E3ME Technical Manual v6.1

cambridge econometrics
clarity from complexity

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Preface and Summary

Acknowledgements

The E3ME model is developed and maintained by the modelling team at Cambridge Econometrics. Any errors in this manual are the responsibility of the team.

The FTT models have been developed by teams led by Jean-Francois Mercure (Exeter University). The energy cost supply curves in the model were developed by Jean-Francois Mercure and Pablo Salas. We are also grateful to Jurgen Doornik (University of Oxford) for development and support of the Ox programming language.

E3ME has been continuously developed under the European Commission's research framework programme. This support is gratefully acknowledged.

Conventions adopted in the manual

4CMR	Cambridge Centre for Climate Change Mitigation Research
AMECO	Annual Macroeconomic database (DG Economic & Financial Affairs, European Commission)
CE	Cambridge Econometrics
CSV	Comma separated value (file format)
E3	Energy-Environment-Economy
E3ME	Energy-Environment-Economy Macro-Econometric Model
E3MG	Global Energy-Environment-Economy Model
EC	European Commission
EMU	Economic and monetary union
EU	European Union
ERM	Exchange rate mechanism (of the EMS)
ESA	Eurostat system of national accounts
ETS	Emission Trading Scheme
EU	European Union
GDP	Gross Domestic Product
GTAP	Global Trade Analysis Project
GVA	Gross Value Added
IDIOM	International Dynamic Input-Output Model software package
IFS	IMF International Financial Statistics
IMF	International Monetary Fund
IO	Input-output
IPCC	Intergovernmental Panel on Climate Change
MDM	Multi-sectoral Dynamic Model of the UK
MEI	OECD Main Economic Indicators
MREG	Matrix Regression software package
NACE	Nomenclature générale des activités économiques dans les communautés européennes (EU industrial classification of economic activities)
OECD	Organisation for Economic Co-operation and Development
ONS	Office for National Statistics (UK)
WDI	World Development Indicators (World Bank)

Units of measurement

m	Million
bn	Billion (thousand million, as French milliard)
mtc	Million tonnes of carbon
pa	Per annum
pb	Per barrel of oil equivalent
pp	Percentage point
toe	Tonnes of oil equivalent
nes	Not elsewhere specified

E3ME variables

The full list of variable names is available on request.

1. Introduction and Background

1.1 Overview

E3ME is a computer-based model of the world's economic and energy systems and the environment. It was originally developed through the European Commission's research framework programmes and is now widely used globally for policy assessment, for forecasting and for research purposes.

The current version of E3ME combines the previous model version with a new global database to cover:

- Europe at Member State level (incl. Croatia)
- three other EU candidate countries, Norway and Switzerland
- 11 other major economies explicitly
- the rest of the world grouped into political regions

This version of the model replaces the previous E3MG model.

Recent applications of E3ME include:

- an assessment of the economic and labour market effects of the EU's long-term strategy for climate policy
- contribution to the EU's Impact Assessment of its 2030 environmental targets and 'Clean Energy Package'
- the 2018 New Climate Economy report

Further examples of model applications are provided in Section 5.5 and are available on the model website, www.e3me.com

1.2 Historical context

E3ME was originally intended to meet an expressed need of researchers and policy makers for a quantitative framework for analysing the impacts of Energy-Environment-Economy (E3) policies. The model was designed for addressing the short-term and medium-term economic effects as well as, more broadly, the long-term effects of such policies, such as those from the supply side of the labour market.

The initial development phase

The first version of the E3ME model was built by an international European team under a succession of contracts in the JOULE/THERMIE and EC research programmes. The projects 'Completion and Extension of E3ME' and 'Applications of E3ME', were completed in 1999. The 2001 contract, 'Sectoral Economic Analysis and Forecasts' generated an update of the E3ME industry output, product and investment classifications to bring the model into compliance with the European System of Accounts, ESA 95. This led to a significant disaggregation of the service sector which has been maintained ever since.

The 2003 contract, Tipmac, led to a full development of the E3ME transport module to include detailed country models for several modes of passenger and freight transport and Seamate (2003/04) resulted in the improvement of the E3ME technology indices. The COMETR (2005-07), Matisse (2005-08) and CEDEFOP (2007-2010) projects allowed the expansion of E3ME to cover 33 European countries, including the twelve accession countries and four candidate countries, and added the materials module.

Current use of the model

More recent model development has been supported by Cambridge Econometrics' internal research programme and has been focused on the needs of the company's clients. For example, the current global version of the model, including the revised specification of international trade, has been developed in this way.

The focus of research has, however, shifted from model development to application. E3ME has been in constant demand from public and private sector clients, at both national and European levels (and more recently globally). Some of this demand has been for forecasting exercises, but the model is usually applied for scenario-based policy analysis.

The model has been used for several recent high-profile assessments, including:

- contribution of employment projections to CEDEFOP's annual skills forecasts
- an assessment of the impacts of high oil prices on the global economy for the 2009 London G20 summit
- input to the EU's Impact Assessment of the revised Energy Taxation Directive
- input to the European Commission's official communication on options for moving beyond the 20% GHG reduction target for 2020
- contribution to the official assessment of the EU's 2030 environmental targets
- input to the EU's Impact Assessment of the Energy Efficiency Directive

E3ME is being used extensively in the forthcoming book *E3 Modelling for a Sustainable Low Carbon Economy in East Asia.*

The current model version

Section 2.8 compares E3ME to other macroeconomic models. In summary, the key features that distinguish E3ME from these models are:

- its global geographical coverage, including all Europe's Member States and candidate countries, the world's largest economies and all other economies in groups
- its detailed sectoral disaggregation, with 69 economic sectors in Europe and 43 sectors for the rest of the world
- its econometric specification that provides a strong empirical grounding and means the model is not reliant on many of the rigid assumptions common to other modelling approaches (see Section 2.8)
- its detailed two-way linkages between the economy, energy system and emissions, including incorporation of the FTT:Power model (see Section 2.5)
- its integrated treatment of material demands

Table 1.1 compares the current version of the model against the previous one that was released in 2012.

Latest developments

Version 6.1 of the model is an interim version, pending the official release of Version 7. Ongoing improvements include:

- incorporation of measures of consumption-based emissions
- revisions to the energy equations and price elasticities
- the addition of several bottom-up sub-models of energy consumption
- an overhaul of the model's treatment of innovation

The interface has also been replaced with a web-based version.

Version 7.0

The next version of E3ME will consolidate a range of developments, including the FTT sub-models for road transport, steel and household heating. It will also include a complete update of the main model database and the incorporation of feedbacks to human health from pollution; and to economic productivity from climate change. It therefore represents a substantial upgrade to the model. Version 7.0 is due to be finalised in mid-2019. An updated manual will be provided with the new version.

1.3 Structure of this manual

Chapter 2 provides a detailed description of E3ME's structure, including how the economic and energy/environment components fit together. Chapter 3 addresses some of the practical aspects of the model, including the data, forecast, econometrics and software. Chapter 4 presents the econometric equations of the model. These chapters are designed for the model user and describe how to run the model, first of all through the command line and then using the user-friendly graphical interface.

The final chapter provides the references for this manual and a list of publications that have resulted from use of the model.

Table 1.1: Changing versions of the E3ME model

Common characteristics		
Main data sources		Eurostat, AMECO, IEA, OECD (new sources for non-EU regions)
Accounting system		ESA95
Number of stochastic equation sets		29
Principal differences	**E3ME 5.5**	**E3ME 6.1**
Regions	33	61
Industries	69	69 (EU), 43 (non-EU)
of which services	38	38 (EU), 16 (non-EU)
Base year input-output tables	2005	2005
Price base	2005	2005
Estimation period:		
from	1970	1970
to	2010	2012
Calibration period	1970-2010	1970-2016
Solution period	1995-2050	1995-2050
Treatment of trade	Pooled	Bilateral
Power sector model	ETM	FTT
Materials indicators	DMI, TMR	DMI, TMR, RMC

2. Description of E3ME

2.1 Introduction and underlying theory

Introduction

The following account of E3ME starts with a brief discussion of the theory behind the model. We then move on to the basic model structure before describing in more detail the main modules (economy, energy/emissions, materials). The final two sections in this chapter describe the model's technological progress indicators and compare E3ME to other common modelling approaches.

The theoretical background

Economic activity undertaken by persons, households, firms and other groups in society has effects on other groups after a time lag, and the effects persist into future generations, although many of the effects soon become so small as to be negligible. But there are many actors and the effects, both beneficial and damaging, accumulate in economic and physical stocks. The effects are transmitted through the environment (with externalities such as greenhouse gas emissions contributing to global warming), through the economy and the price and money system (via the markets for labour and commodities), and through the global transport and information networks. The markets transmit effects in three main ways: through the level of activity creating demand for inputs of materials, fuels and labour; through wages and prices affecting incomes; and through incomes leading in turn to further demands for goods and services. These interdependencies suggest that an E3 model should be comprehensive, and include many linkages between different parts of the economic and energy systems.

These economic and energy systems have the following characteristics: economies and diseconomies of scale in both production and consumption; markets with different degrees of competition; the prevalence of institutional behaviour whose aim may be maximisation, but may also be the satisfaction of more restricted objectives; and rapid and uneven changes in technology and consumer preferences, certainly within the time scale of greenhouse gas mitigation policy. Labour markets in particular may be characterised by long-term unemployment. An E3 model capable of representing these features must therefore be flexible, capable of embodying a variety of behaviours and of simulating a dynamic system. This approach can be contrasted with that adopted by general equilibrium models: they typically assume constant returns to scale; perfect competition in all markets; maximisation of social welfare measured by total discounted private consumption; no involuntary unemployment; and exogenous technical progress following a constant time trend (see Section 2.7 and Barker, 1998, for a more detailed discussion).

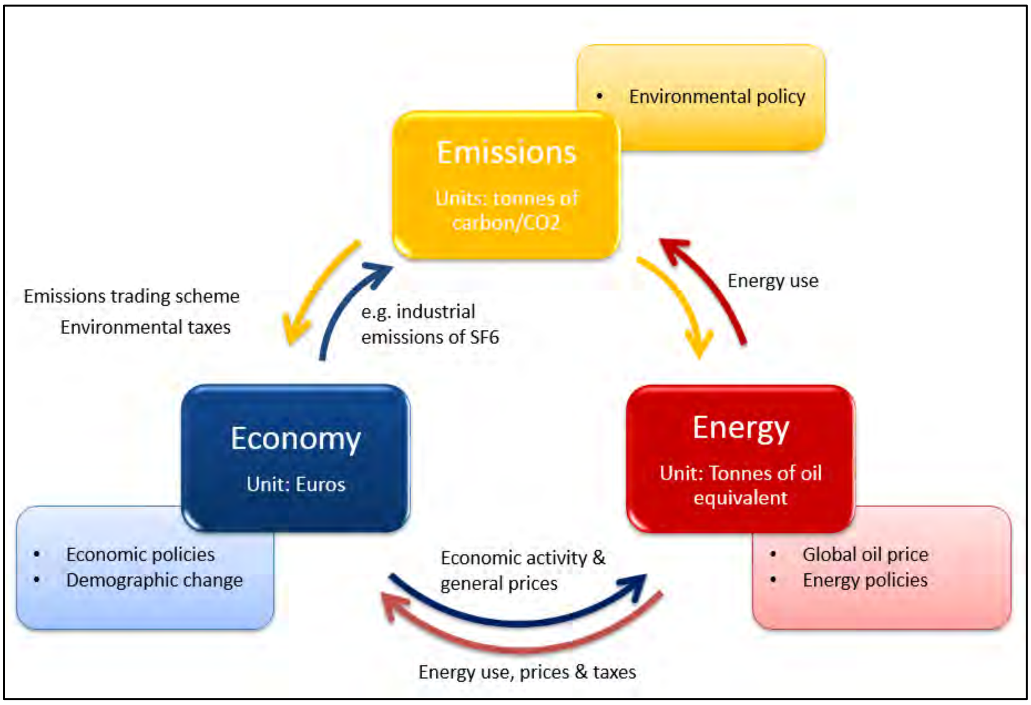
2.2 Basic model structure

The E3ME model comprises:

- the accounting framework of the economy, based on ESA95, coupled with balances for energy and material demands and environmental emission flows
- detailed historical data sets, with time series covering the period since 1970, and sectoral disaggregation at the NACE 2-digit level
- an econometric specification of behavioural relationships in which short-term deviations move towards long-term trends

Figure 2.1 shows how the three components (modules) of the model (energy, environment and economy) fit together. For European countries there is an additional module for material consumption that is currently being expanded to include other countries.

Figure 2.1: E3ME as an E3 Model



The three modules

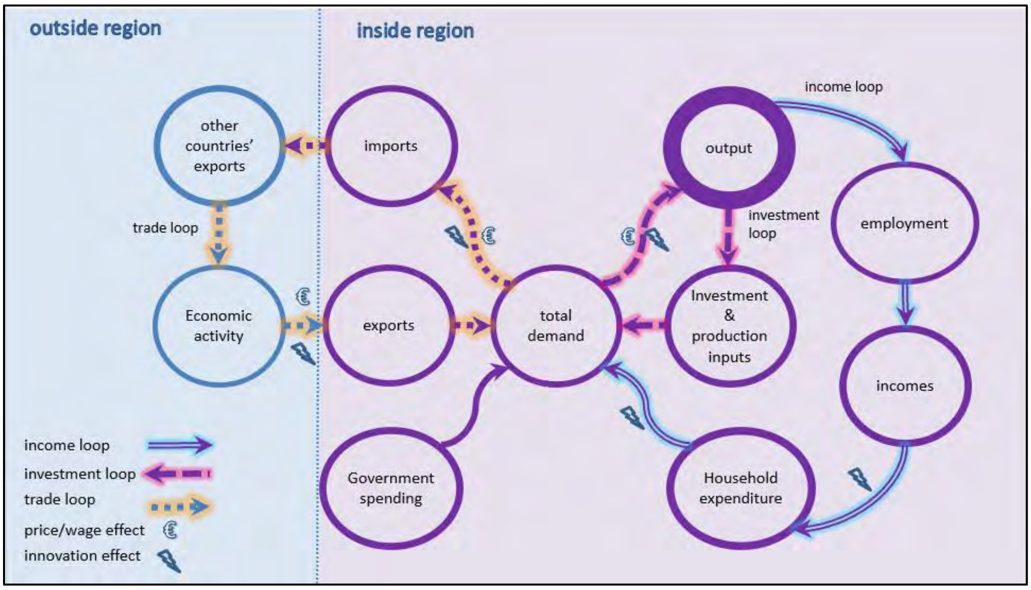
Each component is shown in its own box with its own units of account and sources of data. Each data set has been constructed by statistical offices to conform to accounting conventions. Exogenous factors coming from outside the modelling framework are shown on the outside edge of the chart as inputs into each component. For the economic module these include demographic factors and economic policy (including tax rates, growth in government expenditures, interest rates and exchange rates). For the energy system, the outside factors are the world oil prices and energy policy (including regulation of energy industries). For the environment component, exogenous factors include policies such as reduction in SO_2 emissions by means of end-of-pipe filters from large combustion plants. The linkages between the components of the model are shown explicitly by the arrows that indicate which values are transmitted between components.

The economy module provides measures of economic activity and general price levels to the energy module; the energy module then determines levels and prices of energy consumption, which is passed to the emissions module and is also fed back to the economic module.

2.3 E3ME's economic module

Figure 2.2 shows how E3ME's economic module is solved for each region. Most of the economic variables shown in the chart are solved at the sectoral level. The whole system is solved simultaneously for all industries and all regions, although single-country solutions are also possible.

Figure 2.2: E3ME's basic economic structure



The loops of interdependency

As the figure suggests, output and employment are determined by levels of demand, unless there are constraints on available supply. The figure shows three loops or circuits of economic interdependence, which are described below. In addition there is an interdependency between the sectors that is not shown in the figure. The full set of loops comprises:

- Interdependency between sectors: If one sector increases output it will buy more inputs from its suppliers who will in turn purchase from their own suppliers. This is similar to a Type I multiplier.
- The income loop: If a sector increases output it may also increase employment, leading to higher incomes and additional consumer spending. This in turn feeds back into the economy, as given by a Type II multiplier.
- The investment loop: When firms increase output (and expect higher levels of future output) they must also increase production capacity by investing. This creates demand for the production of the sectors that produce investment goods (e.g. construction, engineering) and their supply chains.

- The trade loop: Some of the increase in demand described above will be met by imported goods and services. This leads to higher demand and production levels in other countries. Hence there is also a loop between countries.

Calculation of each component of demand

We now turn to how the model calculates results for each of the main components in the figure above. There is a mixture of accounting and behavioural relationships involved.

Formal equation definitions for the behavioural relationships are provided in Chapter 4.

Intermediate demand

Intermediate demand (the sum of demand from other production sectors) is determined by the input-output relationships in the model. When one sector increases its production, it requires more inputs to do so. The sectors in its supply chain thus see an increase in demand for their products.

Household consumption

Estimating household consumption is a two-stage process. Total consumer spending by region is derived from functions estimated from time-series data. These equations relate consumption to regional personal disposable income, a measure of wealth for the personal sector, inflation and interest rates. Share equations for each of the 43 consumption categories reported by Eurostat[1] are then estimated. In the model solution, disaggregate consumption is always scaled to be consistent with the total.

Government consumption

Government consumption is given by assumption, split into the main different components of spending. It is therefore exogenous in the simulations and will not change unless explicitly requested by the modeller.

Investment

Gross Fixed Capital Formation is determined through econometric equations estimated on time-series data. Expectations of future output are a key determinant of investment, but investment is also affected by relative prices and interest rates.

Unfortunately, due to data limitations investment is not disaggregated by asset in E3ME, although a split between ICT and non-ICT investment is retained in the historical data for European regions. This split is important in determining endogenous technological progress (see Section 2.7) in the model.

Stockbuilding is treated as exogenous in the model.

International trade

The treatment of international trade has been revised substantially for E3ME version 6.0. The new approach makes use of the time series of bilateral trade that are now available from Comtrade and the OECD. The approach has four stages:

- For each country, total imports are estimated using equations based on time-series national accounts data. Import volumes are determined primarily by domestic activity rates and relative prices (see Section 4.7).
- Separate bilateral equations for import shares are then estimated for each destination region, sector and origin region.
- Bilateral imports are then scaled so that they sum to the total estimated at the first stage.
- Finally, export volumes are determined by inverting the flows of imports.

[1] 28 categories for regions outside Europe.

The treatment of trade is described in more detail in Section 4.7.

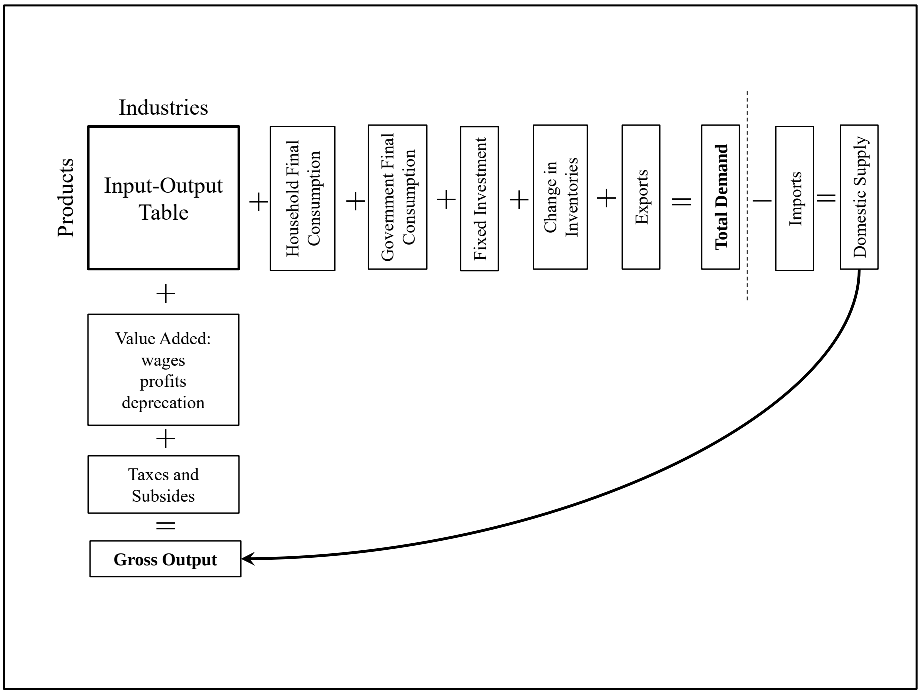
Output and determination of supply

Total product output, in gross terms, is determined by summing intermediate demand and the components of final demand described above. This gives a measure of total demand for domestic production.

It is assumed that, subject to certain constraints, domestic supply increases to match demand (see Figure 2.3 for how this is implemented within the National Accounts structure). The most obvious constraint is the labour market (see below); if there is not enough available labour then production levels cannot increase. However, the model's 'normal output' equations (see Chapter 4) also provide an implicit measure of capacity, for example leading to higher prices and rates of import substitution when production levels exceed available capacity.

The relationship between prices and quantities is discussed later in this section.

Figure 2.3: Determination of supply and demand



The labour market and incomes

Treatment of the labour market is another area that distinguishes E3ME from other macroeconomic models. E3ME includes econometric equation sets for employment (as a headcount, see Section 4.9), average working hours (4.8), wage rates (4.12) and participation rates (4.13). The first three of these are disaggregated by economic sector while participation rates are disaggregated by gender and five-year age band.

The labour force is determined by multiplying labour market participation rates by population. Unemployment (including both voluntary and involuntary unemployment) is determined by taking the difference between the labour force and employment.

Labour market interactions

There are important interactions between the labour market equations. They are summarised below:

Employment = F (Economic output, Wage rates, Working hours, …)

Wage rages = F (Labour productivity, Unemployment, …)

Working hours = F (Economic output in relation to capacity, …)

Participation rates = F (Economic output, Wage rates, Working hours, …)

Labour supply = Participation rate * Population

Unemployment = Labour supply – Employment

The full specification for the econometric equations is given in Chapter 4.

Analysis of skills

E3ME does not include measures of skills demand and supply explicitly, but the model results for sectoral employment and labour supply may be used to derive both of these. Cambridge Econometrics works in collaboration with the Institute for Employment Research (IER) at Warwick University in the UK to produce these results.

Nevertheless, it is important to be aware of the limitation in skills treatment within the main model structure. If a modelled scenario shows an increase in employment it is implicitly assumed that workers with the necessary skills are available. For studying large changes in employment, a supplementary bottom-up analysis is require to test feasibility of the model results.

Incomes

Due to limitations in available time-series data, E3ME adopts a representative household for each region. Household income is determined as:

Income = Wages – Taxes + Benefits + Other income

The taxes currently distinguished are standard income taxes and employees' social security payments (employers' social security payments are not included in wages). A single benefit rate is used for each region.

'Other income' includes factors such as dividend payments, property rent and remittances. At present it is not possible to derive data for these financial flows and so they are either estimated (see Section 4.14), fixed, or held constant in relation to wages.

Household income, once converted to real terms, is an important component in the model's consumption equations, with a one-to-one relationship assumed in the long run (see Section 4.5).

Price formation

So far, the discussion has largely focused on real production (apart from wage rates). However, for each real variable there is an associated price, which influences quantities consumed. For example, each category of household expenditure has a price variable attached to it, which influences consumption patterns within the model.

Aside from wages, there are three econometric price equations in the model (see Chapter 4):

- domestic production prices
- import prices
- export prices

These are influenced by unit costs (derived by summing wage costs, material costs and taxes), competing prices and technology. Each one is estimated at the sectoral level.

One of the key price variables in the model is the price of domestic consumption. It is also determined by sector, by taking a weighted average of domestic and import prices, subtracting off the export component. This price is then used to determine the prices for final consumption goods; for example if the car industry increases prices, this will be reflected in the price consumers pay for cars.

Aggregate deflators, including the Consumer Price Index, are derived by taking the average of prices across all products and sectors.

Social indicators

Policy assessments, including Impact Assessment at European level requires an analysis of 'economic, social and environmental impacts' (European Commission, 2009). In quantitative modelling, the assessment of social impacts is often largely ignored. This is partly due to a lack of quantitative indicators but also that it often does not fit well into the basic structure of most macroeconomic models.

Like other models, E3ME is able to provide less coverage of social factors than economic factors (see above) and environmental impacts (see next two sections) but social factors are not ignored completely. The main social indicators in the model are:

- sectoral employment and working hours
- sectoral wage rates
- unemployment
- an estimate of (real) income distribution

The labour market indicators are discussed above, so the remainder of this section focuses on the estimates of distributional impacts.

Distributional income

E3ME's model of distributional income is relatively basic, including income quintiles and some specific socio-economic groups, as defined by the Eurostat data. For a detailed analysis, a microsimulation model, such as Euromod (Sutherland et al, 1999, 2013) is required[2].

At present, the E3ME treatment is only able to cover European countries although this could easily be expanded if the necessary data are available. The analysis of distributional income also sits outside the main modelling framework, as the time-series data required to estimate econometric equations are not available; this means for example that there is no feedback from the distributional analysis to aggregate household expenditure.

The approach is based on two components. The first of these is the income component. For each social group, the shares of their income from wages, benefits and other income (minus their tax deductions) are scaled in line with the aggregate model results for wages and benefits, etc. So a scenario that

[2] It would also be possible to couple such a model to E3ME to provide both macroeconomic and distributional results.

includes increases in benefit rates would show positive results for low-income groups who rely more on benefits.

The second part links household expenditure survey data to the model results for consumer prices. This is mainly used to assess the effects of higher energy prices, as in many countries low-income households use a larger share of their incomes for space heating. A rise in energy costs would therefore reduce their real incomes disproportionately.

There are many limitations to this approach, reflecting the available data. These include:

- It is not possible to estimate different responses to higher energy costs among the groups. For example, it is often suggested that high-income households have access to finance to pay for energy efficient equipment, which could be reflected by a higher price elasticity.
- It is not possible to consider how changes in wage rates affect particular social groups. For example, there is no linkage between sectoral employment and the social groups, and it is not possible to address differences in wages within sectors.
- The approach cannot address heterogeneity in the groups. For example, model results suggest that higher costs for motor fuels often affect low-income households less, as they are less likely to own a car. But low-income households that do have cars will still be affected.

In summary, the results should be considered carefully in the context of the scenarios modelled and at times perhaps viewed with caution. Nevertheless, the approach is able to give at least an indication of the type of distributional effects expected, possibly suggesting grounds for further analysis with a dedicated tool. An example of distributional analysis is provided in Ekins et al (2011).

The results for distributional income have been extended to provide an expenditure-based version of the GINI coefficient (by interpolating the income quintiles). While the available data mean it is not possible to create a GINI coefficient based on changes in income, we can assess the real expenditure effects to give an equivalent measure. The result would be in the form:

This policy affects the real spending power of all income groups; its distributional impacts are equivalent to a change in the GINI coefficient of X.X%.

2.4 Energy-emissions modelling in E3ME

This section outlines how energy demand and prices are modelled in E3ME, and how this links into the economic modelling.

Appendix A describes the differences between top-down and bottom-up modelling but the current version of E3ME can be described as top-down in its energy modelling, with a bottom-up submodel of the electricity supply sector (described in Section 2.5). In this section we describe how final energy demand and emission levels are calculated; the power sector model is described in the next section.

E3ME's main energy module

The energy module in E3ME is constructed, estimated and solved for each energy user, each energy carrier (termed fuels for convenience below) and each region. Figure 2.4 shows the inputs from the economy and the environment into the components of the module and Figure 2.5 shows the feedback from the energy module to the economic module.

Total energy demand

Aggregate energy demand, shown on the left of Figure 2.4, is determined by a set of econometric equations, with the main explanatory variables being:

- economic activity in each of the energy users
- average energy prices for each energy user in real terms
- technological variables, represented by investment and R&D expenditure and spillovers in key industries producing energy-using equipment and vehicles

Figure 2.4: Inputs to the energy module

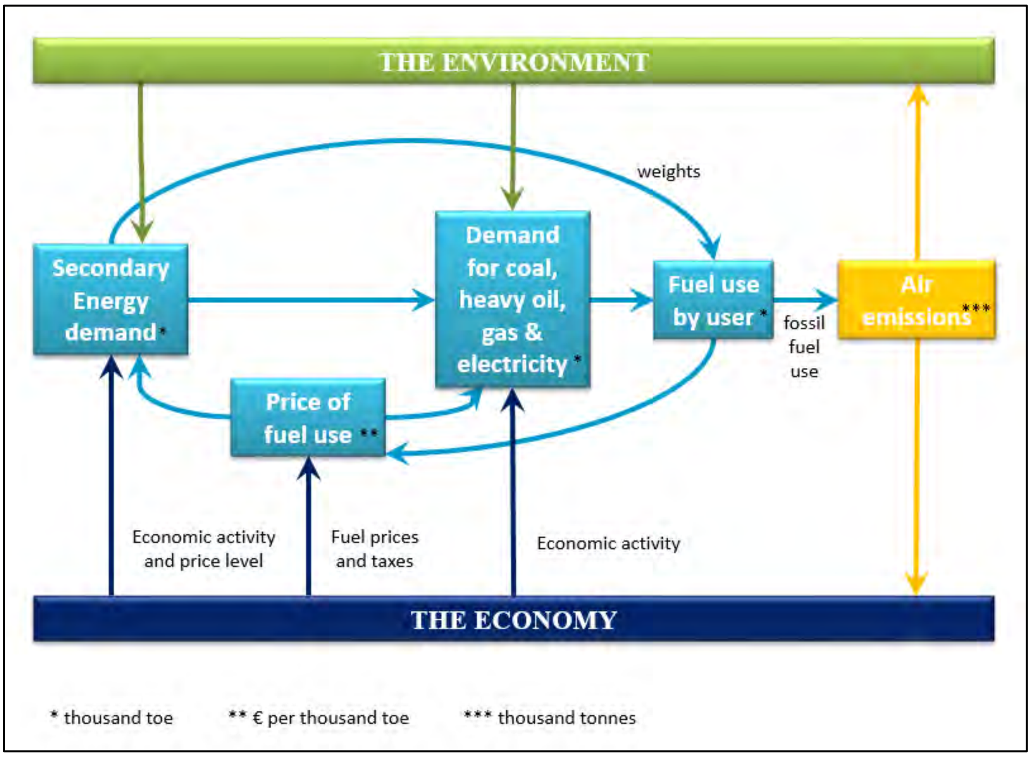
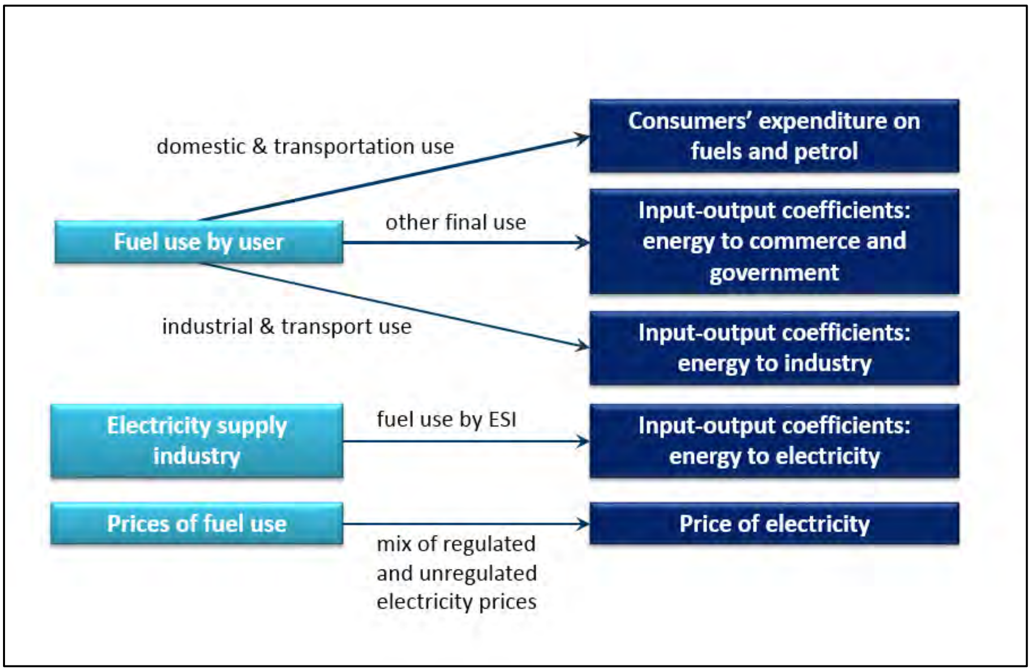


Figure 2.5: Feedback from the energy module



Price elasticities

It should be noted that the long-run price elasticities of demand for energy are the only model parameters that are not derived from the time-series data, as described in Section 3.4[3]. The reason for this is that the past data may not be a good guide to future responses.

