-04	4.04E-03	6.46E-04	3.49E-04	3.11E-04	4
PM10.NL	8.31E-04	5.44E-03	2.64E-03	1.70E-03	3.49E-04	1.24E-03	3.00E-04	7.77E-04	6.46E-04	1.66E-02	3.49E-04	6.10E-04	4
PM10.PL	2.69E-04	3.79E-04	3.11E-04	2.52E-04	1.26E-04	5.78E-04	1.96E-04	4.12E-04	3.49E-04	3.49E-04	8.24E-03	1.74E-04	2
PM10.SV	4.31E-04	5.21E-04	5.78E-04	1.24E-03	1.24E-03	3.49E-04	2.14E-04	3.79E-04	3.11E-04	6.10E-04	1.74E-04	3.20E-03	1
PM10.SP	3.63E-04	4.96E-04	4.12E-04	2.89E-04	1.44E-04	8.31E-04	2.52E-04	4.31E-04	4.96E-04	4.31E-04	2.24E-03	1.96E-04	5
PM10.UK	5.21E-04	1.52E-03	8.31E-04	8.31E-04	3.00E-04	9.62E-04	2.28E-04	1.94E-03	4.51E-04	1.52E-03	4.12E-04	4.96E-04	4
PM10.RW	1.40E-03	5.43E-04	7.67E-04	5.93E-04	5.18E-04	5.01E-04	8.78E-04	2.72E-04	8.54E-04	5.41E-04	2.06E-04	5.50E-04	2

Concentration/Deposition Relations

N deposition to nitrate concentration

NO_3^- [μg m^{-3}] = 9.98 * N deposition [t km^{-2}] + 1.88

S deposition to sulphate concentration

SO_4^{--} [μg m^{-3}] = 2.09 * S deposition [t km^{-2}] + 2.06

S deposition to SO_2 concentration

SO_2 [μg m^{-3}] = 5.74 * S deposition [t km^{-2}] + 2.37

Appendix 3: Equations, Variables & Parameters

Equations

a) Household Equations:

Demand – Consumption of Goods

1. $$HCDTOTV = CH + \frac{stp}{rr}\frac{BH}{PCI}\left(YDISP + PLJ \cdot LJV - Obl\right)$$

Consumption of Leisure

2. $$LJV = CL + \frac{stp}{rr}\frac{BL}{PLJ \cdot}\left(YDISP + PLJ \cdot LJV - Obl\right)$$

Users Cost of Durable Goods Consumption

3. $$\begin{aligned} PDUR_{DG} = {} & PC_{DG}(rr + \delta_{DG}) + TX_{PROP,DG}(1 + rr) + \\ & \sum_{LND} \lambda_{LND,DG} PC_{LND,DG} \end{aligned}$$

Demand of Durable Goods

4. $$SDG = \gamma_{DG} + \left(\frac{\beta_{DG}}{PDUR_{DG}}\right) \cdot \left(HCNDTOT - \sum_{ND} PC_{ND} \cdot \gamma_{ND}\right)$$

Demand for linked-Non Durable Goods

5. $$LLNDC_{ND} = \sum_{DG} \lambda_{DG,ND} \cdot \left(\theta_{ND,DG} SDG\right)$$

Investment in Non-Durable Goods

6. $$\begin{aligned} HCFV_{ND} = {} & CH_{ND} + \left(\frac{\beta_{ND}}{PC_{ND}}\right)\left[HCNDTOT - \sum_{ND} PC_{ND} \cdot \gamma_{ND}\right] \\ & + LLNDC_{ND} \end{aligned}$$

Total Household Expenditure (without non-durable goods)

7. $HCDTOTV = HCNDTOT + \sum_{DG} HCFV + \sum_{ND} LLNDC$

Investment in Durable Goods

8. $HCFV_{DG} = SDG_{DG} - (1-\delta) \cdot SDG_{DG}[-1]$

b) Firms Production Equations:

Derived Demand for Labour – Energy Material

9. $LEM_{PR} = XD_{PR} \cdot \delta_{LEM,PR} \cdot \left(\frac{PD_{PR}}{PLEM_{PR}} \right)^{\sigma}$

Derived Demand for Capital Stock

10. $KAV_{PR} = XD_{PR} \cdot \delta_{KAV,PR} \cdot \left(\frac{PD_{PR}}{PK_{PR}} \right)^{\sigma} \cdot e^{tgk_{PR} \cdot t \cdot (\sigma \; -1)}$

Demand for Electricity

11. $ENL_{PR} = f\left(XD_{PR}, \delta_{ENL,PR}, PEL_{PR}, PD_{PR}, e^{tge_{PR} \cdot t \cdot (\sigma_2 - 1)}\right)$

