The Regulatory Assistance Project

The E3-India Model

Technical model manual, Volume 5:
Theoretical description of E3-India

cambridge econometrics
clarity from complexity

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Contents

1 A Detailed Description of E3-India

1.1 Introduction and underlying theory

Introduction

The following account of E3-India starts with a brief discussion of the theory behind the model. We then move on to the basic model structure before describing in more detail the main modules (the 3 E's, economy, energy and environment). The final two sections in this volume describe the model's technological progress indicators and compare E3-India to other common modelling approaches.

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 general equilibrium models: they typically assume constant returns to scale; perfect competition in all markets; maximisation of social welfare measured by total discounted private consumption; no involuntary unemployment; and exogenous technical progress following a constant time trend (see Section 1.5 and Barker, 1998, for a more detailed discussion).

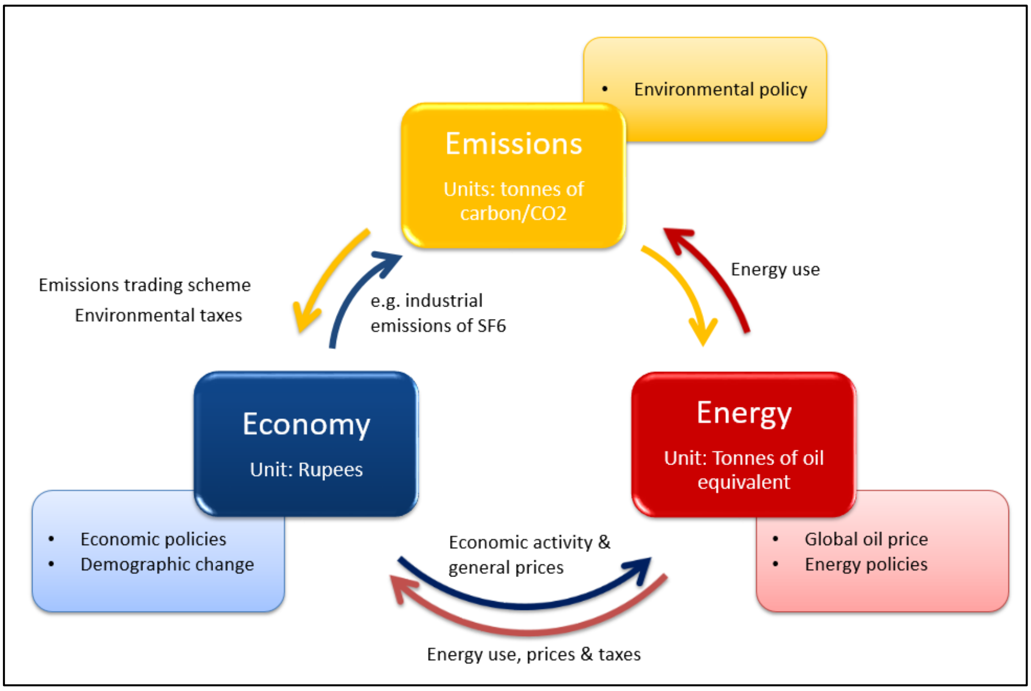
1.2 Basic model structure

The E3-India 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 1993, 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 1-1 shows how the three components (modules) of the model (energy, environment and economy) fit together.