Typically changes in energy prices in the historical data have been due to fluctuations in commodity prices and have been temporary in nature. However, the changes in energy prices that are modelled using E3ME tend to be based on permanent changes in policy and are therefore more likely to lead to behavioural change. Estimating elasticities based on the time-series data could thus lead to a downward bias.

Instead the long-run price elasticities used are taken from a combination of cross-section estimation and reviewed literature. For most sectors the values range from -0.2 to -0.3, meaning that a 1% increase in price leads to a 0.2-0.3% reduction in consumption. For road transport, a higher value of -0.7 is used, taken from Franzen and Sterner (1995) and Johansson and Schipper (1997, p.289) and confirmed by CE's own analysis. Short-run elasticities are based on the time-series data and are usually close to zero.

Fuel substitution

Fuel use equations are estimated for four energy carriers (coal, heavy oils, gas and electricity) with four sets of equations estimated for the fuel users in

[3] There are also some parameters that are fixed by theory, such as the assumption that in the long run household expenditure is equal to household income.

each region. These equations are intended to allow substitution between the four energy carriers by users on the basis of relative prices, although overall fuel use and the technological variables are allowed to affect the choice.

Since the substitution equations cover only four of the twelve fuels, the remaining fuels are determined either as fixed ratios to aggregate energy use or are assumed to be used in a similar way to other, closely related fuels (e.g. other coal and hard coal, crude oil and heavy fuel oil, other gas and natural gas). The final set of fuels used must then be scaled to ensure that it adds up to the aggregate energy demand (for each fuel user and each region).

One point to note is that the current version of E3ME includes only one fuel type for road transport (middle distillates, which is not separated to petrol and diesel). The econometric equations are not able to consider electrification of the transport system as there is no historical precedent for this. In the current model version[4] these developments must therefore be entered by assumption by the model user.

Feedbacks to the economy

The economic feedbacks are based on the fact that the same transactions appear in the energy data and in the economic data, albeit in different units. For example, the iron and steel sector's purchases of coal appear as:

- coal consumption in the IEA energy balances (as time series), measured in toe
- an input-output flow in the National Accounts (for the base year), measured in m$

The feedbacks from the energy module assume a one-to-one relationship between these two measures, once price changes are taken into account.

This places quite a strong reliance on consistency between the two data sets. Theoretically the energy balances multiplied by the fuel costs (excluding taxes) should match against the flows in the input-output table, once distribution costs are taken into account. However, this is often not the case (for example due to differences in definition) and the mismatch in data can lead to apparently non-important uses of fuel having large economic consequences.

The team at Cambridge Econometrics therefore works to ensure consistency in the data sets where reasonably possible. Adjustments are sometimes made to the base-year input-output tables to ensure accuracy in the modelling.

There are also feedbacks from the energy module to household final demand. In the same way that an input-output flow provides and economic representation of industry purchases of energy, consumer expenditure on energy in the national accounts is equivalent to the energy balances for household purchases. In E3ME, the approach is to set the economic variables so that they maintain consistency with physical energy flows. The same issues about consistency of data described above apply here.

E3ME's emission submodel

The emissions module calculates air pollution generated from end-use of different fuels and from primary use of fuels in the energy industries

[4] This is expected to be revised in 2014/15.

themselves, particularly electricity generation. The current emissions included are:

- carbon dioxide (CO_2)
- sulphur dioxide (SO_2)
- nitrogen oxides (NOx)
- carbon monoxide (CO)
- methane (CH_4)
- larger particulates (PM_{10})
- volatile organic compounds (VOC)
- chlorofluorocarbons (CFCs)
- nitrous oxide (N_2O)
- hydrofluorocarbons (HFC)
- perfluorocarbons (PFC)
- sulphur hexafluoride (SF_6)

These last four, together with CO_2 and CH_4, constitute the six greenhouse gases monitored under the Kyoto protocol.

CO_2 emissions

Emissions data for CO_2 from energy consumption are available for each of the energy users in the model. Coefficients (tonnes of carbon in CO_2 emitted per toe) are implicitly derived using historical data (and sometimes also baseline projections). This forms the relationship between energy consumption and emissions.

Process CO_2 emissions, for example from the chemicals and cement sectors, are also included explicitly in the modelling, but are linked to production from those sectors rather than energy consumption.

Other emissions

The treatment of other emissions is less detailed and results are not usually disaggregated by sector. In addition, it should be noted that many of the impacts of the other emissions (e.g. PM_{10}) are localised and cannot be captured by a model that operates at national level.

The general approach is to link these emissions to a small set of sources that fit into the model variables, such as consumption of a particular fuel or output of a particular economic sector. Linear coefficients are then formed to link these activity sources to emission levels.

While this ensures that the model results match published totals, and gives an indication of possible outcomes from policy, it is not intended to replace more specialised tools. For example, E3ME would not be an appropriate tool to assess policies to reduce methane in the agricultural sector because it does not include the necessary detail; a dedicated (partial) agricultural model would instead be required.

Emission damage costs

Using estimated (ExternE) damage coefficients, E3ME may also estimate ancillary costs/benefits relating to a change in associated emissions e.g. PM_{10}, SO_2, NOx within European countries.

The approach is to parameterise the results from the EcoSense LE[5] model that is available online by running a set of queries with a unit increase in

[5] This is the result of the European Commission NEEDS and CASE research projects and is maintained by the University of Stuttgart.

emissions. Characteristics relating to pollution source (e.g. urban/rural, height of release) are attributed to each sector.

The results can be used to give marginal costs/benefits relating to impacts on human health, crops and buildings. The advantage of integrating this in E3ME is that the assessment can be combined with the macroeconomic analysis. In future it would also be interesting to look at some of these outcomes in more detail, for example instead of taking basic costs (in millions of euros) it would be possible to include explicitly changes in labour productivity and costs to national health systems.

This treatment could also be expanded to cover non-European countries, subject to damage coefficients being available.

2.5 The power sector model

Overview

The power sector in E3ME is represented using a novel framework for the dynamic selection and diffusion of innovations, initially developed by J.-F. Mercure (Mercure, 2012), called FTT:Power (Future Technology Transformations for the Power sector). This is the first member of the FTT family of technology diffusion models. It uses a decision-making core for investors wanting to build new electrical capacity, facing several options. The resulting diffusion of competing technologies is constrained by a global database of renewable and non-renewable resources (Mercure & Salas, 2012, 2013). The decision-making core takes place by pairwise levelised cost (LCOE) comparisons, conceptually equivalent to a binary logit model, parameterised by measured technology cost distributions. Costs include reductions originating from learning curves, as well as increasing marginal costs of renewable natural resources (for renewable technologies) using cost-supply curves. The diffusion of technology follows a set of coupled non-linear differential equations, sometimes called ‘Lotka-Volterra' or ‘replicator dynamics', which represent the better ability of larger or well established industries to capture the market, and the life expectancy of technologies. Due to learning-by-doing and increasing returns to adoption, it results in path-dependent technology scenarios that arise from electricity sector policies.

Natural resources

A survey of renewable resources was carried out by Mercure & Salas (2012) for the purpose of limiting the diffusion of technologies in FTT:Power. This database provides cost-supply curves covering 90 countries and can be re-aggregated to various configurations of regions following the development of E3ME. It also includes a review of non-renewable fossil and nuclear fuels. These however are not used as cost-supply curves, since such curves would need to change as consumption progresses. Instead, a dynamic model of resource consumption was introduced in FTT:Power, which tracks how a cost-distribution of resources is gradually depleted. This is parameterised by the current rate of reserves to resources ratios for these fuels, and determines a dynamic marginal cost (Mercure & Salas, 2013).

Technology types

FTT:Power features 24 types of power technologies:

Table 2.1: Power technologies

Nuclear	Solid Biomass	Wind onshore
Oil	Solid Biomass + CCS	Wind offshore
Coal PC	Biomass IGCC	Solar Photovoltaic
Coal IGCC	Biomass IGCC + CCS	Concentrated Solar Power
Coal PC + CCS	Biogas	Geothermal
Coal IGCC + CCS	Biogas + CCS	Wave
Gas CCGT	Tidal	Fuel Cells
Gas CCGT + CCS	Large Hydro	CHP

Resource types

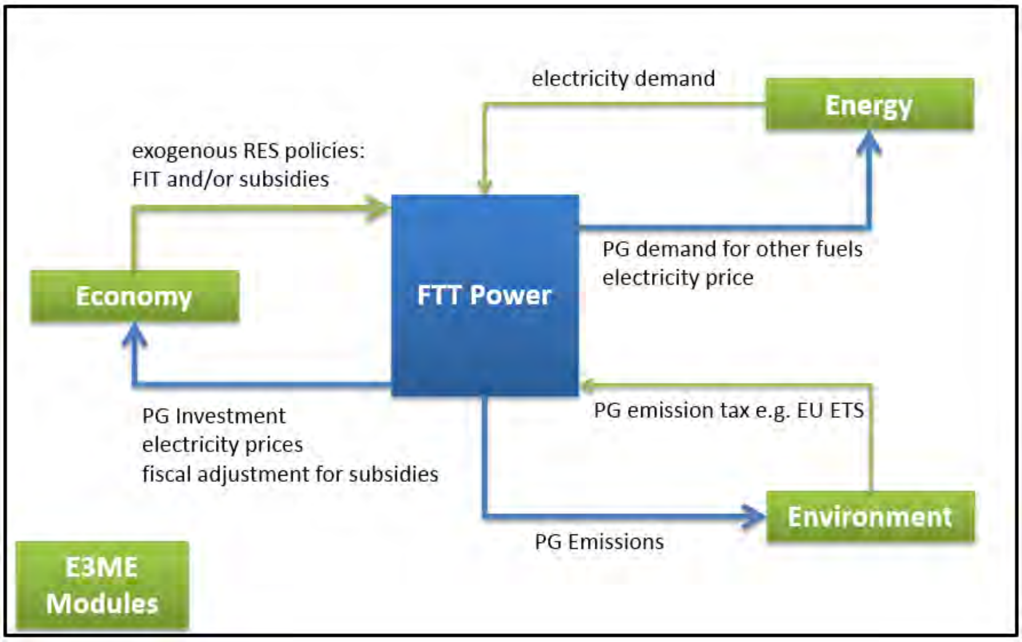
These use 13 types of natural resources:

Table 2.2: Resource types

Uranium	Biogas	Solar sites
Oil	Tidal	Geothermal sources
Coal	Hydro	Waves
Gas	Onshore wind sites	
Sold biofuels	Offshore wind sites	

Among these, the 4 non-renewable resources, uranium, coal, gas and oil, are treated with the resources consumption model. The demand for these fuels includes that of other sectors in E3ME and can be used to determine the cost of these fuels in scenarios of depletion.

Figure 2.6: FTT basic structure



Input and feedbacks

FTT:Power determines a technology mix by region given a scenario of detailed electricity policy: carbon prices, subsidies, feed-in tariffs and regulations by technology. Changes in the power technology mix result in changes of production costs, reflected in the price of electricity. The model takes electricity demand from E3ME and feeds back a price, fuel use and investment for replacements and new generators.

2.6 The model of material consumption

Overview

E3ME's material model was originally developed for the European Matisse research project[6] and documented in Pollitt (2007, 2008). It has since further been applied in the petrE project (Ekins et al, 2012) and analysis for the European Commission. However, it is still the case that very few macroeconomic models currently include physical measures of material consumption, although environmentally extended input-output analysis is much more common. The advantage that E3ME offers over the input-output approach is its dynamic nature, with rates of material intensity allowed to change in response to price and other economic factors; rather than following a fixed input-output structure. This means that, as well as explaining the past, E3ME can be used to project forwards material consumption and to test scenarios of policy aimed to reduce material consumption.

Material types

E3ME models material consumption for each region of the model. At present the following material types are modelled:

- Food
- Feed
- Forestry
- Construction minerals
- Industrial minerals
- Ferrous ores
- Non-ferrous ores

These match against the aggregate categories that feature in most of the standard data sets (e.g. Eurostat). In future they could be expanded further for specific analysis.

Data

Data for material consumption are in general not disaggregated by sector. However, in E3ME consumption is split into a set of material users, so sectoral consumption must be estimated. This is done largely by combining two different data sets: material flows data, which is disaggregated by country and material; and the information from individual country supply and use tables. Some additional assumptions are made, for example that only the agriculture sector consumes animal feed.

Time series are constructed on this basis and used to estimate the model parameters.

Material variables

E3ME principally uses Domestic Material Input (DMI) as its measure of material consumption, although exports (X) can be separated to get Domestic Material Consumption (DMC), and imports (M) removed to get Domestic Extraction (DE).

[6] http://www.matisse-project.net/

The basic model structure does not include rucksack measures or estimates of unused materials, but Total Material Requirement (TMR) is estimated using a coefficient method, fixing the ratio of TMR to DMI.

Imports and exports in raw material equivalent units (RME) are included in the model to derive Raw Material Consumption (RMC) for European regions. Converters from imports and exports in physical units to raw material equivalent units are obtained from Eurostat[7].

Basic structure

The basic structure of the material demand equations is similar to that of the equations for aggregate energy demand. Material consumption (DMI per unit of output) is a function of economic activity, material prices and measures of technology. There is also a term in the equation to account for the changing share of imports in consumption, due to the relatively different weights of imports and domestic extraction.

Feedback to the economic model

The method of feedbacks is also very similar in nature to that of the energy module. It is assumed that all material consumption meets intermediate demands (i.e. materials are used as part of the production process and not bought by households directly). A relatively small number of sectors produce the materials: agriculture and fishing produce food and feed; the forestry sector produces forestry; and other mining produces all mineral categories. The feedback is through adjustments to economic input-output coefficients, as described in the previous section.

2.7 Innovation and endogenous technological progress

E3ME's technological indices

In the past, technological progress has often been represented as exogenous in macroeconomic models (e.g. via a time trend) or as a residual in a neoclassical production function. Both methods have their drawbacks. The neoclassical approach is somewhat circular in its logic, i.e. to know a firm's production possibilities one needs to model technological progress, but in modelling technological progress one is already making an assumption about the production process. The time trend approach is also unappealing given its theoretical background.

Specification

The approach to constructing the measure of technological progress in E3ME is originally adapted from that of Lee et al (1990). It has been further enhanced in the MONROE Horizon 2020 research project, which endogenised R&D expenditure in the model.

There are now two stock variables used in the equations. The first is the capital stock, which is accumulated investment, with a depreciation rate of 10%. The second is the knowledge stock, which is accumulated R&D expenditure, also with a depreciation rate of 10%.

Spillovers have also now been introduced to the model, based on patents data. Spillovers are treated as 'virtual R&D', i.e. as if the sector itself was

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7 http://epp.eurostat.ec.europa.eu/portal/page/portal/environmental_accounts/documents/RME%20project%20-%20Introduction.pdf

carrying out the R&D. The indicator that is used in the accumulation of knowledge (YRDS) incorporates the spillover effects, both across regions and sectors.

Feedbacks

The measures of technological progress include both product and process innovation and this is represented in the various feedbacks to other parts of the model:

- a higher quality product could lead to higher levels of demand or command a higher price, so the technology indices feature in the model's trade and price equations
- an improvement in efficiency increases capacity and potential supply, represented as 'normal' output in the model (see Section 4.16)

Both types of innovation may impact on labour demand so the technology indices also feature in the employment equations.

2.8 E3ME compared to other macroeconomic models

E3ME in comparison to CGE models

E3ME is often compared to other macroeconomic models. The Computable General Equilibrium (CGE) model has become the standard tool for long-term macroeconomic and energy-environment-economy (E3) analysis. Their use is widespread all over the world; notable examples include GTAP (Hertel, 1999), the Monash model (Dixon and Rimmer, 2002) and GEM-E3 (Capros et al, 2012). Many of these models are based on the GTAP database that is maintained by Purdue University in the US.

In terms of basic structure, purpose and coverage, there are many similarities between E3ME and comparable CGE models. Each is a computer-based economic model that considers E3 interactions at the global level, broken down into sectors and world regions. In addition the regional and sectoral disaggregations are broadly similar. Both modelling approaches are based on a consistent national accounting framework and make use of similar national accounts data.

Key differences

However, beneath the surface there are substantial differences in modelling approach and it is important to be aware of this when interpreting model results. The two types of model come from distinct economic backgrounds; while they are in general consistent in their accounting, identity balances, they differ substantially in their treatment of behavioural relationships.

Ultimately this comes down to assumptions about optimisation. The CGE model favours fixing behaviour in line with economic theory, for example by assuming that individuals act rationally in their own self-interest and that prices adjust to market clearing rates; in this way aggregate demand automatically adjusts to meet potential supply and output levels are determined by available capacity.

In contrast, econometric models like E3ME interrogate historical data sets to try to determine behavioural factors on an empirical basis and do not assume optimal behaviour. The model is demand-driven, with the assumption that supply adjusts to meet demand (subject to any constraints), but at a level that is likely to be below maximum capacity.

This has important practical implications for scenario analysis. While the assumptions of optimisation in CGE models mean that all resources are fully utilised, it is not possible to increase output and employment by adding regulation. However, E3ME allows for the possibility of unused capital and labour resources that may be utilised under the right policy conditions; it is therefore possible (although certainly not guaranteed) that additional regulation could lead to increases in investment, output and employment.

Many of the assumptions that underpin CGE (and DSGE) models have been increasingly questioned as to whether they provide an adequate representation of complex real-world behaviour[8]. Examples include perfect competition, perfect knowledge and foresight, and optimal rational behaviour and expectations. Some CGE models have been adapted to relax certain assumptions but the underlying philosophy has not changed.

The main drawback of the E3ME approach in comparison is its reliance on having high-quality time-series data. There is at present no equivalent to the GTAP database for time series, so a large amount of resources must be put into compiling suitable data sets.

Jansen and Klaassen (2000) and Bosetti et al (2009) describe some of the differences between modelling approaches in the context of environmental tax reform.

Comparing E3ME to econometric forecasting models

E3ME is sometimes also compared to short-term econometric forecasting models. Most conventional macroeconomic models, which are typically operational in government, describe short and medium-term economic consequences of policies but with a limited treatment of longer-term effects. This limits their ability to analyse long-term policies and they often lack a detailed sectoral disaggregation.

These models are usually used for short-term forecasting exercises, often with a quarterly or even monthly resolution.

Where E3ME fits in…

E3ME combines the features of an annual short- and medium-term sectoral model estimated by formal econometric methods with the detail and some of the methods of CGE models, providing analysis of the movement of the long-term outcomes for key E3 indicators in response to policy changes. It is essentially a global and dynamic simulation model that is estimated by econometric methods.

The method: long-term equations and short-term dynamic estimation

E3ME has a complete specification of the long-term solution in the form of an estimated equation which has long-term restrictions imposed on its parameters. Economic theory, for example theories of endogenous growth, informs the specification of the long-term equations and hence properties of the model; dynamic equations which embody these long-term properties are estimated by econometric methods to allow the model to provide forecasts. The method utilises developments in time-series econometrics, with the specification of dynamic relationships in terms of error correction models

[8] Beinhocker (2007) provides a good overview, see also the ever-growing field of behavioural economics (e.g. Kahnemann, 2012).

(ECM) which allow dynamic convergence to a long-term outcome (see Section 3.4).

E3ME is therefore the result of a relatively ambitious modelling project which expands the methodology of long-term modelling to incorporate developments both in economic theory and in applied econometrics, while at the same time maintaining flexibility and ensuring that the model is operational.

Comparative advantages of E3ME

To summarise, compared to the other macroeconomic models in operation currently across the world (both CGE and otherwise), E3ME has advantages in the following four important areas:

Geographical coverage

The current version of E3ME provides global coverage, with explicit representation of each Member State in the European Union and explicit coverage of the world's major economies.

Sectoral disaggregation

The detailed nature of the model allows the representation of fairly complex scenarios, especially those that are differentiated according to sector and to country. Similarly, the impact of any policy measure can be represented in a detailed way, for example showing the winners and losers from a particular policy.

Econometric pedigree

The econometric and empirical grounding of the model makes it better able to represent performance in the short to medium terms, as well as providing long-term assessment. It also means that the model is not reliant on the rigid assumptions common to other modelling approaches.

E3 linkages

E3ME is a hybrid model. A non-linear interaction (two-way feedback) between the economy, energy demand/supply, material consumption and environmental emissions is an undoubted advantage over models that may either ignore the interaction completely or only assume a one-way causation.

3. Model Inputs and Outputs

3.1 Introduction

This chapter describes E3ME's main model inputs and outputs. We start with a brief description of the software that is used, as this can be important for understanding the later topics. The discussion then turns to the key model inputs, in particular data and the model parameters that are estimated from the data. The final section in this chapter describes the format of the main model outputs.

Figure 3.1 and Figure 3.2 provide a summary of the most important model inputs and outputs. In the figures, the oval boxes represent data, while the rectangular boxes are the processing software.

Figure 3.1: Model inputs

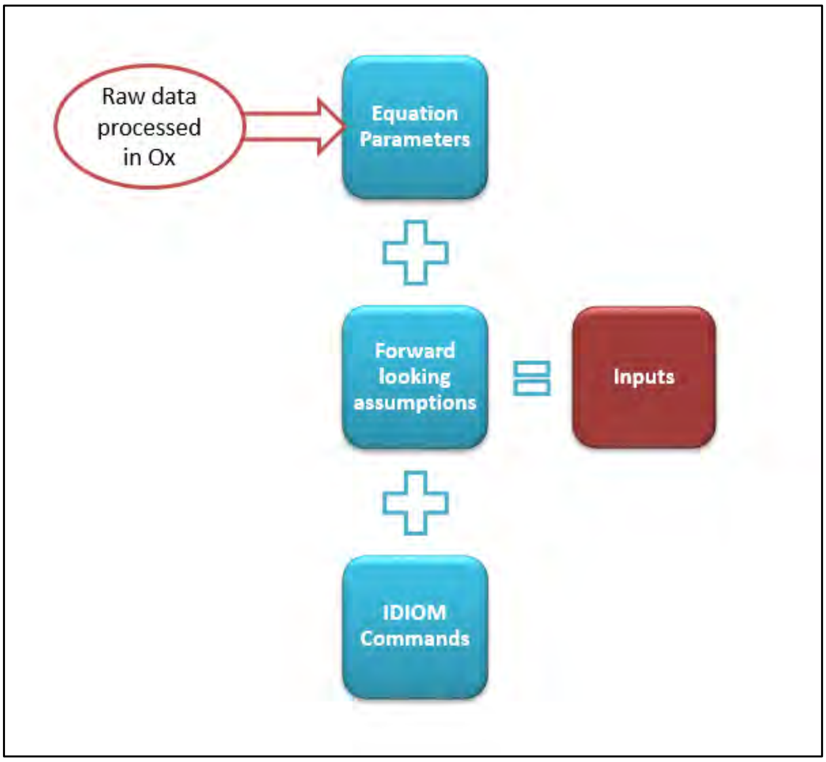
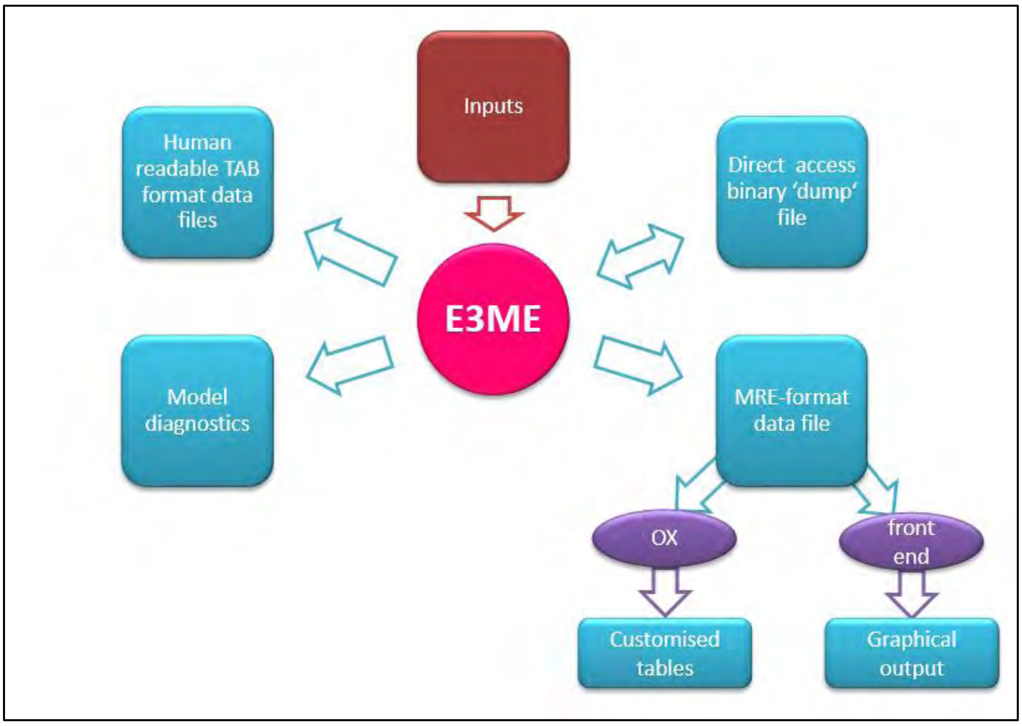


Figure 3.2: Model outputs



3.2 Model software

There are now several well-established packages that can be used for model building, each with its own advantages and disadvantages. However, there is no one single package that fits the requirements of the E3ME model, so a combination of software packages is used.

The following software is used:

- Fortran: E3ME source code is written in the Fortran95 programming language. It is compiled using the Intel Fortran compiler. The standard development environment is Microsoft Visual Studio.
- IDIOM: This is a programming language which is itself a pre-compiled set of Fortran commands. It provides a user interface for the modeller, for example allowing the user to make certain changes without recompiling the source code. The IDIOM manual (Cambridge Econometrics, 2007) provides further details.
- DOS: The model is usually run from a command line, using cmd batch files. This is discussed in Section 5.2.
- Java/Python: The model front end, which allows the model to be run without requiring any programming expertise, is programmed in Python and Javascript.
- Ox: The Ox programming language (Doornik, 2007) is used for data processing, parameter estimation and manipulation of results.

E3ME also operates with a fixed directory structure that is described in Appendix C.

3.3 Data inputs

Introduction to the model databanks

The data are the most important single input to E3ME. A lot of effort is put into ensuring that the model data are accurate and consistent to the maximum degree possible.

The following databanks are used to store the data:

- T – historical time-series data
- F – processed baseline forecast (see Section 3.5)
- X – cross-section data, including input-output tables and equation parameters
- B – bilateral trade data
- E – energy balances, prices and emissions
- M – materials data
- U – classification titles

These other databanks are used for model operation:

- C – holds particular scenario inputs
- S – holds the calibration factors to match the baseline forecast (see Section 3.5)

E3ME's data requirements are extensive and specific. All data must be processed so that they are in the correct classifications and units. Gaps in the data must be filled (see below). All data processing is carried out using the Ox software package.

Time-series economic data

It is a substantial exercise to create and maintain the time series of economic data. The main dimensions involved are:

- indicator
- country/region
- sector
- time period (annually from 1970)

In addition, indicators that are expressed in monetary units have constant and current price versions. Cambridge Econometrics therefore puts a large amount of resources each year into updating the time-series data.

The raw data are gathered from the sources described below and stored on the T databank. The model uses only official sources and international sources are preferred (both for purposes of comparability and practical reasons). It is often necessary to combine data sets to fill out gaps in the data and to estimate remaining missing values (see below).

The main indicators

A 'V' at the start of the name indicates a current price value; otherwise the indicator is expressed in constant prices (2005 euros). The main indicators with full sectoral disaggregation are:

- QR/VQR – output (constant and current price bases)
- YVM/VYVM, YVF/VYVF – GVA at market prices and factor cost

- KR/VKR – investment
- VYRD – R&D spending
- CR/VCR – household expenditure (by product)
- GR/VGR – government final consumption (by category)
- QRX/VQRX – exports
- QRM/VQRM – imports
- YRE – employment
- YRLC – labour costs (current prices)
- YRH – average working hours

There are also time series for population (DPOP) and labour force (LGR), disaggregated by five-year age band and gender.

In addition, there are a number of macro-level time series that are used in the modelling. These include GDP, household incomes, exchange rates, tax and interest rates and the unemployment rate. They are also collected on an annual basis, starting from 1970.