Demand for Labour

12. $LAV_{PR} = f\left(XD_{PR}, \delta_{LAV,PR}, PL_{PR}, PD_{PR}, e^{tgl \cdot t \cdot (\sigma_2 - 1)}\right)$

Intermediate Demand for Energy

13. $IOVE_{BRE,PR} = f\left(XD_{PR}, \delta_{IOVE,PR}, PIO_{BRE}, PD_{PR}, e^{tgi \cdot t \cdot (\sigma_3 - 1)}\right)$

Intermediate Demand for Material Inputs

14. $IOVM_{BRM,PR} = f\left(XD_{PR}, \delta_{IOVM,PR}, PIO_{BRM}, PD_{PR}, e^{tgi \cdot t \cdot (\sigma_4 - 1)}\right)$

Unit Labour Cost

15. $PL_{PR} = f(WR)$

c) Firms Investment Equations:

Volume of firm Investment

16. $$INVV_{PR} = m \times KAV_{PR} \cdot \left[\left(\frac{PK_{PR}}{PINV_{PR} \cdot (r+d)} \right)^{\sigma} \cdot (1+STGR) \cdot e^{tgk(\sigma-1)} - (1-d) \right]$$

Next Period Capital Stock

17. $$KAVC_{PR} = (1-d)^T \cdot KAV_{PR} + \left(\frac{1-(1-d)^T}{d} \right) \cdot INVV_{PR}$$

d) Firms Pricing Equations:

Domestic Supply Price

18. $$PXD_{PR} = PD_{PR} \cdot \left(1 + TXSUB_{PR}\right)$$

Export Supply Price

19. $$PWE_{PR} = PD_{PR} \cdot \left(1 + TXSUB_{PR}\right) / EX$$

e) Domestic Demand Equations:

Price of the Domestic Demand

20. $$PY_{PR} = \frac{1}{AC_{PR}} \left[\delta_{1,PR}{}^{\sigma_x} \cdot PXD_{PR}^{(1-\sigma_x)} + (1-\delta_{1,PR})^{\sigma_x} \cdot PIMP_{PR}^{(1-\sigma_x)} \right]^{\frac{1}{1-\sigma_x}}$$

Demand for Domestic Produced Goods

21. $$XXD_{PR} = Y_{PR} \cdot AC_{PR}{}^{(\sigma_x - 1)} \cdot \delta_{1,PR}{}^{\sigma_x} \cdot \left(\frac{PY_{PR}}{PXD_{PR}} \right)^{\sigma_x}$$

Demand for Imported Goods

22. $$IMP_{PR} = Y_{PR} \cdot AC_{PR}{}^{(\sigma_x - 1)} \cdot (1-\delta_{1,PR})^{\sigma_x} \cdot \left(\frac{PY_{PR}}{PIMP_{PR}} \right)^{\sigma_x}$$

Price of Total Imports of Good PR

23. $PIMP_{PR,EU} = \left[\sum_{CO} \beta^{\sigma_{xx}} \cdot PIMPO_{PR,EU,CO}^{(1-\sigma_{xx})} \right]^{\frac{1}{1-\sigma_{xx}}}$

Imports of Good PR demanded by EU Country

24. $\dfrac{IMPO_{PR,EU,CO}}{IMP_{PR,EU}} = \dfrac{\partial PIMP_{PR,EU}}{\partial PIMPO_{PR,EU,CO}}$

Imports of Good PR demanded by the rest of the world from EU country

25. $IMPO_{PR,RW,EU} = \alpha_{RW} \cdot \left(\dfrac{PWEO_{PR,RW}}{PWEO_{PR,EU} EX_{EU}} \right)^{\varepsilon_{RW}}$

Trade Balance Equation

26. $EXPO_{PR,CO,EU} = IMPO_{PR,EU,CO}$

Aggregation of Total Exports of EU

27. $EXPOT_{PR,EU} = \sum_{CO} EXPO_{PR,EU.CO}$

f) Derived Prices Equations

Prices of Intermediate Consumption Goods

28. $PIO_{PR} = PY_{PR} + \tau_{PR}$

Prices of Goods in Final Consumption for Households

29. $PHC_{PR} = \left(PY_{PR} + \tau_{PR} \right) \cdot \left(1 + vat_{PR} \right)$

