Thailand Greenhouse Gas Management Organization (TGO) and the World Bank

Impacts of carbon pricing instruments on national economy and contribution to NDC – Thailand

E3-Thailand Model Manual

cambridge econometrics
clarity from complexity

November 2018

Cambridge Econometrics
Cambridge, UK

uc@camecon.com
www.camecon.com

Authorisation and Version History

Version	Date	Authorised for release by	Description
1.0	5/10/18	HP	First version
1.1	13/11/18	HP	Additional appendix on scenario file and assumption file inputs, Section 2.6 E3-Thailand limitation

Contents

Acronyms and Abbreviations

BAU	Business-As-Usual
CE	Cambridge Econometrics
CGE	Computable General Equilibrium
CPI	Carbon Pricing Instrument
CO_2	Carbon Dioxide
E3	Energy-Environment-Economy
E3-Thailand	Thailand Econometrics Energy-Environment-Economy Model
E3ME	Global Econometrics Energy-Environment-Economy Model
ETS	Emission Trading Scheme
FTT	Future Technology Transformation Model
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GVA	Gross Value Added
IDIOM	International Dynamic Input-Output Model software package
IO	Input-output
NDC	Nationally Determined Contributions
MACC	Marginal Abatement Cost Curve
R&D	Research and Development

1 Introduction

1.1 What is E3-Thailand?

E3-Thailand is an advanced software tool that can be used to assess energy-economy linkages in Thailand. It is built on the existing structure offered by the global E3ME model but accounts for more detailed data and issues that are specific to Thailand.

The E3-Thailand model has the following dimensions:

- 80 economic sectors, 28 consumer spending categories
- 24users of 5 different energy carriers
- CO_2 emissions from 24 sources
- annual projections out to 2040

1.2 Aims of the model

The E3-Thailand model was constructed with the following aims:

- The model represents best practice for sectoral policy simulations.
- Its development is transparent. It is designed through a collaborative process and it aims to capture local knowledge and expertise in Thailand.
- The data used represent the best available data sources relevant to Thailand.
- The parameters in the model reflect the behavioural characteristics of different stakeholders in Thailand.
- The outputs of model simulations can be readily identified and explained.
- Use of the model is accessible to a broad base of prospective users over time.

1.3 Policy questions that E3-Thailand aims to address

As a general model of the economy, E3-Thailand can be used to assess a wide range of fiscal and general macroeconomic policies. However, it has been designed to have a particular focus on market-based instruments to achieve emission reduction targets. Policies that the model can assess include:

- impacts of Thai carbon tax policies under different design options
- impacts of Thai ETS policies under different design options
- the impacts of Thailand meeting its NDC targets under different carbon tax and policy combinations
- different revenue recycling options for market-based policies
- basic fiscal policies such as taxes and government spending

- sensitivities on global energy prices

The list below provides examples of policies that can also be included:

- energy efficiency
- regulations
- change to the power sector fuel mix

1.4 What are the main outputs from the model?

E3-Thailand cover a wide range of socio-economic outputs at national and sectoral level, for example:

- employment, labour force and unemployment
- wage rate
- GDP and sectoral output
- industry price and consumer price
- investment
- international trade
- household income distribution (by social group)
- household consumption
- public balances: spending, taxes and subsidies
- prices and inflation

The model results also include a full set of energy balances (and prices) by different energy users and by fuels, detailed power sector results by technologies can also be included if required, and emissions.

1.5 How does the model work?

E3-Thailand is based on a series of econometric equations that are similar in design to those in the global E3ME model (see www.e3me.com). Unlike the more common computable general equilibrium (CGE) approach to economic modelling, E3-Thailand does not assume full employment or perfectly competitive markets; instead it estimates behaviour based on available historical data.

1.6 Comparative advantages of E3-Thailand

Compared to other macroeconomic models in operation currently across the world, E3-Thailand has advantages in three important areas:

- Sectoral disaggregation, which allows for representation of fairly complex scenarios and the impact of any policy measure can be represented in a detailed way to show winners and losers.

- The econometric pedigree and empirical grounding of the model makes it better able to represent performance in the short to medium term, as well as providing long-term assessments without being too reliant on rigid assumptions.
- E3 linkages, and the hybrid nature of the model. A non-linear interaction between the economy, energy demand/supply and environmental emissions is an undoubtable advantage over other models.

1.7 Comparison to other econometric models

The macro-econometric approach is often compared to Computable General Equilibrium (CGE) models. In many ways the modelling approaches are similar. They are used to answer similar questions and use similar inputs and outputs.

However, beneath the surface there are 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 in their treatment of behavioural relationships. E3-Thailand is derived from post-Keynesian economic theory.

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, macro-econometric models 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 supply constraints), but at a level that is likely to be below maximum capacity.

This has important practical implications for scenario analysis, including scenarios of energy policy. The assumptions of optimisation in CGE models mean that all resources are fully utilised and it is not possible to increase output and employment by adding regulation. However, macro-econometric models allow for the possibility of unused capital and labour resources that may be utilised under the right policy conditions; it is therefore possible (although not guaranteed) that additional regulation could lead to increases in investment, output and employment. For example, the additional investment required to increase renewable capacity could lead to additional job creation and multiplier effects, depending on how the investment is financed.

Many of the assumptions that underpin CGE models have been increasingly questioned as to whether they provide an adequate representation of complex real-world behaviour. 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. By starting from a different viewpoint, the macro-econometric approach offers an economic representation that is much more in tune with the observed reality.

2 The Model Structure

2.1 Introduction

The theoretical background

The effects of economic interactions between individuals, households, firms and other economic agents are visible 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 (for example through 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 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 (i.e. covering the whole economy), and include a full set of linkages between different parts of the economic and energy systems.

The 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 a basic general equilibrium model; these models 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 Barker, 1998, for a more detailed discussion).

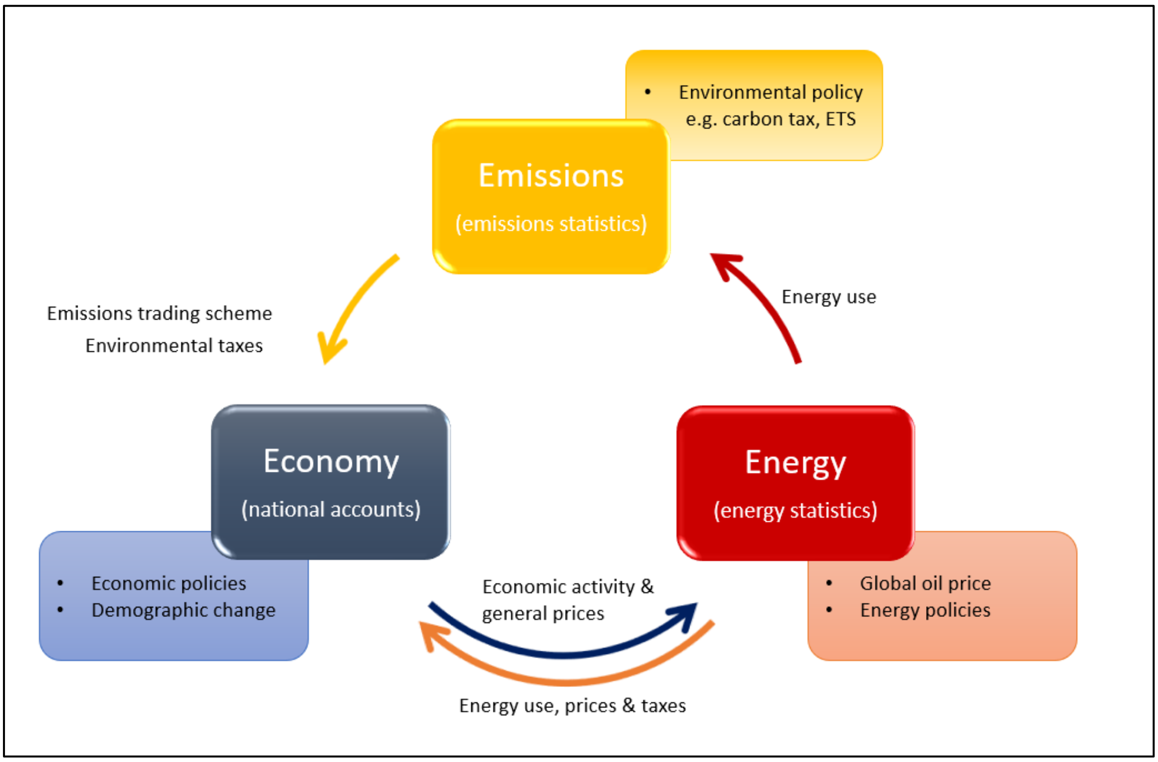
2.2 Basic model structure

The E3-Thailand model comprises:

- the accounting framework of the economy, coupled with balances for energy demands and environmental emission flows
- detailed historical data sets, with time series covering the period since 1990, and sectoral disaggregation
- an econometric specification of behavioural relationships in which short-term deviations move towards long-term trends
- the software to hold together these other component parts

Figure 2.1 shows how the three components (modules) of the E3-Thailand model - energy, environment and economy - fit together. Each component is shown in its own box.

Figure 2.1 E3 linkages in E3-Thailand



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 carbon taxes. 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.

Role of technology

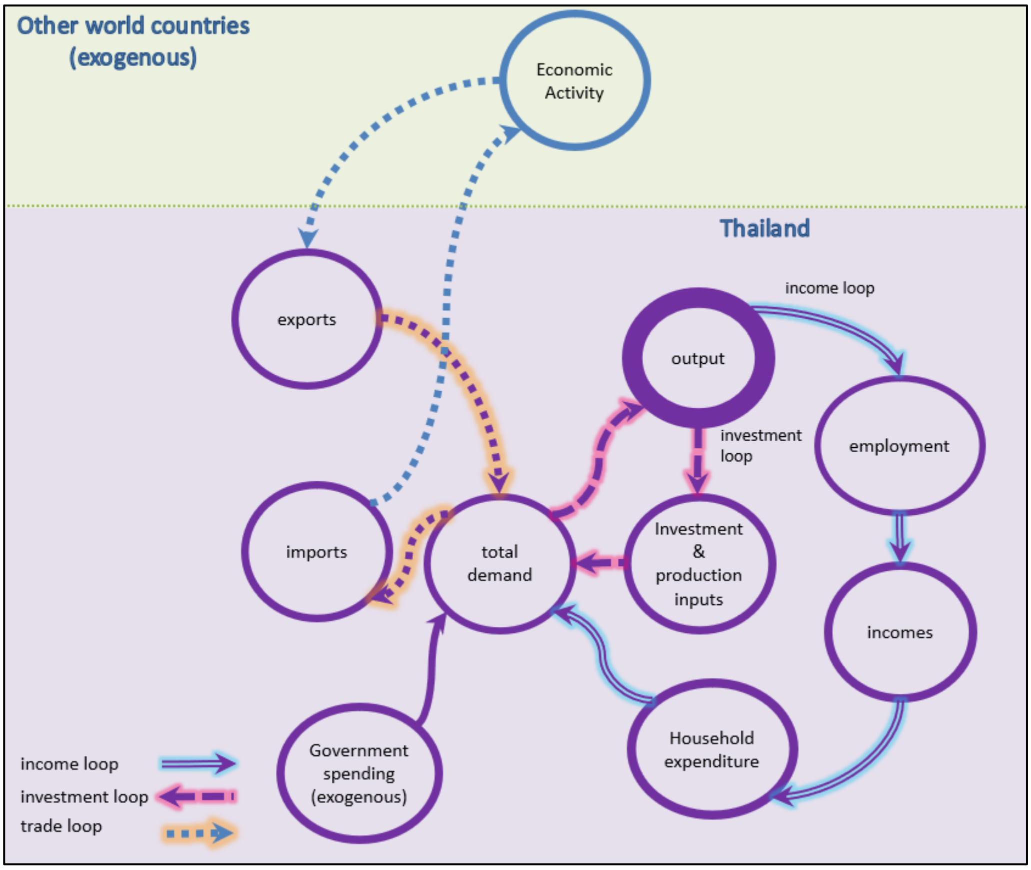
It is now widely recognised that economic models should include a representation of endogenous technological progress to consider shifting patterns of production and consumption. There are various specifications this can take; in E3-Thailand it is similar to the one that is used in the E3ME model, accumulated investment.

These measures, which are derived by sector, represent a deepening and improvement in quality of the capital stock. An improvement in the state of technology will lead to a better quality of output (i.e. positive non-price competitiveness effect) and, through increasing total supply, may also lead to lower prices and greater levels of output. It is thus the basis for future economic growth.

2.3 E3-Thailand's economic module

Figure 2.2 shows how E3-Thailand's economic module is solved. The arrows show flows of money. Most of the economic variables shown in the chart are solved at the sectoral level. The whole system is solved simultaneously for all industries.

Figure 2.2: E3-Thailand'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 will 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: Economic activities outside Thailand are treated as exogenous in E3-Thailand which can be changed in the model inputs. Activities outside Thailand alter demand for Thailand's exports.

Calculation of each component of demand

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

Formal equation definitions 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 is derived from functions estimated from time-series data. These equations relate consumption to personal disposable income, unemployment rates, inflation and interest rates. Share equations for each of the 16 consumption categories 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. It is possible to change the assumptions about levels of government spending in the Manager software.

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.

Stock building is treated as exogenous in the model.

International trade

The model includes equations for both exports and imports, with trade volumes being determined by levels of demand, prices and technology.