Data sources for E3ME's economic data

The following paragraphs give only a summary of the data sources used in the E3ME model.

The data must be consistent across countries and in the same units. For monetary data the euro is used. The data are updated as and when new figures become available, with comprehensive updates carried out once a year. For European countries, data sources are used based on the following ranking:

1 The Eurostat national accounts branch is the primary source for European countries and provides a consistent data source across countries. The OECD's STAN data set also provides some sectoral disaggregation.

2 Data from the AMECO database are used to provide macroeconomic figures and to check totals in the Eurostat data.

3 When Eurostat data are not available or need to be improved, other internationally available sources such as the IMF are consulted.

4 Once these international data sources have been exhausted, national statistical agencies and other data sources are used to update the remaining missing series and gaps in the data.

For non-European countries, the data are typically more limited, particularly for countries outside the OECD. In general, the OECD's STAN database is used as the primary data source. The Asian Development Bank also provides some information for Asian countries. Otherwise the database tends to rely on national sources.

Values and price indices in E3ME

The general principle adopted in E3ME is that variables are defined in the currency unit appropriate for the use of the variable. This usually means that the units of measurement follow those in the data source. The principle of comparability is taken to imply that most current values are measured in millions of euros and most constant values in millions of euros at 2005 prices and exchange rates.

The price indices are calculated by dividing current by constant values in euros. These will not, in general, be suitable as an indicator of price changes in local currencies. For this purpose, the indices are modified by any change between the euro-local currency rate in the current year and that in the base year. This calculation must be made whenever it is appropriate to use prices denominated in local currencies, e.g. when prices appear in behavioural equations.

In some cases the prices which enter the econometric equations are relative prices, so the modification cancels out. It is dangerous to rely on this property, however, because although it is usually applied in the long term, there may be short-term nominal effects.

The treatment of exchange rates in E3ME

E3ME contains two sets of exchange rates, which are defined as follows:

- REX - local currency per euro, nominal rates
- EX - local currency per euro, 2005=1.0

These are average annual rates taken from the AMECO and IMF databases. When E3ME price indices are used in trade equations, since they are in local currencies, they must be modified by a local-currency-euro exchange rate, normalised to 2005=1.0. As the base year in E3ME falls after the introduction of the euro, nominal exchange rates for eurozone members are expressed in euros, and extended back using fluctuations in national currencies. This matches the treatment in the AMECO database.

Exchange rates are exogenous in the current version of the model.

Cross-sectional data

By cross-sectional data we mean data that are not usually available in time-series format. Historically, this has meant input-output tables and bilateral trade data. Other cross-sectional data include converters between model classifications that do not normally change over time.

Input-output tables in E3ME

The input-output tables in E3ME are derived where possible from Eurostat publications and are expressed in basic prices. Where this was not possible data from the OECD and national sources have been used as substitutes. All the input-output tables are expanded to the 69/43 E3ME sectors and moved to a base year of 2005 using RAS techniques. The input-output tables include:

- domestic production
- imports

Input-output flows are converted to coefficients by dividing the columns by industry output. These coefficients thus give the number of units of input required to produce one unit of output.

Although input-output tables are typically only held for a base year, reflecting the available data, the coefficients change over time following a logistic trended path. This path is determined by estimating a historical time series of intermediate demands and fitting this to a logistic curve. This curve is projected forwards into the forecast period. The base-year tables and the projection coefficients are stored on the X databank.

Bilateral trade

E3ME's bilateral trade[9] data have been expanded considerably, in part due to the new two tier trade specification (see Section 4.7). The dimensions in the database are:

- Time (years since 1990)
- Origin
- Sector
- Destination

Clearly there are a large number of matrices, so the data are stored on a separate databank (B).

The primary data source is Comtrade for manufacturing sectors. Data for services were taken from the OECD for all member countries over the period 1995-2010 and expanded to include trade with non-OECD countries. The remaining values were estimated based on data that are available nationally and using share estimates. These data could be further improved upon in future.

Energy and emissions data

In one sense the processing of the energy and emissions data for E3ME is more straight forward as all the figures for each model variable are taken from a single source. However, it is still necessary to fill out gaps in the data, as described below.

Energy fuel use data in E3ME

The energy data in physical units have been provided by IEA energy balances since 1970. The IEA energy balances are given as time-series data. The 54 energy carriers have been aggregated into the twelve energy types in E3ME, and some inconsistencies (comparing items year by year) have been removed.

As the energy balances data separate between inputs and outputs, the treatment of the fuel users Power Generation and Own Energy Use and Transformation must ensure that double-counting is avoided. For these energy users, energy demand is set equal to energy inputs (which are negative by definition, and thus had to be converted into positives). In some cases there is a lack of consistency through the whole of the time series to allocate data to different categories. This happens throughout the data as for example with LPG for various states in the early 1970s where the detailed use by industry sector is reallocated to non-specified industry while after 1973 non-specified industry is zero and the detailed industry use is positive. CE created software to reallocate the values in these cases.

Energy price data in E3ME

Raw data for energy prices are collected from the IEA Energy Statistics publications as total prices in $/toe (i.e. including taxes) by country and by fuel since 1978 and taxes per unit of fuel since 1978. The IEA provides incomplete, delivered price (with and without tax) time series for distillate (light) oil, electricity, natural gas, steam coal, and coke. The raw data have three types of missing data: "not applicable", "not available" and "confidential", which are all treated as missing when read in. CE fills these using these assumptions:

1 If data are missing for all years, the tax is assumed to be zero

[9] Export and import data that include both origin and destination.

2 If data are missing at the end of the series, then taxes stay constant at the final year the data are available

3 If data are missing at the beginning of the series, then taxes rise at 5% per year up to the first year of observation

4 Negative values are assumed to be errors (i.e. CE assumes no subsidies - these data are treated as missing)

Missing years are appended over 1970-77 to the total price data. Underlying price data are formed as total price data minus taxes. These data will therefore have missing values over 1970-77 and at every point where total price data are missing. The data are then organised into arrays corresponding to the E3ME classifications and converted to euros.

CO_2 emissions in E3ME, by fuel and fuel user

Time-series data for CO_2 emissions, disaggregated by energy user are obtained from Eurostat or the EDGAR database. These are allocated to fuels using standard coefficients and then scaled to be consistent with the total.

Adjustments may be made for international shipping and aviation to maintain consistency between the energy and emissions data.

Non-CO_2 emissions in E3ME

Non-CO_2 emissions in E3ME include SO_2, NOx, CO, methane (CH_4), particulates (PM_{10}), volatile organic compounds (VOC), ammonia (NH_3) and the other four greenhouse gases N_2O, HFC, PFC, and SF_6. These data are obtained from the EDGAR database.

Materials data

The primary data source for materials data is Eurostat (Material Flow Accounts) in Europe. These figures are then converted into a sectoral classification using a combination of Eurostat information and economic input-output tables. The OECD and other sources are used for non-European countries.

Time series are held for Domestic Extraction (DE), exports and imports of consumed materials. Coefficients are also stored so that the model can produce estimates of Total Material Requirement (TMR).

The materials data are described in more detail in Section 2.5.

Correcting for missing data points

The team at CE has developed a software package to fill in gaps in any of the E3ME time series. This uses growth rates and shares between sectors and variables to estimate missing data points, both in cases of interpolation and extrapolation. Some time series (e.g. energy prices, see above) have specific rules for filling gaps in the data, but the general procedures are described here.

The most straightforward case is when the growth rates of a variable are known and so the level can be estimated from these growth rates, as long as the initial level is known. Sharing is used when the time-series data of an aggregation of sectors are available but the individual time series is not. In this case, the sectoral time series can be calculated by sharing the total, using either actual or estimated shares.

In the case of extrapolation, it is often the case that aggregate data for a number of sectors are available, although the sectoral disaggregation at the E3ME level is not; for example, government expenditure is a good proxy for the total growth in education, health and defence. A special procedure has been put in place to estimate the growth in more disaggregated sectors so that the sum of these matches the known total, while the individual sectoral growth follows the characteristics of each sector. Interpolation is used when no external source is available, to estimate the path of change during an interval, at the beginning and end of which data are available.

Under different assumptions, time-series forecasts are created for each country and each aggregated variable: consumption, employment, GDP, trade and investment (see Section 3.5).

Naming conventions

E3ME's software limits model variables to four character names. These characters are typically used to identify first the dimensions of the variable (excluding time, which is a dimension for all the variables) and then the indicator. In particular, Q indicates disaggregation by product, Y by industry, F by energy (fuel) user and R by region. If a variable name starts with P then it usually indicates a price. S and 0 can be used to identify sums.

These conventions are used in the data processing and in the model itself. Some examples of common variables names are provided below:

- QR: (Gross) output by product and by region
- YR: (Gross) output by industry and region
- YRE: Employment by industry and region
- YRW: Wage rates by industry and region
- YRVA: Gross value added by industry and region
- CR: Consumption by consumption category and region
- PCR: Consumption prices by category and region
- RSC: Consumption by region
- PRSC: Aggregate consumer price by region
- KR: Investment by investment category and region
- FR0: Total energy consumption by energy user and region
- FRET: Electricity consumption by energy user and region
- FCO2: CO_2 emissions by energy user and region
- RCO2: CO_2 emissions by region

Further databank conventions

The model software only holds one year of data at any one time, so the dimensions of the model variables are as they are given in the examples above. The time-series databanks, however, must hold data for all years and thus have an extra dimension. A separate matrix is therefore held for each region, for example QR_BE is the matrix for product output in Belgium, by 69 sectors and including all years since 1970.

Each matrix that is stored on the databank must also have a unique 8-digit code. The variable type depends on the data, in this case 10 refers to output and the year is the start year for the data (1970 here). Common values are:

- 00 - assumptions
- 10 - industries
- 11 - industry totals
- 20 - consumption categories
- 30 - government categories
- 40 - investment assets

- 50 - population groups
- 51 - labour force groups

The regional code matches with the standard E3ME region codes, the example in Table 3.1 shows the UK (region 15), the unit also follows a standard list (2005 constant prices in the example)

1 constant price values billion euro
2 current price values billion euro
3 price, base year = 1.0
4 thousands (no decimal places)
5 rate as specified (no decimal places)
6 rate as specified (3 decimal places)
7 titles
8 parameters (4 decimal places)
9 working variable

The final digit is the version number that is used to distinguish variables with identical first four codes. This example is for QR_UK. However, it should be noted that the coding differs slightly for the different types of variables and databanks.

Although E3ME largely consists of constant (2005-based) variables and price indices, the historic data on the databanks are stored in current and constant prices. This allows easier checking against the raw published data. The price indices are then calculated in the IDIOM code by dividing current-price series by their constant price equivalents. However, great care must be taken to ensure that the exchange rates used are correct and that the price indices are denominated correctly.

Table 3.1: Example databank code

The general convention for numeric 8-digit codes used is:

	variable type	year	region	unit	version
digit	10	70	15	1	5

3.4 Econometric parameters

The econometric techniques used to specify the functional form of the equations are the concepts of cointegration and error-correction methodology, particularly as promoted by Engle and Granger (1987) and Hendry et al (1984).

In brief, the process involves two stages. The first stage is a levels relationship, whereby an attempt is made to identify the existence of a cointegrating relationship between the chosen variables, selected on the basis of economic theory and a priori reasoning, e.g. for employment demand the list of variables contains real output, real wage costs, hours-worked, energy prices and the two measures of technological progress.

If a cointegrating relationship exists then the second stage regression is known as the error-correction representation, and involves a dynamic, first-difference, regression of all the variables from the first stage, along with lags of the dependent variable, lagged differences of the exogenous variables, and the error-correction term (the lagged residual from the first stage regression). Due to limitations of data size, however, only one lag of each variable is included in the second stage.

Stationarity tests on the residual from the levels equation are performed to check whether a cointegrating set is obtained. Due to the size of the model, the equations are estimated individually rather than through a cointegrating VAR. For both regressions, the estimation technique used is instrumental variables, principally because of the simultaneous nature of many of the relationships, e.g. wage, employment and price determination.

Software used

E3ME's parameter estimation is carried out using a customised set of software routines based in the Ox programming language (Doornik, 2007). The main advantage of using this approach is that parameters for all sectors and countries may be estimated using an automated approach.

The estimation produces a full set of standard econometric diagnostics, including standard errors and tests for endogeneity.

Estimation results

A list of equation results can be made available on request. For each equation, the following information will be given:

- summary of results
- full list of parameter results
- full list of standard deviations

3.5 Baseline projections

Overview

The E3ME model can be used for forming a set of projections but it is usually used for policy analysis. This is usually carried out in the form of a baseline with additional policy scenarios, with the differences in results between the scenarios and the baseline being attributed to the policy being assessed.

This section describes how the baseline is formed.

Role of the baseline

Usually results from E3ME scenarios are presented as (percentage) difference from base, so at first it may appear that the actual levels in the baseline are not important. However, analysis has shown that the values used in the baseline can be very important in determining the outcomes from the analysis. For example:

- If a scenario has a fixed emission target (e.g. 20% below 1990 levels) then the baseline determines the amount of work that must be done in the scenario to meet the target.
- If a scenario adds a fixed amount on to energy prices, then baseline energy prices determine the relative (percentage) impact of that increase.

It is therefore important to have a baseline that does not introduce bias into the scenario results. A common requirement of E3ME analysis is that the baseline is made to be consistent with forecasts used in other analysis, such as the 'PRIMES' projections produced by DG Energy in the European Commission.

Methodology for calibrating

The first stage in matching the E3ME projections to a published forecast is to process these figures into a suitable format. This means that the various dimensions of the model must be matched, including:

- Geographical coverage (i.e. each country in the model)
- Annual time periods
- Sectoral coverage (including fuels and fuel users)
- National Accounts entries

CE uses the Ox software for carrying out this process, and saves the results on to the forecast databank, F.db1.

The next stage is to solve the model to match the results on the forecast databank. This is referred to as the 'calibrated forecast'. In this forecast, the model solves its equations and compares differences in results to the figures that are saved on the databank. The model results are replaced with the databank values but, crucially, the differences are stored and saved to another databank, S.db1. These are referred to as 'residuals' although the meaning is slightly different to the definition used in econometric estimation.

Endogenous baseline and scenarios

The final stage is the 'endogenous solution' in which the model equations are solved but the residuals are added on to these results. In theory the final outcome should be the same as for the calibrated forecast, although in practice there are calibration errors so it is not an exact match.

The key difference, however, is that inputs to the endogenous baseline may be changed in order to produce a different outcome (as opposed to the calibrated forecast where the model would still match databank values). The final outcome is thus a baseline forecast that matches the published projections, but which can also be used for comparison with scenarios.

Operational example

Consider an example for the aggregate consumption equation. If in the first year of forecast, E3ME predicts a value of €100bn but the published forecast suggests €101bn then the calibrated forecast will estimate a residual of 1.01 (i.e. 101/100).

If we then test a scenario in which consumption increases by 2% in this year, the model results will be €100bn (endogenous baseline) and €102bn (scenario). These will be adjusted (multiplied) by the residual to become €101bn and €103.02bn.

When these results are presented as percentage difference from base, the figure that is reported is still 2% (103.02/101), so the calibration does not affect directly the conclusions from the model results.

When are results influenced by calibration?

In this example there is no impact on the results relative to baseline from the calibration exercise. This is typically true for any log-linear relationship within the model structure, as the calibration factors are cancelled out when calculating differences from base.

However, there are relationships in the model that are not log-linear, most commonly simple linear factors. These include the construction of energy prices but also identities for GDP and for (gross) output, and the calculation for unemployment (as labour supply minus demand).

For example, if the calibration results in higher trade ratios in a certain country, then the effects that trade impacts have on GDP will increase in the scenarios.

It is therefore important that the baseline provides a reasonable representation of reality, otherwise it is possible to introduce bias into the results.

3.6 Other model inputs

In the current version of the model there are two additional text files that are used as inputs. These are the assumptions file and the scenario file.

The reason for having these inputs as text files rather than databank entries is that it allows easy manipulation, including through the front end software (see Section 5.3). No programming expertise is therefore required to make the changes.

Assumptions file

The assumptions file contains basic economic information that is necessary for any model run. It consists mainly of exogenous model variables that are set by the model user.

The nature of the Fortran read commands means that the structure of the assumptions text files is very rigid, for example with the right number of white spaces (not tabs) and decimal places required for each entry.

The assumptions files cover the period 2000 to 2050 although historical values will get overwritten by the data stored on the model databanks.

Commodity prices

At the top of the assumption file is a set of global commodity prices, with a particular focus on the energy and material groups that are covered by the model classifications. The figures are annual growth rates, in percentage terms.

National and regional assumptions

This is followed by a set of assumptions that are specific to each region in the model. They are:

- Market exchange rate, local currency per dollar, current prices
- Long-run interest rate
- Short-run interest rate (only used for comparative purposes)
- Change in government final consumption, year on year
- % of government consumption spent on defence, education and health
- Standard VAT rate
- Aggregate rate of direct taxes
- Average indirect tax rates
- Ratio of benefits to wages (giving implicit rate)
- Employees’ social security rate
- Employers’ social security rate

Scenarios file

The scenarios file contains a set of policy inputs that relate to basic model scenarios (see examples in Section 5.5). It can also be modified through the front end. Most of the policies in the scenario files are absent in the baseline with an exception of the baseline EU-ETS price[10]. Policy inputs in the scenario

[10] In the baseline, the EU ETS price is set to be the same as the values published by the European Commission.

file are categorised to four main groups: CO_2 emissions policies, energy policies, materials policies and options to recycle the revenue generated from market-based instruments.

CO_2 emissions policies

In additional to the EU ETS in the baseline, the following CO_2 emissions policies are available in the scenarios file:

- annual CO_2 tax rate, € per tonne of carbon
- annual EU ETS allowance prices, € per tonne of carbon (if level of ETS caps are unknown)
- annual ETS emissions caps, thousand tonnes of carbon
- switches to include different energy users in the policies
- switches to include different fuel types in the policies
- switch to set EU ETS policy to use caps (endogenous price) or exogenous ETS prices

Energy policies

Similar to the CO_2 emissions policies, the following energy policies are available in the scenario file:

- annual energy tax rate, € per toe
- switches to include different users in policies
- switch to include different fuel types in policies
- switch to differentiate tax rates for different groups, e.g. industries or households

Material policies

Options for material policies available in the scenario file are:

- annual material tax rates for seven types of materials, in percentage cost increase
- switches to include different material users in policies

Revenue recycling options

The scenario file includes options to recycle automatically the revenues generated from carbon taxes, energy taxes, ETS (with auctioned allowances) and materials taxes. There are two options in the scenario file for how the revenues are recycled:

- To lower employers' social security contributions, switch 0<X<1: 1=all, 0= none
- To lower income tax, switch 0<X<1: 1=all, 0=none
- To increase levels of R&D spending, switch 0<X<1: 1=all, 0= none

These revenue recycling options do not differentiate sources of revenues. The model automatically sets the revenues to be recycled from the policies so that they are overall 'revenue neutral'. Specific values for offsetting tax reductions can be entered through the assumption file discussed above.

3.7 Model outputs

Overview

The model produces relatively few results automatically. It instead stores results internally so that they can be accessed separately. The separation of model solution, (1) writing the results year by year to a large file (the dump), and then (2) accessing this file to generate time series of results, is necessary because of software constraints and the logic of the model.

Because of the scale of the solution, the model does not hold all the time series of each variable, but only the current and past values necessary for the current year's solution; this reduces the storage requirements dramatically (one year plus lags instead of up to 80 years of values). At the completion of each year's solution, the solved values of most variables are written to the dump where they may be later accessed.

Data analysis files

The files that access the model results are called data analysis files. They are IDIOM model solution files that are run after the model has finished solving (see Section 5.1). They typically produce two types of output:

- Human-readable tables – These files are in tabular (time-series) format with row and column titles added automatically. They appear in the output directory with a '.TAB' file extension.
- Matrix output for further processing – These files are designed as inputs to further processing, for example by Ox routines, or interpretation by the model front end software (see Section 5.3). They appear in the output directory with a '.MRE' extension.

The data analysis files must start with a RESTART command with a year that matches the PUT ALL statement in the IDIOM script (usually the first year of solution). A SELECT command then determines the output stream and format:

- SELECT OUTPUT 7 CARDS – MRE output
- SELECT OUTPUT 8 PRINTER – TAB output

The syntax is then relatively straight forward. The VALUE command is followed by the variable name, start year and end year to give a table in time series format. The CHANGE command gives the equivalent output as annual growth rates. For variables with two dimensions (excluding time) it is necessary to say which column is required. So for example, the command:

- VALUE CR(?:03) 2013 2020

would give a time series for household consumption in Germany (region 3) between 2013 and 2020. In the most recent version of IDIOM, the following command will print out results for all regions:

- VALA CR(?:01) 2013 2020

Input-output tables

As it is not possible to view the model's input-output tables using the standard data analysis files, they are printed out separately in csv (comma separated value) format. Any spreadsheet package can be used to view the results.

The IO tables are printed out after every run and can be found in the IO folder inside the output directory.

Other model outputs

The model creates automatically an output file that repeats the summary outputs shown in the command window (see Section 5.2). This file may be found in the output directory and has the same name as the IDIOM script. Output from the command window may also of course be sent to a text file using the standard DOS commands.

The other model outputs are for diagnostic purposes. A small text file (diagnostics.mre) is created automatically, which contains summary information about whether the model has solved and, if not, which equation caused the breakdown in solution. A longer 'verification' text file contains automatically generated outputs from the model, including warnings and possible non-convergences in the solution (see Section **Error! Reference source not found.**). The verification files are by convention given names that start with the letter Q and are stored in the verification folder in the output directory.

4. Functions in E3ME

4.1 Introduction

In common with other economic models, E3ME consists of a combination of accounting balances and behavioural relationships. The accounting structure is described in Chapter 2; in this chapter we describe the behavioural relationships within the model.

The modelling approach is econometric, meaning that the basis for determining the equation parameters is the historical time-series data. The estimation methods used are described in detail in Section 3.4.

Given the overall size of the model it is perhaps surprising that there are only 29 model variables which are estimated through econometric relationships. However, these variables are in most cases disaggregated in two dimensions (e.g. there are 22 energy users and 61 regions); so overall this version of E3ME includes more than 50,000 individual estimated equations, excluding bilateral trade. In addition, IDIOM allows up to ten alternative functional forms to explain each disaggregated category.

The following section provides an overview of the equation specifications, including a summary of the explanatory variables in each case. The remainder of the chapter considers each of the equation sets in turn. A formal representation is provided, accompanied by a brief description that provides the theoretical background and references of the chosen methodology.

Non-standard equation sets

There are several equation sets that have been developed but are not included in the standard model version:

- The transport equations are not operational in the current version of E3ME but are maintained within the model structure to facilitate possible future linkages with transport models.
- The econometric equations for biofuel demand are not operational, due to a lack of data on biofuel prices. Previous analysis has been carried out for Sweden but the standard model treatment uses a simpler shift-share approach.
- Since the introduction of bilateral trade, the export equations are no longer used in the standard model solution (exports are the adjusted reverse sum of bilateral imports). However, the structure is maintained for applications that consider a country/region in isolation.

The descriptions of these equation sets are provided in Appendix D.

4.2 Summary specification of equations

Table 4.1 provides an overview of the estimated equations. Table 4.2 summarises the variables that are used and the units of measurement for the dependent variable. A full list of model variables is available on request.

Bilateral trade

By including equations defined by both origin and destination (as well as by sector), the bilateral trade equation sets have an additional dimension. Their structure is therefore somewhat different to (and less complex than) the other model equation sets (see Section 4.7). The treatment of trade more generally is described in Section 2.3.

Dummy variables

The use of dummy variables in E3ME is restricted by the limited degrees of freedom offered by the time-series data but there are two important cases where dummy variables are added to all the equation sets. These are:

- A dummy variable for German reunification. For Germany this variable has value zero up to 1990 and value 1 from 1991 onwards. For other countries it is always zero (time series for CEE countries only begin in 1995).
- The financial crisis in 2009 provoked many non-linear reactions. To reduce bias in our parameter estimates, a dummy variable for 2009 (zero before 2009, one from 2009 onwards) is included in all the equation sets.

To avoid excessive repetition, the dummy variables are not included in the formal definitions provided in the rest of this chapter, but they are an important part of the model estimation and solution.

Technology indices

For European countries there are two technology indices, one of which is based on ICT investment (YRKC) and one of which is based on other investment (YRKN). This distinction is based on the EU KLEMS database that covers the EU and other OECD countries. At present only the EU data are used (although this will be explored further in future model versions) so other countries do not have both terms. For non-EU countries the relevant indicator is YRKE which includes all investment spending and R&D where data are available. The other term in the equation is fixed at zero.

The technology indices are discussed in more detail in Section 2.7.

Table 4.1: Stochastic Functions

1	BFR0	Aggregate Energy Demand
2	BFRC	Coal Demand
3	BFRO	Heavy Oil Demand
4	BFRG	Natural Gas Demand
5	BFRE	Electricity Demand
6	BRSC	Aggregate Consumption
7	BCR	Disaggregate Consumption
8		
9	BKR	Industrial Investment
10	BQEX	External Exports
11	BQIX	Internal Exports
12	BQEM	External Imports
13	BQIM	Internal Imports
14	BYRH	Hours Worked
15	BYRE	Industrial Employment
16	BPYH	Industrial Prices
17	BPQX	Export Prices
18	BPQM	Import Prices
19	BYRW	Industrial Average Earnings
20	BLRP	Labour Participation Rate
21	BRRI	Residual Income
22	BRDW	Investment in Dwellings
23	BYRN	Normal Output
24		
25	BRPT	Aggregate Passenger Transport
26	BRFT	Aggregate Freight Transport
27	BPMR	Disaggregate Passenger Transport
28	BFMR	Disaggregate Freight Transport
29		
30	BFRB	Biofuel Demand
31	BMU1	Demand for Food
32	BMU2	Demand for Feed
33	BMU3	Demand for Wood
34	BMU4	Demand for Construction Minerals
35	BMU5	Demand for Industrial Minerals
36	BMU6	Demand for Ferrous Ores
37	BMU7	Demand for Non-Ferrous Ores
	BITRADE	Bilateral Trade

Notes: The equation sets in grey text are not included in the standard model version and are defined in Appendix D.

Table 4.2: Summary of the standard equation sets in E3ME version 6.0

Equ'n set	Endog. var	V1	V2	V3	V4	V5	V6	V7	V8	V9	Units
1	FR0	FRY	PREN	FRTD	ZRDM	ZRDT	FRK				th toe
2-5	FR(fuel)	FR0	PFRF	FRTD	ZRDM	ZRDT[1]	FRK				th toe
6	RSC	RRPD	RRLR	CDEP	ODEP	RVD	RUNR	PRSC/PSC1			m € 2005 prices
7	CR	RRPD	PRCR	RRLR	PRSC/PSC1	CDEP	ODEP				consumption ratio
10	KR	YR	PKR/PYR	YRWC	PQMA(5)[2]	RRLR	YYN				m € 2005 prices
13	QEM	QRDI	PQRM	PYH	EX	YRKC*YRKS[3]	YRKN	SVIM	YYN		m € 2005 prices
14	QIM	QRDI	PQRM	PYH	EX	YRKC*YRKS[3]	YRKN	SVIM	YYN		m € 2005 prices
15	YRH	YRNH	YRKC*YRKS[3]	YRKN	YYN						hours per week
16	YRE	YR	LYLC	YRH	PQMA(5)[2]	YRKC*YRKS[3]	YRKN				thousands
17	PYH	YRUC	PQRM	YRKC*YRKS[3]	YRKN	PQMA(5)[2]	YYN				index 2005=1
18	PQRX	PQRY	PQWE	EX	YRULT	YRKC*YRKS[3]	YRKN				index 2005=1
19	PQRM	PQRF	PQWE	EX	YRUL	YRKC*YRKS[3]	YRKN				index 2005=1
20	YRW	LYWE	LYRXE	LYRP	RUNR	RBNR	APSC	ARET	REIW	YYN	th € per year
21	LRP	RSQ	RWSR	LRUN	RBNR[4]	RSER	RHRS	LRQU	RTIM		rate [0,1]
22	RRI	RWS	PRYM/PRY1	VRYM	RLR						m €
23	RDW	RRPD	RRLR	CDEP	ODEP	RUNR	PRSC/PSC1				m € 2005 prices
24	YRN	YRY	YRX	YRKC*YRKS[3]	YRKN						m € 2005 prices
31-37	MU	MURY	PMAT	KR	YRD	MUM					th tonnes
38	YRD	YR	PYRD	KR/YRE							M € 2005 prices
BiTrade	BIQRM	PQRX	YRKE								m € 2005 prices

Notes: All equations also include dummy variables for German unification and the 2009 financial crisis.
1 R&D on transport equipment is included in as an additional explanatory variables only for the oil equations.
2 The model has a dual classification system. For the first 33 regions PQMA(5) is used, for the rest PQMA(3).
3 From region 34 onwards YRKE is used instead.
4 Age groups 50+ use pensions instead (RPNR).

Conventions adopted for the notation

The names of variables and parameter sets closely follow the conventions for Fortran names, i.e. they are groups of capital letters and numbers beginning with a letter.

Nearly all the variables and parameters are defined over the regional dimension. In order to reduce the complexity of the notation this regional dimension is omitted in the tables below: therefore all variables and parameters should be assumed to vary over the regions of E3ME unless otherwise stated.

Individual elements of vectors, rows, columns or elements of matrices are denoted by replacing the dot by the appropriate number in the classification, e.g. YR(5,.) is gross output of the oil and gas industry (in each region) which is the fifth industry in the European sectoral classification[11].

The full syntax is given below.

+ - * and /	denote addition, subtraction, multiplication and division of scalars and of individual elements of vectors and matrices.
( )	are grouping brackets.
[ ]	enclose comments.
(.)	as a postscript on a name indicates that it is a vector with the dot denoting all the elements.
(.,.)	as a postscript on a name indicates that it is a matrix.
(^)	denotes that the vector is converted to a diagonal matrix.
(.,.)'	denotes that the matrix is transposed.
(-1), (-2) etc.	as applied to a variable or a group of variables as a postscript denote a one, two etc. period lag.
LN(V)	is the natural logarithm of variable V.
DLN(V)	is the change in LN(V).
MATP(M1(.,.),M2(.,.))	denotes matrix multiplication of variable matrices M1 and M2.
ECM	is the error term from the long-run cointegrating equation that gets used (after lagging) in the dynamic equation.

[11] The appropriate sector is used for each region, so in this case it would be sector 3 for non-European regions.