Figure 1-1: E3-India as an E3 Model



The three modules

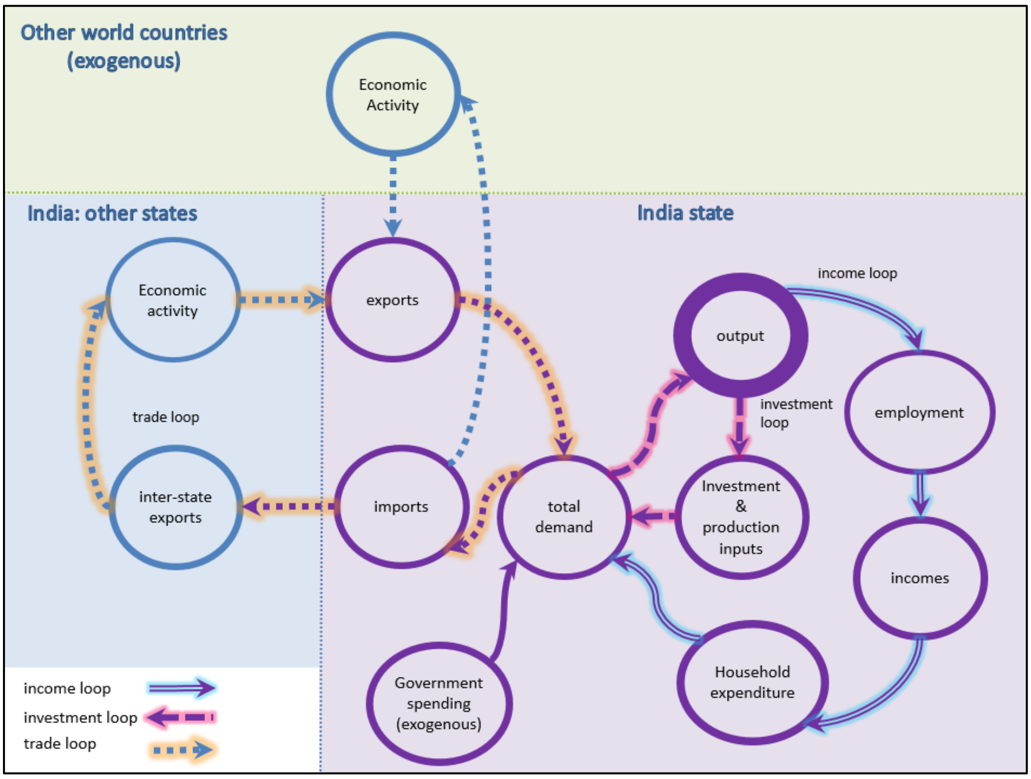
Each component is shown in its own box with its own units of account and sources of data. Each data set has been constructed by statistical offices to conform to accounting conventions. Exogenous factors coming from outside the modelling framework are shown on the outside edge of the chart as inputs into each component. For the economic module, these include demographic factors and economic policy (including tax rates, growth in government expenditures, interest rates and exchange rates). For the energy system, the outside factors are the world oil prices and energy policy (including regulation of energy industries). For the environment component, exogenous factors include policies such as 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.

1.2.1 E3-India's economic module

Figure 1-2 shows how E3-India's economic module is solved for each state. 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 and all states, although single-state solutions are also possible.

Figure 1-2: E3-India'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: Some of the increase in demand described above will be met by imported goods and services (within India and outside India). This leads to higher demand and production levels in other states. Hence there is also a loop between states. Economic activities outside India are treated as exogenous in E3-India.

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 Volume 4.

Intermediate demand

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

Household consumption

Estimating household consumption is a two-stage process. Total consumer spending by region is derived from functions estimated from time-series data. These equations relate consumption to regional personal disposable income, 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.

Unfortunately, due to data limitations investment is not disaggregated by asset in E3-India. Stock building is treated as exogenous in the model.

Inter-state and international trade

In a sub-national model, trade represents a major issue in assessing regional economic impacts. Demand in each state can be met either by production within that state, production in another state in India, or production in another country. With no available data on trade between the states, it is necessary to impose assumptions on the rates of production in the states with relation to developments in neighbouring states.

The approach can be summarised as:

- International exports are estimated at state level, based on the production prices within each state.
- International imports are estimated at national level and applied to the states, based on estimates of current and baseline future state-level imports.
- Trade between states is estimated using production shares (export) and domestic demand shares (import).

The treatment of international trade is described in more detail in Volume 4, Section 8.