Output and determination of supply

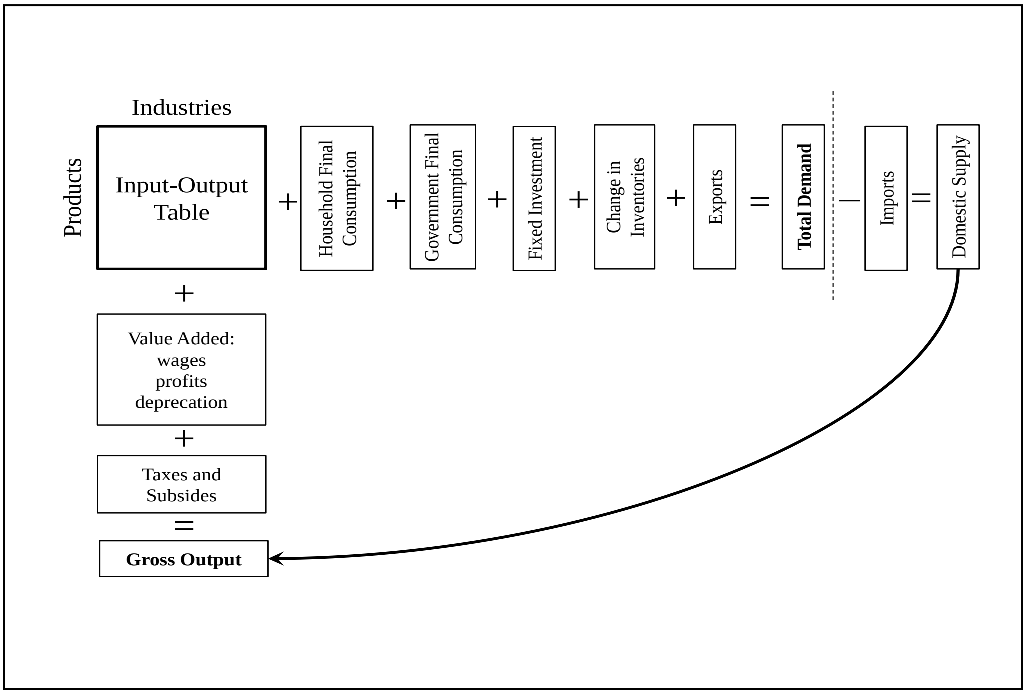
Total product output, in gross terms, is determined by summing intermediate demand and the components of final demand described above. This gives a measure of total demand for domestic production.

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, full employment is an unusual position for the labour market to be in and thus the supply constraint is therefore unlikely to be an issue.

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

Figure



The labour market and incomes

Treatment of the labour market is another area that distinguishes E3-Thailand from other macroeconomic models. E3-Thailand includes econometric equation sets for employment (as a headcount), wage rates and participation rates. Employment and wage rates are disaggregated by economic sector while participation rates are disaggregated by gender.

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, …)

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

Participation rates = F (Economic output, Wage rates, Unemployment, …)

Labour supply = Participation rate * Population

Unemployment = Labour supply – Employment

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

Analysis of skills

E3-Thailand 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. 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 required to test feasibility of the model results.

Incomes

E3-Thailand adopts a representative household. 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.

'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 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.

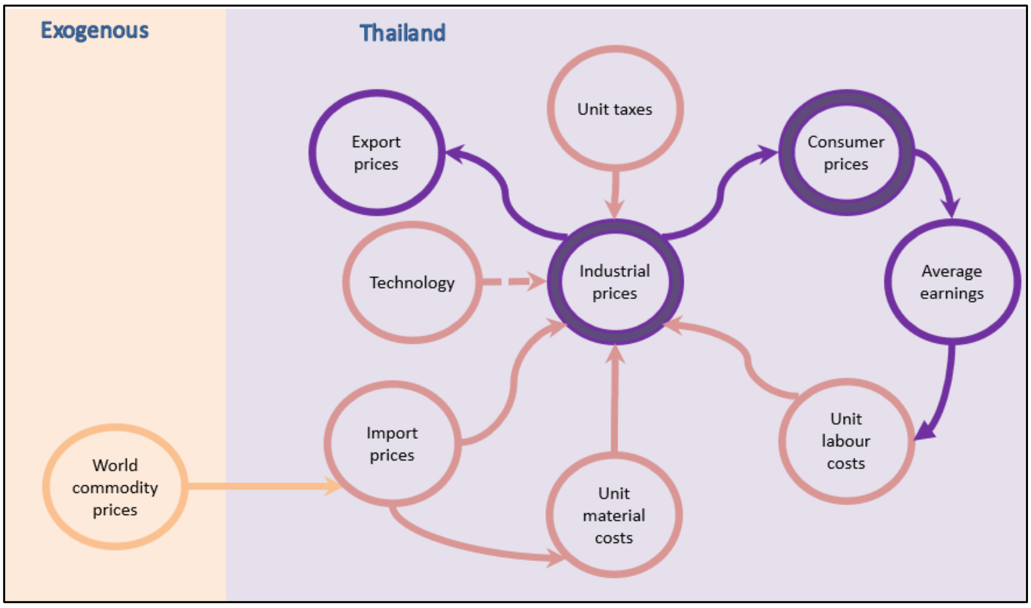
Price formation

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

Figure 2.4: E3-Thailand's basic price formation structure



These are influenced by unit costs (derived by summing wage costs, material costs and taxes), competing prices and technology (see Figure 2.4). 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

In quantitative modelling, the assessment of social impacts is often quite basic in nature. 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, E3-Thailand can provide less coverage of social factors than economic factors and environmental impacts 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.

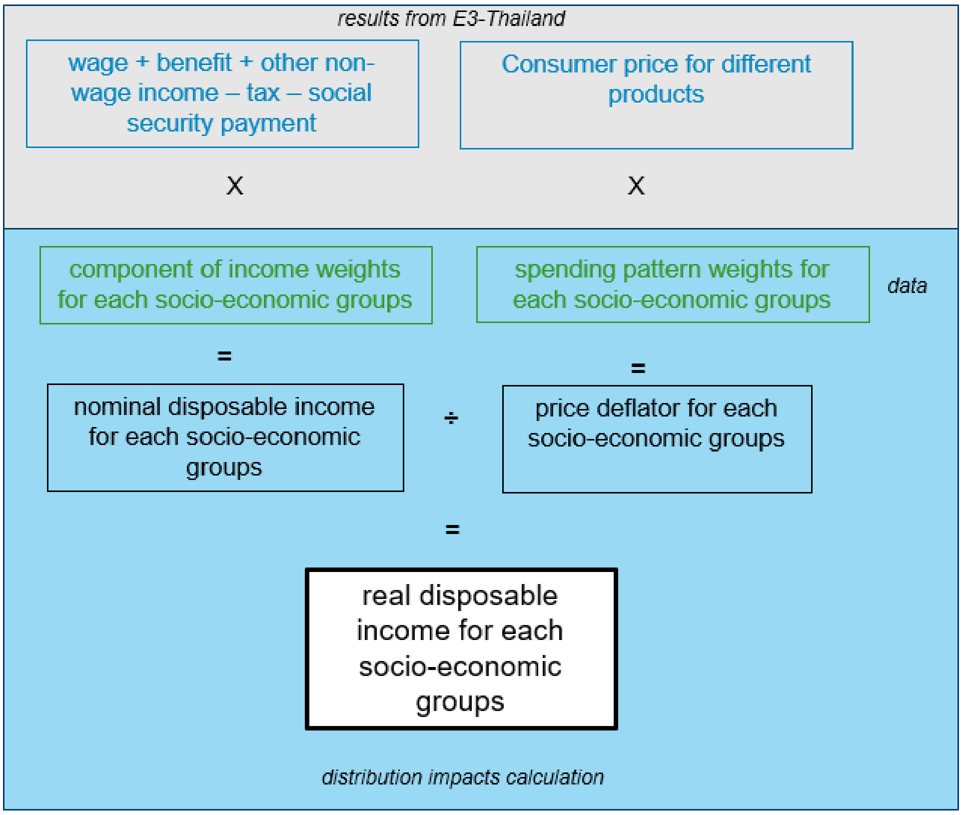
Distributional impact

The E3-Thailand model includes distributional analysis for different socioeconomic groups (see Section 3.3: Model classifications). The approach is based on two components.

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

Figure 2.5: E3-Thailand distribution impacts calculation



Demographic variables

Population projections are treated as exogenous in E3-Thailand. Population projections are made consistent to the baseline population assumptions of the Thailand NDC Roadmap (ONEP, 2017).

National accounting structure

The E3-Thailand model encapsulates a full representation of the National Accounting system, as originally developed by Richard Stone in Cambridge. This structure ensures consistency across economic variables and avoids issues such as double counting. As described below, this is extended to include physical measures of energy consumption and emissions.

Figure 2.6: E3-Thailand basic national accounting structure

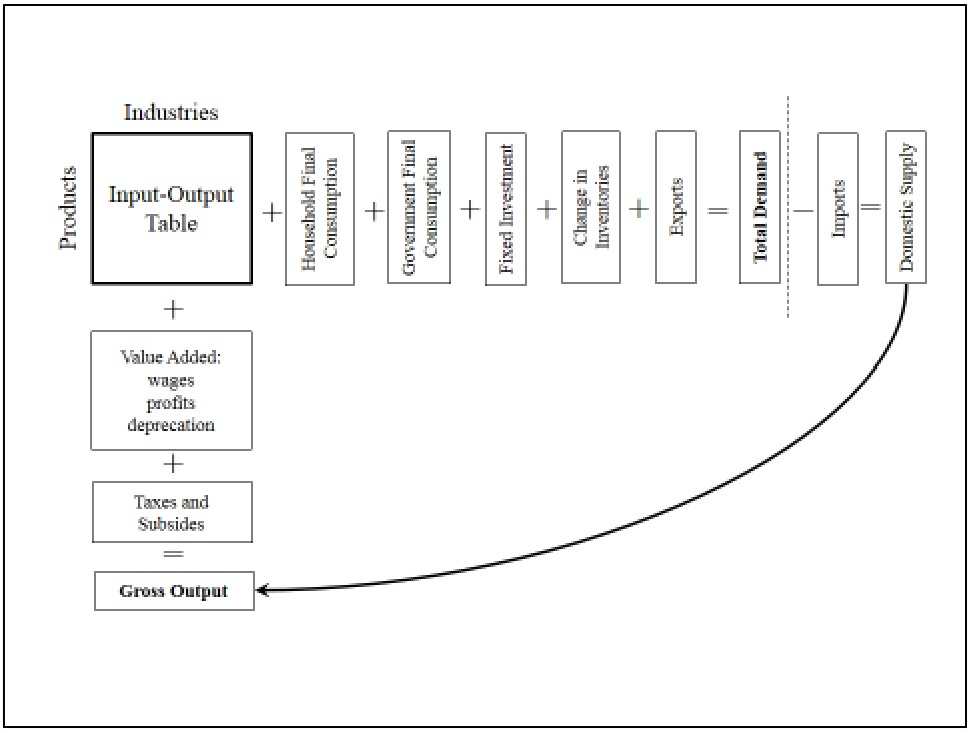


Figure 2.6 summarises the linkages. A short description of how the main economic results are determined is given below.

Intermediate demand

Intermediate demands (inputs to production processes) are determined through input-output linkages (with the exception of energy inputs, see below). In this way the model encapsulates supply chains and multiplier effects. The model uses the most recent input-output table, aggregated to around 80 sectors.

Household consumption

Household expenditure is determined by real incomes, which in turn is dependent on employment levels, wage rates and inflation. While all increases in incomes should be matched by higher expenditure in the long run, there may be short-run deviations due to changes in savings rates.

Government consumption

Government consumption is given as exogenous in the model, although it can be altered in the context of fiscal policies to ensure overall revenue neutrality in the scenarios.

Industrial investment

Investment is determined in the model at sectoral level as a function of expected output and relative prices. As well as contributing to current demand, investment in new capacity is an important way of increasing future potential supply.

International trade

The model includes equations for both exports and imports, with trade volumes being determined by levels of demand, prices and technology.

Output and GDP

Sectoral output is determined by summing together the components of demand across the top of **Error! Reference source not found.**. As long as there are no supply capacity constraints, it is assumed that supply increases to meet this demand. Gross Value Added (GVA) is determined by subtracting costs (including materials and taxes) from revenues. GDP is determined by summing across the components of final demand.

2.4 E3-Thailand's energy and environmental modules

This section outlines how energy demand and prices are modelled in E3-Thailand, and how this links into the economic modelling.

E3-Thailand can be described as top-down in its energy modelling. In this section, we describe how final energy demand and emission levels are calculated.

E3-Thailand's main energy module

The energy module in E3-Thailand is constructed, estimated and solved for each energy user and for each energy carrier (termed fuels for convenience below). Figure 2.7 shows the inputs from the economy and the environment into the components of the module and Figure 2.8 shows the feedback from the energy module to the economic module.

Total energy demand

Aggregate energy demand, shown on the left of Figure 2.7, 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

Figure 2.7: Inputs to the energy module

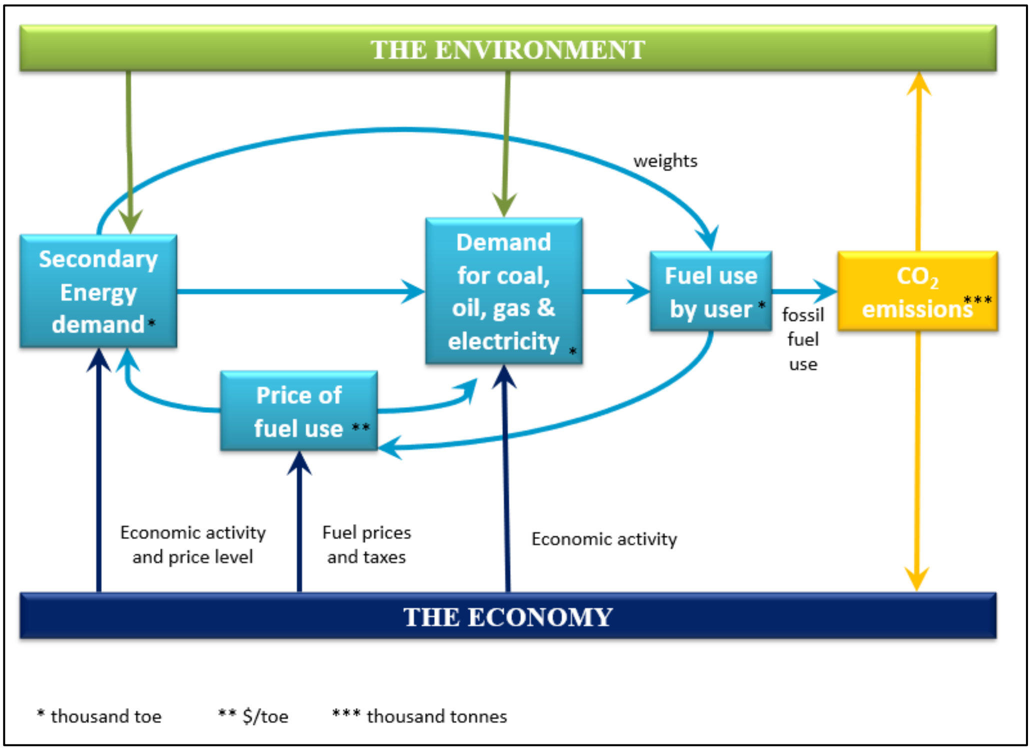
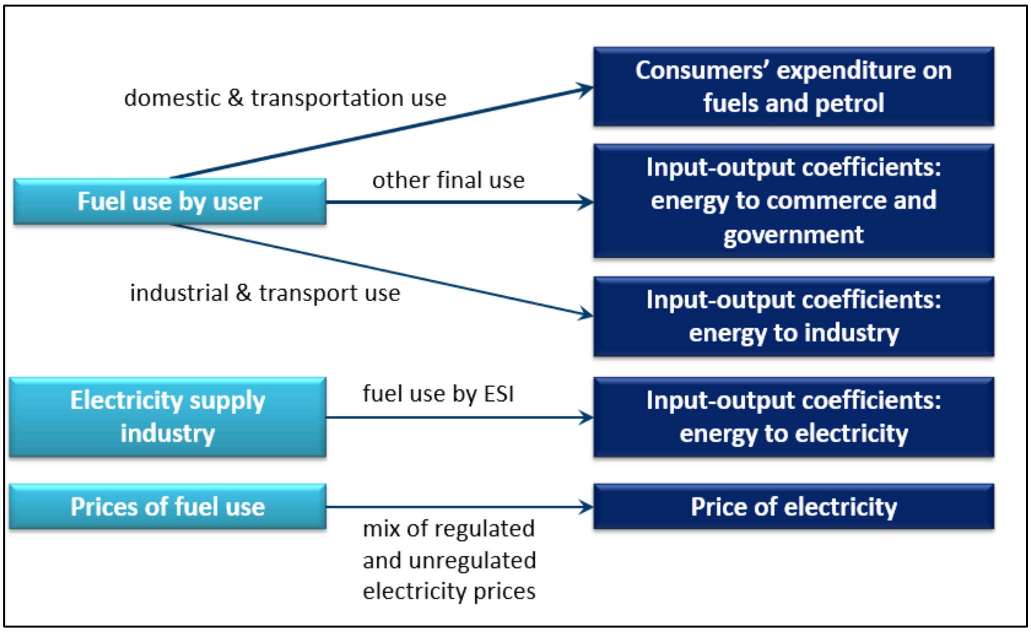