4.3 Aggregate energy demand

The equation specification is given in. The original equation is based on work by Barker, Ekins and Johnstone (1995) and Hunt and Manning (1989). The work by Serletis (1992), and Bentzen and Engsted (1993) has also helped in forming the specification for the cointegrating equation.

Overall structure

Since there are substitutable inputs between fuels, the total energy demand in relation to the output of the energy-using industries is likely to be more stable than the individual components. Even so, total energy demand is also subject to considerable variation, which reflects both technical progress in conservation, and changes in the cost of energy relative to other inputs. The aggregate energy equation considers the total energy used (summation of twelve carriers) in thousand tonnes of oil equivalent (th toe) by each energy user. The demand for energy is dependent on the economic 'activity' for that user (converted from the 69/43 economic sectors). This is chosen as gross economic output for most sectors, but household energy demand is a function of total consumers' expenditure. A restriction is imposed so that higher activity does not result in higher energy use (all other factors being equal).

The average price used in the equations weights the prices of individual energy carriers by their share in consumption by each user. Due to data limitations, the current energy demand equations do not allow for asymmetrical effects (i.e. rising energy prices leading to reductions in fuel demand, but falling prices not leading to an increase). Such asymmetrical price effects in aggregate energy demand equations have been the subject of other research (Gately, 1993; Walker and Wirl, 1993; Grubb, 1995, 2014). The idea is that because energy is used via capital stock with a long lifetime, and since technical change is progressive and is not generally reversed, when energy prices rise and energy savings are introduced, then when energy prices fall again, these savings are not reversed i.e. energy demand responds to rises in real prices, but not falls. This will be revisited in future.

Price elasticities

As described in Section 2.4 the long-run price elasticities are taken from the literature rather than estimated using the time-series data. The long-run price elasticity for road fuel is imposed at -0.7 for all regions, following the research on long-run demand (Franzen and Sterner, 1995) and (Johansson and Schipper, 1997, p. 289). CE's internal research, using cross-sectional analysis of the E3ME data set has confirmed this result. Elasticities for other sectors are around -0.2.

Technology and capital stock

The measures of research and development expenditure and investment capture the effect of new ways of decreasing energy demand (energy saving technical progress) and the elimination of inefficient technologies, such as energy saving techniques replacing the old inefficient use of energy. The variables FRK and FRTD are determined by converting the economic data for investment and R&D into the energy using categories. Research and development expenditure in the engineering sectors (for machinery) and the vehicles sectors for the world as a whole take into account spillover effects from international companies.

The power sector

The power generation sector is solved using the bottom-up FTT model (see Section 2.5) rather than the estimated equations. The top-down approach offered by the econometric equations is not appropriate for this sector because:

- there is a small number of large plants, meaning estimated parameters give a poor performance
- the econometric approach is not well suited to the development of new renewable technologies

Table 4.3: Aggregate Energy Demand Equations

Co-integrating long-term equation:			
LN(FR0(.))			[total energy used by energy user]
	=	BFR0(.,10)	
	+	BFR0(,.11) * LN(FRY(.))	[activity measure]
	+	BFR0(.,12) * LN(PREN(.))	[average price ratio]
	+	BFR0(.,13) * LN(FRTD(.))	[R&D by energy user]
	+	BFR0(.,14) * LN(ZRDM)	[global R&D in machinery]
	+	BFR0(.,15) * LN(ZRDT)	[global R&D in transport]
	+	BFR0(.,16) * LN(FRK(.))	[investment by energy user]
	+	ECM	[error]
Dynamic equation:			
DLN(FR0(.))			[total energy used by energy user]
	=	BFR0(.,1)	
	+	BFR0(.,2) * DLN(FRY(.))	[activity measure]
	+	BFR0(.,3) * DLN(PREN(.))	[average price ratio]
	+	BFR0(.,4) * DLN(FRTD(.))	[R&D by energy user]
	+	BFR0(.,5) * DLN(ZRDM)	[global R&D in machinery]
	+	BFR0(.,6) * DLN(ZRDT)	[global R&D in transport]
	+	BFR0(.,7) * DLN(FRK(.))	[investment by energy user]
	+	BFR0(.,8) * DLN(FR0(-1))	[lagged change in energy use]
	+	BFR0(.,9) * ECM(-1)	[lagged error correction]
Identity:			
PREN	=	PFR0(.) / PRYR	[relative price ratio]
Restrictions:			
BFR0(.,3 .,4 .,5 .,6 .,7 .,12 .,13 .,14 .,15 .,16) <= 0			['right sign']
BFR0(.,2 .,11) >= 0			['right sign']
0 > BFR0(.,9) > -1			['right sign']
Definitions:			
BFR0	is a matrix of parameters		
FR0	is a matrix of total energy used by 22 energy users for 61 regions, th toe		
PFR0	is a matrix of average energy prices for 22 energy users and 61 regions, euro/toe		
PRYR	is a matrix of average producer prices in the economy as a whole (2010 = 1.0, local currency)		
FRY	is a matrix of activity for 22 energy users and 61 regions, m euro at 2010 prices		
FRTD	is a matrix of R&D by 22 energy users for 61 regions, m euro at 2010 prices		
ZRDM	is global R&D in machinery, m euro at 2010 prices		
ZRDT	is global R&D in transport, m euro at 2010 prices		
FRK	is a matrix of investment by 22 energy users for 61 regions, m euro at 2010 prices		

4.4 Disaggregate energy demand for coal, heavy fuel oil, gas and electricity

The specification is shown in Table 4.4.

The equations for disaggregated energy demand have been specified for four energy carriers[12]: coal, heavy fuel oil, natural gas, and electricity. The carriers have the characteristic that in many industries they are highly substitutable inputs to the process of heat generation. The specification of the equations follows similar lines to the aggregate energy demand equations (see previous section). The equations contain the same R&D and investment variables, with the same restrictions imposed, although the measure of transport R&D, ZRDT, is only used in the oil equation. Instead of using a measure of economic activity, total energy consumption by the sector is used.

The price term is a ratio of the price for the particular energy carrier in question to that of the aggregate energy price. The relative fuel prices have changed dramatically over the period of historical data, particularly towards the start and end of the time series.

The other independent variables match those for the aggregate equation (see above). Again, the power generation sector is solved using the FTT submodel, and does not use the estimated equation.

[12] These are also referred to as ‘fuels’ for brevity.

Table 4.4: The Disaggregate Energy Demand Equations

Equations used for F = coal (C), Heavy Fuel Oil (O), Natural Gas (G), Electricity (E).

Co-integrating long-term equation:

LN(FRF(.))			[fuel used by energy user]
	=	BFRF(.,10)	
	+	BFRF(.,11) * LN(FR0(.))	[total energy used by energy user]
	+	BFRF(.,12) * LN(PFRP(.))	[price ratio]
	+	BFRF(.,13) * LN(FRTD(.))	[R&D by energy user]
	+	BFRF(.,14) * LN(ZRDM)	[global R&D in machinery]
	+	BFRF(.,15) * LN(ZRDT)	[global R&D in transport]
	+	BFRF(.,16) * LN(FRK(.))	[investment by energy user]
	+	ECM	[error]

Dynamic equation:

DLN(FRF(.))			[fuel used by energy user]
	=	BFRF(.,1)	
	+	BFRF(.,2) * DLN(FR0(.))	[total energy used by energy user]
	+	BFRF(.,3) * DLN(PFRP(.))	[price ratio]
	+	BFRF(.,4) * DLN(FRTD(.))	[R&D by energy user]
	+	BFRF(.,5) * DLN(ZRDM)	[global R&D in machinery]
	+	BFRF(.,6) * DLN(ZRDT)	[global R&D in transport]
	+	BFRF(.,7) * DLN(FRK(.))	[investment by energy user]
	+	BFRF(.,8) * DLN(FRF(-1))	[lagged change in energy use]
	+	BFRF(.,9) * ECM(-1)	[lagged error correction]

Identity:

PFRP = PFRF(.)/PFR0(.)	[price ratio]

Restrictions:

BFRF(.,3 .,4 .,5 .,6 .,7 .,12.,13 .,14 .,15 .,16) <= 0	['right sign']
BFRF(.,2 .,11) >= 0	['right sign']
0 > BFRF(.,9) > -1	['right sign']

Definitions:

BFRF	is a matrix of parameters
FRF	is a matrix of fuel used by 22 energy users for 61 regions, th toe
FR0	is a matrix of total energy used by 22 energy users for 61 regions, th toe
PFRF	is a matrix of prices for energy carrier F, by 22 energy users for 61 regions, $/toe
PFR0	is a matrix of average energy prices for 22 energy users and 61 regions, $/toe
FRTD	is a matrix of R&D by 22 energy users for 61 regions, m euro at 2010 prices
ZRDM	is R&D in machinery by the EU, m euro at 2010 prices
ZRDT	is R&D in transport by the EU, m euro at 2010 prices (oil equation only)
FRK	is a matrix of investment by 22 energy users for 61 regions, m euro at 2010 prices

4.5 Household consumption

Aggregate household consumption

The equation specification is given in Table 4.5. It should be noted that the dependent variable and terms for income and wealth are converted into per capita measures, although this is excluded from the table for conciseness. As consumption accounts for around 50% of final demand the equation is very important within the model structure as a whole.

Most studies have followed those of Hendry et al (1978) which have examined the dynamic links between consumption, income and wealth in an error correction model. In more recent studies, attention has focused more upon the role of wealth (housing wealth in particular) and financial liberalisation (Barrell and Davis, 2007; Carruth and Kerdrain, 2011).

The specification of the equation is similar to that used in the previous HERMES model, which generalises the permanent income and the lifecycle theories in an error correction model. Indeed the long-run elasticity of consumption in relation to income has been set equal to one to ensure the lifecycle theory is fulfilled.

These equations relate total consumption to regional personal disposable income, a measure of wealth for the personal sector, inflation and interest rates. Variables covering child and old-age dependency rates are also included in an attempt to capture any change in consumption patterns caused by an ageing population. The unemployment rate is used as a proxy for the degree of uncertainty in the economy and has been found to have significant effects on short-term consumption levels.

Due to a lack of available data on household wealth, cumulative investment in dwellings was used as a proxy for the housing stock (and there is no proxy for financial wealth). However, in line with other findings, E3ME's equations show only a modest link between household wealth and spending (very few studies find an elasticity greater than 0.1, and 0.02-0.03 is not uncommon).

Disaggregate consumption

The specification is shown in Table 4.6.

Both the long-term and dynamic equations have a similar specification to the aggregation consumption equations, but include the relative prices of each consumption category.

Table 4.5: The Aggregate Consumption Equations

Co-integrating long-term equation:

LN(RSC)			[real consumers' expenditure]
	=	BRSC(11)	
	+	BRSC(12) * LN(RRPD)	[real gross disposable income]
	+	BRSC(13) * LN(RRLR)	[real rate of interest]
	+	BRSC(14) * LN(CDEP)	[child dependency ratio]
	+	BRSC(15) * LN(ODEP)	[OAP dependency ratio]
	+	BRSC(16) * LN(RVD)	[household wealth]
	+	ECM	[error]

Dynamic equation:

DLN(RSC)			[real consumers' expenditure]
	=	BRSC(1)	
	+	BRSC(2) * DLN(RRPD)	[real gross disposable income]
	+	BRSC(3) * DLN(RRLR)	[real rate of interest]
	+	BRSC(4) * DLN(CDEP)	[child dependency ratio]
	+	BRSC(5) * DLN(ODEP)	[OAP dependency ratio]
	+	BRSC(6) * DLN(RVD)	[household wealth]
	+	BRSC(7) * LN(RUNR)	[unemployment rate]
	+	BRSC(8) * DLN(RPSC)	[consumer price inflation]
	+	BRSC(9) * DLN(RSC(-1))	[lagged change in consumers' expenditure]
	+	BRSC(10) * ECM(-1)	[lagged error correction]

Identities:

RRLR	=	1 + (RLR–DLN(PRSC))/100	[real rate of interest]
RRPD	=	(RGDI*EX/PRSC)	[real gross disposable income]
CDEP, ODEP	=	CPOP/RPOP, OPOP/RPOP	[dependency ratios]

Restrictions:

BRSC(12) = 1	['life cycle hypothesis']
BRSC(2, 6, 16) >= 0	['right sign']
BRSC(3, 7, 8, 13) <= 0	['right sign']
0 > BRSC(10) > -1	['right sign']

Definitions

BRSC	is a matrix of parameters
RSC	is a vector of total consumers' expenditure for 61 regions, m euro at 2010 prices
RGDI	is a matrix of gross disposable income for 61 regions, m euro at current prices
RLR	is a matrix of long-run nominal interest rates for 61 regions
EX	is a vector of exchange rates, local currency per euro, 2010=1.0
RPOP	is a vector of regional population for 61 regions, in thousands of persons
CPOP	is a vector of child population for 61 regions, in thousands of persons
OPOP	is a vector of old-age population for 61 regions, in thousands of persons
RUNR	is a vector of unemployment rates for 61 regions, measured as a percentage of the labour force
PRSC	is a vector of consumer price deflator for 61 regions, 2010=1.0
RPSC	is a vector of consumer price inflation for 61 regions, in percentage terms
RVD	is the cumulative sum of investment in dwellings for 61 regions, m euro at 2010 prices

Table 4.6: The Disaggregate Consumption Equations

Co-integrating long-term equation:			
LN(SHAR(.))			[consumers' budget share, logistic form]
	=	BCR(.,10)	
	+	BCR(.,11) * LN(RRPD)	[real gross disposable income]
	+	BCR(.,12) * LN(PRCR(.))	[relative price of consumption]
	+	BCR(.,13) * LN(RRLR)	[real rate of interest]
	+	BCR(.,14) * LN(PRSC)	[consumer price deflator]
	+	BCR(.,15) * LN(CDEP)	[child dependency ratio]
	+	BCR(.,16) * LN(ODEP)	[OAP dependency ratio]
	+	ECM	[error]
Dynamic equation:			
DLN(SHAR(.))			[consumers' budget share, logistic form]
	=	BCR(.,1)	
	+	BCR(.,2) * DLN(RRPD)	[real gross disposable income]
	+	BCR(.,3) * DLN(PRCR(.))	[relative price of consumption]
	+	BCR(.,4) * DLN(RRLR)	[real rate of interest]
	+	BCR(.,5) * DLN(PRSC)	[consumer price deflator]
	+	BCR(.,6) * DLN(CDEP)	[child dependency ratio]
	+	BCR(.,7) * DLN(ODEP)	[OAP dependency ratio]
	+	BCR(.,8) * DLN(SHAR)(-1)	[lagged change in consumers' budget share]
	+	BCR(.,9) * ECM(-1)	[lagged error correction]
Identities:			
SHAR	=	(VCR(.)/VCRT) / (1-(VCR(.)/VCRT))	[consumers' budget share, logistic form]
RRPD	=	(RGDI*EX/RPSC)/RPOP	[real gross disposable income]
PRCR	=	VCR(.)/CR(.)/PRSC	[real price of consumption]
RRLR	=	1+(RLR-DLN(PRSC))/100	[real rate of interest]
CDEP	=	CPOP/RPOP	[child dependency ratio]
ODEP	=	OPOP/RPOP	[OAP dependency ratio]
Restriction:			
0 > BCR(.,9) > -1			['right sign']

Definitions:

BCR	is a matrix of parameters
CR	is a matrix of consumers' expenditure for 43 commodities for 61 regions, m euro at 2010 prices
VCR	is a matrix of consumers' expenditure for 43 commodities for 61 regions, m euro at current prices
VCRT	is a vector of total consumers' expenditure for 61 regions, m euro at current prices
RGDI	is a matrix of gross disposable income for 61 regions, in m euro at current prices
RLR	is a matrix of long-run nominal interest rates for 61 regions
RPOP	is a vector of regional population for 61 regions, in thousands of persons
CPOP	is a vector of child population for 61 regions, in thousands of persons
OPOP	is a vector of old-age population for 61 regions, in thousands of persons
PRSC	is a vector of total consumer price deflator for 61 regions, in percentage terms
RPSC	is a vector of the real consumer price inflation for 61 regions, in percentage terms
EX	is a vector of exchange rates, local currency per euro, 2010=1.0

4.6 Industrial investment

Investment (see Table 4.7) is a very important and very volatile component of final demand, so its treatment in the model is of central importance to model simulation and forecasting performance. Ideally, the treatment of investment in a sectoral model such as E3ME should disaggregate by asset (e.g. vehicles, plant and machinery, and buildings) as well as by investing industry, but this has not proved possible due to data limitations.

The specification of the investment equations in E3ME has built upon earlier work published in Barker and Peterson (1987). The theory behind the choice of variables that explain the long-run path of investment is a mix between the neoclassical tradition, whereby factor demands are explained solely in terms of other factor prices, and the accelerator model, which recognises the importance of output as a determining influence. For the dynamic representation, other variables are added, including the real rate of interest and the ratio of actual to normal (expected) output, the latter being designed to capture the decision to invest for increased capacity, as opposed to solely for replacement needs.

E3ME is bound by the investment-savings national accounts identity but the representation of capital markets in E3ME does not assume full ‘crowding out’, as is typically the case in CGE models. E3ME allows for the possibility of non-optimal allocation of capital and the transfers of financial funds from existing assets (which push up prices but does not lead directly to higher rates of economic activity) to the development and construction of new assets. This means that it is possible for total gross fixed capital formation to increase, without there being necessarily an equivalent increase in savings.

Table 4.7: The Industrial Investment Equations

Co-integrating long-term equation:

LN(KR(.))			[investment]
	=	BKR(.,10)	
	+	BKR(.,11) * LN(YR(.))	[real output]
	+	BKR(.,12) * LN(PKR(.)/PYR(.))	[relative price of investment]
	+	BKR(.,13) * LN(YRWC(.))	[real average labour cost]
	+	BKR(.,14) * LN(PQRM(5,.))	[real oil price effect]
	+	ECM	[error]

Dynamic equation:

DLN(KR(.))			[change in investment]
	=	BKR(.,1)	
	+	BKR(.,2) * DLN(YR(.))	[real output]
	+	BKR(.,3) * DLN(PKR(.)/PYR(.))	[relative price of investment]
	+	BKR(.,4) * DLN(YRWC(.))	[real average labour costs]
	+	BKR(.,5) * DLN(PQRM(5,.))	[real oil price effect]
	+	BKR(.,6) * LN(RRLR)	[real rate of interest]
	+	BKR(.,7) * LN(YYN(.))	[actual/normal output]
	+	BKR(.,8) * DLN(KR)(-1)	[lagged change in investment]
	+	BKR(.,9) * ECM(-1)	[lagged error correction]

Identities:

YRWC	=	(YRLC(.) / PYR(.)) / YREE(.)	[real labour costs]
RRLR	=	1 + (RLR – DLN(PRSC)) / 100	[real rate of interest]

Restrictions:

BKR(.,2 .,4 .,7 .,11 .,13) >= 0	['right sign']
BKR(.,3 .,6 .,12) <= 0	['right sign']
0 > BKR(.,9) > -1	['right sign']

Definitions:

BKR	is a matrix of parameters
KR	is a matrix of investment expenditure for 69/43 industries and 61 regions, m euro at 2010 prices
YR	is a matrix of gross industry output for 69/43 industries and 61 regions, m euro at 2010 prices
PYR	is a matrix of industry output price for 69/43 industries and 61 regions, 2010=1.0, local currency
PKR	is a matrix of industry investment price for 69/43 industries and 61 regions, 2010=1.0, local currency
PQRM	is a matrix of import prices for 69/43 industries and 61 regions, 2010=1.0, local currency
PRSC	is a vector of consumer price deflator for 61 regions, 2010=1.0
YRLC	is a matrix of wage costs (including social security contributions) for 69/43 industries and 61 regions, local currency at current prices
YREE	is a matrix of employees for 69/43 industries and 61 regions, in thousands of persons
RLR	is a vector of long-run nominal interest rates for 61 regions
YYN	is a matrix of the ratio of gross output to normal output, for 69/43 industries and 61 regions

4.7 The trade equations

Modelling trade is an important feature in a regional model such as E3ME for two main reasons. Firstly, globalisation has meant that international trade has accounted for an increasing share of total production (expected to increase further in the future). Secondly, exports and imports represent the linkage between countries in E3ME, so effects moving from one country to another are transmitted via this area of the model.

Previous approach

The original specification of the trade equations in E3ME was based around the proposals in Ragot (1994). It also draws on the variety hypothesis (Barker, 1977) and its incorporation in a UK multisectoral model (Barker and Peterson, 1987). Trade was treated as if it takes place through a 'pool', i.e. a transport and distribution network, with the export and import volume equations representing each country's exports into this pool and imports from it. In previous versions of E3ME trade was split into transactions within and external to the EU.

Bilateral trade

This split is maintained in the current version of the model and has been expanded to include other trade zones as well. However, the modelling approach has been revised considerably and now uses a bilateral approach, similar in method to a Two Tier Armington model (Armington 1969). It can be summarised in the following steps:

- solve the model equations for total imports in each sector (split within and external to trading zones)
- solve the model equations for bilateral imports
- scale the bilateral trade results for consistency with the aggregate results
- derive total exports as the sum and inverse of bilateral imports

Aggregate import volumes

The equations for aggregate import volumes are largely unchanged from previous versions of the model. Imports are split into those within a country's trading zone (internal imports) and those from the rest of the world (external imports).

In the equations, activity is modelled by sales to the domestic market, while the three price effects are import price, price of sales to the domestic market and the relative price of the currency, i.e. the exchange rate. Aside from the restrictions on sign and significance, price homogeneity is imposed between the price of imports and price of sales to the domestic market. This has the effect of making the price relative, removing the long-term effect of the exchange rate variable. The technical progress measures are included to allow for the effects of innovations on trade performance. In the internal imports equations there is an additional synthetic indicator for the development of the trading zone (e.g. the European single market).

The formal specification of the import equations is shown in Table 4.8 and Table 4.9.

Bilateral imports

The bilateral trade data are defined at the 43 sector level. The other dimensions in the data are origin (61 regions), destination (61 regions) and year (1995-2012). Initial attempts were made to carry out time-series estimation at this level of detail (i.e. 61*61*43 equations) but this proved to be infeasible due to computation time and gaps in the data.

The following adjustments were therefore made to the estimation procedure:

- the regions were aggregated to five global areas (Europe, US, China, North America and Rest of World)
- the 43 sectors were aggregated to 19
- only a levels based estimation was carried out

The equation specification allows the bilateral import share to be determined by export prices of the exporting region and technology in the exporting region. As the time series grow in length, additional explanatory factors (e.g. to take into account scale effects) will be added to the equation. The functional form will also be revisited.

The equations were estimated at the more aggregate level and then the parameters applied to each of the more disaggregated sectors. We plan to gradually expand the number of regions included in the estimation as the data are cleaned and further improved. Although the sectoral aggregation may seem quite severe, it has only limited impact on the results because the sectors aggregated are principally non-traded ones (e.g. utilities, distribution/retail or public services) or thinly traded service sectors.

Export volumes

Given the results for bilateral imports, the model results for exports (either bilaterally or as a region's total) are relatively simplistic to derive; trade flows are reversed and aggregated to give regional totals.

It is important to note that there is a further scaling 'calibration' exercise to ensure that model outputs are consistent with historical figures for regional exports. This scaling takes into account the discrepancy between the sums of global imports and exports.

Table 4.8: The Internal Import Volume Equations

Co-integrating long-term equation:			
LN(QIM(.))			[internal import volume]
	=	BQIM(.,12)	
	+	BQIM(.,13) * LN(QRDI(.))	[home sales]
	+	BQIM(.,14) * LN(PQRM(.))	[import price]
	+	BQIM(.,15) * LN(PYH(.))	[price home sales by home producers]
	+	BQIM(.,16) * LN(EX)	[exchange rate]
	+	BQIM(.,17) * LN(YKNO(.))	[stock of knowledge]
	+	BQIM(.,18) * LN(YCAP(.))	[stock of capital]
	+	BQIM(.,19) * SVIM	[proxy for internal market programme]
	+	ECM	[error]
Dynamic equation:			
DLN(QIM(.))			[change in internal import volume]
	=	BQIM(.,1)	
	+	BQIM(.,2) * DLN(QRDI(.))	[home sales]
	+	BQIM(.,3) * DLN(PQRM(.))	[import price]
	+	BQIM(.,4) * DLN(PYH(.))	[price home sales by home producers]
	+	BQIM(.,5) * DLN(EX)	[exchange rate]
	+	BQIM(.,6) * DLN(YKNO(.))	[stock of knowledge]
	+	BQIM(.,7) * DLN(YCAP(.))	[stock of capital]
	+	BQIM(.,8) * DSVIM	[proxy for internal market programme]
	+	BQIM(.,9) * LN(YYN(.))	[actual/normal output]
	+	BQIM(.,10) * DLN(QIM)(-1)	[lagged change in import volume]
	+	BQIM(.,11) * ECM(-1)	[lagged error correction]
Identity:			
QRDI	=	QR(.) + QRM(.)	[home sales]
PYH	=	(VQR(.) - VQRX(.)) / (QR(.) - QRX(.))	[price home sales by home producers]
Restrictions:			
BQIM(.,14) + BQIM(.,15) = 0			[price homogeneity]
BQIM(.,16) = BQIM(.,14) + BQIM(.,15)			[price and exchange rate symmetry]
BQIM(.,2 .,4 .,13 .,15) >= 0			['right sign']
BQIM(.,3 .,5 .,6 .,7 .,14 .,16 .,17 .,18) <= 0			['right sign']
0 > BQIM(.,11) > -1			['right sign']
Definitions:			
BQIM	is a matrix of parameters		
QIM	is a matrix of internal imports for 69/43 industries and 61 regions, m euro at 2010 prices		
PQRM	is a matrix of import prices for 69/43 industries and 61 regions, 2010=1.0, local currency		
EX	is a vector of exchange rates, local currency per euro, 2010=1.0		
QR	is a matrix of gross output for 69/43 industries and 61 regions, m euro at 2010 prices		
QRM	is a matrix of imports for 69/43 industries and 61 regions, m euro at 2010 prices		
QRX	is a matrix of exports for 69/43 industries and 61 regions, m euro at 2010 prices		
YKNO	is a matrix of the knowledge stock for 69/43 industries and 61 regions, m euro at 2010 prices		
YCAP	is a matrix of the capital stock for 69/43 industries and 61 regions, m euro at 2010 prices		
YRKS	is a matrix of skills for 69/43 industries and 61 regions		
SVIM	is an indicator of progress in the trade bloc		
YYN	is a matrix of the ratio of gross output to normal output, for 69/43 industries and 61 regions		

V-	indicates a current price version of the variable

Table 4.9: The External Import Volume Equations

Co-integrating long-term equation:			
LN(QEM(.))			[external import volume]
	=	BQEM(.,12)	
	+	BQEM(.,13) * LN(QRDI(.))	[home sales]
	+	BQEM(.,14) * LN(PQRM(.))	[import price]
	+	BQEM(.,15) * LN(PYH(.))	[price home sales by home producers]
	+	BQEM(.,16) * LN(EX)	[exchange rate]
	+	BQEM(.,17) * LN(YKNO(.))	[stock of knowledge]
	+	BQEM(.,18) * LN(YCAP(.))	[stock of capital]
	+	BQEM(.,19) * SVIM	[=0 for external trade]
	+	ECM	[error]
Dynamic equation:			
DLN(QEM(.))			[change in external import volume]
	=	BQEM(.,1)	
	+	BQEM(.,2) * DLN(QRDI(.))	[home sales]
	+	BQEM(.,3) * DLN(PQRM(.))	[import price]
	+	BQEM(.,4) * DLN(PYH(.))	[price home sales by home producers]
	+	BQEM(.,5) * DLN(EX)	[exchange rate]
	+	BQEM(.,6) * DLN(YKNO(.))	[stock of knowledge]
	+	BQEM(.,7) * DLN(YCAP(.))	[stock of capital]
	+	BQEM(.,8) * DSVIM	[=0 for external trade]
	+	BQEM(.,9) * LN(YYN(.))	[actual/normal output]
	+	BQEM(.,10) * DLN(QEM)(-1)	[lagged change in import volume]
	+	BQEM(.,11) * ECM(-1)	[lagged error correction]
Identities:			
QRDI	=	QR(.) + QRM(.)	[home sales]
PYH	=	(VQR(.) - VQRX(.)) / (QR(.) - QRX(.))	[price home sales by home producers]
Restrictions:			
BQEM(.,14) + BQEM(.,15) = 0			[price homogeneity]
BQEM(.,16) = BQEM(.,14) + BQEM(.,15)			[price and exchange rate symmetry]
BQEM(.,2 .,4 .,13 .,15) >= 0			['right sign']
BQEM(.,3 .,5 .,6 .,7 .,14 .,16 .,17 .,18) <= 0			['right sign']
0 > BQEM(.,11) > -1			['right sign']
Definitions:			
BQEM	is a matrix of parameters		
QEM	is a matrix of internal imports for 69/43 industries and 61 regions, m euro at 2010 prices		
PQRM	is a matrix of import prices for 69/43 industries and 61 regions, 2010=1.0, local currency		
EX	is a vector of exchange rates, local currency per euro, 2010=1.0		
QR	is a matrix of gross output for 69/43 industries and 61 regions, m euro at 2010 prices		
QRM	is a matrix of imports for 69/43 industries and 61 regions, m euro at 2010 prices		

QRX	is a matrix of exports for 69/43 industries and 61 regions, m euro at 2010 prices
YKNO	is a matrix of the knowledge stock for 69/43 industries and 61 regions, m euro at 2010 prices
YCAP	is a matrix of the capital stock for 69/43 industries and 61 regions, m euro at 2010 prices
SVIM	is zero for the external trade equations
YYN	is a matrix of the ratio of gross output to normal output, for 69/43 industries and 61 regions
V-	indicates a current price version of the variable

4.8 Average working hours

Overview

A measure of hours worked (see Table 4.10) in each industry is needed because employment is modelled as number of employees, rather than as person-hours. A priori, one would expect the related coefficient in the employment equation to be negative; if (on average) people are working longer hours then this should have an adverse effect on job opportunities, and vice versa. The effect of identifying an hours worked variable will even out when it comes to analysing productivity effects, but in countries with relatively flexible labour markets, such as the UK, it is a good idea to try and model the effects explicitly.