Prices of Goods in Final Consumption for Government

30. $PGC_{PR} = PY_{PR} + \tau_{PR}$

Prices of Investment Goods

31. $PINVP_{PR} = PY_{PR} + \tau_{PR}$

Unit cost of Investment

32. $PINV_{BR} = \sum_{PR} tcf_{PR,BR} \cdot PINVP_{PR}$

g) Income Accounts Equations

Surplus/Deficit of the Government

33.
$$SURPLUS_G = \sum_{PR} \tau_{PR} \left[\begin{array}{l} \sum_{BR} IOV_{PR,BR} + HC_{PR} \\ \qquad + \sum_{BR} tcf \cdot INVV_{BR} + INVH_{PR} + INVG_{PR} \end{array} \right]$$

$$+ \sum_{PR} vat_{PR} \cdot \left[\left(PY_{PR} + \tau_{PR} \right) \cdot HC_{PR} + \left(PINVH_{PR} + \tau_{PR} \right) \cdot INVH_{PR} \right]$$
$$+ \sum_{EU} TXDUT_{EU,CO} \cdot PIMPO_{PR,EU,CO} \cdot IMPO_{PR,EU}$$
$$+ \tau s \cdot \sum_{PR} PL_{PR} \cdot LAV_{PR} \quad - HTRA - \sum_{PR} \left(PGC_{PR} \cdot GC_{PR} + PINVP_{PR} \cdot INVG_{PR} \right)$$

Surplus/Deficit of the Firms

34. $SURPLUS_F = \sum_{PR} PK_{PR} \cdot KAV_{PR} - \sum_{PR} PINV_{PR} \cdot INVV_{PR}$

Surplus/Deficit of the Households

35.
$$SURPLUS_H = HTRA + \sum_{PR} PL_{PR} \cdot LAV_{PR} \cdot \left(1 - \tau_i\right) - PC \cdot HCT$$
$$- \sum_{PR} TINV_{PR} \cdot PINV_{PR} \cdot INVV_{PR}$$

Surplus/Deficit of the Foreign Sector

36. $SURPLUS_W = \sum_{PR} PIMPO_{PR} \cdot IMPO_{PR} - \sum_{PR} PEX_{PR} \cdot EXPOT_{PR}$

h) Equilibrium Equations

Total Production

37. $XD_{PR} = XXD_{PR} + EXPOT_{PR}$

The Total Amount of Capital Stock (Capital Mobile)

38. $KAV\_Supply = \sum_{PR} KAV_{PR}$

The total Amount of Capital Stock (Capital Mobility across Countries)

39. $KAV\_Supply = \sum_{EU}\sum_{PR} KAV_{PR}$

Equilibrium in Labour Market

40. $\sum_{PR} LAV_{PR} = TOTTIME - LJV$

i) Equivalent Variation Equations

Expenditure Function

41. $C_t^H = (\frac{rr}{\rho})(\frac{PC_t^B}{BH})^{BH}(\frac{PLJ_t^B}{BL})^{BL} U_t$

Present Value of Equivalent Variation

42. $EV = \sum_{t=0}^{T}\left[\frac{1}{1+\rho}\cdot \Delta PC_t^B \cdot \Delta PLJ_t^B \left(CH_t^A - CH_T^B\right)\right]$

j) Imperfect Competition Extension

Firm – specific Exports of a Firm

43. $xxd_{PR,EU}^{k} = xxd_{PR,EU}^{\lambda}$ and $exot_{PR,EU}^{k} = exot_{PR,EU}^{\lambda}$

Price for Aggregate Domestically Produced Goods

44. $$PXD_{PR} = \left[\sum_{k}^{n_{PR}} (pxdf_{PR})^{1-s_{PR}} \right]^{\frac{1}{1-s_{PR}}} = n_{PR}^{\frac{1}{1-s_{PR}}} \cdot pxdf_{PR}$$

Derived Demand Equation for Individual Firm-Specific Products

45. $$xxdf_{PR} = XXD_{PR}^{k} \cdot \left(\frac{PXD}{pxdf} \right)^{s_k}$$

Price Indices for Bilateral Imports of Good PR

46. $$PIMPO_{PR,EU,CO} = \left[\sum^{n_{CO}} (pimpof_{PR,EU,CO})^{1-s_{CO}} \right]^{\frac{1}{1-s_{CO}}} = n^{\frac{1}{1-s_{CO}}} \cdot pimpof_{PR,EU,CO}$$

Firm Specific Volume of Imports Equation

47. $$impof_{PR,EU,CO} = IMPO_{PR,EU,CO} \cdot \left(\frac{PIMPO_{PR,EU,CO}}{pimpof_{PR,EU,CO}} \right)^{s_{CO}}$$

Firms Total Cost Equation

48. $$Costf_{PR} = \{ marginal\ cost\ \ function \} \cdot xdf_{PR} + \{ \ fixed\ cost \} \ F_{PR}$$