Figure 2.8:Feedbacks from the energy module



Price elasticities

The estimated energy demand price elasticities from E3-Thailand energy demand equations are the key in determining sectors' responsiveness to a carbon price.

In the long-run, energy demand is restricted to have minimum negative response to price increase in our energy demand equation. 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 will be modelled using E3-Thailand 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.

For most sectors, the restrictions range from -0.2 to -0.3, meaning a 1% increase in price lead to a minimum of 0.2-0.3% reduction in energy demand consumption. For the transport sector, a higher value of -0.45 can be used, taken from Franzen and Sterner (1995) and Johansson and Schipper (1997, p.289).

The long term price responses can be more than the minimum restrictions if the parameters estimated exceed the restricted values. Short-run elasticities are based on the time-series data and are usually close to zero.

Fuel substitution

Fuel use equations are estimated for five energy carriers (coal, oils, gas, electricity and biomass) with five sets of equations estimated for the fuel users. 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 can affect the choice.

One point to note is that the current version of E3-Thailand includes only existing fuel types for road transport. The econometric equations are not able to consider electrification of the transport system as there is no historical precedent for this.

These developments must therefore be entered by assumption by the model user.

Treatment of the power sector

The E3-Thailand model includes a detailed treatment of renewable technologies in the power sector, in the manner of the FTT:Power model (Mercure, 2012) in which 24 different technologies are defined (see Appendix B). However, the share of power sector technology are set to exogenous to allow users to specify their own fuel mix. For a given power sector mix, the FTT:Power model will provide the following feedbacks to E3-Thailand :

- electricity price feedback (calculated from average levelised costs of the power technology mix);
- power sector fuel consumption and emissions; and
- electricity investment.

In addition, model users can choose to include indirect emissions from electricity consumption when running a carbon tax or ETS scenario (see Section 3.7 Policy scenarios)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 energy balances (as time series), measured in toe
- an input-output flow in the National Accounts (for the base year), measured in m Baht

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

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 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 an 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 E3-Thailand, 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.

E3-Thailand's emission sub model

The emissions module calculates carbon dioxide emissions generated from end-use of different fuels and from primary use of fuels in the energy industries themselves, particularly electricity generation.

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) and so the source for the emissions factors is a combination of the sources for energy and emissions data. This forms the relationship between energy consumption and emissions.

Non-energy emissions

Non-energy emissions and processed emissions are not included in the current version of the E3-Thailand model. There is a scope to expand the model to use existing MACC curve to work out abatement cost per unit of emission reduction for non-energy emissions. This is subjected to data availability.

2.5 Innovation and endogenous technological progress

E3-Thailand's technology 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 E3-Thailand is adapted from that of Lee et al (1990). It adopts a direct measure of technological progress by using cumulative gross investment, but this is altered by using data on R&D expenditure, thus forming a quality adjusted measure of investment. The equation for Tt is written as:

$$T_t = c + \alpha dt(\tau 1)$$

where $dt(\tau 1)$ satisfies the following recursive formula

$$dt(\tau 1) = \tau 1 d_{t-1}(\tau 1) + (1 - \tau 1)\log(GI_t + \tau 2 RD_t)$$

where

GI_t = the level of gross investment

RD_t = constant-price research and development expenditure

τ1 = a measure of the impact of past-quality adjusted investment on the current state of technical advance, while

τ2 = a measure of the weight attached to the level of R&D expenditure.

To initialise the recursive process for d_t, the assumption is made that in the pre-data period the process generating $\log(GI_t)$ is characterised by a random walk. Under this assumption, the first value of d_t can be written as

$$d_t = \log(GI)$$

where the right-hand side represents the average of gross investment over the first five-year sample period. The series dt(τ1) is then calculated by working the recursive procedure forward given the initial value, d_0.

$\tau 1$ is set at 0.3 following an estimate of impacts based on the economic literature (Cambridge Econometrics, 2005). $\tau 2$ is set to 1 for the R&D expenditure.

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. Additionally, the term is included in the model's energy demand equations to represent efficiencies.

2.6 E3-Thailand limitation

General limitation

As a macroeconomic model for Thailand, it is not possible for firm-based level, individuals, labour skills or very detailed product groups to be included in the model. For this type of analysis our recommendation is that the model (which provides an indication of indirect and rebound effects) is used in conjunction with a more detailed bottom-up or econometric analysis (which can capture detailed industry-specific effects).

The other main limitation is related to its dimensions and boundaries. Broadly speaking E3-Thailand covers the economy, energy and energy-related CO_2 emissions in Thailand. Other world regions are treated as exogenous. While it is possible to provide an assessment of other policy areas, it is necessary to make assumptions about how this is translated into model inputs.

Limitation specific to CPI analysis

As mentioned previously, the current version of the E3-Thailand model does not include non-energy CO_2 emissions nor non-CO_2 greenhouse gases. This is mainly due to data limitation but also due to the characteristic of the E3-Thailand model. For example, E3-Thailand 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.

Despite the above caveat, a simple representation of the non-energy related CO_2 and other non-CO_2 emissions can be included in the future version of the E3-Thailand mode to ensure that the model emission results match published totals, and gives an indication of possible outcomes from policy. The following are data requirement:

- Industrial process emission split by energy users by time
- Other non-CO_2 emissions split by emission sources and by time:
  - sulphur dioxide (SO2)
  - nitrogen oxides (NOx)
  - carbon monoxide (CO)
  - methane (CH4)
  - larger particulates (PM10)
  - volatile organic compounds (VOC)
  - chlorofluorocarbons (CFCs)
  - nitrous oxide (N2O)
  - hydrofluorocarbons (HFC)
  - perfluorocarbons (PFC)
  - sulphur hexafluoride (SF6)

The general approach will be 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.

A more advanced approach of modelling the above emissions is to introduce existing MACC curve for each emission sources. The model can incorporate a simple look-up function to estimate an X% reduction in emission per Baht. However, this approach requires existing MACC curve study that is specific to Thailand case.

3 Data, databank and baseline

3.1 E3-Thailand data requirement

This chapter describes E3-Thailand's main model inputs and outputs. The following sections describe the main inputs that the model relies on, including data and econometric parameters.

All macroeconomic models are highly dependent on their data inputs, but this is particularly the case for econometric models where behavioural relationships are determined empirically.

E3-Thailand'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 Oxmetrics 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
- sector
- time period (annually from 1990)

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

The raw data are gathered from the sources described below and stored on the T databank (see next section). The model uses official sources as much as possible. 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 (2002 Baht). 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
- 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)

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

In addition, there are several macro-level time series that are used in the modelling. These include GDP, household incomes, tax and interest rates and the unemployment rate. They are also collected on an annual basis, starting from 1990.

Values and price indices in E3-Thailand

The general principle adopted in E3-Thailand 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 Baht and most constant values in millions of Baht at 2002 prices.

The price indices are calculated by dividing current by constant values in baht.

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. Other cross-sectional data include converters between model classifications that do not normally change over time.

Input-output tables in E3-thailand

Input-output flows in Thailand are converted to coefficients by dividing the columns by industry output. These coefficients give the number of units of input required to produce one unit of output. Furthermore, there is an adjustment to make sure that economic input-output relationships are consistent with the energy balances in physical terms in Thailand.

Energy and emissions data

Similar to economic time series data, the main dimensions for energy and emissions data are:

- indicator
- sector/ users/ fuels
- time period (annually from 1990)

The raw energy and emissions data are gathered from the sources described below and stored on the E databank (see next section). As above, 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

The main indicators for energy and environmental variables are:

- FR0 – total energy consumption by energy user
- FRET – electricity consumption by energy user
- FRCT – coal consumption by energy user
- FRGT – gas consumption by energy user
- FROT – oil consumption by energy user
- FRBT – biofuels consumption by energy user
- PFRE – electricity price by energy user
- PFRC – coal price by energy user
- PFRG – gas price by energy user
- PFRO – oil price by energy user
- PFRB – biofuel price by energy user
- FCO2 - CO_2 emissions by energy user

3.2 Data sources

Main data sources

The main data sources are:

- Office of the National Economic and Social Development Board of Thailand (NESDB)
- Bank of Thailand (BOT)
- The Revenue Department of Thailand
- Thailand National Statistical Office (TNSO)
- World Development Indicators (WDI), World Bank
- United Nations (UN)
- World Trade Organisation (WTO)
- International Energy Agency (IEA)
- Electricity Generating Authority of Thailand (EGAT)
- Department of Alternative Energy Department and Efficiency, Ministry of Energy (DEDE)
- Energy Policy and Planning Office, Ministry of Energy (EPPO)
- Other sources suggested by national experts

Table 3.1 data sources for the key variables in the model.

Table 3.1 Main data sources

Variable	Sources
GDP	NESDB
GVA by sectors	NESDB
IO table by sector	NESDB
Consumer spending by consumer sectors	NESDB
Investment by sectors	NESDB
Import and export by sectors	WTO
Import and export by sectors (services)	World Bank
Population by age and gender	UN
Employment by sector	LFS - TNSO
Compensation of employees by sector	NESDB
Labour force by age and gender	ILO
VAT	World Bank
Income tax	NESDB
Social security	NESDB
Benefit rate	NESDB
Income distribution	NESDB
Interest rate (base rate)	BOT
Government final spending by government sector	NESDB
Energy demand by energy types and users	DEDE IEA Energy balance
Energy price by energy types and users	EPPO IEA
CO2 emissions by users	EPPO
Other GHG emissions (preferably by users)	WB

Electricity capacity/generation by technology	EGAT

Note(s)* preliminary version, will be updated when final data processing is completed

3.3 Model classifications

Sector coverage

The following are list of main model classifications:

1 Agriculture
2 Forestry and logging
3 Fishing & aquaculture
4 Mining coal & lignite
5 Extraction oil & gas
6 Mining of metal ores
7 Other mining
8 Food products
9 Beverages
10 Tobacco products
11 Textiles
12 Wearing apparel
13 Leather products
14 Wood products
15 Paper products
16 Printing & publishing
17 Manufactured fuels
18 Chemicals products
19 Pharmaceutical
20 Rubber & plastics
21 Non-metallic minerals
22 Basic metals
23 Metal products
24 Computer & electronic
25 Electrical equipment
26 Other machinery
27 Motor vehicles
28 Oth transport equip.
29 Furniture
30 Other manufacturing
31 Repair & install
32 Electricity supply
33 Gas supply
34 Water supply
35 Private construction
36 Public construction
37 Sale of cars
38 Trade except cars
39 Land transport
40 Water transport
41 Air transport
42 Warehousing
43 Postal activities
44 Accommodation
45 Catering activities
46 Publishing activities
47 Motion pic & music
48 Program & broadcast
49 Telecommunications
50 Computer programming
51 Information services
52 Financial services
53 Insurance & pension
54 Finance auxiliary
55 Real estate activities
56 Imputed rents
57 Legal and accounting
58 Management consultant
59 Architect & engineer
60 Scientific R&D
61 Advertising
62 Other professionals
63 Veterinary
64 Rental and leasing
65 Employment activities
66 Travel agency etc
67 Security activities
68 Property maintenance
69 Office admin
70 Public admin & defense
71 Education
72 Health care
73 Arts & entertainment
74 Libraries & museums
75 Gambling & betting
76 Sport & recreation
77 Membership org.
78 Repair of HH goods
79 Other pers services
80 HH as employers

Consumer spending classification

1 Food
2 Drink (no-alcohol)
3 Drink (alcoholic)
4 Tobacco
5 Clothing & footwears
6 Housing & water
7 Electricity
8 Gas
9 Other fuels
10 Furniture & text
11 HH equip & maintenance
12 Health
13 Cars
14 Petrol
15 Cars operation
16 Transport
17 Communication
18 Equipment
19 Other recreation
20 Books etc
21 Education
22 Restaurants& hotels
23 Personal care
24 Personal effects
25 Financial services
26 Other services n.e.c.
27 Health, education, social protection
28 Other services n.e.c.