The chosen model follows the methodology of Neal and Wilson (1987). The relationship at its simplest level can be explained by the identity:

$$yh_t = ynh_t + \beta 1 yoh_t + \beta 2 ysh_t$$

where:

yh_t = average hours per person per week

ynh_t = normal hours per person per week

yoh_t = overtime hours per person per week

ysh_t = short-time hours per person per week

$\beta 1, \beta 2$ = proportion of people on overtime and short-time, respectively

The main issue is then to develop a theory that expresses the demand for hours worked in terms of the RHS variables, or proxies for them. Using the firm's cost-minimisation framework:

$$\min_{v}(wv) s.t. f(v) = q$$

where:

q = output

$f(v)$ = a production function defined over a vector of v inputs

w = input prices

The level of 'optimal hours' (yh^*) can be derived as a function of factor prices, but it is only under very restrictive assumptions that optimal hours are equal to normal hours worked, which is usually taken to mean the level of utilisation that minimises the hourly wage rate.

Specification in E3ME

There is clearly some relation between the two concepts, however. The procedure adopted is of a general relationship:

$$yh_t^* = h^*(const, ynh_t, T_t)$$

where:

$h^*(.)$ has a log-linear specification

T_t = technological progress

The discrepancy between desired actual hours and optimal hours is assumed to arise mainly from short-run output adjustments. With a fixed capital stock, any deviation of output from its forecast level will be met largely through adjustment in hours worked, i.e. either by overtime or short-time working, while employment levels are adjusted by the firm. Thus we have:

$$yh_t^d = h^d(\frac{q^e}{qt}, yh^{*t}, n_t)$$

which gives desired actual hours as a function of output forecast errors, optimal hours and employment, n_t.

To form an equation for actual hours worked, the hours worked identity and disaggregate consumption equation are combined to substitute out for yh^*. However, to avoid a feedback loop with the employment equations in the model solution, employment is left out of the final specification. This gives the general model form:

$$yh_t = h\left(ynh_t, \frac{q^e}{q_t}, T_t\right)$$

This general form can, on finding a cointegrating relationship between the above variables, be represented by an error correction mechanism, the first stage of which is the levels regression and the second stage provides the dynamic regression.

Table 4.10: The Industrial Hours-Worked Equations

Co-integrating long-term equation:		
LN(YRH(.))		[average hours worked]
=	BYRH(.,8)	
+	BYRH(.,9) * LN(YRNH(.))	[normal hours worked]
+	BYRH(.,10) * LN(YKNO(.))	[stock of knowledge]
+	BYRH(.,11) * LN(YCAP(.))	[stock of capital]
+	ECM	[error]
Dynamic equation:		
DLN(YRH(.))		[change in average hours worked]
=	BYRH(.,1)	
+	BYRH(.,2) * DLN(YRNH(.))	[normal hours worked]
+	BYRH(.,3) * DLN(YKNO(.))	[stock of knowledge]
+	BYRH(.,4) * DLN(YCAP(.))	[stock of capital]
+	BYRH(.,5) * LN(YYN(.))	[actual/normal output]
+	BYRH(.,6) * DLN(YRH)(-1)	[lagged change in average hours worked]
+	BYRH(.,7) * ECM(-1)	[lagged error correction]
Restrictions:		
BYRH(.,3 .,4 .,10 .,11) <= 0		[‘right sign’]
BYRH(.,5) >= 0		[‘right sign’]
BYRH(.,2 .,9) = 1		[normal hours homogeneity]
0 > BYRH(.,7) > -1		[‘right sign’]
Definitions:		
BYRH	is a matrix of parameters	
YRH	is a matrix of average hours worked per week for 69/43 industries and 61 regions	
YKNO	is a matrix of the knowledge stock for 69/43 industries and 61 regions, m euro at 2010 prices	
YCAP	is a matrix of the capital stock for 69/43 industries and 61 regions, m euro at 2010 prices	
YRNH	is a matrix of normal hours worked per week for 69/43 industries and 61 regions	
YYN	is a matrix of the ratio of gross output to normal output, for 69/43 industries and 61 regions	

4.9 Industrial employment

The chosen model follows the work of Lee, Pesaran and Pierse (1990) but also incorporates insights from the work on growth theory developed by Scott (1989). A detailed methodological description with empirical results is contained in E3ME working papers no. 28 (Gardiner, 1994) and no. 43 (Barker and Gardiner, 1994). This includes a formal representation of the theoretical optimisation problem for firms to minimise costs for a given level of output.

In the econometric representation in E3ME, employment is determined as a function of real output, real wage costs, hours-worked, the oil import price (used as a proxy for energy prices) and the measures of technological progress. This is shown in Table 4.11.

Over the forecast period the oil import price effect has been set to zero, as sometimes large oil price shocks are modelled. However, the equation specification does still allow for switching from energy to labour in response to higher prices. Industry prices are formed from sectoral unit costs and included in the wage term; higher energy prices within each sector therefore have a similar effect to reducing wage rates.

Table 4.11: The Industrial Employment Equations

Co-integrating long-term equation:			
LN(YRE(.))			[total employment]
	=	BYRE(.,10)	
	+	BYRE(.,11) * LN(YR(.))	[real output]
	+	BYRE(.,12) * LN(LYLC(.))	[real wage costs]
	+	BYRE(.,13) * LN(YRH(.))	[hours worked]
	+	BYRE(.,14) * LN(PQRM(5,.))	[real oil price]
	+	BYRE(.,15) * LN(YKNO(.))	[stock of knowledge]
	+	BYRE(.,16) * LN(YCAP(.))	[stock of capital]
	+	ECM	[error]
Dynamic equation:			
DLN(YRE(.))			[change in total employment]
	=	BYRE(,.1)	
	+	BYRE(,.2) * DLN(YR(.))	[real output]
	+	BYRE(,.3) * DLN(LYLC(.))	[real wage costs]
	+	BYRE(,.4) * DLN(YRH(.))	[hours worked]
	+	BYRE(,.5) * DLN(PQRM(5,.))	[real oil price]
	+	BYRE(,.6) * DLN(YKNO(.))	[stock of knowledge]
	+	BYRE(,.7) * DLN(YCAP(.))	[stock of capital]
	+	BYRE(,.8) * DLN(YRE)(-1)	[lagged change in employment]
	+	BYRE(,.9) * ECM(-1)	[lagged error correction]
Identity:			
LYLC	=	(YRLC(.)/PYR(.)) / YREE(.)	[real labour costs]
Restrictions:			
BYRE(.,2 .,11) >= 0			['right sign']
BYRE(.,3 .,4 .,12 .,13) <= 0			['right sign']
0 > BYRE(.,9) > -1			['right sign']
Definitions:			
BYRE	is a matrix of parameters		
YRE	is a matrix of total employment for 69/43 industries and 61 regions, in thousands of persons		
YR	is a matrix of gross industry output for 69/43 industries and 61 regions, m euro at 2010 prices		
YRH	is a matrix of average hours worked per week for 69/43 industries and 61 regions		
YRLC	is a matrix of employer labour costs (wages plus imputed social security contributions) for 69/43 industries and 61 regions, local currency at current prices		
YKNO	is a matrix of the knowledge stock for 69/43 industries and 61 regions, m euro at 2010 prices		
YCAP	is a matrix of the capital stock for 69/43 industries and 61 regions, m euro at 2010 prices		
PYR	is a matrix of industry output prices for 69/43 industries and 61 regions, 2010=1.0, local currency		
YREE	is a matrix of wage and salary earners for 61 regions, in thousands of persons		
PQRM	is a matrix of import prices for 69/43 industries and 61 regions, 2010=1.0, local currency		

4.10 Domestic industry prices

The following model of industry price formation (see Table 4.12) was developed from Lee (1988), having previously been derived from Layard et al

(1991). The original empirical results were presented in E3ME working paper no. 43 (Barker and Gardiner, 1994).

The basis for price setting is a measure of unit costs, which is formed by summing material, labour and taxation costs, and dividing this by sectoral output. Material costs are estimated using input-output coefficients and the relative prices in each sector that provides inputs. Each industry is assumed to produce a homogenous product but does not necessarily operate in a fully competitive market place. The degree to which cost increases are passed on in final product prices is determined by the level of competition in the sector.

Although import prices are included in unit costs, depending on the import content of production, import prices are added separately in the equation to allow for the effects of international competition on domestic price formation. In the long-term relationship, homogeneity is imposed between higher domestic and import cost effects, so that their combined impact is unitary. The equations also include the technology indices, as a higher quality product may command a higher price.

An important relationship in the short-term equation is the actual/normal output ratio. If actual output increases above expected/trend levels, this can cause prices to rise due to capacity constraints. However, if capacity increases (represented in the model by an increase in normal output, see Section 4.16) then prices can fall, leading to higher real incomes and economic growth.

Some sectors have a specific treatment of price and do not use the estimated equations, instead using a simpler relationship:

- Commoditised sectors – domestic prices are assumed to be the same as global market prices and therefore track import prices.
- The electricity sector – electricity prices are set by average levelised costs of generation.
- Government sectors – these are assumed to move in line with aggregate regional consumer price inflation.
- Regulated sectors – these are also assumed to move in line with aggregate inflation.

Table 4.12: The Industrial Price Equations

Co-integrating long-term equation:			
LN(PYH(.))			[price of home sales by home producers]
	=	BPYH(.,9)	
	+	BPYH(.,10) * LN(YRUC(.))	[unit costs]
	+	BPYH(.,11) * LN(PQRM(.))	[import price]
	+	BPYH(.,12) * LN(YKNO(.))	[stock of knowledge]
	+	BPYH(.,13) * LN(YCAP(.))	[stock of capital]
	+	ECM	[error]
Dynamic equation:			
DLN(PYH(.))			[change in price of home sales by home prods.]
	=	BPYH(.,1)	
	+	BPYH(.,2) * DLN(YRUC(.))	[unit costs]
	+	BPYH(.,3) * DLN(PQRM(.))	[import price]
	+	BPYH(.,4) * DLN(YKNO(.))	[stock of knowledge]
	+	BPYH(.,5) * DLN(YCAP(.))	[stock of capital]
	+	BPYH(.,6) * LN(YYN(.))	[actual/normal output]
	+	BPYH(.,7) * DLN(PYH)(-1)	[lagged change in price]
	+	BPYH(.,8) * ECM(-1)	[lagged error correction]
Identities:			
PYH	=	(VQR(.) - VQRX(.)) / (QR(.) - QRX(.))	[price of home sales by home producers]
YRUC	=	YRUM(.) + YRUL(.) + YRUT(.)	[unit costs]
YRUM	=	SUM (QYC(.) * PQRD(.)) / YR(.)	[material input unit costs]
YRUL	=	YRLC(.) / YR(.)	[unit labour costs]
YRUT	=	YRT(.) / YR(.)	[unit tax costs]
PQRD	=	(VQR(.) + VQRM(.) – VQRX(.)) / (QR(.) + QRM(.) – QRX(.))	[price of sales to the domestic market]
Restrictions:			
BPYH(.,10) + BPYH(.,11) = 1			[price homogeneity]
BPYH(.,2 .,3 .,4 .,5 .,6 .,10 .,11 .,12.,13) >= 0			['right sign']
0 > BPYH(.,8) > -1			['right sign']

Definitions:

BPYH	is a matrix of parameters
PQRM	is a matrix of import prices for 69/43 industries and 61 regions, m euro at 2010 prices
YR	is a matrix of gross industry output for 69/43 industries and 61 regions, m euro at 2010 prices
YKNO	is a matrix of the knowledge stock for 69/43 industries and 61 regions, m euro at 2010 prices
YCAP	is a matrix of the capital stock for 69/43 industries and 61 regions, m euro at 2010 prices
QR	is a matrix of gross output for 69/43 industries and 61 regions, m euro at 2010 prices
QRM	is a matrix of imports for 69/43 industries and 61 regions, m euro at 2010 prices
QRX	is a matrix of exports for 69/43 industries and 61 regions, m euro at 2010 prices
YYN	is a matrix of the ratio of gross output to normal output, for 69/43 industries and 61 regions
QYC	is an input-output coefficient matrix
YRLC	is a matrix of labour costs for 69/43 industries and 61 regions, local currency at current prices
YRT	is a matrix of net taxes for 69/43 industries and 61 regions, local currency at current prices
V-	indicates a current price version of the variable

4.11 Export and import prices

The export price equations and the import price equations (see Table 4.13 and Table 4.14) play a large role in the response to exchange rate movements, acting as an important transmission mechanism for effects such as currency devaluation. The effects can be dissipated in a number of ways, creating inflationary pressures, leading to movements in the balance of payments, etc.

The basic model of trade prices used in E3ME assumes that the each region operates in oligopolistic markets and is a small economy in relation to the total market. Certain commodities, e.g. crude mineral oil, have prices treated exogenously, but the majority are treated in the following manner. Following from the assumption on market structure, prices are set by producers as mark-ups on costs, i.e. unit costs of production. Aside from this, the same variables are used for both import and export prices, within a general log-log functional form.

Alongside the unit cost variable, there are three price terms included in each regression to deal with developments outside the region in question. They are an 'other region' price (created from other countries' export prices in the same manner as described in the trade volume equations), a world commodity price variable and the exchange rate. The measures of technological progress are also included to cope with the quality effect on prices caused by increased levels of investment and R&D.

Restrictions are imposed to force price homogeneity and exchange rate symmetry on the long-term equations, again in much the same manner as for the trade volume equations.

Table 4.13: The Export Price Equations

Co-integrating long-term equation:			
LN(PQRX(.))			[export price]
	=	BPQX(.,10)	
	+	BPQX(.,11) * LN(PQRY(.))	[other regions' export prices]
	+	BPQX(.,12) * LN(PQWE(.))	[world commodity prices]
	+	BPQX(.,13) * LN(EX)	[exchange rate]
	+	BPQX(.,14) * LN(YRULT(.))	[unit labour and tax costs]
	+	BPQX(.,15) * LN(YKNO(.))	[stock of knowledge]
	+	BPQX(.,16) * LN(YCAP(.))	[stock of capital]
	+	ECM	[error]
Dynamic equation:			
DLN(PQRX(.))			[change in export prices]
	=	BPQX(.,1)	
	+	BPQX(.,2) * DLN(PQRY(.))	[other regions' export prices]
	+	BPQX(.,3) * DLN(PQWE(.))	[world commodity prices]
	+	BPQX(.,4) * DLN(EX)	[exchange rate]
	+	BPQX(.,5) * DLN(YRULT(.))	[unit labour and tax costs]
	+	BPQX(.,6) * DLN(YKNO(.))	[stock of knowledge]
	+	BPQX(.,7) * DLN(YCAP(.))	[stock of capital]
	+	BPQX(.,8) * DLN(PQRX)(-1)	[lagged change in export prices]
	+	BPQX(.,9) * ECM(-1)	[lagged error correction]
Identities:			
PQRY	=	SUM(QZXC(.)*VQRX(.)) / SUM(QZXC(.))*QRX(.))	[other regions' export prices]
PQWE	=	QMC(.) * PM	[world commodity price index]
YRULT	=	(YRLC(.) + YRT(.)) / QR(.)	[unit labour and tax costs]
Restrictions:			
BPQX(.,11) + BPQX(.,12) = 1 - BPQX(.,14)			[price homogeneity]
BPQX(.,11) + BPQX(.,12) = BPQX(.,13)			[exchange rate symmetry]
BPQX(.,2 .,3 .,4 .,5 .,6 .,7 .,11 .,12 .,13 .,14 .,15 .,16) >=0			['right sign']
0 > BPQX(.,9) > -1			['right sign']

Definitions:

BPQX	is a matrix of parameters
PQRX	is a matrix of export prices for 69/43 industries and 61 regions, 2010=1.0, local currency
EX	is a vector of exchange rates, local currency per euro, 2010=1.0
QZXC	is a matrix of bilateral trade shares of industry exports by destination for 69/43 industries and 61 regions
QMC	is a converter matrix between 69/43 industry and 7 world commodity classifications
PM	is a vector of commodity prices (in euros) for 7 commodities, 2010=1.0
YKNO	is a matrix of the knowledge stock for 69/43 industries and 61 regions, m euro at 2010 prices
YCAP	is a matrix of the capital stock for 69/43 industries and 61 regions, m euro at 2010 prices
YRLC	is a matrix of employer labour costs for 69/43 industries and 61 regions, local currency at current prices
YRT	is a matrix of tax costs, for 69/43 industries and 61 regions, m euro at current prices
QR	is a matrix of industry gross output for 69/43 industries and 61 regions, m euro at 2010 prices
VQRX	is a matrix of industry exports for 69/43 industries and 61 regions, m euro at current prices
QRX	is a matrix of industry exports for 69/43 industries and 61 regions, m euro at 2010 prices

Table 4.14: The Import Price Equations

Co-integrating long-term equation:			
LN(PQRM(.))			[import price]
	=	BPQM(.,10)	
	+	BPQM(.,11) * LN(PQRF(.))	[other regions' export prices]
	+	BPQM(.,12) * LN(PQWE(.))	[world commodity prices]
	+	BPQM(.,13) * LN(EX)	[exchange rate]
	+	BPQM(.,14) * LN(YRUL(.))	[unit labour costs]
	+	BPQM(.,15) * LN(YKNO(.))	[stock of knowledge]
	+	BPQM(.,16) * LN(YCAP(.))	[stock of capital]
	+	ECM	[error]
Dynamic equation:			
DLN(PQRM(.))			[change in import price]
	=	BPQM(.,1)	
	+	BPQM(.,2) * DLN(PQRF(.))	[other regions' export prices]
	+	BPQM(.,3) * DLN(PQWE(.))	[world commodity prices]
	+	BPQM(.,4) * DLN(EX)	[exchange rate]
	+	BPQM(.,5) * DLN(YRUL(.))	[unit labour costs]
	+	BPQM(.,6) * DLN(YKNO(.))	[ICT technological progress]
	+	BPQM(.,7) * DLN(YCAP(.))	[stock of knowledge]
	+	BPQM(.,8) * DLN(PQRM)(-1)	[stock of capital]
	+	BPQM(.,9) * ECM(-1)	[lagged error correction]
Identities:			
PQRF	=	SUM(QZMC(.)) * VQRX(.)) / SUM(QZMC(.) * QRX(.))	[other regions' export prices]
PQWE	=	QMC(.) * PM	[world commodity price index]
YRUL	=	YRLC(.) * EX / QR(.)	[unit labour costs]
Restrictions:			
BPQM(.,11) + BPQM(.,12) = 1 – BPQM(.,14)			[price homogeneity]
BPQM(.,11) + BPQM(.,12) = BPQM(.,13)			[exchange rate symmetry]
BPQM(.,2 .,3 .,4 .,5 .,11 .,12 .,13 .,14) >= 0			['right sign']
BPQM(.,6 .,7 .,15 .,16) <= 0			['right sign']
0 > BPQM(.,9) >- 1			['right sign']
Definitions:			
BPQM	is a matrix of parameters		
PQRM	is a matrix of import prices for 69/43 industries and 61 regions, 2010=1.0, local currency		
EX	is a vector of exchange rates, local currency per euro, 2010=1.0		
QZMC	is a matrix of bilateral trade shares of industry imports by origin for 69/43 industries and 61 regions		
QMC	is a converter matrix between the 69/43 industry and 7 commodity classifications		
PM	is a vector of commodity prices (in euros) for 7 commodities, 2010=1.0		
YKNO	is a matrix of the knowledge stock for 69/43 industries and 61 regions, m euro at 2010 prices		
YCAP	is a matrix of the capital stock for 69/43 industries and 61 regions, m euro at 2010 prices		
YRLC	is a matrix of employer labour costs for 69/43 industries and 61 regions, local currency at current prices		
QR	is a matrix of industry gross output for 69/43 industries and 61 regions, m euro at 2010 prices		
VQRX	is a matrix of industry exports for 69/43 industries and 61 regions, m euro at current prices		
QRX	is a matrix of industry exports for 69/43 industries and 61 regions, m euro at 2010 prices		

4.12 Industrial average earnings

The specification is given in Table 4.15.

The starting point for the equation formation of wage rates used in E3ME is the approach adopted by Lee and Pesaran (1993), which is general enough to accommodate differing degrees of market power on both sides of the labour market. More information and empirical results are provided in E3ME working paper no. 43 (Barker and Gardiner, 1994).

The treatment of wage determination is based on a theory of the wage-setting decisions made by a utility-maximising union, where the union derives utility (as the representative of its members) from higher real consumption wages (relative to the fallback level and from higher levels of employment (again relative to a fallback level, which is taken to be proportional to a simple average of employment levels in the last two years in the empirical work). The wage rate is set by unions choosing wage rates to maximise utility subject to the labour-demand constraint imposed by profit-maximising firms. The form of the equation is relatively straightforward: real wages in a sector rise, with weights, if there are internal, sector-specific shocks which cause revenue per worker to rise (e.g. productivity innovations in the sector), or if employment levels are rising; and real wages are also influenced by external effects, including changes in the real wage that can be obtained in the remainder of the economy, changes in incomes received if unemployed, and changes in the unemployment rate itself.

Ignoring other terms, Lee and Pesaran (1993) impose long-run restrictions on the equations, so that the weights on the internal and external influences sum to one, the growth of real product wage rates equals that of labour productivity in the whole economy and all taxes are paid by employees (pp. 37-38). In this model, employer taxes only affect the wage rate through consumer prices, along with import prices, prices of goods and services from other industries and indirect taxes.

The empirical evidence on the wage equation (surveyed by Layard, Nickell and Jackman, 1991) strongly suggests that, in the long-term, bargaining takes place over real pay, and this is imposed in all the equations presented below. However, in the dynamic equation for the change in wage rates, a response of real rates is allowed and tested by introducing the change in consumer prices. In addition, it has been assumed that long-run price homogeneity holds, so that the long-run economy-wide real product wage rates grow at the same rate as economy-wide labour productivity.

The basic model can be extended further to cover industrial wage determination by country as well as by industry, introducing wage rates in the same industry but in other countries into the information set. This means that the external influences on wage bargaining in an industry are divided into those from other industries in the same country, and those from the same industry in other countries.

The specification allows for external industry and regional effects on an industry's wage rates, internal effects of productivity growth and general economy-wide effects of the unemployment and benefit rates. The parameter on the adjusted price index is imposed at unity in all equations, implying that the explanation given is of the real consumer wage.

Table 4.15: The Industrial Average Earnings Equations

Co-integrating long-term equation:			
LN(YRW(.))			[gross nominal average earnings]
	=	BYRW(.,13)	
	+	BYRW(.,14) * LN(YRWE(.))	[external industry wage rates]
	+	BYRW(.,15) * LN(YRXE(.))	[external regional wage rates]
	+	BYRW(.,16) * (LYR(.)-LYRE(.)+LPYR(.)-LAPSC)	[productivity]
	+	BYRW(.,17) * LN(RUNR)	[unemployment rate]
	+	BYRW(.,18) * LN(RBNR)	[benefit rate]
	+	BYRW(.,19) * LAPSC	[adjusted consumer prices]
	+	BYRW(.,20) * ARET	[adjusted wage retention rate]
	+	ECM	[error]
Dynamic equation:			
DLN(YRW(.))			[change in gross earnings]
	=	BYRW(.,1)	
	+	BYRW(.,2) * DLN(LYRWE(.))	[external industry wage rates]
	+	BYRW(.,3) * DLN(LYRXE(.))	[external regional wage rates]
	+	BYRW(.,4) * D(LYR(.)-LYRE(.)+LPYR(.)-LAPSC)	[productivity]
	+	BYRW(.,5) * DLN(RUNR(.))	[unemployment rate]
	+	BYRW(.,6) * DLN(RBNR(.))	[benefit rate]
	+	BYRW(.,7) * D(LAPSC)	[adjusted consumer prices]
	+	BYRW(.,8) * DLN(ARET)	[adjusted wage retention rate]
	+	BYRW(.,9) * D(LAPSC)	[change in adjusted consumer prices]
	+	BYRW(.,10) * LN(YYN(.))	[normal/actual output]
	+	BYRW(.,11) * DLN(YRW)(-1)	[lagged change in wage rates]
	+	BYRW(.,12) * ECM(-1)	[lagged error correction]
Identities:			
LAPSC	=	LN(PRSC) + RRET	[log adjusted consumer price deflator]
ARET	=	RRET * RETR * RITR	[adjusted wage retention rate]
YRWE(.)	=	SUM OVER I (I = all other industries) (LN(YRW(I)) * YRLC(I) / SUM(YRLC(I)) - LAPSC)	[external industry wage rates]
YRXE(.)	=	LN(YRW(.)) * RRDD + LN(EX) - LAPSC	[external regional wage rates]
RBNR	=	RBEN / RWS	[the benefit rate]
Restrictions:			
BYRW(.,14) + BYRW(.,15) + BYRW(.,16) = 1			[price homogeneity]
BYRW(.,2 .,3 .,4 .,6 .,7 .,14 .,15 .,16 .,18 .,19) >= 0			['right sign']
BYRW(.,5 .,17) <= 0			['right sign']
0 > BYRW(.,12) > -1			['right sign']
Definitions:			
BYRW	is a matrix of parameters		
YRW	is a matrix of nominal average earnings (contractual wage) for 69/43 industries and 61 regions, national currency per person-year		
YRLC	is a matrix of nominal employer costs (wages and salaries plus employers' and imputed social security contributions) for 69/43 industries and 61 regions, local currency at current price		

RWS	is a vector of total wages for 61 regions, local currency at current price
LYRE	is a matrix of the log of total employment for 69/43 industries and 61 regions, in thousands of persons
LYR	is a matrix of the log of gross industry output for 69/43 industries and 61 regions, m euro at 2010 prices
LPYR	is a matrix of the log of prices of gross output for 69/43 industries and 61 regions, 2010=1.0, local currency
YYN	is a matrix of the ration of gross output to normal output, for 69/43 industries and 61 regions
PRSC	is the price deflator for total consumers' expenditure, 2010=1.0, local currency
RRET	is a vector of wage retention rate for 61 regions
RETR	is a vector of 1 + employers' social security rate for 61 regions
RITR	is a vector of 1 + indirect tax rate for 61 regions
RUNR	is the standardised unemployment rate
RBEN	is the social benefit paid to households, m euro at current prices for 61 regions
RRDD	is a normalized distance indicator matrix for 61 regions with zeros down the leading diagonal and rows summing to one
EX	is a vector of exchange rates, local currency per euro, 2010=1.0

4.13 Labour participation rate

The theoretical model for labour force participation rates (see Table 4.16) stems from a paper by Briscoe and Wilson (1992). The standard analysis of participation in the labour force is based around the idea of a reservation wage, such that if the market wage is greater than an individual's reservation wage, they will actively seek employment, and vice versa. It should be noted here that this type of model assumes an excess demand for labour.

The reservation wage is normally described via a group of personal characteristics such as non-wage income, educational level, age, etc. Many of these personal traits are inherently unobservable, e.g. value of leisure, and the reservation wage can thus be written as:

$W^* = w^*(X^*, o^*)$

where:

W^* is the reservation wage

X^* is a vector of observed characteristics

o^* is a variable of unobserved characteristics

Workers choose to participate in the labour force if $W > W^*$,where W is the market wage. Combined with the factors determining the market wage, the decision to participate can then be represented by:

$P = p(W, X^*, o^*)$

where:

P is the participation rate

In time-series studies, much of the personal background data usually used in cross-section studies is unavailable, so any model is necessarily limited to variables describing human wealth (in the narrowest of senses) and market wage determination. The original variables that were available for inclusion were the market wage rate, a measure of market activity (output), a proxy for non-labour income and some measure of the tightness of the labour market, e.g. the unemployment rate. Pollitt and Chewpreecha (2008) later expanded on this after an empirical assessment found that average working hours and qualifications had significant impacts on participation. The same study found that defining unemployment by demographic group (using LFS data) and including a measure of pension income for older age groups improved performance.

The basic model, capturing variables in both the cointegrating and dynamic regressions, can therefore be written as:

$P = f(W, GDP, RUNR, RYH, RBEN, RQU, RSER)$

where:

W is the real market wage

GDP is real output

RUNR is the unemployment rate in each population group

RYH is average hours worked

RBEN is a measure of social benefit or pensions

RQU is the qualifications mix

RSER is a measure of economic structure, i.e. manufacturing versus services

The participation rate is estimated separately for male and females in five-year age bands to capture the different factors behind activity in the labour force between different population groups. Data limitations, however, mean that few of the explanatory variables (e.g. wages) are gender-specific. The equation is estimated in logistic form, which means that the dependent variable is subject to the transformation

$L\_i = \ln[p\_i/(1 - p\_i\ )].$

This is because the participation rate, p_i, is constrained within the [0,1] interval, something which the shape of the resulting logistic transformation ensures.

Table 4.16: The Participation Rate Equations

Co-integrating long-term equation:			
LN(LRP/(1-LRP))			[participation rate, logistic form]
	=	BLRP(.,11)	
	+	BLRP(.,12) * LN(RSQ)	[industry output]
	+	BLRP(.,13) * LN(RWSR)	[real retained wage rates]
	+	BLRP(.,14) * LN(LRUN(.))	[unemployment rate by group]
	+	BLRP(.,15) * LN(RBPR)	[benefit or pension rate]
	+	BLRP(.,16) * LN(RSER)	[economic structure]
	+	BLRP(.,17) * LN(RYH)	[average hours worked]
	+	BLRP(.,18) * LN(LRQU)	[qualification mix]
	+	ECM	[error]
Dynamic equation:			
DLN(LRP/(1-LRP))			[participation rate, logistic form]
	=	BLRP(.,1)	
	+	BLRP(.,2) * DLN(RSQ)	[industry output]
	+	BLRP(.,3) * DLN(RWSR)	[real retained wage rates]
	+	BLRP(.,4) * DLN(LRUN(.))	[unemployment rate by group]
	+	BLRP(.,5) * DLN(RBPR)	[benefit or pension rate]
	+	BLRP(.,6) * DLN(RSER)	[economic structure]
	+	BLRP(.,7) * DLN(RYH)	[average hours worked]
	+	BLRP(.,8) * DLN(LRQU)	[qualifications mix]
	+	BLRP(.,9) * DLN(LRP/(1-LRP))(-1)	[lagged change in participation rate]
	+	BLRP(.,10) * ECM(-1)	[lagged error correction]
Identities:			
RWSR	=	EX*(RWS) / (PRSC*REEM)	[real retained wage rates]
LRP	=	RLAB / RPOP	[participation rate]
RSER	=	RSERV / NSERV	[economic structure]
Restrictions:			
BLRP(.,2 .,3 .,12 .,13) >= 0			['right sign']
BLRP(.,4 .,5 .,7 .,14 .,15 .,17) <= 0			['right sign']
0 > BLRP(.,10) > - 1			['right sign']
Definitions:			
BLRP	is a matrix of parameters		
LRP	is a vector of labour force participation rate for 27 age/gender groups and 61 regions, as a proportion		
RLAB	is a matrix of labour force for 27 age/gender groups and 61 regions, in thousands of persons		
RPOP	is a matrix of population of working age for 27 age/gender groups and 61 regions, in thousands of persons		
RSQ	is a vector of total gross industry output for 61 regions, m euro at 2010 prices		
RWS	is a vector of total nominal wages and salaries (wages and salaries excluding employers' imputed social security contributions) for 61 regions, m euro at current prices		
LRUN	is the standardized unemployment rate for 27 age/gender groups and 61 regions		
PRSC	is a vector of total consumer price deflator for 61 regions, in thousands of persons		
REEM	is a vector of total wage and salary earners for 61 regions, in thousands of persons		
RBPR	is the social benefit rate paid to households (15-49 age groups) compared to wages, or average pensions in euros pa (50+ age groups)		
RSERV	is total gross output of service industries for 61 regions, m euro at 2010 prices		

NSERV	is total gross output of non-service industries for 61 regions, m euro at 2010 prices
RSER	is the sectoral concentration variable for 61 regions to represent increased female participation rates
RYH	is the average hours worked per week for 61 regions
LRQU	is the (logged) qualifications mix for 27 age/gender groups for 61 regions
EX	is a vector of exchange rates, local currency per euro, 2010=1.0

4.14 Residual (non-wage) income

The specification is given in Table 4.17.