Firm-specific Demand for Capital

49. $$KAVf_{PR} = kavf_{PR}^{\mathrm{var}} + kavf_{PR}^{fix}$$

Firm-specific Demand for Intermediate Inputs

50. $$IOVf_{PR} = iovf_{PR}^{\mathrm{var}} + iovf_{PR}^{fix}$$

Firm-specific Demand for Labour

51. $$LAVf_{PR} = lavf_{PR}^{\mathrm{var}} + lavf_{PR}^{fix}$$

Industry Level Total Output Equation

52. $$XD_{PR} = n_{PR} \cdot xdf_{PR}$$

Industry Level Demand for Intermediate Inputs

53. $IOV_{PR,BR} = n_{PR} \cdot IOVf_{PR,BR}$

Industry Level Demand for Labour Equation

54. $LAV_{PR} = n_{PR} \cdot LAVf_{PR}$

Total Fixed Cost by Sector

55. $Fixed\ Cost_{PR} = n_{PR} \cdot \left(KAVf_{PR}^{fix} + LAVf_{PR}^{fix} + \sum_{BR} IOVf_{PR,BR}^{fix} \right)$

Industry Level total Profits/Losses Equation

56. $$profitf_{PR} = PS_{PR} xd_{PR} - \sum_{BR} PI_{PR,BR} \cdot xif_{PR,BR} + PL_{PR} \cdot lf_{PR} + PK_{PR} kf_{PR,t} - fixed\cos tf_{PR}$$

Optimal Mark-up price for Domestically Produced Goods

57. $PXD_{PR} \cdot \left(1 - \frac{1}{\psi do_{PR}} \right) = PD_{PR}$

Optimal Mark-up price for Exported Goods

58. $PEX_{PR} \cdot \left(1 - \frac{1}{\psi \mathrm{ex}_{PR}} \right) = PD_{PR}$

Price Elasticity Equation

59. $Y_{PR} = \alpha_{PR} \cdot \left(PY_{PR} \right)^{\Omega_{PR}}$

Inverse Price Elasticity of Domestic Market

60. $\frac{1}{\psi do_{PR,EU}} = -\frac{1}{s} + \frac{1}{s}\frac{1}{n} - \frac{1}{\kappa}\frac{1}{n}(1 - share_{Y}^{XXD}) + \frac{1}{\Omega}\frac{1}{n} share_{Y}^{XXD}$

Weighted Average Elasticity of the demand functions of the various countries

61. $\psi \exp_{PR,EU} = \sum_{CO} \frac{IMPO_{PR,CO,EU}}{EXPOT_{PR,EU}} \cdot \phi_{CO,EU}$

Firm Numbers Dynamic Adaptation Equation

62. $n_{i,t+1} = n_{i,t} + g \cdot \left(n^{\otimes}{}_{i,t} - n_{i,t} \right)$

Variables

HCDTOTV = consumption of goods (in volume)

YDISP = disposable income

CL = subsistence quantity of leisure

CH = subsistence quantity of consumption

LJV = consumption of leisure

PLJ = price of total time resource

PCI =consumer price index

PDUR = cost of durable goods

PC = consumption price

TX = property tax for the durables

SDG = stock of durables

LLNDC = demand for linked non-durable goods

HCFV = net investments in durable goods

HCNDTOT =consumption of non-linked, non-durable goods

PD =deflator of domestic production/ price

XD = domestic production

KAV =fixed capital stock

LEM =labour – energy – material bundle in production

PK = effective capital rate of return for fixed capital

PLEM = deflator of Labour-Energy-Materials bundle

ENL = demand for electricity

PEL = deflator of demand of electricity

LAV =labour demand

PL =unit cost of labour

$IOVE$ = intermediate consumption of energy in a production process

$IOVM$ = intermediate consumption of material inputs in a production process

PIO = unit cost of intermediate good

WR =average wage rate

$PINV$ = investment deflator

K = demand for capital

Y = volume of production

$INVV$ = investment demand of a firm

$INVG$ = investment demand of a government

$INVH$ = Investment demand of household

PXD =price of domestic supply

PWE =domestic supply price addressed to exports

$TXSUB$=rate of subsidies

XXD = demand for domestic production

IMP = demand for imports

PY =absorption price of composite good

$PIMP$ =price of imported goods

$EXPO$ =exports of good

PHC = price of goods in total household consumption

PGC = price of goods in total government consumption

$PINVP$ = prices of investment-used goods

GC = government consumption

$HTRA$= income transfers from government to households

$SURPLUS$ = surplus or deficit

PEX =Price of Export Goods

LAV =labour demanded by firm

Parameters

stp = subjective discount rate of the households

rr = real discount rate

γ = minimum obliged consumption

δ = replacement rate

θ = minimum consumption of a good, in order to be created a positive service flow

σ = elasticity of substitution

tgk =technical progress of capital

d = depreciation rate

$stgr$ = expected growth rate of the sector

ex = exchange rate

$txsub$ =rate of subsidies

ac =scale parameter in Arminghton function

β = share parameter for Armington

τ = indirect taxation

tcf =technical coefficient of investment goods composition

n =number of firms

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Table of Figures

Tables