Fuels type classification

1 Coal
2 Oil
3 Gas

4 Electricity
5 Biofuels

Fuel users classification

1 Power own use & trans.
2 Other energy own use & transformation
3 Iron & steel
4 Non-ferrous metals
5 Chemicals
6 Cement
7 Other non-metallics
8 Ore-extra.(non-energy)
9 Food, drink & tobacco
10 Tex., cloth. & footwear
11 Paper & pulp
12 Plastic
13 Engineering etc
14 Other industry
15 Construction
16 Rail transport
17 Road transport
18 Air transport
19 Other transp. serv.
20 Households
21 Agriculture, forestry
22 Fishing
23 Other final use
24 Non-energy use

Government spending classification

1 Defense
2 Education
3 Health
4 Other
5 Unallocated

Global commodity classification

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 Others

Trading partners classification

1 China
2 USA
3 Japan
4 Vietnam
5 Malaysia
6 Indonesia
7 Rest of ASEAN
8 EU28
9 Rest of Annex I
10 Middle East
11 Africa
12 Rest of World

Household categories classification

1 All households
2 Farmer-Land owner
3 Farmer-rent
4 Farmer- others
5 Self-emp (non-farm)
6 Professional
7 Labourer (farm)
8 Labourer (logis &trans)
9 Services workers
10 Const & manuf workers
11 Inactive
12 Quintile 1
13 Quintile 2
14 Quintile 3
15 Quintile 4
16 Quintile 5

Dealing with data gaps

The team at Cambridge Econometrics has developed a software package to fill in gaps in any of the E3-Thailand time series. The approach uses growth rates and shares between sectors and variables to estimate missing data points, both in cases of interpolation and extrapolation. Some time series 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 are available but sectoral data are not; for example, government expenditure is a good proxy for the total growth in education, health and defence spending. 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.

3.4 Model databanks

Introduction to the model databanks

The following databanks are used to store the data for E3-Thailand:

- T – historical time-series data
- F – processed baseline forecast
- X – cross-section data, including input-output tables and equation parameters
- E – energy balances, prices and emissions
- U – classification titles

One other databank is used for model operation:

- S – holds the calibration factors to match the baseline forecast

3.5 Naming conventions

E3-Thailand'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 and F by energy (fuel) user. 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
- YR: (Gross) output by industry
- YRE: Employment by industry
- YRW: Wage rates by industry
- YRVA: Gross value added by industry
- CR: Consumption by consumption category
- PCR: Consumption prices by category

- RSC: Total consumption
- PRSC: Aggregate consumer price
- KR: Investment by investment category
- FR0: Total energy consumption by energy user
- FRET, FRGT, FROT, FRCT, FRBT: Electricity, gas, oil, coal biomass consumption by energy user
- FCO2: CO_2 emissions by energy user
- RCO2: CO_2 emissions

3.6 Exogenous assumptions

Assumptions file

Most of E3-Thailand exogenous inputs are stored in the model's assumption 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 2040 although historical values will get overwritten by the data stored on the model.

Commodity prices

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

Other world economies

Also, at the top of the assumption file there is a set of twelve other countries' GDP assumptions that form demand for Thai exports. The E3-Thailand model assumes that rates of growth in the rest of the world are exogenous, matching the numbers in the assumptions file. The figures are annual growth rates, in percentage terms.

Thailand assumptions

This is followed by a set of assumptions that are specific to Thailand. They are:

- Market exchange rate (Baht to Dollar)
- 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

3.7 Policy scenarios

Scenario file

E3-Thailand standard policy inputs are stored in a scenario file. The scenario file contains a set of policy inputs that relate to model scenarios. It can also be modified through the model Manager. Most of the policies in the scenario files are absent in the baseline. Policy inputs in the scenario file are categorised to three main groups: CO_2 emissions policies, energy policies and options to recycle the revenue generated from market-based instruments.

CO_2 emissions policies

The following CO_2 emissions policies are available in the scenarios file:

- annual CO_2 tax rate, Baht per tonne of CO_2
- annual CO2 allowances
- shares of allowances being auctioned
- offsets level
- sectors selling offsets
- costs of offsets
- option to include indirect emissions from electricity consumption in the carbon pricing policy
- switches to include different energy users in the policies
- switches to include different fuel types in the policies

Energy policies

The following energy policies are available in the scenario file:

- annual energy tax rate, Baht per toe
- switches to include different users in policies
- switch to include different fuel types in policies
- exogenous reduction in energy consumption by fuels and by energy users (modelling energy efficiency, regulations or fuel switching)
- costs of energy efficiency programs by energy users
- Exogenous power generation mix

Revenue recycling options

The scenario file includes options to recycle automatically the revenues generated from carbon taxes, auctioned revenues and energy taxes (so that government balances remain unchanged). There are three 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 rates, switch 0<X<1: 1=all, 0=none
- to lower VAT rates, switch 0<X<1: 1=all, 0= none
- to invest in general energy efficiency programs

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.

3.8 Baseline forecast

Overview

The E3-Thailand model can be used for forming a set of projections, but it is usually used only for policy analysis. Policy analysis is 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 E3-Thailand 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 2005 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 E3-Thailand analysis is that the baseline is made to be consistent with official published forecasts. The current E3-Thailand baseline is calibrated to the Business as Usual (BAU) baseline of the Thai NDC Roadmap (ONEP, 2017).

Methodology for calibrating

The first stage in matching the E3-Thailand 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:

- annual time periods
- sectoral coverage (including fuels and fuel users)
- National Accounts entries

The team at Cambridge Econometrics 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, E3-Thailand predicts a value of Baht100bn but the published forecast suggests Baht101bn 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 Baht100bn (endogenous baseline) and Baht102bn (scenario). These will be adjusted (multiplied) by the residual to become Baht101bn and Baht103.02bn.

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.

4 Econometric specifications

4.1 Introduction

This chapter provides the formal specification for the model's equations. There is a combination of identity (accounting) relationships and econometric equations.

We have grouped the equations into four main sections, covering the economy, labour market, trade and final energy demand.

The final section of this chapter provides a short description of the econometric specification that is used in the estimated equations.

Overview of econometric equations

We anticipate that the model will consist of 16 sets of econometric equations (see Table 4.1). These equation sets cover energy consumption, the main economic indicators, international trade and the labour market.

Table 4.2 and Table 4.3 summarise the variables that appear in each equation set. This table provides a quick reference; each term is explained in the following sections.

Most of these equation sets are disaggregated by sector.

Table 4.1: E3-Thailand's econometric equation sets

	Short Name	Description
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	BKR	Industrial Investment
9	BQRM	Imports
10	BQRX	Exports
11	BYRE	Industrial Employment
12	BPYH	Industrial Prices
13	BPQX	Export Prices
14	BPQM	Import Prices
15	BYRW	Industrial Average Earnings
16	BLRP	Labour Participation Rate

Table 4.2: Summary for equation specifications in E3-Thailand

Econometric equation	Main explanatory variables
Consumer spending (total)	real disposable income, interest rates, unemployment rates, inflation
Disaggregated consumer spending	real disposable income, relative prices of consumer products

Investment (by sector)	industry output, relative price of investment, future expected production, interest rate
International imports (by sector)	domestic demand, import price, domestic price, exchange rate, technology
International exports (by sector)	Global demand, export price, competing prices, exchange rate, technology
Employment (by sector)	industry output, wages, technology
Wages (by sector)	wage rates elsewhere, unemployment rate, benefit rates, expected inflation, expected production
Labour participation rate (by gender)	total output, average wage rate, unemployment rate
Output prices (by sector)	unit costs (materials, labour and taxes), competing import prices, technology, expected production
International import prices	export prices from trading partners, exchange rate, technology
International export prices	unit cost, other region export prices, exchange rate, technology
Total energy demand (by sector)	economic activity, weighted price of energy, investment, technology
Disaggregated energy demand (by fuel by sector)	economic activity, relative price of specific fuel, investment, technology

Table 4.3: Summary of econometric equations

	Endog. var	V1	V2	V3	V4	Units
1	FR0	FRY	PREN	FRKE		th toe
2-5	FR(fuel)	FR0	PFRF	FRKE		th toe
6	RSC	RRPD	RRLR	RUNR	PRSC/PSC1	m Baht 2002 prices
7	CR	RRPD	PRCR	RRLR	PRSC/PSC1	consumption ratio
8	KR	YR	PKR/PYR	RRLR		m Baht 2002 prices
9	QM0	QRDI	PYH/PQM	YRKE		m Baht 2002 prices
10	QRX	QRDW	PQX	YRKE		m Baht 2002 prices
11	YRE	YR	LYLC	PQMA		thousands
12	PYH	YRUC	PQM	YRKE		index 2002=1.0
13	PQRX	PQWE	EX	YRULT		index 2002=1.0
14	PQM	PQWE	EX	YRUL		index 2002=1.0
15	YRW	LYWE	YRWE	LYRP	RUNR	Baht per year
16	LRP	RSQ	RWS/REMP	RUNR		rate [0,1]

Use of dummy variables in estimation

The use of dummy variables in E3-Thailand will be restricted by the number of degrees of freedom offered by the time-series data but there one important case where a dummy variable is expected to be added to all the equation sets. This is to account for the financial crisis in 2009, which provoked many non-linear reactions across the world. To reduce bias in our parameter estimates, a dummy variable for 2009 (zero before 2009, one from 2009 onwards) will be tested in all the equation sets. If there are obvious alternatives for dummy variables (e.g. apparent breaks in the data), this will be tested as appropriate.

To avoid excessive repetition, the dummy variable is not included in the formal definitions of the econometric equations provided in the rest of this chapter, but it is an important part of the model estimation and solution.

4.2 Specification of economic equations

In this section we present the main economic equations, which cover the components of GDP and price formation. First, however, we show the most important accounting identities.

GDP, output and value added

The main measure of GDP is determined by demand-side factors in E3-Thailand, following the definition shown below. This follows the standard accounting definition.

Table 4.4: GDP identity

RGDP =	RSC + RSK + RSG + RSX - RSM + RSS
Definitions:	
RGDP	is GDP, m Baht at 2002 prices
RSC	is total consumer expenditure, m Baht at 2002 prices
RSK	is total investment (GFCF), m Baht at 2002 prices
RSG	is total final government expenditure, m Baht at 2002 prices
RSX	is total exports, m Baht at 2002 prices
RSM	is total imports, m Baht at 2002 prices
RSS	is total inventories, m Baht at 2002 prices

Output

While GDP provides a measure of net production at the whole-economy level, at the sectoral level we have (gross) output and gross value added. Output is equivalent to turnover in that it includes intermediate inputs to production, while value added does not include purchases from other sectors.

The measure of output is also determined from the demand side, in a similar way to GDP but also including the intermediate demands, as shown below. Each variable in the box is defined by sector.

Table 4.5: Calculation of output

QR =	QRY + QRC + QRK + QRG + QRX - QRM + QRR
Definitions:	
QR	Is a vector of output (by product), m Baht at 2002 prices
QRY	is a vector of intermediate goods, m Baht at 2002 prices
QRC	is a vector of final consumer output goods, m Baht at 2002 prices
QRK	is a vector of final investment goods, m Baht at 2002 prices
QRG	is a vector of final government goods, m Baht at 2002 prices
QRX	is a vector of final exported goods, m Baht at 2002 prices
QRM	is a vector of final imported goods, m Baht at 2002 prices

QRR	is a residual value to balance accounts, m Baht at 2002 prices

A fundamental part of the national accounting structure is that supply and demand must match. In the demand-driven structure of E3-Thailand this is imposed by ensuring that production matches the level of the goods demanded (if there are supply constraints that prevent this from happening then demand must be adjusted separately).

The basic relationship is presented below.

Table 4.6: Balancing supply and demand

YR	=	QR
Definitions:		
YR	is a vector of output (by industry), m Baht at 2002 prices	
QR	is a vector of output (by product), m Baht at 2002 prices	

Value added

Value added is defined as the difference between output and material input costs. Value added itself is the sum of wages, company profits and production taxes.

Table 4.7: Calculating GVA

YRF	=	YR - YRQ - YRT
Definitions:		
YRF	is a vector of value added, m Baht at 2002 prices	
YR	is a vector of output (by industry), m Baht at 2002 prices	
YRQ	is a vector of intermediate demands by industry, m Baht at 2002 prices	
YRT	is a vector of taxes on products, m Baht at 2002 prices	

Other important macroeconomic identities

GDP and value added are among the most important model results but there are other identity relationships that play an important role in determining these results. The key ones are presented in the following paragraphs, starting with the measures of consumer prices and inflation.

Consumer prices

Consumer prices are determined by converting industry prices to the relevant consumer products. For example, the prices of cars are determined by the output prices of the car industry, plus the contribution from transport and retail costs, plus the taxes on purchases of new cars.

The general structure of the relationships is shown below.

Table 4.8: Consumer prices

PCR	=	(BQRC * PQRD * CR) * ((1+CRTR) / CR)
Definitions:		
PCR	is a vector of consumer prices, by product, m Baht at 2002 prices	

BQRC	is a matrix that converts industry production to consumer products
PQRD	is a vector of prices of industry sales to the domestic market, m Baht at 2002 prices
CR	is a vector of consumer products, m Baht at 2002 prices
CRTR	is a vector of indirect tax rates on consumer products

The consumer price index

The aggregate consumer price index is obtained by taking the sum across all consumer products. Inflation is the annual change in the consumer price index.

Table 4.9: The consumer price index

PRSC = sum (PCR * CR) / RSC

Definitions:

PRSC	is the aggregate consumer price index, 2002 = 1.0
PCR	is a vector of consumer products' prices, 2002 = 1.0
CR	is a vector of expenditure on consumer products, m Baht at 2002 prices
RSC	is the sum of expenditure on consumer products, m Baht at 2002 prices

Household real incomes

Real incomes are the main driver of consumption, which is often the largest component of GDP. The level of real incomes is therefore a key model result. The variable is determined by summing wage and non-wage income in nominal terms, and converting to real terms.

Non-wage income includes rents from property and other financial and non-financial assets, plus remittances. It is very difficult to model and so will likely be held as a fixed differential to wage income (i.e. if wage income increases by 2% then it is assumed that non-wage income increases by 2% as well).

Table 4.10: Calculating real incomes

RRPD = (sum (YRW * YRE) + RRI) / PRSC

Definitions:

RRPD	is a measure of real household income, m Baht at 2002 prices
YRW	is the average annual wage in each sector, th Baht
YRE	is the employment level in each sector, th people
RRI	is a measure of non-wage ('residual') income, m Baht
PRSC	is the aggregate consumer price index, 2002 = 1.0

The remainder of this section describes the econometric equations that are used to determine economic outcomes in the model.

Household consumption

The model equations for household consumption are split into two separate sets. The first set estimates total consumption volumes, while the second set allocates this consumption according to the available budget.

Aggregate household consumption

The equation specification is given in Table 4.11. It should be noted that the dependent variable and terms for income in this equation are converted into per capita measures, although this is excluded from the table below for conciseness. As consumption accounts for around 50% of final demand in Thailand, the equation is very important within the model structure as a whole.