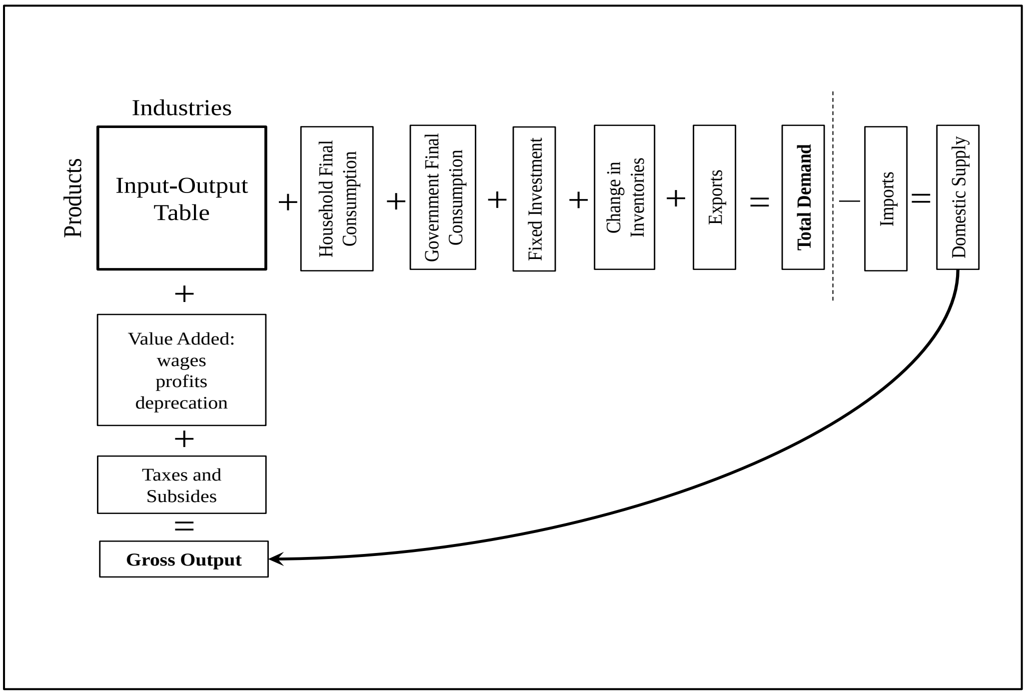
Output and determination of supply

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 1-3 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 1-3: Determination of supply and demand



The labour market and incomes

Treatment of the labour market is another area that distinguishes E3-India from other macroeconomic models. E3-India includes econometric equation sets for employment (as a headcount, see Section (Volume 4, Section 11), wage rates (Volume 4, Section 12) and participation rates (Volume 4, Section 13). 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 volume 4.

Analysis of skills

E3-India 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

Due to limitations in available time-series data, E3-India adopts a representative household for each region[1]. Household income is determined as:

Income = Wages – Taxes + Benefits + Other income

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

'Other income' includes factors such as dividend payments, property rent and remittances. At present, it is not possible to derive data for these financial flows and so they are 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.

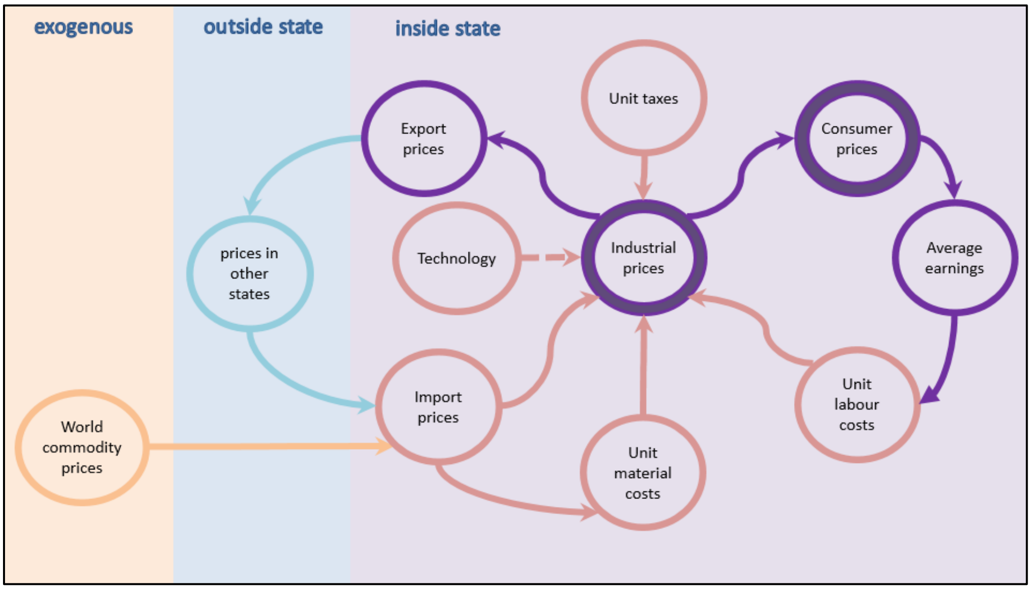
Aside from wages, there are three econometric price equations in the model (see Volume 4):