With wage rates explained by price levels and conditions in the labour market, the wage and salary payments by industry can be calculated from the industrial employment levels. These are some of the largest payments to the personal sector, but not the only ones.

To complete the income loop, a method had to be devised to cope with the difference between income from wages and salaries and gross disposable income less social security benefits. The solution was an equation that models the residual income between the two; the long-run equation relationship includes the real wage, the index of output price, GDP, and the real rate of interest as explanatory variables.

This equation set is by its nature, a temporary one, and will be replaced when a complete accounting structure for institutional payments and receipts can be established. The econometric equation is often not used, with residual income either fixed as exogenous or determined by a simpler treatment (e.g. as a fixed share of wage income).

Table 4.17: The Residual Income Equations

Co-integrating long-term equation:			
LN(RRI)			[residual income]
	=	BRRI(8)	
	+	BRRI(9) * LN(RWS)	[total wages]
	+	BRRI(10) * LN(RPSY)	[inflation]
	+	BRRI(11) * LN(VRYM)	[GDP (current prices)]
	+	BRRI(12) * LN(RLR)	[interest rates]
	+	ECM	[error]
Dynamic equation:			
DLN(RRI)			[residual income]
	=	BRRI(1)	
	+	BRRI(2) * DLN(RWS)	[total wages]
	+	BRRI(3) * DLN(RPSY)	[inflation]
	+	BRRI(4) * DLN(VRYM)	[GDP (current prices)]
	+	BRRI(5) * DLN(RLR)	[interest rates]
	+	BRRI(6) * DLN(RRI(-1))	[lagged changes in residual income]
	+	BRRI(7) * ECM(-1)	[lagged error correction]
Identities:			
RRI	=	RGDI + RDTX + REES - RWS - RBEN	[residual income]
RPSY	=	Growth(PRYM)	[inflation]
Restriction:			
0 > BRRI(.,7) > -1			['right sign']

Definitions:

BRRI	is a matrix of parameters
VRYM	is a vector of GDP at market prices for 61 regions, m euro at current prices
RGDI	is a matrix of nominal gross disposable income for 61 regions, m euro at current prices
RLR	is a matrix of long-run interest rates for 61 regions
RWS	is a vector of nominal wages for 61 regions, m euro at current prices
PRYM	is a vector of price for GVA for 61 regions, 2010=1.0
EX	is a vector of exchange rates, local currency per euro, 2010=1.0
RDTX	is a vector of total direct tax payments made by households, for 61 regions, m euro at current prices
REES	is a vector of total of employees' NI contributions, for 61 regions, m euro at current prices
RBEN	is a vector of social benefit paid to households, for 61 regions, m euro at current prices

4.15 Investment in dwellings

Given that investment in dwellings (see Table 4.18) is a big component of investment it was felt that the industrial investment equation was inadequate in explaining the investment in dwellings and should be treated separately due to the different factors driving the decision-making process.

For the long-run equation the demand for housing is expected to have a positive relationship with real gross disposable income. Since most of the housing market is financed through borrowing, e.g. mortgages, the demand for housing also seems likely to be sensitive to variations in the real rate of interest. Variables covering child and old-age dependency rates are included to capture changes in investment in dwellings caused by changing demography. For the dynamic equation the unemployment rate is included, to capture the variation in the labour market, as well as the total consumer price deflator.

Table 4.18: The Investment in Dwellings Equations

Co-integrating long-term equation:

LN(RDW)			[investment in dwellings]
	=	BRDW(10)	
	+	BRDW(11) * LN(RRPD)	[real gross disposable income]
	+	BRDW(12) * LN(RRLR)	[real rate of interest]
	+	BRDW(13) * LN(CDEP)	[child dependency ratio]
	+	BRDW(14) * LN(ODEP)	[OAP dependency ratio]
	+	ECM	[error]

Dynamic equation:

DLN(RDW)			[investment in dwellings]
	=	BRDW(1)	
	+	BRDW(2) * DLN(RRPD)	[real gross disposable income]
	+	BRDW(3) * DLN(RRLR)	[real rate of interest]
	+	BRDW(4) * DLN(CDEP)	[child dependency ratio]
	+	BRDW(5) * DLN(ODEP)	[OAP dependency ratio]
	+	BRDW(6) * DLN(RUNR)	[unemployment rate]
	+	BRDW(7) * DLN(PRSC)	[total consumer price deflator]
	+	BRDW(8) * DLN(RDW(-1))	[lagged changes in residual income]
	+	BRDW(9) * ECM(-1)	[lagged error correction]

Identities:

RRPD	=	(RGDI * EX / PRSC)	[real gross disposable income]
RRLR	=	1 + (RLR - DLN(PRSC)) / 100	[real rate of interest]
CDEP	=	CPOP / RPOP	[child dependency ratio]
ODEP	=	OPOP / RPOP	[OAP dependency ratio]

Restrictions:

BRDW(.,2 .,11) >= 0	['right sign']
BRDW(.,3 .,6 .,7 .,12) <= 0	['right sign']
0 > BRDW(.,9) > -1	['right sign']

Definitions:

BRDW	is a matrix of parameters
RDW	is a vector of investment in dwellings, m euro at 2010 prices
RGDI	is a matrix of gross disposable income for 61 regions, m euro at current prices
RLR	is a matrix of long-run interest rates for 61 regions
EX	is a vector of exchange rates, local currency per euro, 2010=1.0
PRSC	is a vector of total consumer price deflators for 61 regions, 2010=1.0
RPOP	is a vector of working-age population for 61 regions, thousands of persons
CPOP	is a vector of child population for 61 regions, thousands of persons
OPOP	is a vector of old-age population for 61 regions, thousands of persons
RUNR	is a vector of unemployment rates for 61 regions, as a percentage of the labour force

4.16 Normal output equations

The specification is provided in Table 4.19.

In E3ME, normal output is a measure of production capacity in each economic sector. Normal output appears in the dynamic part of many of the other equation sets, as the denominator of the ratio (output / normal output); so, for example, a higher level of normal output can lead to lower prices and wage demands.

The basic specification follows from the work of Lee and Shields (1997). The normal output level for a particular sector in a particular region is modelled as a function of the output level for the rest of the sectors within the same region and the level of output in the same sector for the rest of the regions. In both cases simple arithmetic averages are calculated.

A positive relationship points to spill-over effects from other regions and sectors. A unit long-run elasticity with respect to the external regional output reflects the belief that there is a large amount of sectoral output spill-over effects across the world (Lee and Shields, 1997).

The technology variables also feature in the normal output equations, as accumulated investment and R&D can lead to increases in capacity. Normal output is therefore a key component of the representation of endogenous growth in the model; investment leads to higher capacity, lower prices, increases in real income, higher GDP and in turn more investment.

The fitted values of the equation below are used as a proxy for normal output.

Table 4.19: The Normal Output Equations

Co-integrating long-term equation:		
LN(YRN)		[normal industrial output]
=	BYRN(.,8)	
+	BYRN(.,9) * LN(YRY(.))	[external industrial output - same region other industries]
+	BYRN(.,10) * LN(YRX(.))	[external regional output - same industry other regions]
+	BYRN(.,11) * LN(YKNO(.))	[stock of knowledge]
+	BYRN(.,12) * LN(YCAP(.))	[stock of capital]
+	ECM	[error]
Dynamic equation:		
DLN(YRN)		[normal industrial output]
=	BYRN(.,1)	
+	BYRN(.,2) * DLN(YRY(.))	[external industrial output - same region other industries]
+	BYRN(.,3) * DLN(YRX(.))	[external regional output - same industry other regions]
+	BYRN(.,4) * DLN(YKNO(.))	[stock of knowledge]
+	BYRN(.,5) * DLN(YCAP(.))	[stock of capital]
+	BYRN(.,6) * DLN(YR)(-1)	[lagged change in industrial output]
+	BYRN(.,7) * ECM(-1)	[lagged error correction]
Restrictions:		
BYRN(.,9) = 0		[no long-run effect from YRY]
BYRN(.,10) = 1		[long-run homogeneity with respect to YRX]
0 > BYRN(.,7) > -1		['right sign']

Definitions:

BYRN	is a matrix of parameters
YRN	is a matrix of normal industrial output for 69/43 sectors and 61 regions, m euro at 2010 prices, calculated as the fitted values of the dependent variable
YR	is a matrix of gross industry output for 69/43 industries and 61 regions, m euro at 2010 prices
YRY	is a matrix of average industrial output (excluding own sector) for 69/43 sectors and 61 regions, m euro at 2010 prices
YRX	is a matrix of average industrial output (excluding own region) for 69/43 sectors and 61 regions, m euro at 2010 prices
YKNO	is a matrix of the knowledge stock for 69/43 industries and 61 regions, m euro at 2010 prices
YCAP	is a matrix of the capital stock for 69/43 industries and 61 regions, m euro at 2010 prices

4.17 Material demand equation for food, feed, forestry, construction minerals, industrial minerals, ores and water

This section refers to the materials submodel that was developed as part of the Matisse FP5 research project (Pollitt, 2007, 2008), and more recently applied in analysis for DG Environment. The equations are included in the standard model specification and form an important part of the overall structure.

Following the framework of E3ME's fuel demand equations, material demand is modelled as a function of economic activity, material prices and two measures of innovation (investment and R&D spending). An additional variable to take into account the differences in definition between domestically extracted and imported materials was also added; this has recently been investigated more closely with the expansion of the model to include Raw Material Consumption (RMC).

For each material an equation is estimated for the 16 user groups. However, in reality a large proportion of these equations are not used as not all the material user groups demand all the materials. For example, construction is the only user group to demand construction minerals.

Table 4.20 outlines the specification of the material demand equations, giving material 1, food, as an example.

The equation set for water demand is not currently operational due to data limitations – but could easily be activated if data became available.

Table 4.20: The Material Demand Equations

Note: MU1 refers to material 1 (Food). The equations below are applicable to materials 1-7.

Co-integrating long-term equation:

LN(MU1(.)/QR(.))			[material intensity]
	=	BMU1(.,8)	
	+	BMU1(.,9) * LN(QR(.))	[output by material users]
	+	BMU1(.,10) * LN(PMAT1(.))	[price of material]
	+	BMU1(.,11) * LN(KR(.)/QR(.))	[investment ratio by material users]
	+	BMU1(.,12) * LN(YRD(.)(.)/QR(.)))	[R&D ratio by material users]
	+	BMU1(.,13) * (MUM1(.)/MUD1(.))	[trade ratio: import/domestic consumption]
	+	ECM	[error]

Dynamic equation:

DLN(MU1(.)/QR(.))			[material intensity]
	=	BMU1(.,1)	
	+	BMU1(.,2) * DLN(QR(.))	[output by material users]
	+	BMU1(.,3) * DLN(PMAT1(.))	[price of material]
	+	BMU1(.,4) * DLN(KR(.)/QR(.))	[investment ratio by material users]
	+	BMU1(.,5) * DLN(YRD(.)/QR(.))	[R&D ratio by material users]
	+	BMU1(.,6) * D(MUM1(.)/MUD1(.))	[trade ratio: import/domestic consumption]
	+	BMU1(.,7) * ECM(-1)	[lagged error correction]

Restrictions:

BMU1(.,2 .,9) >= 0	['right sign']
BMU1(.,3 .,4 .,5 .,9 .,10 .,11) <= 0	['right sign']
0 > BMU1(.,7) > -1	['right sign']

Definitions:

BMU1	is a matrix of parameters (for material 1)
MU1	is a matrix of material use (for material 1) by material user for 16 material users and for 61 regions, 000s of tonnes
QR	is a matrix of output of products converted here to 16 material users and 61 regions, m euros at 2010 prices
PMAT1	is the price of material 1, 2010=1.0
KR	is a matrix of investment by 16 material users and for 61 regions, m euros at 2010 prices
YRD	is a matrix of R&D by 16 material users and for 61 regions, m euros at 2010 prices
MUM1	is a matrix of imports of material 1 by 16 material users and for 61 regions, 000s of tonnes
MUD1	is a matrix of domestic extraction of material 1 by 16 material users and for 61 regions, 000s of tonnes

4.18 R&D expenditure

As part of the MONROE Horizon 2020 project, a new equation for R&D expenditure was introduced to E3ME. Previously R&D had been treated either as exogenous or as a fixed ratio to Gross Fixed Capital Formation.

Several different versions of the equation were tested throughout the course of the project. The level of human capital was expected to be a strong determinant of R&D spending but we were unable to find statistically significant relationships (perhaps due to data issues). The final specification of the equation relates R&D spending to production levels, relative prices and the investment/labour ratio (a measure of capital intensity).

In the model simulations, the investment-labour term is fixed so this link is broken. The reason for excluding this link is that R&D feeds directly into both the investment and employment equations, so a reverse link can lead to unstable behaviour in the model projections.

Table 4.21: The R&D Expenditure Equations

Co-integrating long-term equation:			
LN(YRD)			[R&D expenditure]
	=	BYRD(6)	
	+	BYRD(7) * LN(YR)	[real output]
	+	BYRD(8) * LN(PYRD/PYR)	[relative price of R&D]
	+	BYRD(9) * LN(KR/YRE)	[investment/labour ratio]
	+	ECM	[error]
Dynamic equation:			
DLN(YRD)			[investment in dwellings]
	=	BYRD(1)	
	+	BYRD(2) * LN(YR)	[real output]
	+	BYRD(3) * LN(PYRD)	[relative price of R&D]
	+	BYRD(4) * LN(KR/YRE)	[investment/labour ratio]
	+	BYRD(5) * ECM(-1)	[lagged error correction]
Identities:			
PYRD	=	PYR(R&D sector)	[price of R&D]
Restrictions:			
BRDW(.,2 .,7) >= 0			['right sign']
BRDW(.,3 .,8) <= 0			['right sign']
0 > BRDW(.,5) > -1			['right sign']
Definitions:			
BYRD	is a matrix of parameters		
YRD	is a matrix of R&D expenditure, m euro at 2010 prices		
PYR	is a matrix of industry prices, 2010=1.0		
KR	is a matrix of industry investment, m euro at 2010 prices		
YRE	is a matrix of employment, thousands		

5. Guide to Running E3ME

5.1 Getting started

This chapter describes the steps required to install and run the model. We start with a general overview in this section and then describe how to run the model from the command line. The remainder of this chapter provides details of how the model may be operated through the graphical front end user interface.

It should be noted that the front end is expected to be revised towards the end of 2014.

System requirements

E3ME can be run on any modern Windows desktop PC. The maximum time required to run a scenario, for all regions up to 2050, is around ten minutes on a mid-range computer. Around 1GB of disk space is required, although more space may be required to store large numbers of results files.

Installation

The model must be copied to a local drive to operate. As it generates outputs on this drive, administrator rights are required.

There is a separate procedure to install the graphical model front end. This is described in Section 5.3.

Basic file structure

It is important that the correct file structure is in place, otherwise the model will not run. Appendix C shows the necessary input files (in relation to the root directory where the executable file is held) and also some of the output files that the model produces.

Not all of the files in the appendix will be provided with the licensed version of the model.

The user operates the model by creating a batch (.cmd) file that is usually stored in the main model directory (e.g. C:\e3me\). This file contains the command line arguments that form the inputs to a model run; these may all be changed although this manual assumes some default values are kept.

After the call to the model executable, the command line arguments are:

- the directory in which the IDIOM scripts are stored (assumed to be 'in')
- the name of the IDIOM script
- the name and location of the assumptions file (the location is assumed to be 'in\assumptions\')
- the name and location of the scenario file (the location is assumed to be 'in\scenarios\')
- the directory where the databanks are held (assumed to be 'databank')
- the folder where output is stored (assumed to be 'output')
- the name of the output file
- the name and location of the verification file (location assumed to be 'VER\')

These are discussed below and later in this chapter. When running the model through the graphical front end interface, the software automatically generates the command line arguments, but the call to the command line is still the same.

The IDIOM script

The basic model commands are held in the IDIOM script file. These include setting values for various model switches and reading in data from the model databanks. There are two key commands that pass control to the model's central fortran code:

- UPDATE – this sets the lagged values and solves the long-term part of the econometric equations.
- COMPUTE – this solves the short-term dynamic part of the econometric equations.

As there is a dynamic interaction between the short-term equations (e.g. the present year's wage rates affect employment levels and vice versa), the COMPUTE command is usually held inside an iteration loop.

The IDIOM programming language is described in more detail in its own manual (Cambridge Econometrics, 2007).

Text inputs

There are two text files that get read in for every model run. These include user forward-looking assumptions and policy variables. They are held as text files rather than databanks so that they can be easily manipulated by the model user. These are usually held within the assumptions and scenarios directories (inside the 'in' directory). They are described in detail in Section 3.6.

Model outputs

The model generates relatively few outputs automatically from a model run. They are:

- a short text file called 'diagnostics.mre' in the output directory that provides summary solution information
- a short text file that reflects the output sent to the command prompt
- a text-based verification file that include automatically generated diagnostics from the model
- CSV files that provide the input-output tables in each year of solution

The vast majority of model outputs are instead stored internally on a binary 'dump' file. This may then be accessed by 'data analysis' IDIOM scripts that produce the following outputs:

- text-based '.TAB' files that are human-readable
- text-based '.MRE' files that can be interpreted by the front end software and used for further processing

These can both be found in the output directory. The output files are described further in Section 3.7.

Fortran source code

The source code is not made available in the licensed version of the model.

The IDIOM main program and subroutines is stored at:

- model\IDIOM\

These routines contain the 'housekeeping' software, most of which is unchanged from version to version of E3ME. The subroutines which open input files are collected together in the 'openf' routine. These subroutines only need updating when there is a new version of IDIOM.

The subroutines for E3ME are in the directories:

- model\E3ME\m - master routines
- model\E3ME\s - slave subroutines

- model\E3ME\FTT – slave subroutine specific to the Future Technology Transformation model for the power sector

5.2 Running E3ME from the command line

Solving E3ME over the forecast period

This section of the manual is aimed primarily at advanced users who are running the model using the Windows DOS command prompt. In some cases it may be necessary to open the command prompt 'as administrator' by right-clicking.

Before running the model, it is necessary to ensure that the following are in place:

- the IDIOM scripts
- databanks containing model data and the databank containing titles
- the assumptions file
- the scenario file
- the folder structure for output file \e3me\output\io and \e3me\output\ver

The batch file (e.g. run.cmd) can be accessed for editing by right-clicking on it. It will contain a series of comments (lines starting with colons) and commands to run E3ME. The commands to run the model will include the arguments described in the previous section.

The different types of model runs

There are five types of calls to run the model:

- **Titles** run with the IDIOM input file usually just called titles.idiom. This run stores the row and column titles for later outputs. It should last only a few seconds.
- The model solution over **history** (e.g. history.idiom). This run initialises the model, inputs the data and parameters and solves the model from 1995 - 2006. It provides the basis for all forecast runs
- The **calibrated forecast**. This IDIOM script (e.g. exforecast.idiom) solves the model annually over the forecast period so that it matches values on the forecast databank. The scaling factors (called 'residuals') are saved so that they can be written to the S databank. See Section 3.5 for further details.
- The **endogenous** forecast. This is a full endogenous solution over the forecast period that forms the baseline that all policy scenarios are compared to. The model solves annually, using the scaling factors on the S databank to ensure that results are consistent with the published forecast. A common name is enforecast.idiom.
- **Data analysis** files are used to extract results from the model runs. By convention the IDIOM scripts for data analysis files start with either the letter D or the letters DAN.

Other commands in the batch file

In addition there are some other commands that are entered into the batch files. These include calls to the Ox programming language[13] to set up the S databank between the model runs for the calibrated and endogenous forecasts.

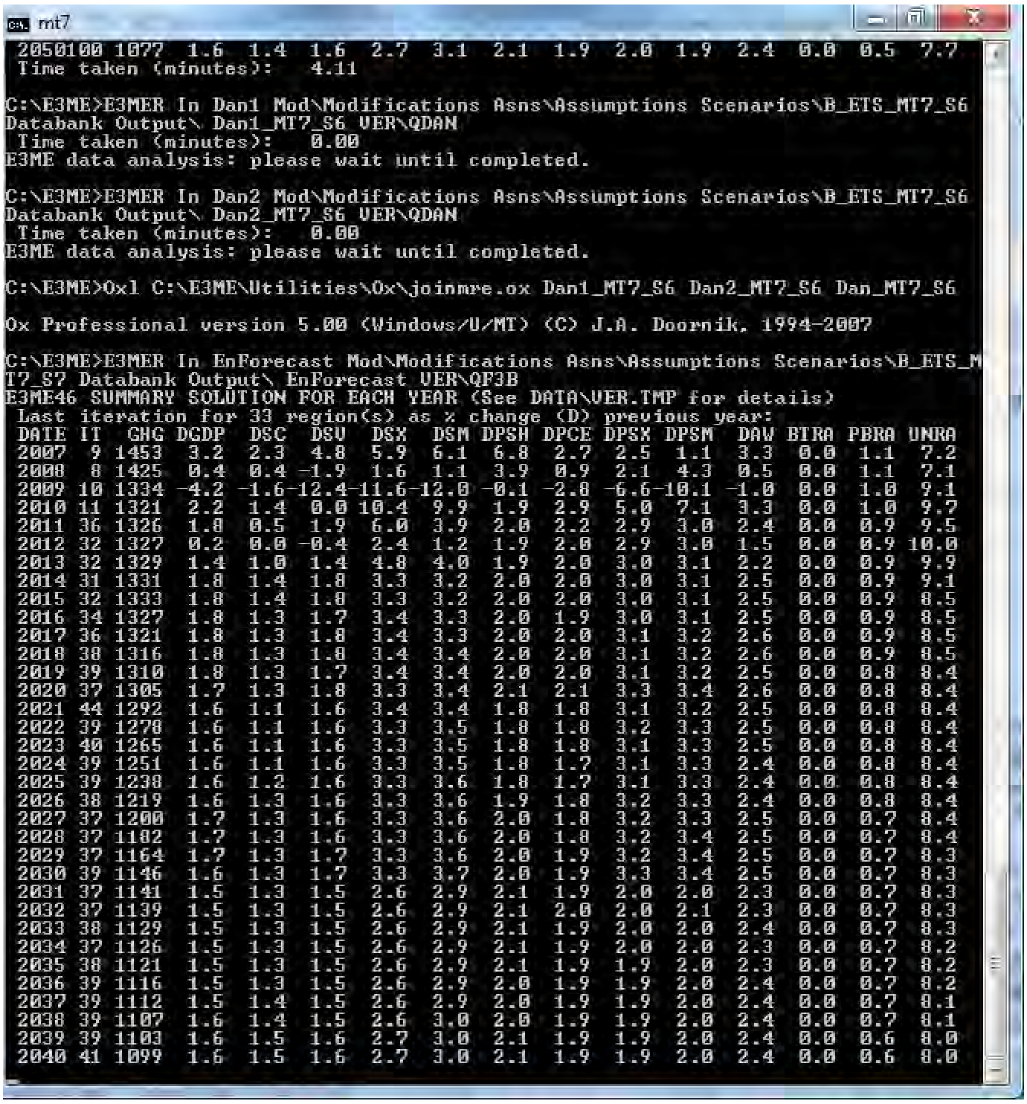
[13] If the 'Oxl' command is not recognised, it may be necessary to add the location of the Ox executable file to the Windows PATH environment variable.

If it is not necessary to do all model runs, the GOTO statement can be used to move between labels (lines starting with colons). Other common DOS commands for copying and moving files may also be included.

While an IDIOM script is running

While the model is running, the command prompt will show summary model outputs for each year of solution. An example is provided in Figure 5.1.

Figure 5.1: Command prompt window



```
mt7
 2050100 1077  1.6  1.4  1.6  2.7  3.1  2.1  1.9  2.0  1.9  2.4  0.0  0.5  7.7
 Time taken (minutes):   4.11

C:\E3ME>E3MER In Dan1 Mod\Modifications Asns\Assumptions Scenarios\B_ETS_MT7_S6
Databank Output\ Dan1_MT7_S6 VER\QDAN
 Time taken (minutes):   0.00
E3ME data analysis: please wait until completed.

C:\E3ME>E3MER In Dan2 Mod\Modifications Asns\Assumptions Scenarios\B_ETS_MT7_S6
Databank Output\ Dan2_MT7_S6 VER\QDAN
 Time taken (minutes):   0.00
E3ME data analysis: please wait until completed.

C:\E3ME>Oxl C:\E3ME\Utilities\Ox\joinmre.ox Dan1_MT7_S6 Dan2_MT7_S6 Dan_MT7_S6

Ox Professional version 5.00 (Windows/U/MT) (C) J.A. Doornik, 1994-2007

C:\E3ME>E3MER In EnForecast Mod\Modifications Asns\Assumptions Scenarios\B_ETS_M
T7_S7 Databank Output\ EnForecast VER\QF3B
E3ME46 SUMMARY SOLUTION FOR EACH YEAR (See DATA\VER.TMP for details)
 Last iteration for 33 region(s) as % change (D) previous year:
 DATE IT  GHG DGDP  DSC  DSV  DSX  DSM DPSH DPCE DPSX DPSM  DAW BTRA PBRA UNRA
 2007  9 1453  3.2  2.3  4.8  5.9  6.1  6.8  2.7  2.5  1.1  3.3  0.0  1.1  7.2
 2008  8 1425  0.4  0.4 -1.9  1.6  1.1  3.9  0.9  2.1  4.3  0.5  0.0  1.1  7.1
 2009 10 1334 -4.2 -1.6-12.4-11.6-12.0 -0.1 -2.8 -6.6-10.1 -1.0  0.0  1.0  9.1
 2010 11 1321  2.2  1.4  0.0 10.4  9.9  1.9  2.9  5.0  7.1  3.3  0.0  1.0  9.7
 2011 36 1326  1.8  0.5  1.9  6.0  3.9  2.0  2.2  2.9  3.0  2.4  0.0  0.9  9.5
 2012 32 1327  0.2  0.0 -0.4  2.4  1.2  1.9  2.0  2.9  3.0  1.5  0.0  0.9 10.0
 2013 32 1329  1.4  1.0  1.4  4.8  4.0  1.9  2.0  3.0  3.1  2.2  0.0  0.9  9.9
 2014 31 1331  1.8  1.4  1.8  3.3  3.2  2.0  2.0  3.0  3.1  2.5  0.0  0.9  9.1
 2015 32 1333  1.8  1.4  1.8  3.3  3.2  2.0  2.0  3.0  3.1  2.5  0.0  0.9  8.5
 2016 34 1327  1.8  1.3  1.7  3.4  3.3  2.0  1.9  3.0  3.1  2.5  0.0  0.9  8.5
 2017 36 1321  1.8  1.3  1.8  3.4  3.3  2.0  2.0  3.1  3.2  2.6  0.0  0.9  8.5
 2018 38 1316  1.8  1.3  1.8  3.4  3.4  2.0  2.0  3.1  3.2  2.6  0.0  0.9  8.5
 2019 39 1310  1.8  1.3  1.7  3.4  3.4  2.0  2.0  3.1  3.2  2.5  0.0  0.8  8.4
 2020 37 1305  1.7  1.3  1.8  3.3  3.4  2.1  2.1  3.3  3.4  2.6  0.0  0.8  8.4
 2021 44 1292  1.6  1.1  1.6  3.4  3.4  1.8  1.8  3.1  3.2  2.5  0.0  0.8  8.4
 2022 39 1278  1.6  1.1  1.6  3.3  3.5  1.8  1.8  3.2  3.3  2.5  0.0  0.8  8.4
 2023 40 1265  1.6  1.1  1.6  3.3  3.5  1.8  1.8  3.1  3.3  2.5  0.0  0.8  8.4
 2024 39 1251  1.6  1.1  1.6  3.3  3.5  1.8  1.7  3.1  3.3  2.4  0.0  0.8  8.4
 2025 39 1238  1.6  1.2  1.6  3.3  3.6  1.8  1.7  3.1  3.3  2.4  0.0  0.8  8.4
 2026 38 1219  1.6  1.3  1.6  3.3  3.6  1.9  1.8  3.2  3.3  2.4  0.0  0.8  8.4
 2027 37 1200  1.7  1.3  1.6  3.3  3.6  2.0  1.8  3.2  3.3  2.5  0.0  0.7  8.4
 2028 37 1182  1.7  1.3  1.6  3.3  3.6  2.0  1.8  3.2  3.4  2.5  0.0  0.7  8.4
 2029 37 1164  1.7  1.3  1.7  3.3  3.6  2.0  1.9  3.2  3.4  2.5  0.0  0.7  8.3
 2030 39 1146  1.6  1.3  1.7  3.3  3.7  2.0  1.9  3.3  3.4  2.5  0.0  0.7  8.3
 2031 37 1141  1.5  1.3  1.5  2.6  2.9  2.1  1.9  2.0  2.0  2.3  0.0  0.7  8.3
 2032 37 1139  1.5  1.3  1.5  2.6  2.9  2.1  2.0  2.0  2.1  2.3  0.0  0.7  8.3
 2033 38 1129  1.5  1.3  1.5  2.6  2.9  2.1  1.9  2.0  2.0  2.4  0.0  0.7  8.3
 2034 37 1126  1.5  1.3  1.5  2.6  2.9  2.1  1.9  2.0  2.0  2.3  0.0  0.7  8.2
 2035 38 1121  1.5  1.3  1.5  2.6  2.9  2.1  1.9  1.9  2.0  2.3  0.0  0.7  8.2
 2036 39 1116  1.5  1.3  1.5  2.6  2.9  2.0  1.9  1.9  2.0  2.4  0.0  0.7  8.2
 2037 39 1112  1.5  1.4  1.5  2.6  2.9  2.0  1.9  1.9  2.0  2.4  0.0  0.7  8.1
 2038 39 1107  1.6  1.4  1.5  2.6  3.0  2.0  1.9  1.9  2.0  2.4  0.0  0.7  8.1
 2039 39 1103  1.6  1.5  1.6  2.7  3.0  2.1  1.9  1.9  2.0  2.4  0.0  0.6  8.0
 2040 41 1099  1.6  1.5  1.6  2.7  3.0  2.1  1.9  1.9  2.0  2.4  0.0  0.6  8.0
```

The summary outputs are provided as a total for the countries that are solving (the first line will say how many countries the model is solving for). The outputs are:

- Date – year of solution
- IT – number of iterations to solve (see Section **Error! Reference source not found.**)
- GHG – greenhouse gas emissions (mtC)
- DGDP – annual GDP growth
- DSC – annual household consumption growth
- DSV – annual investment growth
- DSX – annual exports growth
- DSM – annual imports growth

- DPSH – change in price of home sales by local producers
- DPCE – change in consumer prices
- DPSX – change in export prices
- DPSM – change in import prices
- DAW – change in wages
- BTRA – trade balance
- PBRA – public balance
- UNRA – unemployment rate

Stopping the model run

When running from a batch file, the model runs will take place in order and will end when the last command is complete. It is also possible to run more than one instance of the model at a time (to take advantage of multi-processor PCs). The model run can be cancelled by holding Control-C.