When assessing consumption levels, most studies have followed those of Davidson 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). However, in Thailand, we expect wealth effects to be small (and also data difficult to obtain) and so wealth is not included in the equations.

The specification of the equation generalises the permanent income and the lifecycle theories in an error correction model. 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 personal disposable income, inflation and interest rates. 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 in other countries.

Table 4.11: Aggregate consumption equations

Co-integrating long-term equation:			
LN(RSC)			[real consumers' expenditure]
	=	BRSC(8)	
	+	BRSC(9) * LN(RRPD)	[real gross disposable income]
	+	BRSC(10) * LN(RRLR)	[real rate of interest]
	+	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) * LN(RUNR)	[unemployment rate]
	+	BRSC(5) * DLN(RPSC)	[consumer price inflation]
	+	BRSC(6) * DLN(RSC(-1))	[lagged change in consumers' expenditure]
	+	BRSC(7) * ECM(-1)	[lagged error correction]
Identities:			
RRLR	=	1 + (RLR–DLN(PRSC))/100	[real rate of interest]
RRPD	=	(RGDI / PRSC)	[real gross disposable income]
Restrictions:			
BRSC(9) = 1			['life cycle hypothesis']
BRSC(2) >= 0			['right sign']
BRSC(3, 4, 5, 10) <= 0			['right sign']
0 > BRSC(7) > -1			['right sign']
Definitions			
BRSC	is a matrix of parameters		
RSC	is a vector of total consumers' expenditure, m Baht at 2002 prices		

RGDI	is a matrix of gross disposable income, m Baht at current prices
RLR	is a matrix of long-run nominal interest rates
RUNR	is a vector of unemployment rates, measured as a percentage of the labour force
PRSC	is a vector of consumer price deflator, 2002 = 1.0
RPSC	is a vector of consumer price inflation, in percentage terms

Disaggregate consumption

Both the long-term and dynamic equations in the disaggregate consumption equations have a similar specification to the aggregation consumption equations, but include the relative prices of each consumption category rather than an aggregate price index.

The equation specification for disaggregate consumption is shown in Table 4.12.

Table 4.12: Disaggregate consumption equations

Co-integrating long-term equation:			
LN(SHAR(.))			[consumers' budget share, logistic form]
	=	BCR(.,8)	
	+	BCR(.,9) * LN(RRPD)	[real gross disposable income]
	+	BCR(.,10) * LN(PRCR(.))	[relative price of consumption]
	+	BCR(.,11) * LN(RRLR)	[real rate of interest]
	+	BCR(.,12) * LN(PRSC)	[consumer price deflator]
	+	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(SHAR)(-1)	[lagged change in consumers' budget share]
	+	BCR(.,7) * ECM(-1)	[lagged error correction]
Identities:			
SHAR	=	(VCR(.)/VCRT) /	[consumers' budget share, logistic form]
		(1-(VCR(.)/VCRT))	
RRPD	=	(RGDI/RPSC)/RPOP	[real gross disposable income]
PRCR	=	VCR(.)/CR(.)/PRSC	[real price of consumption]
RRLR	=	1+(RLR-DLN(PRSC))/100	[real rate of interest]
Restriction:			
0 > BCR(.,7) > -1			['right sign']
Definitions:			
BCR	is a matrix of parameters		
CR	is a matrix of consumers' expenditure by commodity, m Baht at 2002 prices		
VCR	is a matrix of consumers' expenditure by commodity, m Baht at current prices		
VCRT	is a vector of total consumers' expenditure, m Baht at current prices		
RGDI	is a matrix of gross disposable income, in m Baht at current prices		

RLR	is a matrix of long-run nominal interest rates
PRSC	is a vector of total consumer price deflator, in percentage terms
RPSC	is a vector of consumer price inflation, in percentage terms

Investment

Investment (see Table 4.13) 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 E3-Thailand should disaggregate by asset (e.g. vehicles, plant and machinery, and buildings) as well as by investing industry, but this has not proved possible in most countries due to data limitations.

The specification of the investment equations in E3-Thailand builds upon earlier work in the E3ME model and 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.

E3-Thailand is bound by the investment-savings national accounts identity but the representation of capital markets in the model does not assume full ‘crowding out’, as is typically the case in CGE models. E3-Thailand allows for the possibility of non-optimal allocation of capital and takes into account theories of ‘endogenous money’, meaning that banks are not restricted to lending the funding they receive as deposits (i.e. fractional reserve banking is represented). This means that it is possible to have an increase in investment in one sector without necessarily seeing a reduction in investment elsewhere.

Table 4.13: The investment equations

Co-integrating long-term equation:			
LN(KR(.))			[investment]
	=	BKR(.,7)	
	+	BKR(.,8) * LN(YR(.))	[real output]
	+	BKR(.,9) * LN(PKR(.)/PYR(.))	[relative price of investment]
	+	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) * LN(RRLR)	[real rate of interest]
	+	BKR(.,5) * DLN(KR)(-1)	[lagged change in investment]
	+	BKR(.,6) * ECM(-1)	[lagged error correction]
Identities:			
RRLR	=	1 + (RLR – DLN(PRSC)) / 100	[real rate of interest]
Restrictions:			

BKR(.,2 .,8) >= 0	['right sign']
BKR(.,3 .,4 .,9) <= 0	['right sign']
0 > BKR(.,6) > -1	['right sign']

Definitions:

BKR	is a matrix of parameters
KR	is a matrix of investment expenditure by industry, m Baht at 2002 prices
YR	is a matrix of gross industry output by industry, m Baht at 2002 prices
PKR	is a matrix of industry investment price by industry, 2002 = 1.0
PRSC	is a vector of consumer price deflator, 2002 = 1.0
RLR	is a vector of long-run nominal interest rates
PYR	is a matrix of industry output price by industry, 2002 = 1.0

Industrial prices

The suggested model of industry price formation was developed from Lee (1988), having previously been derived from Layard et al (1991).

The basis for price setting is a measure of unit costs, which is formed by summing labour and taxation costs, and dividing this by sectoral output. 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.

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

- The electricity sector – based on long-run 'levelised' costs, or could be modelled as part of a regulated system.
- Government sectors – these are assumed to move in line with aggregate consumer price inflation.
- Regulated sectors – these are also assumed to move in line with aggregate consumer price inflation.

Table 4.14: Industrial price equations

Co-integrating long-term equation:			
LN(PYH(.))			[price of home sales by home producers]
	=	BPYH(.,7)	
	+	BPYH(.,8) * LN(YRUC(.))	[unit costs]
	+	BPYH(.,9) * LN(PQRM(.))	[import price]
	+	BPYH(.,10) * LN(YRKE(.))	[technological progress]
	+	ECM	[error]
Dynamic equation:			
DLN(PYH(.))			[change in price of home sales by home producers]
	=	BPYH(.,1)	
	+	BPYH(.,2) * DLN(YRUC(.))	[unit costs]
	+	BPYH(.,3) * DLN(PQRM(.))	[import price]
	+	BPYH(.,4) * DLN(YRKE(.))	[technological progress]
	+	BPYH(.,5) * DLN(PYH)(-1)	[lagged change in price]
	+	BPYH(.,6) * ECM(-1)	[lagged error correction]
Identities:			
PYH	=	(VQR(.) - VQRX(.)) / (QR(.) - QRX(.))	[price of home sales by home producers]
YRUC	=	YRUM(.,) + YRUL(.) + YRUT(.)	[unit costs]
YRUL	=	YRLC(.) / YR(.)	[unit labour cost]
YRUT	=	YRT(.) / YR(.)	[unit tax cost]
YRUM	=	(BQRY(.)*YR(.))* PQRD(.)	[unit material cost]
Restrictions:			
BPYH(.,2 .,3 .,8 .,9) >= 0			['right sign']
BPYH(.,8) + BPYH(.,9) = 1			[long-run cost pass-through]
0 > BPYH(.,6) > -1			['right sign']
Definitions:			
BPYH	is a matrix of parameters		
PQRM	is a matrix of import prices by industry, m Baht at 2002 prices		
YRKE	is a matrix of technological progress by industry		
YRLC	is a matrix of labour costs by industry, m Baht at current prices		
YRT	is a matrix of net taxes by industry, m Baht at current prices		
YR	is a matrix of gross industry output by industry, m Baht at 2002 prices		
QR	is a matrix of gross output by product, m Baht at 2002 prices		
QRX	is a matrix of exports by industry, m Baht at 2002 prices		
BQRY	is a matrix of input-output relationships		
PQRD	is a matrix of prices of sales to domestic markets, 2002 = 1.0		
V-	indicates a current price version of the variable		

4.3 Specification of labour market equations

Employment demand

The equation for employment demand follows the basic structure of the equations in the E3ME model. These equations are based on the work of Lee, Pesaran and Pierse (1990) but they also incorporate insights from the work on growth theory developed by Scott (1989).

In the econometric representation in E3-Thailand, employment is determined as a function of real output and real wage costs. This is shown in Table 4.15.

Table 4.15: Employment equations

Co-integrating long-term equation:			
LN(YRE(.))			[total employment]
	=	BYRE(.,6)	
	+	BYRE(.,7) * LN(YR(.))	[real output]
	+	BYRE(.,8) * LN(LYLC(.))	[real wage costs]
	+	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(YRE)(-1)	[lagged change in employment]
	+	BYRE(,.5) * ECM(-1)	[lagged error correction]
Identity:			
LYLC	=	(YRLC(.)/PYR(.)) / YREE(.)	[real labour costs]
Restrictions:			
BYRE(.,2 .,7) >= 0			['right sign']
BYRE(.,3 .,8) <= 0			['right sign']
0 > BYRE(.,5) > -1			['right sign']
Definitions:			
BYRE	is a matrix of parameters		
YRE	is a matrix of total employment by industry, in thousands of persons		
YR	is a matrix of gross output by industry, m Baht at 2002 prices		
YRLC	is a matrix of employer labour costs (wages plus imputed social security contributions) by industry, Baht at current prices		
PYR	is a matrix of output prices by industry, 2002 = 1.0		
YREE	is a matrix of wage and salary earners, in thousands of persons		

Industrial average earnings

The starting point for the equation formation of wage rates used in E3-Thailand 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 is provided in Barker and Gardiner (1996).

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. 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 specification allows for external industry effects on an industry's wage rates, effects of inflation and general economy-wide effects of the unemployment. 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 4.16: Industrial average earnings equations

Co-integrating long-term equation:			
LN(YRW(.))			[gross nominal average earnings]
	=	BYRW(.,7)	
	+	BYRW(.,8) * LN(YRWE(.))	[external industry wage rates]
	+	BYRW(.,9) * LN(PRSC(.))	[consumer price deflator]
	+	BYRW(.,10) * LN(RUNR(.,))	[unemployment rate]
	+	ECM	[error]
Dynamic equation:			
DLN(YRW(.))			[change in gross earnings]
	=	BYRW(.,1)	
	+	BYRW(.,2) * DLN(LYRWE(.))	[external industry wage rates]

	+	BYRW(.,3) * DLN(PRSC(.))	[consumer price deflator]
	+	BYRW(.,4) * DLN(RUNR(.))	[unemployment rate]
	+	BYRW(.,5) * DLN(YRW)(-1)	[lagged change in wage rates]
	+	BYRW(.,6) * ECM(-1)	[lagged error correction]

Identities:

YRWE(.)	=	SUM OVER I, J (I, J = all other industries) (LN(YRW(I)) * YRLC(I) / SUM(YRLC(I)))	[external industry wage rates]

Restrictions:

BYRW(.,9) = 1	[long-run in real terms]
BYRW(.,2 .,3 .,8) >= 0	['right sign']
BYRW(.,4 .,10) <= 0	['right sign']
0 > BYRW(.,6) > -1	['right sign']

Definitions:

BYRW	is a matrix of parameters
YRW	is a matrix of nominal average earnings (contractual wage) by industry, Baht per person-year
YRLC	is a matrix of nominal employer costs (wages and salaries plus employers' and imputed social security contributions) by industry, Baht at current prices
PRSC	is a vector of the consumer price deflator, 2002 = 1.0
RUNR	is a vector of the standardised unemployment rate

Labour market participation

The theoretical model for labour force participation rates (see Table 4.17) 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. Specifically, labour participation rates in E3-Thailand are modelled as a positive function of industry output and average wages. Moreover, they are also negatively related to the evolution of unemployment.

Table 4.17: Participation rate equations

Co-integrating long-term equation:			
LN(LRP/(1-LRP))			[participation rate, logistic form]
	=	BLRP(.,6)	
	+	BLRP(.,7) * LN(RSQ(.,))	[industry output]
	+	BLRP(.,8) * LN(RWS(.,)/(REMP(.,)))	[average wages]
	+	BLRP(.,9) * LN(RUNR(.,))	[unemployment rate]
	+	ECM	[error]
Dynamic equation:			
DLN(LRP/(1-LRP))			[participation rate, logistic form]
	=	BLRP(.,1)	
	+	BLRP(.,2) * DLN(RSQ(.,))	[industry output]
	+	BLRP(.,3) * DLN(RWS(.,)/(REMP(.,)))	[average wages]
	+	BLRP(.,4) * DLN(RUNR(.,))	[unemployment rate]
	+	BLRP(.,5) * ECM(-1)	[lagged error correction]
Identities:			
LRP	=	LABF / POP	[participation rate]
Restrictions:			
BLRP(.,2 .,3 .,7 .,8) >= 0			['right sign']
BLRP(.,4 .,9) <= 0			['right sign']
0 > BLRP(.,5) > - 1			['right sign']
Definitions:			
BLRP	is a matrix of parameters		
LRP	is a vector of labour force participation rates by gender and age group		
LABF	is a matrix of labour force by gender and age group, in thousands of persons		
POP	is a matrix of population of working age by gender and age group, in thousands of persons		
RSQ	is a vector of total gross industry output, m Baht at 2002 prices		
RWS	is a vector of total wages, m Baht at current prices		
RUNR	is a vector of the standardised unemployment rate		
REMP	is a vector of total employment, in thousands of persons		

4.4 Modelling trade

Demand in each sector can be met either by production in Thailand or production in another country.

Modelling changes in trade

There are four sets of econometric equations for international trade. They are:

- Export prices
- Export volumes
- Import prices
- Import volumes

The formal specification of the econometric equations is provided below.

Export volumes

In the E3-Thailand model exports are explained as a function of the demand of the rest of world for Thailand production, export prices and the technology variable. The technology variable is included to allow for the effects of innovations on trade performance.