- domestic production prices
- import prices
- export prices

These are influenced by unit costs (derived by summing wage costs, material costs and taxes), competing prices and technology (see Figure 1-4). Each one is estimated at the sectoral level.

[1] Due to data constraints, E3-India only includes a limited treatment of income distribution across different household groups (see social indicators later in this section).

Figure 1-4: E3-India's basic price formation structure



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 largely ignored. This is partly due to a lack of quantitative indicators but also that it often does not fit well into the basic structure of most macroeconomic models.

Like other models, E3-India can provide less coverage of social factors than economic factors (see above) and environmental impacts (see next two sections) but social factors are not ignored completely. The main social indicators in the model are:

- sectoral employment and working hours
- sectoral wage rates
- unemployment
- an estimate of (real) income distribution when looking at issue of electricity price subsidies

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

Distributional income

There is no explicit modelling of the distribution of income in E3-India, except when looking at the issue of electricity price subsidies.

The model has an option to adjust electricity price subsidies by household group (five income quintiles and a rural/urban split), which enables users to adjust the subsidy rates and then assess the distributional impacts of electricity price policies (although without feedback to the rest of the model). The distributional impacts among households are calculated from state-level data on different electricity tariffs, average electricity consumption and income distribution by household group.

Demographic variables

Population projections are treated as exogenous in E3-India, apart from migration between Indian states. Aside from the endogenous treatment of migration, state population projections follow the overall population trends for India published by the UN (World Population Prospects).

Inter-state migration is modelled using a simplified concept of spatial transactions. The decision to migrate between states is determined by economic distance, i.e. pair-wise differences in GDP growth rates, weighted by physical distance between the states.

1.2.2 Energy-emissions modelling in E3-India

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

Volume 7 describes the differences between top-down and bottom-up modelling but the current version of E3-India can be described as top-down in its energy modelling, with a bottom-up submodel of the electricity supply sector (described in section 5). In this section, we describe how final energy demand and emission levels are calculated; the power sector model is described in the next section.

E3-India's main energy module

The energy module in E3-India is constructed, estimated and solved for each energy user, each energy carrier (termed fuels for convenience below) and each state. Figure 1-5 shows the inputs from the economy and the environment into the components of the module and Figure 1-6 shows the feedback from the energy module to the economic module.

Total energy demand

Aggregate energy demand, shown on the left of Figure 1-5, 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 1-5: Inputs to the energy module