If a model variable steps outside its predefined bounds, an error will be reported in the command window (showing the equation that caused the problem – see Section **Error! Reference source not found.**) and the model w ill stop solving. This may prevent subsequent data analysis model runs from completing and they will report (often many) error messages.

Multiple model runs

The command line also allows the option for running the model many times, for example to assess uncertainty or test model properties. This requires external software which can call the model. At Cambridge Econometrics the Ox package (Doornik, 2007) is generally used but other options such as Matlab, R or Python could also be used for this purpose.

One important application for multiple model runs is to run the model repeatedly until it produces a desired outcome. This could be used, for example, to answer the question of what rate of carbon tax would be required to achieve a reduction in CO_2 emissions of 10%[14]. The software, which sits external to the model, sets the input rate and runs the model, then evaluates the results and tries a different input value. Once the desired outcome is achieved, the software returns the input values used. This allows many additional types of scenario to be run without making changes to the model source code.

5.3 The E3ME Windows Interface

Most model users outside Cambridge Econometrics prefer to access the model through a graphical interface that is based in a web browser. The latest version of the interface runs in any modern browser. Through the interface the user may:

- set up scenarios
- run the model
- compare results from scenarios

The interface comes with its own installation and operations guide.

[14] In fact in this example, the question could be rephrased by treating the target as the number of allowances in an emission trading scheme; see Section 5.5.

5.4 How the model solves

Introduction

This section describes in detail the solution process within the compiled model code. In most instances the user will not need to understand the solution process, but some basic knowledge would be helpful on occasions when the model fails to solve. An outline is therefore provided.

Iteration loops in the solution

As described in Chapter 2, there are several simultaneous loops and interactions in E3ME. While theoretically it might be possible to solve all the equations as a system, in practice the model is far too complex and an iterative approach is required.

The method of solution is Gauss-Seidel iteration, in which the different equations sets are solved in a predetermined order[15], starting with the values of the previous year's solution. The equations are solved, then the whole process repeated (the 'iteration') and the differences in the values of selected variables from one iteration to the next are calculated; they will usually decrease quite quickly between iterations. When these differences are small enough, the solution is deemed to be ‘converged’.

Reports are written to the verification file during the solution on (1) any very large absolute differences in solutions between iterations, (2) any non-converged values at the end of the solution, (3) the 30 items with the largest absolute differences between iterations at two different points in the solution[16], and (4) possible multiple soluctions.

Problems in the solution

A large, complex, non-linear model such as E3ME inevitably can sometimes have problems of convergence and stability in model solution. Generally there are two reasons that the model may fail to solve:

- explosive behaviour where a model variable keeps on increasing until it breaches a pre-specified limit
- non-convergence, where the model becomes trapped between two different solutions and is unable to move to a single point

When a model variable goes out of bounds, an error message is displayed telling the user which variable, region and sector has breached its limit (this is also recorded in the output diagnostics file). This is designed to help the user identify the source of the problem as easily as possible, although it should be noted that the error message may identify a symptom rather than a cause.

Cases of non-convergence are shown when the model reaches a maximum limit on the number of iterations (usually set at 100) without reaching a unique solution. As described above, the verification file is the best place to identify the source of the problem.

Common types of error pre-solution

Expertise has been developed to identify reasons for both causes and to remove the sources wherever possible. Failures in solution can come from errors in the data, in the Fortran code, and in the estimation. The first response is to check for errors and remove any. Indeed a set of procedures

[15] The order is not important in determining results; it was chosen on the basis of solution speed and stability and largely follows the order of the functions shown in Chapter 4.

[16] These are chosen by the user by setting the ITR1 and ITR2 (iteration number) variables in the IDIOM script.

should be followed before any solution of the model is undertaken to ensure that the data, the parameters and the programming is free of certain types of error:

- Data errors: e.g. zero prices, disaggregate energy demand does not add up to aggregated energy demand value, wage payments when employment is zero, current non-zero values when constant-priced values are zero, so implicit unit-prices are infinite.
- Parameter errors: where there are discrepancies between the model variables and the variables used for parameter estimation.
- Model errors: e.g. repeated adding of a value to a variable in each iteration, so that the solution will never converge; two solutions for the same variable in different parts of the model.

Alternative model specifications

When all these checks have been done, certain extreme values of parameters or combinations of parameter values in different equations may still cause problems in solution. These have to be identified and removed, usually by changing the specification from the default econometric equation (as specified in Chapter 4), to a simpler specification. Common alternatives are:

- SHAR – The specified model variable changes in line with the same variable for other sectors in the region.
- RATE – The specified model variable changes in line with the same variable for the same sector in other regions.
- EXOG – The specified model variable is not allowed to change and is fixed at the value on the databank.

The function specifications are set early in an Excel spreadsheet which gets exported to csv files for the model to read. The Excel file can usually be found in the C:\E3ME\In\Switches directory.

In general, considerable care should be used when changing specifications. For example, the RATE specification would not be appropriate when running the model for a single region. Unless there is a theoretical reason, model variables should usually only be held as exogenous for model testing.

Other alternative specifications are available for the individual equation sets.

Common problems in the solution – when output becomes zero

While in the past data and parameters have often been the cause of model instability, most problems in solution now relate to model variables approaching zero. In particular when output (QR) for a particular sector approaches zero, certain ratios (e.g. industry prices, labour productivity) can become unstable:

$$QR = QRY + QRC + QRK + QRG + QRX - QRM + QRR$$

where the terms on the right hand side relate to intermediate demand and the components of final demand, plus imports as a negative demand and the calibration residual QRR (see Section 3.5). It is quite obvious that fast-growing imports could result in zero or negative output (the model software will not allow negative output).

This can lead to both model collapse and non-convergence. Any one sector can cause problems in the solution so, with a large number of sectors and regions, it is not difficult to see how this could lead to instability.

Other solution problems – zero unemployment

Another important reason for non-convergence is when the economy of a region in the model approaches full employment. In this case the effect of the unemployment rate (the log of the rate is used) can change dramatically in several of the equations, leading to sudden changes in solution from one iteration to another. This effect is compounded by a check in the solution to prevent unemployment going negative by forcing a floor on the unemployment rate: the solution can bounce off this floor from one iteration to the next.

The full-employment areas of non-convergence are difficult to solve and the user is warned that they are liable to enter such areas if changes are made to the model or its assumptions which increase employment. The modelling problem has its roots in the actual performance of economies, which become more unstable at very low levels of unemployment. Similar warning is also applicable for when output of a sector is heading toward zero.

5.5 Example policy scenarios

In this section we consider four common types of scenarios:

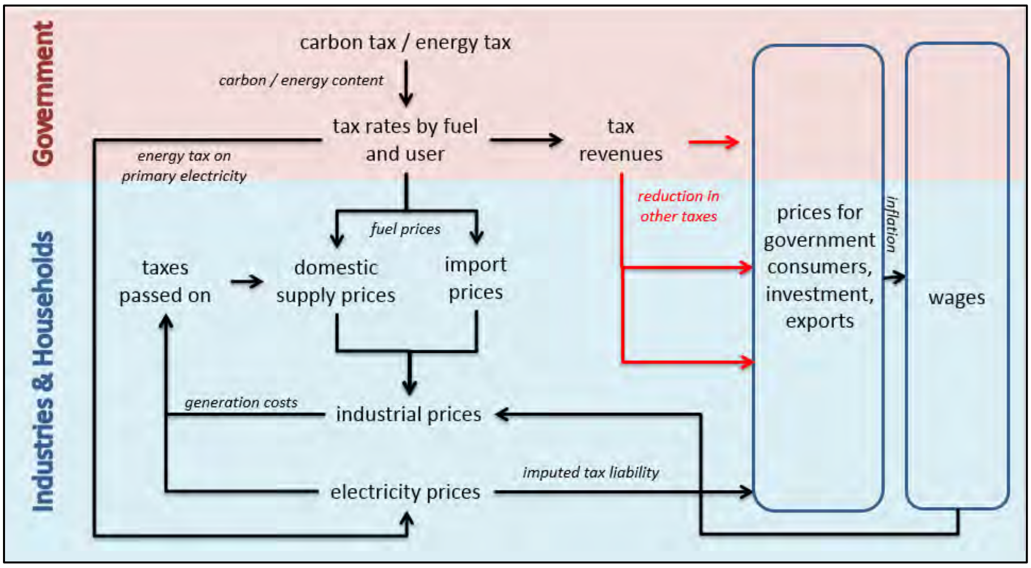
- a carbon/energy tax
- the EU ETS
- policies to improve energy efficiency
- a tax on material consumption

The aim of this section is not to present specific results, but to show how these policies are represented in the E3ME modelling framework, and the necessary assumptions involved.

A carbon or energy tax

One of the most common uses of the model is to provide a consistent and coherent treatment of fiscal policy in relation to greenhouse gas emissions. Some form of carbon/energy tax is an important component of such policy and E3ME is capable of exploring scenarios involving such a tax, as well as other fiscal policies and alternative means of reducing emissions. Figure 5.2 shows how the tax affects prices and wage rates in the model.

Figure 5.2: The impact of the carbon/energy tax on prices and wage rates



Assumptions and price effects

There are inevitably certain simplifying assumptions made in modelling a carbon/energy tax.

The first assumption is that the effects of the tax in the model are derived entirely through the impact of the tax on fuel prices, and through any use of the subsequent revenues from the tax in reducing other tax rates (i.e. revenue recycling). Other effects, including awareness or announcement effects, are not modelled. For example, if the introduction of a high carbon tax caused the electricity industry to scrap coal plants in advance of the tax being levied, this effect would have to be imposed on the model results[17].

The two components of the tax are treated separately. The carbon component of the tax is given as a rate in euros per tonne of carbon (€/tC) emitted in the form of CO_2. The carbon tax liability of all fuels is calculated on the basis of their CO_2 emissions, and converted into euros per tonne of oil equivalent (€/toe). The energy component of the tax is expressed in terms of €/toe directly. A matrix of total energy tax rates (in €/toe), by energy user, fuel and region may then be calculated for each year. Tax revenues can be calculated from fuel use.

The second assumption is that imports and domestic production of fuels will be taxed in the same manner, with exports exempt from the tax coverage. The treatment is assumed to correspond to that presently adopted by the authorities for excise duties imposed on hydrocarbon oils.

The third assumption is that any increase in fuel prices due to carbon/energy taxes are treated as the same as changes in fuel prices for any other reason. This means that the same price elasticities may be applied to determine the behavioural response (see Section 4.3). A share of cost increases will be passed on to final users through the estimated pass-through rates in the model (see Section 4.10).

The net effect on industrial and import prices feeds through to consumer prices and will affect relative consumption of goods and services depending on the carbon/energy content and on their price elasticities. Higher consumer prices will then lead to higher wage claims.

Real effects

Figure 5.3 shows the consequent effects of these price and wage rate changes. Energy consumption and fuel mixes will adjust, depending on price and substitution elasticities. The energy price increases will be passed on to more general increases in prices, which will cause substitution in consumers' expenditure, in exports and between imports and domestic production. These changes will feed back to fuel use.

CO_2 emissions are derived directly from the use of different fuels.

Revenue recycling

Depending on how the tax revenues are used, they may also affect real outcomes; standard options for revenue recycling include:

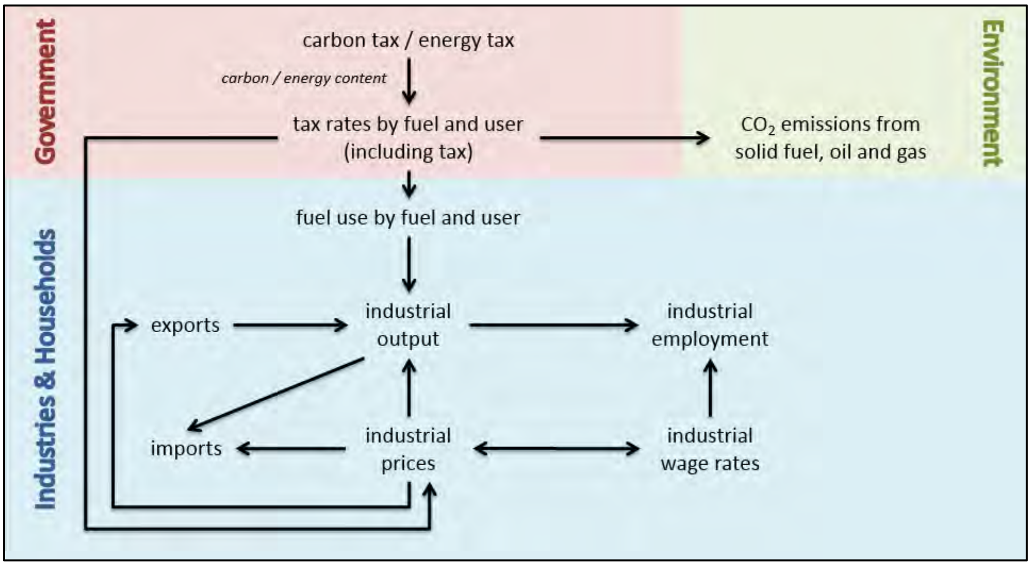
- reductions in standard income tax rates
- reductions to employees' national insurance contributions
- reductions to employers' national insurance contributions
- reductions in VAT rates (either standard or reduced rates)
- increases in social benefits

[17] A separate study of this 'Announcement Effect' in the UK is described in Agnolucci et al (2004).

- increases in public investment or R&D spending
- paying for renewable energy subsidies
- increases in government consumption, e.g. of education or health

The macroeconomic outcome may be highly dependent on the option chosen (see e.g. Barker et al, 2009). In the past the results from E3ME have shown that a small positive effect on output and employment at the macroeconomic level is possible when other tax rates are reduced in response (see e.g. Ekins et al, 2012).

Figure 5.3: The impact of the carbon/energy tax on fuel use, CO_2 emissions and industrial employment



Emission Trading Schemes

There are several different ways of modelling Emission Trading Schemes like the EU ETS in E3ME. The nature of scenarios depends on:

- whether the allowance price is treated as exogenous or endogenous
- how the allowances are allocated
- how any revenues from auctioned allowances are used

Emission trading schemes can be set to cover all or any of the energy user groups in the model (variable FETS in the scenario file). Similarly, the choice of countries/regions to include can be chosen by the user. For the EU ETS, the default coverage is the EU Member States and the sectors included are:

- Power generation
- Other energy production
- Iron and steel
- Non-ferrous metals
- Chemicals
- Non-metallic mineral products
- Paper and pulp
- Other industry
- Air transport (from 2014)

How prices are set

When the allowance price is exogenous, it is entered by the model user through the scenario or IDIOM code. For an endogenous allowance price, the user must set the emission cap, again through either the scenario file or the

IDIOM code. The model will then estimate the price required to meet the cap through an iterative process.

Higher costs of allowances will feed through to final product prices in the same way as a carbon tax (see above).

Allocation of allowances

The choice in allocation method essentially can be reduced to free allocation or government auctioning. If the allowance price is greater than zero, auctioning will always create public revenues that may be recycled through spending elsewhere or offsetting reductions in other tax rates.

The question of the effects of providing allowances free to industry is a difficult one. There are two opposing views:

- ETS allowances are provided on a lump-sum basis. They do not affect marginal costs and therefore do not affect pricing decisions (where marginal cost = marginal revenue). The lump sum is treated as a subsidy and leads to an increase in profits.
- ETS allowances are necessary for industry to compete. Industry uses the revenues from the free allowances to reduce final product prices, offsetting the higher carbon costs.

For the power sector, which is not open to international competition, it is now widely believed that free allocation of allowances did not reduce electricity prices, and power companies must now buy their ETS allowances. At present there is not enough empirical evidence to make a judgment on which option is more realistic for the industrial sectors, although it is recognised that this is an important policy debate. De Bruyn et al (2010) have attempted to quantify the effects for several industrial sectors and show that effects may vary between sectors.

The default option in E3ME is for prices to be set on a marginal basis with allocated allowances not affecting pricing decisions. However, this assumption can be changed in the model code.

Revenue recycling

If there are revenues from auctioned allowances, these may be recycled back to the economy. The options for revenue recycling are the same as for carbon taxes, discussed above.

Assumptions

The modelling of emission trading schemes is necessarily stylised and it is important to be aware of the main underlying assumptions. These are summarised below:

- The ETS is modelled by sector rather than by installation. Coverage is therefore approximate, for example small installations are not included in the EU ETS in reality but are picked up in the modelling.
- A single annual average allowance price is estimated for each year. There is no measure of price volatility in the ETS price variable.
- There is no allowance made for uncertainty about future carbon prices; the price signal from the ETS is therefore the same as the price signal from a carbon tax of the same rate.
- Transaction costs are not included.

- CDMs may be included in the analysis, but the share of emissions met by CDMs is fixed by assumption. This reflects the level of uncertainty about developments in the CDM market.
- Banking and borrowing is possible but must be imposed by the assumption. E3ME solves year by year and does not assume perfect foresight, so intertemporal decisions must be made by assumption.
- As in the rest of the model, there is no feedback to global energy prices.

Investment in energy efficiency

Energy efficiency is a key component of decarbonisation strategies and has further advantages in terms of competitiveness and energy security. E3ME has been used several times to model energy efficiency scenarios, including input to the Impact Assessment of the Energy Efficiency Directive.

The level of detail in the modelling is determined by the available data. At a most basic level, E3ME needs as inputs:

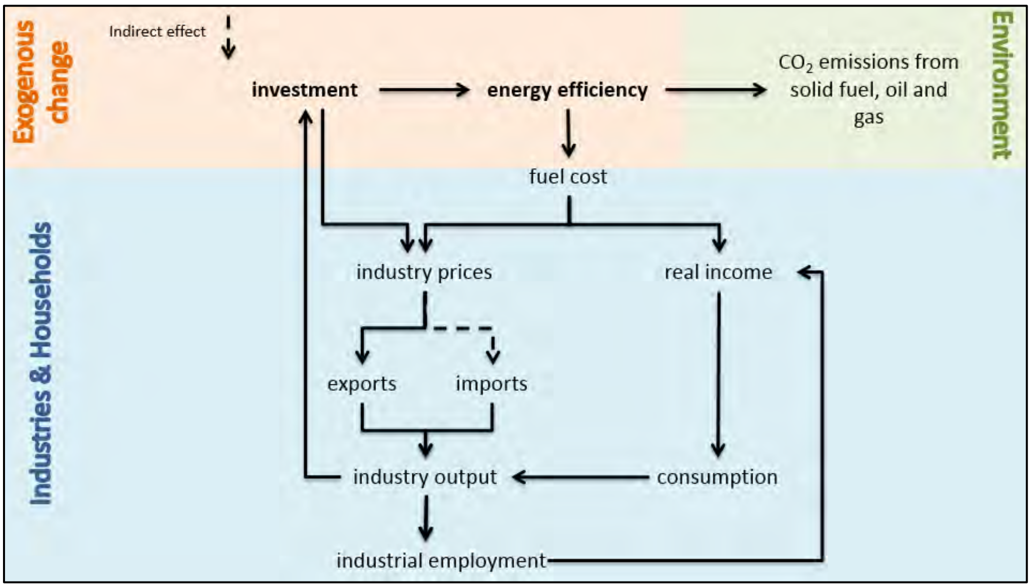
- potential energy savings
- the investment cost of these savings
- the sector and the fuel that is displaced

In the past, figures from *World Energy Outlook* published by the IEA have been used to estimate potential savings, and the unit investment costs associated with these savings. However, it is also possible to take into account specific technologies if the necessary data are available. This could, for example, be the results of a bottom-up sectoral model.

The energy savings are entered into the model as exogenous reductions in fuel consumption (FRGH, FREH, etc), possibly with a correction for direct rebound effect. The investment is added as an exogenous increase in investment in the relevant sector (KRX). The cost of the investment can then be recouped by higher prices in the sector making the investment, or through higher tax rates if the investment is publically funded.

Scenarios that assess energy efficiency therefore typically show gains in investment and output of the sectors that supply investment goods. The sectors that supply energy lose out. Investment in household energy efficiency allows a shift in consumer spending patterns. For most European countries there is a reduction in fossil fuel imports, which leads to a modest increase in GDP. Figure 5.4 summarises the main economic interactions.

Figure 5.4: The main economic interactions of energy efficiency



Materials taxes

The materials submodel is described in Section 2.5. Materials taxes are added by setting the variables MT01-MT07 for each of the material types. They can be set by sector and country using the variables MEDS. All of these may be accessed through the scenario file.

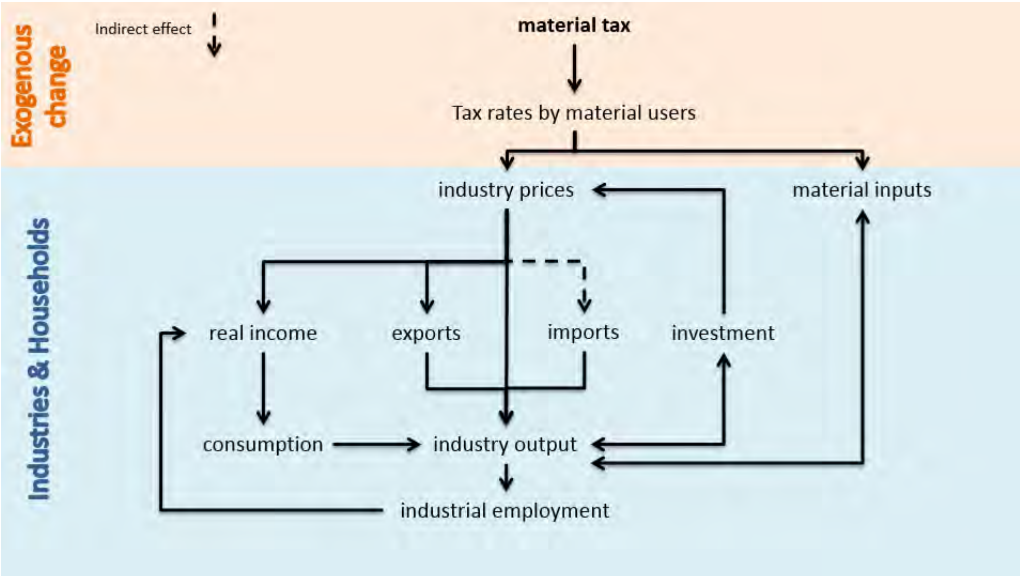
As the material categories do not have explicit price variables the tax rates are implicit rather than valued in $/tonne. For example a value of 0.1 in MT01 represents a tax that is large enough to increase food prices by 10%.

Tax revenues are then calculated using input-output flows, with assumptions about the linkages between material types and economic sectors. The revenues may be recycled using any of the methods described in the case for carbon taxes above.

The sectors that pay the taxes will face an increase in unit costs that may or may not be passed on to their customers (depending on the estimated pass-through rate). As in the case of energy taxes, this may in turn lead to higher inflation and wage demands, and a loss of competitiveness. The largest users of minerals are typically sectors that produce investment goods (e.g. construction or engineering) so a minerals tax may affect investment disproportionately. On the other hand, the food and catering sectors are the largest biomass consumers, so increases in prices are most likely to affect household spending.

Figure 5.5 summarises the main impact of a material tax.

Figure 5.5: The main impacts of a materials tax



Other material-related policy options available in the E3ME model include

- direct regulation
- resource efficiency investments
- caps or targets on DMC or RMC (similar to the EU-ETS principle), where the model calculates material tax rates endogenously

Users can also enter maximum limits on DMI by material and country. The model will warn the user if these limits are ever breached.

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Appendix A Top-Down and Bottom-Up Modelling Approaches

A.1 Overview

The terms 'top-down' and 'bottom-up' are often used in economic and energy modelling. Unfortunately they have more than one meaning which can lead to confusion. This appendix aims to clarify the position of E3ME with regards to top-down and bottom-up modelling, and discusses the issues in the context of energy modelling more generally.

A.2 Top-down and bottom-up in the economic context

For E3 modelling the terms top-down and bottom-up in general refer to the approach used for the energy sector, as discussed in the next section. However, the labels are still sometimes applied to economic sectoral models.

A top-down economic model is one where macro-level indicators are determined first and then the sectoral outputs are estimated by sharing out the macro results. In contrast, a bottom-up economic model is one where output is determined at the sectoral level, and then the macro impacts are derived as the sum of the sectoral results.

In economic terms, E3ME is a bottom-up model. It consists of 69 sectors in Europe and 43 sectors for the rest of the world. The outcomes of macro-level indicators, such as GDP, are determined by taking the sum of the sectors.

The one exception to this is the model's consumption equations, where a top-down approach is applied for theoretical reasons. First, total household expenditure is estimated based on available incomes; this is then shared between different consumption categories. These equations are described in more detail in Chapter 4.

A.3 Top-down and bottom-up in the energy-environment context

The basic methodologies

E3ME is intended to be an integrated top-down, bottom-up model of E3 interaction. The current model can be summarised as:

- including a bottom-up model of the electricity supply industry
- being otherwise top-down in approach

Future bottom-up submodels are being planned for the domestic and transport sectors but are not included in the current model version.

Top-down economic analyses and bottom-up engineering analyses of changes in the pattern of energy consumption possess distinct intellectual origins and distinct strengths and weaknesses (see Table A1).

Similarly the mechanisms which represent the driving forces in the respective analyses are very different. In economic models change is usually modelled using elasticities, such as substitution between factors, or price and income elasticities. In bottom-up modelling the determinant force is captured by the relationship between technological options and usually by some notion of the discount rate employed by economic agents (households, firms and the government). In some sense, the discount rate employed in bottom-up models is the mirror image of an elasticity employed in top-down models. Both factors will determine the extent to which agents react to changes in the conditions associated with the energy supply chain (see Barker, Ekins and Johnstone, 1995).

Perhaps the most significant difference is in the treatment of capital and technology. In top-down models capital is usually treated as a homogeneous input, which is related to energy only insofar as it is assumed to possess a degree of substitutability with energy inputs in production. Technological change (i.e. qualitative change in the characteristics of capital) is usually represented as an exogenous trend, sometimes explicitly related to energy consumption, affecting the productivity of the homogeneous capital input. Conversely, in bottom-up models capital is given an explicit empirical content and is related to energy in a very specific way, either in terms of generating equipment, other energy-related capital, or public infrastructure. Technological change is represented as a menu of options presently available or soon-to-be available which enjoy increasing market penetration.

Table A1: Comparison of top-down and bottom-up modelling methodology

	Bottom-up	Top-down
Classifications employed	Engineering-based	Economics-based
Treatment of capital	Precise description of capital equipment	Homogenous and abstract concept
Motive force	Discount rate employed by agents	Income and price elasticities
Perception of market	Market imperfections and barriers	Perfect markets (usually)
Potential efficiency improvements	Usually high-costless improvements	Usually low-constraint on economy

The two approaches also start from different conceptions of the nature of markets. Most top-down models, although not E3ME, do not admit to the possibility of market imperfections (e.g. imperfect competition). Most importantly, the existence of costless opportunities is often assumed away (except at the margin). Energy consumption (and thus carbon dioxide emissions) are a reflection of revealed preferences and thus any alternative technological scenarios which have not been taken up in the economy are left unexploited for sound economic reasons, such as agent uncertainty (with respect to supply and demand factors) or 'hidden' factors (such as disruption or management costs). Conversely, in bottom-up models the inability of the economy to reach a technologically efficient supply chain in terms of the provision of energy services is attributed to market imperfections (e.g. credit constraints, information asymmetries, transaction costs). The relationship between such imperfections and decision-making is, however, left unexplored.

As noted, both types of analysis possess important strengths, but both have weaknesses when used to address long-term issues. On the one hand in top-down models, the notion that an elasticity of substitution between capital and other factors (estimated on the basis of 30-40 years of data, or imposed on the basis of intuition or the requirements of functional form) can be used to make useful comments about the world over the next 50 or 100 years from now is suspect. Indeed, beyond a certain number of years it is the engineering characteristics of the 'back-stop' technology, and not the behavioural relations themselves, around which the carbon-energy-output relationship revolves. On the other hand the depiction of the long-run in bottom-up models as a menu of technological options is clearly unsatisfactory as well. At best, the technological options can be presented in chronological form (commercially available, in development stages, technologically feasible), coming on line progressively. By defining capital precisely the models cannot be made dynamic in a satisfactory manner unless the path of technological change is known, and as such are restricted in their relevance to short and medium-term analysis.

In addition, the characteristics of the two approaches limit the relevance of the respective analyses. For instance, top-down models are not able to analyse the effects of non-price based policies which affect the nature of the market itself and not just prices within the market. Institutions and regulations are (implicitly) not subject to change. Given the prevalence of imperfections in the market for energy services, such an omission is significant. Conversely, bottom-up models are not able to analyse the price effects of the introduction of the options enumerated, or associated feedback effects. For instance, an analysis which examines the technological options available to the electricity supply industry misses important feedback effects unless it examines the effects of such a programme on the construction industry which undertakes the conversion, on the energy sector which is faced with significant dislocation, and on those sectors which use electricity and other energy carriers intensively as inputs in production.