Import volumes

In the import equations, activity is modelled by sales to the domestic market, the relative price of sales to the domestic market and the technical progress variable.

The price equations

The basic model of trade prices used in E3-Thailand assumes that each sector operates in oligopolistic markets and is small in relation to the total global 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 two price terms included in each regression to deal with developments outside Thailand. They are a world commodity price variable and the exchange rate.

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

Table 4.18: Export volume equations

Co-integrating long-term equation:			
LN(QRX(.))			[export volume]
	=	BQRX(.,7)	
	+	BQRX(.,8) * LN(QRDW(.))	[rest of the world demand]
	+	BQRX(.,9) * LN(PQRX(.))	[exports price]
	+	BQRX(.,10) * LN(YRKE(.))	[technological progress]
	+	ECM	[error]
Dynamic equation:			
DLN(QRX(.))			[change in internal export volume]
	=	BQRX(.,1)	
	+	BQRX(.,2) * DLN(QRDW (.))	[rest of the world demand]
	+	BQRX(.,3) * DLN(PQRX(.))	[exports price]

+	BQRX(.,4) * DLN(YRKE(.))	[technological progress]
+	BQRX(.,5) * DLN(QRX)(-1)	[lagged change in export volume]
+	BQRX(.,6) * ECM(-1)	[lagged error correction]

Restrictions:

BQRX(.,2 .,4 .,8 .,10) >= 0	['right sign']
BQRX(.,3 .,9) <= 0	['right sign']
0 > BQRX(.,6) > -1	['right sign']

Definitions:

BQRX	is a matrix of parameters
PQRX	is a matrix of export prices by industry, 2002 = 1.0
QRDW	is a matrix of production in the rest of the world, m Baht at 2002 prices
QRX	is a matrix of exports by industry, m Baht at 2002 prices
YRKE	is a matrix of technological progress by industry

Table 4.19: Export price equations

Co-integrating long-term equation:

LN(PQRX(.))		[export price]
=	BPQX(.,7)	
+	BPQX(.,8) * LN(PQWE(.)*EX)	[world commodity prices]
+	BPQX(.,9) * LN(YRULT(.))	[unit labour and tax costs]
+	ECM	[error]

Dynamic equation:

DLN(PQRX(.))		[change in export prices]
=	BPQX(.,1)	
+	BPQX(.,2) * DLN(PQWE(.)*EX)	[world commodity prices]
+	BPQX(.,4) * DLN(YRULT(.))	[unit labour and tax costs]
+	BPQX(.,5) * DLN(PQRX)(-1)	[lagged change in export prices]
+	BPQX(.,6) * ECM(-1)	[lagged error correction]

Identities:

PQWE	=	QMC(.) * PM	[world commodity price index]
YRULT	=	(YRLC(.) + YRT(.)) / QR(.)	[unit labour and tax costs]

Restrictions:

BPQM(.,8) = 1 – BPQM(.,9)	[price homogeneity]
BPQX(.,2 .,4 .,8 .,9) >=0	['right sign']
0 > BPQX(.,6) > -1	['right sign']

Definitions:

BPQX	is a matrix of parameters
EX	is a vector of exchange rates, Baht per Baht, 2002 = 1.0
QMC	is a converter matrix between industries and the world commodity classification
PM	is a vector of commodity prices (in Baht) for 7 commodities, 2002 = 1.0
YRLC	is a matrix of employer labour costs by industry, Baht at current prices
YRT	is a matrix of tax costs, by industry, m Baht at current prices
QR	is a matrix of gross output by industry, m Baht at 2002 prices

Table 4.20: Import volume equations

Co-integrating long-term equation:			
LN(QM0(.))			[import volume]
	=	BQRM(.,7)	
	+	BQRM(.,8) * LN(QRDI(.))	[home sales]
	+	BQRM(.,9) * LN(PYH(.)/PQRM(.))	[relative price]
	+	BQRM(.,10) * LN(YRKE(.))	[technological progress]
	+	ECM	[error]
Dynamic equation:			
DLN(QM0(.))			[change in internal import volume]
	=	BQRM(.,1)	
	+	BQRM(.,2) * DLN(QRDI(.))	[home sales]
	+	BQRM(.,3) * DLN(PYH(.)/PQRM(.))	[relative price]
	+	BQRM(.,4) * DLN(YRKE(.))	[technological progress]
	+	BQRM(.,5) * DLN(QRM)(-1)	[lagged change in import volume]
	+	BQRM(.,6) * ECM(-1)	[lagged error correction]
Identity:			
QRDI	=	QR(.) + QRM(.)	[home sales]
PYH	=	(VQR(.) - VQRX(.)) / (QR(.) - QRX(.))	[price home sales by home producers]
Restrictions:			
BQRM(.,2 .,3 .,8 .,9) >= 0			[‘right sign’]
BQRM(.,4 .,10) <= 0			[‘right sign’]
0 > BQRM(.,6) > -1			[‘right sign’]
Definitions:			
BQRM	is a matrix of parameters		
PQM	is a vector of import prices by industry, 2002 = 1.0		
QR	is a vector of gross output by industry, m Baht at 2002 prices		
QM0	is a vector of imports to Thailand by industry, m Baht at 2002 prices		
QRX	is a matrix of exports by industry, m Baht at 2002 prices		
YRKE	is a matrix of technological progress by industry		
V-	indicates a current price version of the variable		

Table 4.21: Import price equations

Co-integrating long-term equation:			
LN(PQM(.))			[import price]
	=	BPQM(.,7)	
	+	BPQM(.,8) * LN(PQWE(.)*EX)	[world commodity prices]
	+	BPQM(.,9) * LN(YRULT(.))	[unit labour and tax costs]
	+	ECM	[error]
Dynamic equation:			
DLN(PQM(.))			[change in export prices]
	=	BPQM(.,1)	
	+	BPQM(.,2) * DLN(PQWE(.)*EX)	[world commodity prices]
	+	BPQM(.,4) * DLN(YRULT(.))	[unit labour and tax costs]
	+	BPQM(.,5) * DLN(PQRX)(-1)	[lagged change in export prices]
	+	BPQM(.,6) * ECM(-1)	[lagged error correction]
Identities:			
PQWE	=	QMC(.) * PM	[world commodity price index]
YRULT	=	(YRLC(.) + YRT(.)) / QR(.)	[unit labour and tax costs]
Restrictions:			
BPQM(.,8) = 1 – BPQM(.,9)			[price homogeneity]
BPQM(.,2 .,4 .,8 .,9) >=0			[‘right sign’]
0 > BPQM(.,6) > -1			[‘right sign’]
Definitions:			
BPQM	is a matrix of parameters		
PQM	is a vector of imports to Thailand, by industry, m Baht at 2002 prices		
EX	is a vector of exchange rates, Baht per Baht, 2002 = 1.0		
QMC	is a converter matrix between industry and world commodity classifications		
PM	is a vector of commodity prices (in Baht) for 7 commodities, 2002 = 1.0		
YRLC	is a matrix of employer labour costs by industry, Baht at current prices		
YRT	is a matrix of tax costs, by industry, m Baht at current prices		
QR	is a matrix of gross output by industry, m Baht at 2002 prices		
PQRX	is a matrix of export prices by industries , 2002 = 1.0		

4.5 Specification of energy system equations

Overview

The energy model in E3-Thailand consists of four different parts:

- estimates of aggregate final energy demand
- estimates of final energy demand by carrier
- the power sector
- feedback to the economy

Final energy demand is solved using a two-stage process. First aggregate energy demand is estimated and then the estimates by fuel. A scaling process is applied to ensure consistency within the energy system. Finally, the feedback to the economy ensures consistency within the model as a whole.

Aggregate energy demand

The equation specification 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. The text below is based on the description in the E3ME model manual which has gradually been adapted over time to reflect the global coverage of the model.

It should be noted that the equations described here relate to final demand and refineries. The modelling scope for primary energy demand from the power sector is still to be decided during the model scoping workshop.

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 fuel equation considers the total fuel used 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 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 but this could be revisited in future.

Price elasticities

The long-run energy price elasticities in CE’s models are taken from the literature rather than estimated using the time-series data because the model will be used to assess permanent changes in price rather than the temporary fluctuations seen in the historical data. For example, in the E3ME model, the long-run price elasticity for road fuel is imposed at -0.7, 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 set at around -0.2.

Energy demand by carrier

The equations for disaggregated energy demand have been specified for five energy carriers[1]: coal, heavy fuel oil, natural gas, electricity and biofuels. 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 fuel demand equations (see above).

The price term is a ratio of the price for the particular energy carrier in relation to that of the aggregate energy price, taking into account variations in the prices for different fuels. Thus fuel switching is possible in the model.

Feedback to the economy

The feedbacks ensure that the economic impacts are consistent with those in the energy system. They occur through two main channels:

- adjustments to household expenditure to match the energy equations
- adjustments to input-output coefficients to match the energy equations

In both cases values that are measured in monetary terms are revised to be consistent with measures that are in physical units. There is an implicit (and widely accepted) assumption that these are consistent (e.g. after accounting for price changes, the energy content of Rs1m of coal does not change).

[1] These are also referred to as ‘fuels’ for brevity. Electricity is counted as a fuel.

Table 4.22: Aggregate energy demand equations

Co-integrating long-term equation:			
LN(FR0(.))			[total energy used by energy user]
	=	BFR0(.,7)	
	+	BFR0(,.8) * LN(FRY(.))	[activity measure]
	+	BFR0(.,9) * LN(PREN(.))	[average price ratio]
	+	BFR0(.,10) * LN(FRKE(.))	[technology measure]
	+	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(FRKE(.))	[technology measure]
	+	BFR0(.,5) * DLN(FR0(-1))	[lagged change in energy use]
	+	BFR0(.,6) * ECM(-1)	[lagged error correction]
Identity:			
PREN	=	PFR0(.) / PRYR	[relative price ratio]
Restrictions:			
BFR0(.,3 .,4 .,9 .,10) <= 0			['right sign']
BFR0(.,2 .,8) >= 0			['right sign']
0 > BFR0(.,6) > -1			['right sign']
Definitions:			
BFR0	is a matrix of parameters		
FR0	is a matrix of total energy used by energy user, th toe		
PFR0	is a matrix of average energy prices by energy user, Baht/toe		
PRYR	is a matrix of average producer prices in the economy as a whole, 2002 = 1.0		
FRY	is a matrix of activity by energy user, m Baht at 2002 prices		
FRKE	is a matrix of technological progress by industry, converted to energy users		

Table 4.23: Disaggregate energy demand equations

Equations used for F = Coal (C), Heavy Fuel Oil (O), Natural Gas (G), Electricity (E), and Biofuels (B)

Co-integrating long-term equation:

LN(FRF(.))			[fuel used by energy user]
	=	BFRF(.,7)	
	+	BFRF(.,8) * LN(FR0(.))	[total energy used by energy user]
	+	BFRF(.,9) * LN(PFRP(.))	[price ratio]
	+	BFRF(.,10) * LN(FRKE (.))	[technology index]
	+	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(FRKE (.))	[technology index]
	+	BFRF(.,5) * DLN(FRF(-1))	[lagged change in energy use]
	+	BFRF(.,6) * ECM(-1)	[lagged error correction]

Identity:

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

Restrictions:

BFRF(.,3 .,4 .,9 .,10) <= 0	['right sign']
BFRF(.,2 .,8) >= 0	['right sign']
0 > BFRF(.,6) > -1	['right sign']

Definitions:

BFRF	is a matrix of parameters
FRF	is a matrix of fuel used by energy user, th toe
FR0	is a matrix of total energy used by energy user, th toe
PFRF	is a matrix of prices for energy carrier F, by energy user, Baht/toe
PFR0	is a matrix of average energy prices by energy user, Baht/toe
FRKE	is a matrix of technological progress by industry, converted to energy users

4.6 Estimating emissions

The emissions module calculates air pollution generated from end-use of different fuels and from primary use of fuels in the energy industries themselves, particularly electricity generation. The full list of emissions is provided in the appendix; all the main GHGs are covered plus several 'local' pollutants.

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 tonne of oil equivalent) 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 model, 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.

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, the model 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.

4.7 Econometric technique

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, and as described earlier in this chapter.

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

E3-Thailand'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 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 and parameters are stored on the X databank. For each equation, the following information is given:

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

5 Software & hardware requirements and user interface

5.1 Introduction

The model and visualisation software can be run on any reasonably modern laptop or desktop PC with an internet connection and web browser. CE will provide the compiled version of the model so that any external users are not required to have experience of computer programming, and can run scenarios based on:

- different coverage of emission trading scheme
- modelling offsets
- variations in carbon prices
- different coverage of carbon or energy taxation
- different revenue recycling methods
- other climate, economic and labour market policies such as energy efficiency and renewable policy in the power sector

5.2 E3-Thailand model code

The model code is written in Fortran (based on existing routines in E3ME) and the code are compiled. An executable of the model and its input files are made available, but the normal user will not have any interaction directly with the code. Further to this, supporting files such as databanks, scenario inputs and model assumptions are provided in an easy to use format where users will be able to manipulate model inputs independently after an initial model training course.

The software routines can be separated into four sub-groups.

1. The first group consists of behavioural relationships that are empirically derived in the econometric estimation task. For this group of routines, alternative simplified calculations will also be included in the code for specific cases where the econometric estimations do not produce robust relationships, or in cases where econometric specifications are not appropriate. For example, investment made by the government sector is often based on a political decision and not influenced by the same factors that drive demand for investment in the private sector. In this case, we can introduce options for government investment to grow at the same rate as inflation, GDP or simply set to an exogenous value.
2. The second group of software routines represent identity relationships. For example, a national accounting balance where GDP must equal the sum of its components would fall into this category.
3. Routines in the third group are based on mathematical equations and/or imposed theories. The electricity technology sub model falls under this group of routines as it includes a mixture of behavioural and identity aspects.

4 The last group of software routines are measures included to declare, read and write model variables as well as performing basic operations such as calculating lags over time. These routines tend to be more technical than the others but, in many cases, can be taken from the existing E3ME model without further modification.

E3-Thailand is designed for scenario-application purposes and the code written reflected this. The model structure allows for calibration to an agreed set of projections to which scenarios can be compared.

Once the model is complete, we produce an executable file for E3-Thailand.

The next stage is to run this executable and solve the full model version. This process can take some time as there are many econometric equations interacting simultaneously. As described above, there may be an equation that does not produce a robust solution which can have knock on effects to other variables. The model solving phase is where we try to identify these equations and introduce alternative rules for them so as to ensure stability in the model as a system. The end goal of this phase is to have ‘converged’ model solutions throughout forecast period (2016-2040) for E3-Thailand.