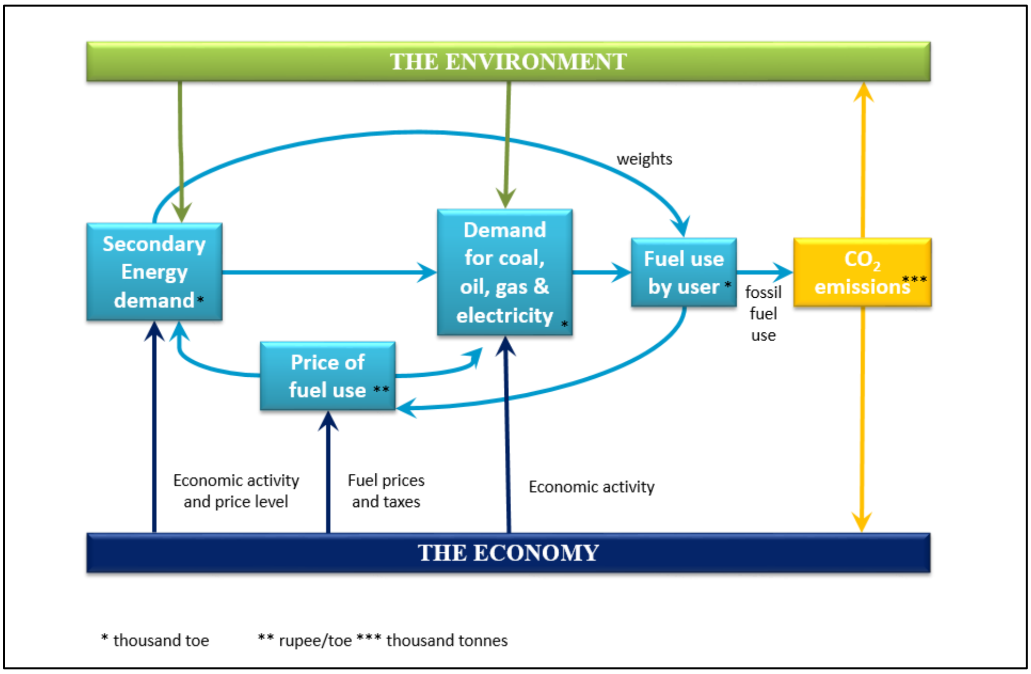
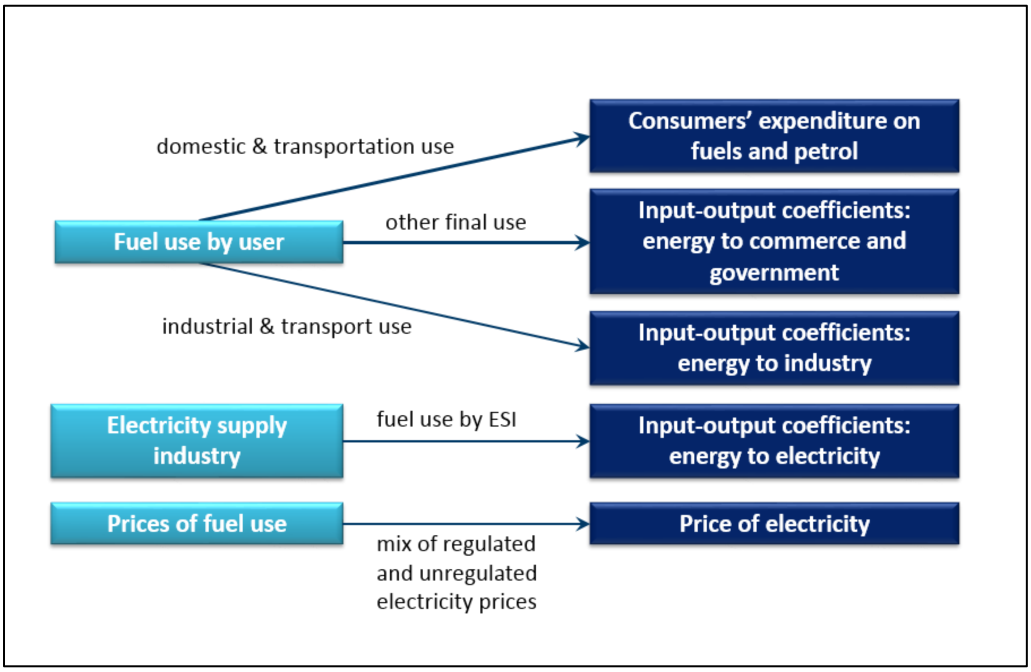


Figure 1-6: Feedback from the energy module



Price elasticities

It should be noted that the long-run price elasticities of demand for energy are the only model parameters that are not derived from the time-series data, as described in Volume 3, Section 3[2]. The reason for this is that the past data may not be a good guide to future responses.

Typically changes in energy prices in the historical data have been due to fluctuations in commodity prices and have been temporary in nature. However, the changes in energy prices that are modelled using E3-India tend to be based on permanent changes in policy and are therefore more likely to lead to behavioural change. Estimating elasticities based on the time-series data could thus lead to a downward bias.