Appendix B Model Classifications

CLASSIFICATIONS IN E3ME

R Regions

1 Belgium
2 Denmark
3 Germany
4 Greece
5 Spain
6 France
7 Ireland
8 Italy
9 Luxembourg
10 Netherlands
11 Austria
12 Portugal
13 Finland
14 Sweden
15 UK
16 Czech Republic
17 Estonia
18 Cyprus
19 Latvia
20 Lithuania
21 Hungary
22 Malta
23 Poland
24 Slovenia
25 Slovakia
26 Bulgaria
27 Romania
28 Norway
29 Switzerland
30 Iceland
31 Croatia
32 Turkey
33 Macedonia
34 USA
35 Japan
36 Canada
37 Australia
38 New Zealand
39 Russian Federation
40 Rest of Annex I
41 China
42 India
43 Mexico

R Regions (cont)

44 Brazil
45 Argentina
46 Colombia
47 Rest of Latin America
48 Korea
49 Taiwan
50 Indonesia
51 Rest of ASEAN
52 Rest of OPEC
53 Rest of world
54 Ukraine
55 Saudi Arabia
56 Nigeria
57 South Africa
58 Rest of Africa
59 Africa OPEC
60 Malaysia
61 Kazakhstan

M Global Commodities

1 Food/Feed
2 Wood
3 Construction minerals
4 Industrial minerals
5 Ferrous metals
6 Non-ferrous metals
7 Energy- Coal
8 Energy- Brent oil
9 Energy- Gas
10 World Inflation

G Govt sectors

1 Defence
2 Education
3 Health
4 Other
5 Unallocated

C Consumers' Expenditure

1 Food
2 Drink
3 Tobacco
4 Clothing and footwear
5 Actual rent
6 Imputed rentals
7 Maintenance and repair
8 Water and misc. services
9 Electricity
10 Gas
11 Liquid Fuels
12 Other Fuels
13 Furniture and flooring
14 Household textiles
15 Household appliances
16 Glassware tableware
17 Tools and equipment
18 Household maintenance
19 Medical products
20 Medical Services
21 Purchase of vehicles
22 Petrol etc.
23 Rail Transport
24 Air Transport
25 Other Transport
26 Postal services
27 Photographic equipment
28 Other recreational durables
29 Other recreational items
30 Recreational/cultural services
31 News, books, stationery
32 Package holidays
33 Education (pre & prim)
34 Catering services
35 Accommodation
36 Personal care
37 Other personal effects
38 Social protection
39 Insurance
40 Other financial services
41 Other services
42 CVM Residuals
43 Unallocated

CLASSIFICATIONS IN E3ME

Q, Y Products, Industries

1 Crops, animals, etc
2 Forestry & logging
3 Fishing
4 Coal
5 Oil and Gas
6 Other mining
7 Food, drink & tobacco
8 Textiles & leather
9 Wood & wood prods
10 Paper & paper prods
11 Printing & reproduction
12 Coke & ref petroleum
13 Other chemicals
14 Pharmaceuticals
15 Rubber & plastic products
16 Non-metallic mineral prods
17 Basic metals
18 Fabricated metal prods
19 Computer, optical & electronic
20 Electrical equipment
21 Other machinery & equipment
22 Motor vehicles
23 Other transport equipment
24 Furniture; other manufacturing
25 Repair & installation machinery
26 Electricity
27 Gas, steam & air conditioning
28 Water, treatment &supply
29 Sewerage & waste management
30 Construction
31 Wholesale/retail motor vehicles
32 Wholesale excl. motor vehicles
33 Retail excluding motor vehicles
34 Land transport, pipelines
35 Water transport
36 Air transport
37 Warehousing
38 Postal & courier activities
39 Accommodation & food services
40 Publishing activities
41 Motion picture, video, television
42 Telecommunications
43 Computer programming, info services
44 Financial services
45 Insurance
46 Aux to financial services
47 Real estate

Q, Y Products, Industries (cpnt)

48 Imputed rents
49 Legal, account, & consulting services
50 Architectural & engineering
51 R&D
52 Advertising & market research
53 Other professional
54 Rental & leasing
55 Employment activities
56 Travel agency
57 Security & investigation, etc.
58 Public administration & defence
59 Education
60 Human health activities
61 Residential care
62 Creative, arts, recreational
63 Sports activities
64 Membership organisations
65 Repair computers & personal goods
66 Other personal services.
67 Households as employers
68 Extraterritorial organisations
69 Unallocated
70 Hydrogen supply

SE Socio-economic groups

1 All households
2 First quintile
3 Second quintile
4 Third quintile
5 Fourth quintile
6 Fifth quintile
7 Manual workers
8 Non-manual workers
9 Self-employed
10 Unemployed
11 Retired
12 Inactive
13 Densely populated
14 Sparsely populated

T Taxes

1 Motor spirit
2 DERV
3 Other oil
4 Coal
5 Gas
6 Electricity
7 Carbon/energy tax
8 VAT
9 Import duties
10 Material taxes
11 Other indirect taxes

LG Labour groups

1 Male 15-19
2 Male 20-24
3 Male 25-29
4 Male 30-34
5 Male 35-39
6 Male 40-44
7 Male 44-49
8 Male 50-54
9 Male 55-59
10 Male 60-64
11 Male 65+
12 Female 15-19
13 Female 20-24
14 Female 25-29
15 Female 30-34
16 Female 35-39
17 Female 40-44
18 Female 45-49
19 Female 50-54
20 Female 55-59
21 Female 60-64
22 Female 65+
23 Total 15-19
24 Total 20-24
25 Total 25-29
26 Total 30-34
27 Total 35-39
28 Total 40-44
29 Total 45-49
30 Total 50-54
31 Total 55-59
32 Total 60-64
33 Total 65+

CLASSIFICATIONS IN E3ME

PA Population groups
1 Male Children
2 Male 15-19
3 Male 20-24
4 Male 25-29
5 Male 30-34
6 Male 35-39
7 Male 40-44
8 Male 44-49
9 Male 50-54
10 Male 55-59
11 Male 60-64
12 Male OAPs
13 Female Children
14 Female 15-19
15 Female 20-24
16 Female 25-29
17 Female 30-34
18 Female 35-39
19 Female 40-44
20 Female 45-49
21 Female 50-54
22 Female 55-59
23 Female 60-64
24 Female OAPs

AR Regional assumptions
01 YEAR
02 Exchange rate
03 SR Interest rate
04 LR interest rate
05 Total govt spending
06 Defence spending
07 Education spending
08 Health spending
09 Indirect tax rates
10 VAT rates
11 Direct tax rates
12 Benefit rates
13 Employees' Soc Sec rate
14 Employers Soc Sec rate
15 Unused

SF Stochastic Functions
1 BFR0 Agg Energy Demd
2 BFRC Coal Demd
3 BFRO Heavy Oil Demd
4 BFRG Nat Gas. Demd
5 BFRE Electricity Demd
6 BRSC Agg Consumption
7 BCR Disag Consumption
8 BCR Disag Consumption
9
10 BKR Ind. Investment
11 BQEX External Exports
12 BQIX Internal Exports
13 BQEM External Imports
14 BQIM Internal Imports
15 BYRH Hours Worked
16 BYRE Ind. Employment
17 BPYH Ind. Prices
18 BPQX Export Prices
19 BPQM Import Prices
20 BYRW Ind. Ave. Earn
21 BLRP Participation
22 BRRI Residual Income
23 BRDW Invst Dwellings
24 BYRN Normal Output
25
26 BRPT Agg Passenger
27 BRFT Agg Freight
28 BPMR Disag Passenger
29 BFMR Disag Freight
30
31 BMU1 Food
32 BMU2 Feed
33 BMU3 Wood
34 BMU4 Construction Min
35 BMU5 Industrial Mins
36 BMU6 Ferrous Ores
37 BMU7 Non-Ferrous ores
38 BYRD R&D expenditure
39
40

MT Materials
1 Food
2 Feed
3 Forestry
4 Construction Minerals
5 Industrial Minerals
6 Ferrous Ores
7 Non-ferrous ores
8 Water
9 Waste
10 Unallocated

MU Material Users
1 Agriculture
2 Mining
3 Energy
4 Food, Drink & Tobacco
5 Wood and Paper
6 Chemicals
7 Non-metallic Minerals
8 Basic Metals
9 Engineering etc
10 Other Industry
11 Construction
12 Transport
13 Services
14 Households
15 Unallocated

J Fuel types
1 Hard coal
2 Other coal etc
3 Crude oil etc
4 Heavy fuel oil
5 Middle distillates
6 Other gas
7 Natural gas
8 Electricity
9 Heat
10 Combustible waste
11 Biofuels
12 Hydrogen

CLASSIFICATIONS IN E3ME

EM Emissions
1 Carbon dioxide
2 Sulphur dioxide
3 Nitrogen oxides
4 Carbon monoxide
5 Methane
6 Particulates
7 VOCs
8 Radiation - air
9 Lead - air
10 CFCs
11 N2O (GHG)
12 HFCs (GHG)
13 PFCs (GHG)
14 SF6 (GHG)

EP Energy prices
1 Auto fuels: leaded
2 Auto fuels: unleaded
3 Auto fuels: diesel
4 Light fuel oil: indus
5 Light fuel oil: hhold
6 High S fuel oil: indu
7 High S fuel oil: elec
8 Low S fuel oil: indus
9 Low S fuel oil: elec
10 Electricity: indust
11 Electricity: hholds
12 Natural gas: indust
13 Natural gas: hholds
14 Natural gas: elec
15 Steam coal: indust
16 Steam coal: hholds
17 Steam coal: elec
18 Coking coal

ET Energy Technologies
1 Nuclear
2 Oil
3 Coal
4 Coal + CCS
5 IGCC
6 IGCC + CCS
7 CCGT
8 CCGT + CCS
9 Solid Biomass
10 S Biomass CCS
11 BIGCC

ET Energy Technologies (cont)
12 BIGCC + CCS
13 Biogas
14 Biogas + CCS
15 Tidal
16 Large Hydro
17 Onshore
18 Offshore
19 Solar PV
20 CSP
21 Geothermal
22 Wave
23 Fuel Cells
24 CHP

FU Fuel Users
1 Power own use & transformation
2 O energy own use & transformation
3 Hydrogen production
4 Iron and steel
5 Non-ferrous metals
6 Chemicals
7 Non-metallic minerals
8 Ore-extraction (non-energy)
9 Food, drink and tobacco
10 Textiles, clothing & footwear
11 Paper and pulp
12 Engineering etc
13 Other industry
14 Construction
15 Rail transport
16 Road transport
17 Air transport
18 Other transport services
19 Households
20 Agriculture, forestry, etc
21 Fishing
22 Other final use
23 Non-energy use

VT Vehicle Technologies
1 Petrol Econ
2 Petrol Mid
3 Petrol Lux
4 Adv Petrol Econ
5 Adv Petrol Mid
6 Adv Petrol Lux
7 Diesel Econ
8 Diesel Mid
9 Diesel Lux
10 Adv Diesel Econ
11 Adv Diesel Mid
12 Adv Diesel Lux
13 LPG Econ
14 LPG Mid
15 LPG Lux
16 Hybrid Econ
17 Hybrid Mid
18 Hybrid Lux
19 Electric Econ
20 Electric Mid
21 Electric Lux
22 motorcycles Econ
23 motorcycles Lux
24 Adv motorcycles Econ
25 Adv motorcycles Lux

CLASSIFICATIONS IN E3ME

Non-EU regions product/industry and consumer expenditure

Q, Y Products, Industries

1 Agriculture etc
2 Coal
3 Oil & Gas etc
4 Other Mining
5 Food, Drink & Tob.
6 Text., Cloth. & Leath
7 Wood & Paper
8 Printing & Publishing
9 Manuf. Fuels
10 Pharmaceuticals
11 Chemicals nes
12 Rubber & Plastics
13 Non-Met. Min. Prods.
14 Basic Metals
15 Metal Goods
16 Mech. Engineering
17 Electronics
18 Elec. Eng. & Instrum.
19 Motor Vehicles
20 Oth. Transp. Equip.
21 Manuf. nes
22 Electricity
23 Gas Supply
24 Water Supply
25 Construction
26 Distribution
27 Retailing
28 Hotels & Catering
29 Land Transport etc
30 Water Transport
31 Air Transport
32 Communications
33 Banking & Finance
34 Insurance
35 Computing Services
36 Prof. Services
37 Other Bus. Services
38 Public Admin. & Def.
39 Education
40 Health & Social Work
41 Misc. Services
42 Unallocated
43 Forestry
44 Hydrogen supply

C Consumers' expenditure

1 Food
2 Drink
3 Tobacco
4 Clothing and footw.
5 Gross rent and water
6 Electricity
7 Gas
8 Liquid fuels
9 Other fuels
10 Furniture etc
11 Household text. etc
12 Major appliances
13 Hardware
14 Household operation
15 Domestic services
16 Medical care etc
17 Cars etc
18 Petrol etc
19 Rail transport
20 Buses and coaches
21 Air transport
22 Other transport
23 Communication
24 Equipment etc
25 Entertainment etc
26 Exp rest and hotel
27 Misc. goods and serv
28 Unallocated

Appendix C File Structure

C.1 DOS box users

Directory	File name	Description
C:\e3me		
All model versions - Inputs		
	Run.cmd E3mer.exe, e3med.exe CreateES.cmd	Runs model from command line Executables for model (release and debug) Used by the model to create residual databank
\output\dumptitles	Dump Titles	Direct access binary file used by model for storage
\databank	*.db1	See Section 3.3 for description of databanks
\in	History.idiom Exforecast.idiom Enforecast.idiom Dan.idiom Esput.idiom Esput2.idiom	Commands to run model over history Commands to run model to match published forecast Commands to run model forecast Commands to extract model results Both used internally to create residual databank
\in\switches	FunctionFixes.xlsm	Excel macro file contains model specification fixes
\in\asns	Assumptions.idiom	Assumptions text file (others can be added)
\in\scenarios	B_ETS.idiom	Scenario input file (others can be added)
All model versions - Outputs		
\output	*.mre *.tab *.txt	Output files for front end or further processing Human readable output files Not used
\output\io	*.csv	Input-output tables
\output\ver	*.txt	Model diagnostics
All model versions – Other files		
\utilities\mretodb	mretodb.exe	Used to create residual databank
\utilities\tabls	tables.exe	Files used for adding new model variables
\model\e3me\dats\	Tabs.dat Tabs1.datTablo.dat	List of matrix variables (with descriptions)

Directory	File name	Description
C:\e3me		
	units.dat	List of scalar and integer variables (with descriptions) List of scalar and integer variables List of model main display units
All model versions – model source code		
\model\e3me\s	*.f90	Fortran files contain model source codes
\model\e3me\m	*.for *.f90	Fortran files contain calls to model source codes
\model\e3me\ftt	*.for	Fortran files contain model source codes specific to the FTT model
\model\idiom\idm	*f90	Fortran files contain IDIOM source codes

C.2 Front end users

Directory	File name	Description
C:\e3me\manager		
All model versions - Inputs		
	Runmodel.cmd e3me5.exe	Runs model from command line Launch Frontend version of the E3ME software
\scripts	baseline.sct	Runs model from a solution script
\e3me5\	e3me5.exe	E3ME complied executable
\databank	*.db1	See Section 3.3 for description of databanks
\in	Dump.idiom Enforecast.idiom Dan.idiom	Commands to run model over history Commands to run model forecast Commands to extract model results
\in\asns	Assumptions.idiom f1a.ast	Assumptions text file Assumption set of individual assumption files
\in\scenarios	B_ETS.idiom	Scenario input file
All model versions - Outputs		
\output	*.mre	Output files for front end or further processing
\output\io	*.csv	Input-output tables

Appendix D Non-Standard Equations

D.1 Introduction

This appendix provides a formal specification of some equation sets that are not included in the current version of E3ME:

- Since the introduction of bilateral trade, the export equations are no longer used in the standard model solution (exports are the reverse sum of bilateral imports). However, the structure is maintained for applications that consider a country/region in isolation.
- The transport equations are not operational in the current version of E3ME but are maintained within the model structure to facilitate possible future linkages with transport models.
- The econometric equations for biofuel demand are not operational, due to a lack of data on biofuel prices. Previous analysis has been carried out for Sweden but the standard model treatment uses a simpler shift-share approach.

These are described briefly in the following sections. As described in Chapter 4, each of these equations includes dummy variables for German reunification and the financial crisis in 2009 but these are omitted from the specifications for brevity. The notation is similar to that used in Chapter 4.

D.2 Export volumes

The export volume equations are described below. The specification is similar to that described in Chapter 4 for imports, with exports being a function of price, competing prices and technology.

Similarly to the import equations, exports are split into internal and external transactions. In the internal equations there is also an indicator for development of the relevant trade bloc.

Table D2: The Intra-EU Export Volume Equations

Co-integrating long-term equation:

LN(QIX(.))			[internal exports]
	=	BQIX(.,10)	
	+	BQIX(.,11) * LN(QZXI(.))	[domestic demand in region]
	+	BQIX(.,12) * LN(PQRX(.)/EX)	[export price]
	+	BQIX(.,13) * LN(PQRZ(.)/EX)	[competing export price]
	+	BQIX(.,14) * LN(YRKC(.)*YRKS(.))	[ICT technological progress]
	+	BQIX(.,15) * LN(YRKN(.))	[non-ICT technological progress]
	+	BQIX(.,16) * SVIM	[proxy for internal market programme]
	+	ECM	[error]

Dynamic equation:

DLN(QIX(.))			[change in internal exports]
	=	BQIX(.,1)	
	+	BQIX(.,2) * DLN(QZXI(.))	[domestic demand in region]
	+	BQIX(.,3) * DLN(PQRX(.)/EX)	[export price]
	+	BQIX(.,4) * DLN(PQRZ(.)/EX)	[competing export price]
	+	BQIX(.,5) * DLN(YRKC(.)*YRKS(.))	[ICT technological progress]
	+	BQIX(.,6) * DLN(YRKN(.))	[non-ICT technological progress]
	+	BQIX(.,7) * DSVIM	[proxy for internal market programme]
	+	BQIX(.,8) * DLN(QIX)(-1)	[lagged change in exports]
	+	BQIX(.,9) * ECM(-1)	[lagged error correction]

Identities:

QZXI	=	SUM(((QZXC(.)*VQR(.)+VQRM(.)-VQR(.))/(QR(.)+QRM(.)-QRX(.)))	[domestic demand in region]
PQRZ	=	SUM(QZXC(.)*PQRX(.))	[competing export price]

Restrictions:

BQIX(.,12) + BQIX(.,13) = 0	[price homogeneity]
BQIX(.,2 .,4 .,5 .,6 .,11 .,13 .,14 .,15) >= 0	['right sign']
BQIX(.,3 .,12) <= 0	['right sign']
0 > BQIX(.,9) > -1	['right sign']

Definitions:

BQIX	is a matrix of parameters
PQRX	is a matrix of price of export prices for 69/43 industries and 53 regions, 2005=1.0, local currency
EX	is a vector of exchange rates, local currency per euro, 2005=1.0
YRKC	is a matrix of ICT technological progress for 69/43 industries and 53 regions
YRKN	is a matrix of non-ICT technological progress for 69/43 industries and 53 regions
YRKS	is a matrix of skills for 69/43 industries and 53 regions
QZXC	is a matrix of shares of industry exports by destination for 69/43 industries and 53 regions
QR	is a matrix of gross outputs for 69/43 industries and 53 regions, m euro at 2005 prices
QRM	is a matrix of imports for 69/43 industries and 53 regions, m euro at 2005 prices
SVIM	is an indicator of progress in the internal market for the EU and other trade blocs
V-	*indicates current price variable*

Table D3: The External Export Volume Equations

Co-integrating long-term equation:

LN(QEX(.))			[external exports]
	=	BQEX(.,10)	
	+	BQEX(.,11) * LN(QWXI(.))	[domestic demand outside region]
	+	BQEX(.,12) * LN(PQRX(.)/EX)	[export price]
	+	BQEX(.,13) * LN(PQRE(.)/EX)	[competing export price]
	+	BQEX(.,14) * LN(YRKC(.)*YRKS(.))	[ICT technological progress]
	+	BQEX(.,15) * LN(YRKN(.))	[non-ICT technological progress]
	+	BQEX(.,16) * SVIM	[=0 for external exports]
	+	ECM	[error]

Dynamic equation:

DLN(QEX(.))			[change in external exports]
	=	BQEX(.,1)	
	+	BQEX(.,2) * DLN(QWXI(.))	[domestic demand outside region]
	+	BQEX(.,3) * DLN(PQRX(.)/EX)	[export price]
	+	BQEX(.,4) * DLN(PQRE(.)/EX)	[competing export price]
	+	BQEX(.,5) * DLN(YRKC(.)*YRKS(.))	[ICT technological progress]
	+	BQEX(.,6) * DLN(YRKN(.))	[non-ICT technological progress]
	+	BQEX(.,7) * DSVIM	[=0 for external exports]
	+	BQEX(.,8) * DLN(QEX)(-1)	[lagged change in exports]
	+	BQEX(.,9) * ECM(-1)	[lagged error correction]

Identities:

QWXI	=	SUM(((QWXC(.)*VQR(.)+VQRM(.)-VQR(.))/(QR(.)+QRM(.)-QRX(.)))	[domestic demand outside region]
PQRE	=	SUM(QWXC(.)*PQRX(.))	[competing export price]

Restrictions:

BQEX(.,12) + BQEX(.,13) = 0	[price homogeneity]
BQEX(.,2 .,4 .,5 .,6 .,11 .,13 .,14 .,15) >= 0	[‘right sign’]
BQEX(.,3 .,12) <= 0	[‘right sign’]
0 > BQEX(.,9) > -1	[‘right sign’]

Definitions:

BQEX	is a matrix of parameters
PQRX	is a matrix of price of export prices for 69/43 industries and 53 regions, 2005=1.0, local currency
EX	is a vector of exchange rates, local currency per euro, 2005=1.0
YRKC	is a matrix of ICT technological progress for 69/43 industries and 53 regions
YRKN	is a matrix of non-ICT technological progress for 69/43 industries and 53 regions
YRKS	is a matrix of skills for 69/43 industries and 53 regions
QWXC	is a matrix of shares of industry exports by destination for 69/43 industries and 53 regions
QR	is a matrix of gross outputs for 69/43 industries and 53 regions, m euro at 2005 prices
QRM	is a matrix of imports for 69/43 industries and 53 regions, m euro at 2005 prices
SVIM	is set to zero for the external export equations
V-	*indicates current price variable*

D.3 Transport equations

These equations form the transport submodel in E3ME, which was built as part of the TIPMAC project for DG Energy and Transport. The transport submodel consists of four equations: Total passenger travel, Passenger travel by mode, Total freight demand and Freight travel by mode (see Table - Table). The equations are not operational in the standard version of the model, but could be used for analysis with updated data.

The dependent variables are bn person kilometres for passenger transport, and bn tonne kilometres for freight transport. The explanatory variables include real incomes and gross output and price variables.

In recent project work, E3ME has been coupled with a technology-based stock model to provide inputs on investment and energy demand within the transport sector. This approach could be combined with the transport equations.

Table D4: Total Passenger Travel

Co-integrating long-term equation:			
LN(RPT)			[total passenger travel]
	=	BAPT(8)	
	+	BAPT(9) * LN(RRPD)	[real gross disposable income]
	+	BAPT(10) * LN(PRPT)	[price of passenger travel]
	+	BAPT(11) * LN(PRSC)	[price of consumers' expenditure]
	+	BAPT(12) * LN(RNCH)	[number of passenger cars per head]
	+	ECM	[error]
Dynamic equation:			
DLN(RPT)			[total passenger travel]
	=	BRPT(1)	
	+	BRPT(2) * DLN(RRPD)	[real gross disposable income]
	+	BRPT(3) * DLN(PRPT)	[price of passenger travel]
	+	BRPT(4) * DLN(PRSC)	[price of consumers' expenditure]
	+	BRPT(5) * DLN(RNCH)	[number of passenger cars per head]
	+	BRPT(6) * DLN(PRPT)(-1)	[lagged change in total passenger travel]
	+	BRPT(7) * ECM(-1)	[lagged error correction]
Identity:			
RNCH	=	RNPC / (RPOP*0.001)	[number of passenger cars per head]
Restrictions:			
BRPT(3, 10) <= 0			['right sign']
BRPT(2, 4, 5, 9, 11, 12) >= 0			['right sign']
0 > BRPT(7) > -1			['right sign']
Definitions:			
BRPT	is a matrix of parameters		
RPT	is a vector of total passenger travel for 53 regions, bn person kilometres		
RRPD	is a vector of gross disposable income for 53 regions, in m euro at 2005 prices		
PRPT	is a vector of total prices of passenger travel for 53 regions, in euro/person kilometres		
RNPC	is a vector of numbers of passenger cars for 53 regions, in millions		
RPOP	is a vector of regional population for 53 regions, in thousands of persons		
PRSC	is a vector of the consumer price index, 2005=1.0		

Table D5: Passenger Travel by Mode

Co-integrating long-term equation:			
LN(PMR(.))			[passenger travel by mode]
	=	BPMR(.,8)	
	+	BPMR(.,9) * LN(RPT)	[total passenger travel]
	+	BPMR(.,10) * LN(PPMA(.))	[price of travel by mode]
	+	BPMR(.,11) * LN(PRPT)	[price of all travel]
	+	BPMR(.,12) * LN(RNCH)	[number of passenger cars per head]
	+	ECM	[error]
Dynamic equation:			
DLN(PMR(.))			[passenger travel by mode]
	=	BPMR(.,1)	
	+	BPMR(.,2) * DLN(RPT)	[total passenger travel]
	+	BPMR(.,3) * DLN(PPMA(.))	[price of travel by mode]
	+	BPMR(.,4) * LN(PRPT)	[price of all travel]
	+	BPMR(.,5) * DLN(RNCH)	[number of passenger cars per head]
	+	BPMR(.,6) * DLN(PMR(.))(-1)	[lagged change in passenger travel by mode]
	+	BPMR(.,7) * ECM(-1)	[lagged error correction]
Identity:			
RNCH	=	RNPC / (RPOP*0.001)	[number of passenger cars per head]
Restrictions:			
BPMR(.,3 .,10) <= 0			['right sign']
BPMR(.,4 .,11) >= 0			['right sign']
0 > BRPT(.,7) > -1			['right sign']

Definitions:

BPMR	is a matrix of parameters
PMR	is a matrix of passenger travel by mode for 5 modes and for 53 regions, bn person kilometres
RPT	is a vector of total passenger travel for 53 regions, bn person kilometres
PPMA	is a matrix of prices of passenger travel by mode for 5 modes and for 53 regions, euro per person kilometres
PRPT	is a vector of total prices of passenger travel for 53 regions, in euro/person kilometres
RNPC	is a vector of numbers of passenger cars for 53 regions, in thousands of persons
RPOP	is a vector of regional population for 53 regions, in thousands of persons

Table D6: Total Freight Demand

Co-integrating long-term equation:

LN(RFT)			[total freight]
	=	BRFT(8)	
	+	BRFT(9) * LN(RSQ)	[real gross output]
	+	BRFT(10) * LN(PRFT)	[price of freight]
	+	BRFT(11) * LN(PRSQ)	[price of gross output]
	+	BRFT(12) * LN(RSHP)	[share of road freight in total freight]
	+	ECM	[error]

Dynamic equation:

DLN(RFT)			[total freight]
	=	BRFT(1)	
	+	BRFT(2) * DLN(RSQ)	[real gross output]
	+	BRFT(3) * DLN(PRFT)	[price of freight]
	+	BRFT(4) * DLN(PRSQ)	[price of gross output]
	+	BRFT(5) * DLN(RSHP)	[share of road freight in total freight]
	+	BRFT(6) * DLN(PRFT)(-1)	[lagged change in total freight]
	+	BRFT(7) * ECM(-1)	[lagged error correction]

Identity:

RSHP	=	RFT(1) / SUM(RFT)	[share of road freight in total freight]

Restrictions:

BRFT(3, 10) <= 0	['right sign']
BRFT(2, 4, 9, 11) >= 0	['right sign']
0 > BRFT(7) > -1	['right sign']

Definitions:

BRFT	is a matrix of parameters
RFT	is a vector of total freight for 53 regions, bn tonne kilometres
RSQ	is a vector of gross output for 53 regions, in m euro at 2005 prices
PRFT	is a vector of total prices for freight for 53 regions, in euro/tonne kilometres
PRSQ	is a vector of gross output prices for 53 regions, 2005=1.0

Table D7: Freight by Mode

Co-integrating long-term equation:			
LN(FMR(.))			[freight by mode]
	=	BFMR(.,8)	
	+	BFMR(.,9) * LN(RFT)	[total freight]
	+	BFMR(.,10) * LN(PFMA(.))	[price of freight by mode]
	+	BFMR(.,11) * LN(PRFT)	[price of all freight]
	+	BFMR(.,12) * LN(RSHP)	[share of road freight in total freight]
	+	ECM	[error]
Dynamic equation:			
DLN(FMR(.))			[freight by mode]
	=	BFMR(.,1)	
	+	BFMR(.,2) * DLN(RFT)	[total freight]
	+	BFMR(.,3) * DLN(PFMA(.))	[price of freight by mode]
	+	BFMR(.,4) * LN(PRFT)	[price of all freight]
	+	BFMR(.,5) * DLN(RSHP)	[share of road freight in total freight]
	+	BFMR(.,6) * DLN(FMR(.))(-1)	[lagged change in freight mode]
	+	BFMR(.,7) * ECM(-1)	[lagged error correction]
Identity:			
RSHP	=	RFT(1) / SUM(RFT)	[share of road freight in total freight]
Restrictions:			
BFMR(.,3 .,10) <= 0			[‘right sign’]
BFMR(.,4 .,11) >= 0			[‘right sign’]
0 > BRFT(.,7) > -1			[‘right sign’]
Definitions:			
BFMR	is a matrix of parameters		
FMR	is a matrix of freight by mode for 5 modes and for 53 regions, bn tonne kilometres		
RFT	is a vector of total freight for 53 regions, bn tonne kilometres		
PFMA	is a matrix of prices of freight for 5 modes and for 53 regions, euro per tonne kilometre		
PRFT	is a vector of total prices of freight for 53 regions, in euro per tonne kilometre		

D.4 Biofuel demand

The structure of the biofuel demand equation matches that of the other energy carriers described in Section 4.4. It is not included in the standard model version due to a lack of data on the prices of different types of biofuels, but could easily be integrated if such data became available.