Box 2 Delivering the model code

E3-Thailand runs on the existing IDIOM software platform, which provides many of the basic functions (e.g. reading in data). This is not be modified in the project and will not need to be changed in future.

The code for the E3-Thailand model are written using the Fortran 95 standard. The choice of programming language is for practical reasons to ensure fast execution. Although CE works with the Intel Fortran compiler the choice of language should not tie the TGO into a particular software package.

CE will provide the E3-Thailand model code to the TGO so that they can make further modifications in future without having to rely on input from CE. As with any large program, a certain degree of expertise is required to implement changes. CE is happy to advise on this.

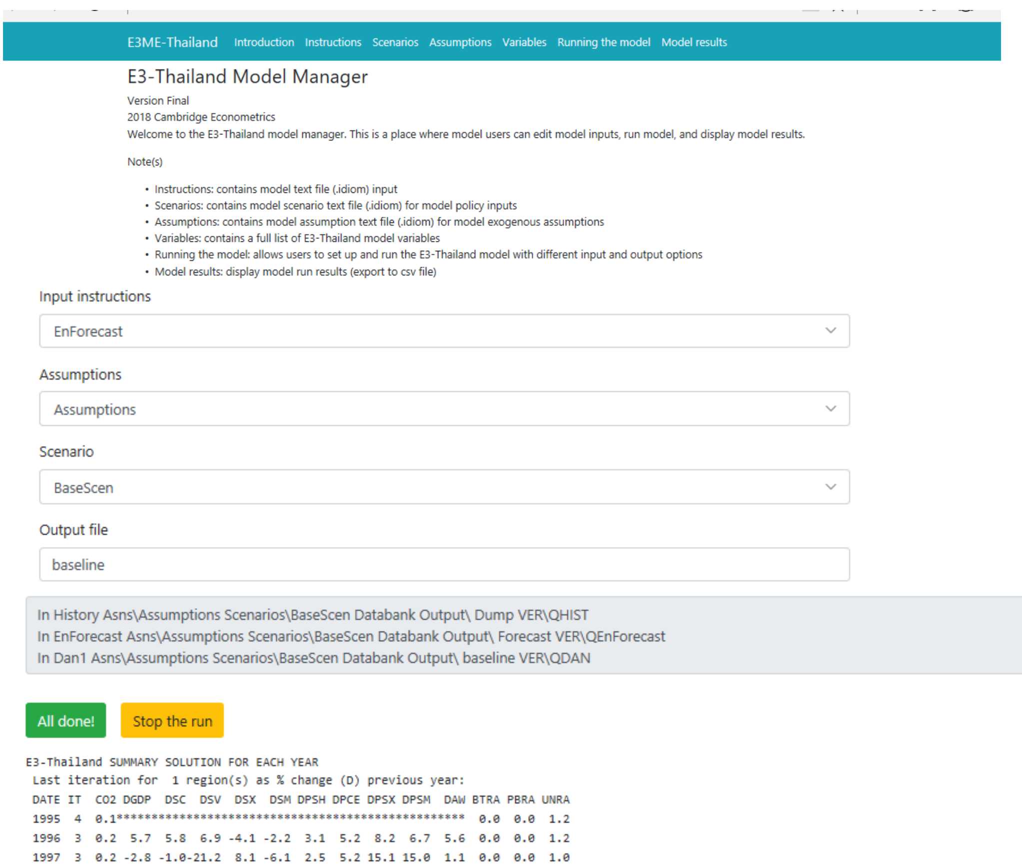
5.3 User interface

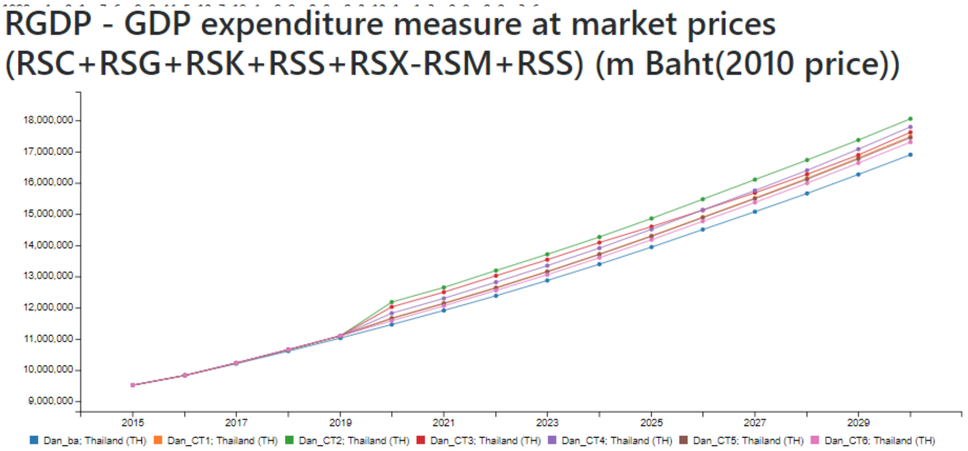
The last step of the model construction is to transfer the E3-Thailand model executable to our inhouse user-friendly visualisation software called ‘Manager’.

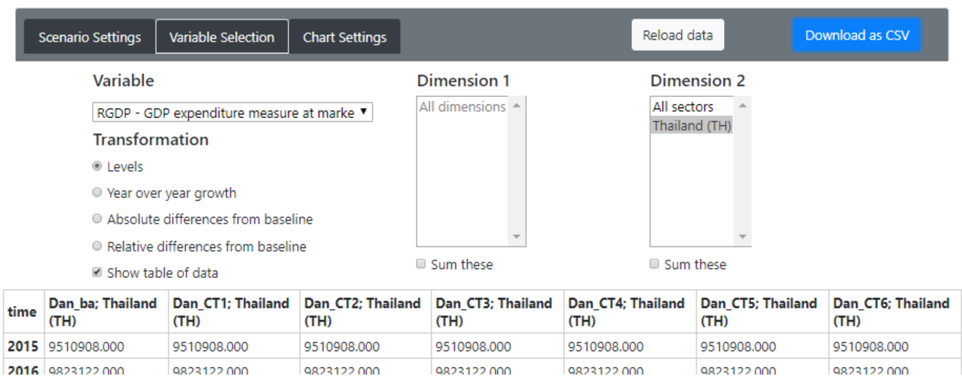
The visualisation software is designed to operate in a standard web browser. It shows a graphical representation of results in the form of line charts over time, and allows for an easy comparison of different model scenarios

The Manager software collates all E3-Thailand model inputs into one place, enabling users to make changes directly to the input files or to load files that have been edited elsewhere and run the model. It is also used for viewing the model results.

Below are examples of the E3-Thailand users model interface







5.4 Software installation

System requirement

E3-Thailand is set up to run on a PC running Windows version 8 or higher . There are otherwise no specific computer requirements but the software works best in Google Chrome, and we highly recommend using Chrome as a platform for the software. The model has also been tested in Microsoft Edge but it does not operate in older versions of Internet Explorer.

The Manager software is provided as part of a package for the E3-Thailand model. It collates all E3- Thailand model inputs into one place, enabling users to make changes directly to the input files or to load files that have been edited elsewhere (e.g. using other text editor software) and viewing the model results.

Getting started

To get started:

1. Download the software from the E3-Thailand website to the directory C:\E3-Thailand on your local drive.

2. In the C:\E3-Thailand\ directory, launch the shortcut manager.exe.

This will launch the E3-Thailand Model Manager software in your default internet browser. The link may be copied into another browser window, so it is not necessary to set Chrome as your default browser.

Appendix A References

Barker, T S (1977), 'International trade and economic growth: an alternative to the neoclassical approach', Cambridge Journal of Economics, 1, pp153-172.

Barker, T S and A W A Peterson (1987), ‘The Cambridge Multisectoral Dynamic Model of the British Economy’, Cambridge University Press.

Barker, T S, R van der Putten and I Stern (1993), 'HERMES: a macrosectoral model for the UK economy', in CEC (eds), HERMES: Harmonised Econometric Research for Modelling Economic Systems, North Holland

Barker, T S, Ekins, P and N Johnstone (1995), ‘Global Warming and Energy Demand’, Routledge, London.

Barker, T S and B Gardiner (1996), 'Employment, wage formation and pricing in the European Union: empirical modelling of environment tax reform', in C Carraro and D Siniscalco (eds), Environmental Fiscal Reform and Unemployment, pp. 229-272, Kluwer.

Barker, T S (1998), 'The effects on competitiveness of coordinated versus unilateral fiscal policies reducing GHG emissions in the EU: an assessment of a 10% reduction by 2010 using the E3ME model', Energy Policy, vol. 26, no. 14, pp. 1083-1098.

Barker, T S (1998), 'Use of energy-environment-economy models to inform greenhouse gas mitigation policy', Impact Assessment and Project Appraisal, vol. 16, no. 2, pp. 123-131.

Barker, T S (1998), 'Large-scale energy-environment-economy modelling of the European Union', in Iain Begg and Brian Henry (eds), Applied Economics and Public Policy, Cambridge University Press.

Barker, T S and K E Rosendahl (2000), ‘Ancillary Benefits of GHG Mitigation in Europe: SO2, NOx and PM10 reductions from policies to meet Kyoto targets using the E3ME model and EXTERNE valuations’, Ancillary Benefits and Costs of Greenhouse Gas Mitigation, Proceedings of an IPCC Co-Sponsored Workshop, March, 2000, OECD, Paris.

Barker, T S, A W A Peterson and A Winters (1984), 'IDIOM: an international dynamic input-output model', pp. 183-192 in UNIDO (ed.) Proceedings of the Seventh International Conference on Input-Output Techniques, United Nations, New York.

Barker, T S, S De-Ramon and H Pollitt (2009), 'Revenue recycling and labour markets: effects on costs of policies for sustainability', in (eds) V. Bosetti, R. Gerlagh and S. Schleicher, Modelling Transitions to Sustainable Development, Elgar, Cheltenham, UK.

Barrell, R and P Davis (2007), ‘Financial liberalisation, consumption and wealth effects in seven OECD countries’, Scottish Journal of Political Economy, 54(2) 254-67.

Bentzen, J and T Engsted, (1993), 'Short- and long-run elasticities in energy demand: a cointegration approach', Energy Economics, 15(1) 9-16.

Briscoe, G and R Wilson (1992), 'Forecasting economic activity rates', International Journal of Forecasting, 8, pp201-217.

Cambridge Econometrics (2007), 'IDIOM International Dynamic Input-Output Modelling Language User's Guide', available on request.

Cambridge Econometrics and Université Libre de Bruxelles (2005), 'Simulation of R&D investment scenarios and calibration of the impact on a set of multi-country models', Final Report.

Davidson, J, D Hendry, F Srba and S Yeo (1978), 'Economic modelling of the aggregate time series relationship between consumers' expenditure and income in the UK', Economic Journal, Vol 80, pp899-910.

Doornik, J A (2007), 'Ox: An Object-Oriented Matrix Language', London: Timberlake Consultants Press.

Ekins, P, H Pollitt, J Barton and D Blobel (2011), 'The Implications for Households of Environmental Tax Reform (ETR) in Europe', Ecological Economics, Volume 70, Issue 12, pp2472-2485, Elsevier.

Ekins, P, H Pollitt, P Summerton and U Chewpreecha (2012), 'Increasing carbon and material productivity through environmental tax reform', Energy Policy, 42, 365-376.

Engle, R F and C W J Granger (1987), 'Cointegration and error correction: representation, estimation and testing', Econometrica, 55, 251-76.

Engle, R F and C W J Granger (1991), 'Long-Run Economic Relationships (Readings in Cointegration)', Oxford University Press.

Franzén, M and T Sterner (1995), 'Long-run Demand Elasticities for Gasoline', in Barker, T., N. Johnstone and P. Ekins (eds.), Global Warming and Energy Elasticities, Routledge.

Gateley, D (1993), 'The imperfect price-reversibility of world oil demand', The Energy Journal, Vol. 14, No. 4, pp. 163-181.

Hendry, D F (1994), 'Dynamic Econometrics', Oxford: Oxford University Press.

Hendry, D F and M P Clements (1994), 'On a theory of intercept corrections in macro-economic forecasting', in S. Holly (eds) Money, Inflation and Employment: Essays in Honour of Sir James Ball, Edward Elgar.

Hendry, D F, Pagan, A and J D Sargan (1984), 'Dynamic specification, in Handbook of Econometrics', Vol II, Griliches, Z and M D Intriligator (eds), Amsterdam, North Holland.

Hunt, L and N Manning (1989), 'Energy price- and income-elasticities of demand: some estimates for the UK using the cointegration procedure', Scottish Journal of Political Economy, 36(2) pp183-193.

Johansson, O and L Schipper (1997), 'Measuring the long-run fuel demand of cars', Journal of Transport Economics and Policy, Vol XXXI, No 3, pp 277-292.

Layard, P R G and S J Nickell (1986), 'Unemployment in Britain', Economica, Vol. 53, No. 210(S).

Layard, R, Nickell, S and R Jackman (1991), 'Unemployment', Oxford University Press, Oxford, UK.

Lee, K, M H Pesaran and R G Pierse (1990), 'Aggregation Bias in Labour Demand Equations for the UK Economy', Chapter 6 in Barker, T and M H Pesaran (eds) Disaggregation in Econometric Modelling, Routledge.

Lee, K & K Shields (1997), 'Modelling sectoral output growth in the EU economies', Workpackage 4.1: Supply-side Specification for Output, University of Leicester.

Lee, K C and M H Pesaran (1993), 'The Role of Sectoral Interactions in Wage Determination in the UK Economy', The Economic Journal, January 1993.

Lee K and K Shields (1997), 'Modelling Sectoral Output Growth in the EC Economies', E3ME Working Paper No 15, Workpackage 4.1: Supply-Side Specification for Output.

Lee K (1988), 'Labour Market Adjustment in a Disaggregated Model of the UK Supply Side', DAE Working Paper No. 8810.

Mercure, J-F (2012), 'FTT:Power A global model of the power sector with induced technological change and natural resource depletion', Energy Policy, 48, 799–811.

Mercure, J-F and P Salas (2012), 'An assessment of global energy resource economic potentials', Energy, 46(1), 322–336.

Mercure, J-F, and P Salas (2013), 'On the global economic potentials and marginal costs of non-renewable resources and the price of energy commodities', Energy Policy, (63), 469–483.