Instead the long-run price elasticities used are taken from a combination of cross-section estimation and reviewed literature. For most sectors the values range from -0.2 to -0.3, meaning that a 1% increase in price leads to a 0.2-0.3% reduction in consumption. For the transport sector, a higher value of -0.45 is used, taken from Franzen and Sterner (1995) and Johansson and Schipper (1997, p.289) and confirmed by CE's own analysis. Short-run elasticities are based on the time-series data and are usually close to zero. The exact values of the price elasticities will be tested further in future.

Fuel substitution

Fuel use equations are estimated for four energy carriers (coal, oils, gas and electricity) with four sets of equations estimated for the fuel users in each region. These equations are intended to allow substitution between the four energy carriers by users on the basis of relative prices, although overall fuel use and the technological variables can affect the choice.

Due to limitations in biomass prices, biomass consumption in E3-India is treated as a residual fuel demand and is modelled as a fixed ratio to aggregate energy use (final use only). Biomass used in power generation comes from FTT results.

One point to note is that the current version of E3-India 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.

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 rupees

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 a lack of state-level input-output data) and the

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

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-India, 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-India's emission submodel

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. The current E3-India version does not cover other non-CO_2 atmospheric emissions due to data limitations at state-level.

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 (see Volume 3). This forms the relationship between energy consumption and emissions.

1.3 The power sector model

Overview

The power sector in E3-India is represented using a novel framework for the dynamic selection and diffusion of innovations, initially developed by J.-F. Mercure (Mercure, 2012), called FTT: Power (Future Technology Transformations for the Power sector)[3]. This is the first member of the FTT family of technology diffusion models. FTT 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; adapted for the states of India, see below). 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.

[3] A pre-print is available online here: https://arxiv.org/abs/1205.4868

Technology types

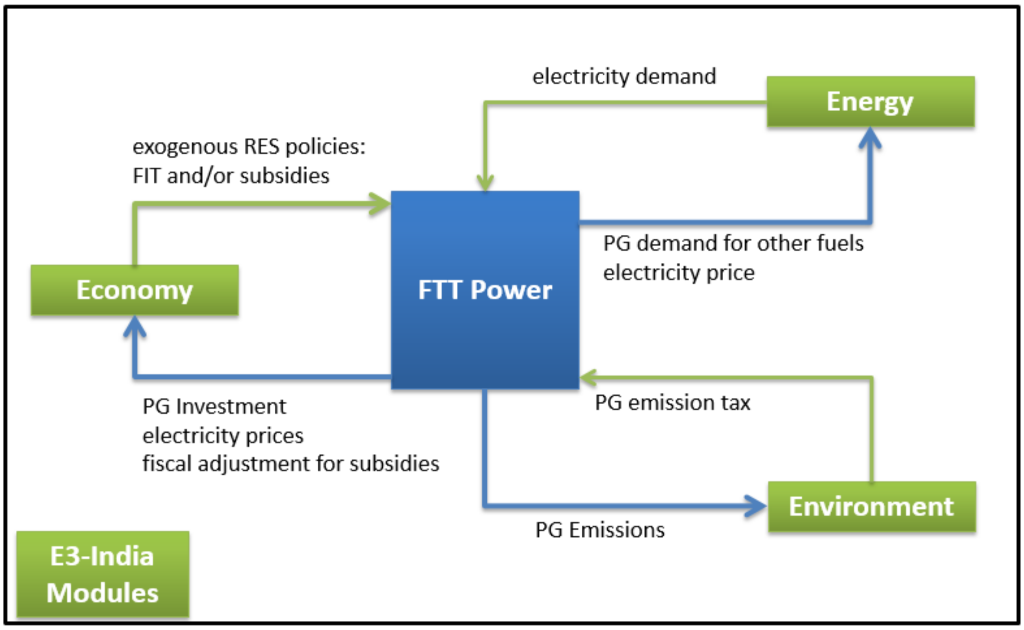
FTT: Power features 24 types of power technologies (see Table 1.1). However, not all technologies are available in all states. For example, wave and tidal power is not available in landlocked states and there are natural limits on hydro power (see below).

Table 1.1: Power technologies

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

Input and feedbacks

Figure 1-7: FTT basic structure



FTT: Power determines a technology mix by each state 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 E3-India and feeds back a price, fuel use and investment for replacements and new generators.