Ministry of Natural Resources and Environment (Thailand) ONEP (2017), Thailand’s Nationally Determined Contribution Roadmap on Mitigation 2021 - 2030.

Pesaran, M H (1988), 'Costly Adjustment Under Rational Expectations: A Generalisation', UCLA Working Paper No 480.

Pesaran, M H and R J Smith (1994), 'A Generalised R2 for Regression Models Estimated by the Instrumental Variables Method', Econometrica, pp705-710.

Pesaran, M H and R Smith (1992), ‘Estimating Long-Run Relationships from Dynamic Heterogenous Panels’, presented at Fourth conference on Panel Data, Budapest, June 18-19th 1992.

Peterson, A W A, T S Barker and R van der Ploeg (1983), 'Software support for multisectoral dynamic models of national economies', Journal of Economics Dynamics and Control, Vol. 5, l983, pp. l09-l30.

Scott, M F G (1989), ‘A New View of Economic Growth’, Oxford: Clarendon Press.

Serletis, A (1992), 'Unit root behaviour in energy future prices', The Economic Journal, 13(2), pp119-128.

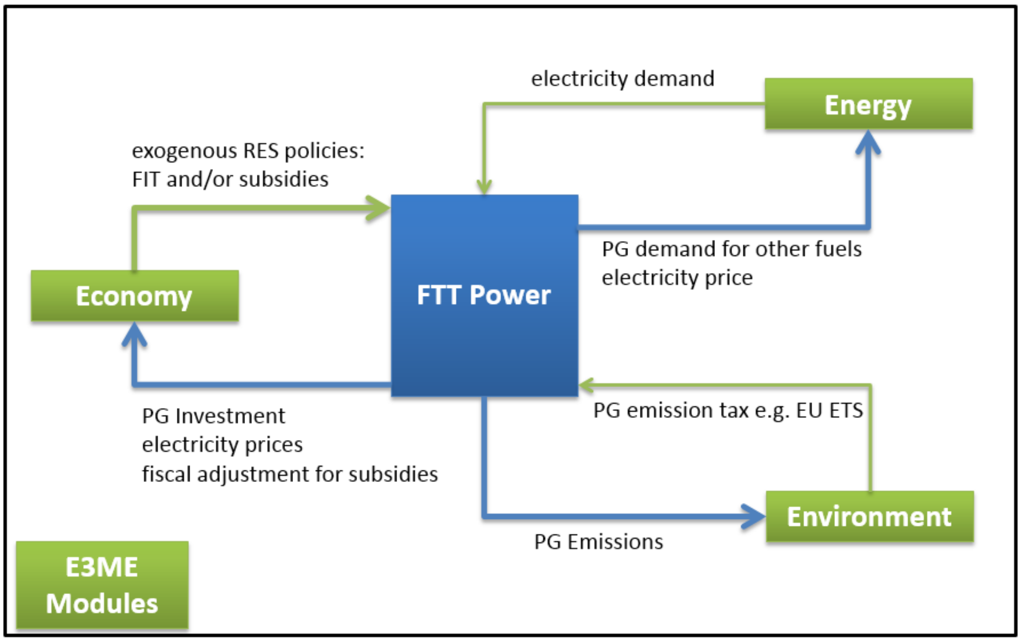
Appendix B Power Sector Modelling

B.1 Representation of renewables and the power sector

Overview

The power sector in E3ME is represented using a 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.

Figure 5.1: FTT basic structure



Input and feedbacks

FTT:Power determines a technology mix 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 an electricity price, fuel use and investment for replacements and new generators.

Application of FTT:Power in E3-Thailand

The FTT:Power model is designed to assess the effects of policies that influence the deployment of renewable power. Policies that it considers include Feed-in-Tariffs, direct subsidies and various energy and carbon pricing mechanisms. The model can also be used as a framework to assess exogenous renewable shares, as it estimates levelised costs based on inputs on capital and fuel prices. The model will be set up so that both options are available.

Natural resource constraints

The representation of FTT:Power in E3ME includes constraints on the supply of both renewable and non-renewable resources (Mercure & Salas, 2012, 2013, e.g. barrels of oil, or suitable sites for wind farms). We will aim to incorporate a measure of renewable resources into E3-Thailand. This is of course dependent on the necessary data being available.

FTT-Power technology classification

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
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

Appendix C Scenario file inputs

Name	Description	Dimension	Unit	Examples	Note
			ETS inputs		
IDEE	Switch to include indirect emission from electricity consumption in carbon tax or ETS	n/a	0 or 1 only	0 = exclude 1 = include	Values other than 0 or 1 will not work
RETS	Annual emissions caps (need to reflect coverage FETS, JEDS and indirect emissions if included)	Years	th tCO2	167377 th tCO2	Obtain baseline emissions for the selected ETS sectors from the model FCO2 (excludes indirect emissions) or FCE2 (includes indirect emissions). Then work out the new cap for the selected ETS sectors.
FETS	Exemptions from ETS(fuel user)	Energy users	0 to 1	0=fully exempt 1=fully included 0.5=half of emissions by this fuel are included	Selection of the sectors to be included in the trading scheme. FETS are used for both cases of ETS modelling endogenous price (exogenous cap RETS) or exogenous price REPX (endogenous reduction)
JETS	Exemptions from ETS(fuel)	Fuels	0 to 1	0=fully exempt 1=fully included 0.5=half of emissions by this fuel are included	Selection of the fuels to be included in the trading scheme (carbon price get applied to their carbon content). JETS are used for both cases of ETS modelling endogenous price (exogenous cap RETS) or exogenous price REPX (endogenous reduction)
RAUC	Annual percentage of caps being auctioned	Years 2001-50	0 to 1	0=0% (grandfathered) 1=100% (auctioned) 0.5=50% (half grandfathered, half auctioned)	If there is no sectoral differences in term of how permits are allocated (FEPA switch below) then user can set this main switch which will get applied to all covered sectors. If RAUC is > 0 (some auctioned) make sure FEPA is set to 1 for all sectors.

Name	Description	Dimension	Unit	Examples	Note
					The calculation of auctioned revenues are sum of (permit price x permit used x RAUC(total) x FEPA(sectors)).
FEPA	Emission permit allocation (1= 100% allocation 0 = 100% grandfathered)	Energy users	0 to 1	0=0% (grandfathered) 1=100% (auctioned) 0.5=50% (half grandfathered, half auctioned)	Use this to differentiate different allocation method by sectors. This needs to correspond the ETS sectors (FETS). Make sure if there are distinctions by sectors then RAUC (main switch) is set to 1. The calculation of auctioned revenues are sum of (permit price x permit used x RAUC(total) x FEPA(sectors))
ROST	Annual total offsets allowed	Years 2001-50	th tCO2	4405 th tCO2	This is the amount of mitigation offsets that the ETS sectors can purchase from uncovered sectors
FOST	Offsets allocation to other sectors, share of total offsets ROST	Energy users	0 to 1 (sum must equal to 1)	0.1 = 10% share of ROST	This is where the offsets come from. Only make sense if the offsets come from sectors outside the ETS sectors. The share must equal to 1, e.g. 0.5 from power generation (50%) and 0.5 from road transport (50%)
POST	Annual costs of offsets sold by sector providing offsets	Energy users x Years 2001-50	Baht/tCO2	500 Bath per tonne of CO2	Users can define the costs of offsets that the ETS sector must pay. It only makes sense if these costs are less than ETS price but the model doesn't have this in-build condition so users can still If leave as 0 the model assumes the same costs as ETS price.
REPX	Annual exogenous carbon price as additional excise duties	Years 2001-50	Baht/tCO2	500 Bath per tonne of CO2	ETS price (if exogenous) applied to fuel user **i** consumption of fuel **j** in time **t** is REPX**t** x FETS**i** x JETS**j**
			Carbon tax inputs		

Name	Description	Dimension	Unit	Examples	Note
RTCA	Annual carbon tax as additional excise duties	Years 2001-50	Baht/tCO2	500 Bath per tonne of CO2	Carbon tax applied to fuel user **i** consumption of fuel **j** in time **t** is RTCA**t** x FEDS**i** x JEDS**j**
FEDS	Exemptions from carbon tax (fuel user)	Energy users	0 to 1	0=fully exempt 1=fully included 0.5=half of emissions by energy user are included	Selection of the sectors to be included in the carbon tax.
JEDS	Exemptions from carbon tax (fuel)	Fuels	0 to 1	0=fully exempt 1=fully included 0.5=half of emissions by this fuel are included	Selection of the fuels to be included in the carbon tax (carbon tax get applied to their carbon content).
			Energy tax inputs		
RTEA	Annual energy tax as additional excise duties	Years 2001-50	Baht/toe	5000 Bath per tonne of oil equivalent	Energy tax applied to fuel user **i** consumption of fuel **j** in time **t** is RTEA**t** x FEES**i** x JEES**j** Tip: you can also model removal of energy subsidies using energy tax as a proxy
FEES	Exemptions from energy tax (fuel user)	Energy users	0 to 1	0=fully exempt 1=fully included 0.5=half of emissions by energy user are included	Selection of the sectors to be included in the energy tax.
JEES	Exemptions from energy tax (fuel)	Fuels	0 to 1	0=fully exempt 1=fully included 0.5=half of emissions by this fuel are included	Selection of the fuels to be included in the energy tax (not this is a tax on fuel consumption not the carbon content of fuels)
			Revenue recycling inputs		
RRTE	Proportion of energy and emissions tax revenues to reduce RERS (social security)	Years 2001-50	0 to 1	0 = no revenue recycling 0.5 = 50% of revenues are used to reduce	

Name	Description	Dimension	Unit	Examples	Note
				standard employer's security contribution rate 1 = 100% of revenues	
RRTR	Proportion of energy and emissions tax revenues to reduce RDTR (direct tax)	Years 2001-50	0 to 1	0 = no revenue recycling 0.5 = 50% of revenues are used to reduce standard direct income tax rate 1 = 100% of revenues	The model automatically calculate total revenues from carbon tax, energy tax and auctioned ETS revenues. If user wishes to have more than one recycling method then make sure that the sum of RRTE, RRTR, RRVT and RREE add to 1 (i.e. the full amount of revenues generated). There is no build-in error message to prevent users from recycling more than 100% of revenues generated.
RRVT	Proportion of energy and emissions tax revenues to reduce RSVT (VAT)	Years 2001-50	0 to 1	0 = no revenue recycling 0.5 = 50% of revenues are used to reduce standard VAT rate 1 = 100% of revenues	
RREE	Proportion of energy and emissions tax revenues to invest in energy efficiency	Years 2001-50	0 to 1	0 = no revenue recycling 0.5 = 50% of revenues are used to reduce standard employer's security contribution rate 1 = 100% of revenues	
Energy efficiency inputs					
FSEE	Switch for eligibility for EE investment (model allocate savings based on existing use)	Energy users	0 to 1	0 = not eligible 0.5 = half of the sector eligible 1 = 100% eligible	This switch compliments RREE (revenue recycling through energy efficiency investment). It tells the model which sectors are eligible for the investment.
FEEC	Costs of energy efficiency investment per user (default 5m Bath per ktoe reduction)	Energy users x Years 2001-50	Bath per ktoe	10.2 = 10.2 million Baht per one kilo tonne of oil equivalent energy savings (this can be varied by sectors and by time)	The default values of approximately 5m Baht per toe are taken from the IEA Energy Efficiency (2017)

Name	Description	Dimension	Unit	Examples	Note
FCX	Exogenous changes in coal consumption by energy users	Energy users x Years 2001-50	th toe	-10 = 10 th toe coal consumption savings (this can be varied by energy user and by time)	This scenario input is used for modelling exogenous energy efficiency (on top of endogenous from revenue recycling).
FOX	Exogenous changes in oil consumption by energy users	Energy users x Years 2001-50	th toe	-10 = 10 th toe oil consumption savings (this can be varied by energy user and by time)	
FGX	Exogenous changes in gas consumption by energy users	Energy users x Years 2001-50	th toe	-10 = 10 th toe gas consumption savings (this can be varied by energy user and by time)	
FEX	Exogenous changes in electricity consumption	Energy users x Years 2001-50	th toe	-10 = 10 th toe electricity consumption savings (this can be varied by energy user and by time)	
FBX	Exogenous changes in biofuel consumption	Energy users x Years 2001-50	th toe	-10 = 10 th toe biofuel consumption savings (this can be varied by energy user and by time)	
Renewables in the power sectors					
MTKS	Share of power generation capacity in Thailand (%)	Power generation technologies x Years 2001-50	0 to 1 (must add up to 1)	0.1 = 10%	Users can use this input to determine exogenously the power mix in Thailand. The model will calculated electricity price, feedback on fuel demand by the power sector and investment required from this power mix automatically.

Appendix D Assumption file inputs

Code	Description	Unit
Global		
CPRICE_FOOD_FEED	Commodity Price: Food/ feed	Year-on-year growth
CPRICE_WOOD	Commodity Price: Wood	Year-on-year growth
CPRICE_CONS_MIN	Commodity Price: Construction minerals	Year-on-year growth
CPRICE_IND_MIN	Commodity Price: Industrial minerals	Year-on-year growth
CPRICE_FER_ORES	Commodity Price: Ferrous metals	Year-on-year growth
CPRICE_NFER_ORES	Commodity Price: Non-ferrous metals	Year-on-year growth
CPRICE_COAL	Commodity Price: Coal	Year-on-year growth
CPRICE_BRENT_OIL	Commodity Price: Brent oil	Year-on-year growth
CPRICE_GAS	Commodity Price: Gas	Year-on-year growth
CPRICE_OTHERS	Global Inflation	Year-on-year growth
Thailand		
EXCH_THB_PER_USD	Exchange rate	Thailand Baht per one US dollar
SR_INTEREST	Interest rate: short run	Percent
LR_INTEREST	Interest rate: long run	Percent
TOT_GOV_SPENDING	Government spending	Year-on-year growth
SHAR_DEFENCE	Government spending: Defence	Share of total government spending
SHAR_EDUCATION	Government spending: Education	Share of total government spending
SHAR_HEALTH	Government spending: Health	Share of total government spending
TAX_INDIRECT	Tax: Indirect	1 + Share of household spending
VAT_RATE	Tax: VAT	Rate
TAX_DIRECT	Tax: Direct	Rate (wages)
BENEFIT_PAYMENT	Benefit Payment	Share of wage
SOCSEC_EMPLOYEES	Soc sec employees' contributions	Rate
SOCSEC_EMPLOYERS	Soc sec employers' contributions	Rate