Natural resource constraints

The representation of FTT:Power in the global E3ME model 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).

The supply of non-renewable resources is treated as exogenous in E3-India since the rest of the world is not included. The working assumption is that India can continue to produce coal with extraction costs similar to the current ones (allowing for inflation) over the period to 2035. Due to data restrictions, it is only possible to introduce state-level constraints for some renewable technologies:

- for wind and solar, using information from MapRE[4], we introduce cost-curves to include diminishing capacity factors
- for hydro, state level maximum potentials are added using information from Energy Alternative India (EAI)[5]
- landlocked states have zero potentials for wave, tidal and offshore wind

1.4 Innovation and endogenous technological progress

E3-India'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-India 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.

[4] http://mapre.lbl.gov/rez/irez/ MapRE (Berkeley University)

[5] http://www.eai.in/ref/ae/hyd/hyd.html

$\tau 1$ 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.

E3-India investment and R&D data

Data availability for state-level investment is poor and there are no data for R&D. For this reason, R&D is set to zero in the technological progress indicator equation. In the future, R&D could be incorporated when data become available. Overall, the indicator is constructed using investment data of variable quality and users should exercise caution when using the indicator.

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.

1.5 E3-India compared to other macroeconomic models

E3-India in comparison to CGE models

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

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

Key differences

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

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

In contrast, econometric models like E3-India interrogate historical data sets to try to determine behavioural factors on an empirical basis and do not assume optimal behaviour. The model is demand-driven, with the assumption that supply adjusts to meet demand (subject to any constraints), but at a level that is likely to be below maximum capacity.

This has important practical implications for scenario analysis. While the assumptions of optimisation in CGE models mean that all resources are fully utilised, it is not possible to increase output and employment by adding regulation. However, E3-India allows for the possibility of unused capital and labour resources that may be utilised under the right policy conditions; it is therefore possible (although certainly not guaranteed) that additional regulation could lead to increases in investment, output and employment.

Many of the assumptions that underpin CGE (and DSGE) models have been increasingly questioned as to whether they provide an adequate representation of complex real-world behaviour[6]. Examples include perfect competition, perfect knowledge and foresight, and optimal rational behaviour and expectations. Some CGE models have been adapted to relax certain assumptions but the underlying philosophy has not changed.

The main drawback of the E3-India approach in comparison is its reliance on having high-quality time-series data. Constructing state-level data was thus a key part of the model-building exercise but there remains substantial room for improvement.

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

Comparing E3-India to econometric forecasting models

E3-India could also be compared to short-term econometric forecasting models. These models, which are typically operational in government, describe short and medium-term economic consequences of policies but with a limited treatment of longer-term effects. This limits their ability to analyse long-term policies and they often lack a detailed sectoral disaggregation.

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

Where E3-India fits in…

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

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

E3-India has a complete specification of the long-term solution in the form of an estimated equation which has long-term restrictions imposed on its parameters. Economic theory informs the specification of the long-term equations and hence properties of the model; dynamic equations which embody these long-term properties are estimated by econometric methods to allow the model to provide forecasts. The method utilises developments in time-series econometrics, with the specification of dynamic relationships in terms of error correction models (ECM) which allow dynamic convergence to a long-term outcome (see volume 3 section 3).

E3-India is therefore the result of an ambitious modelling project which expands the methodology of long-term modelling to incorporate developments both in economic theory and in applied econometrics, all applied at the state level in India.

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

Comparative advantages of E3-India

To summarise, compared to the other macroeconomic models in operation currently across the world (both CGE and otherwise), E3-India has advantages in the following four important areas:

Geographical coverage

The current version of E3-India provides state-level coverage, with explicit representation of each state and territory in India.

Sectoral disaggregation

The sectoral disaggregation of the model allows the representation of fairly complex scenarios at state level, especially those that are differentiated by sector. Similarly, the impact of any policy measure can be represented in a detailed way, for example showing the winners and losers from a particular policy.

Econometric pedigree

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

E3 linkages

E3-India is a hybrid model. A non-linear interaction (two-way feedback) between the economy, energy demand/supply and environmental emissions is an undoubted advantage over models that may either ignore the interaction completely or only assume a one-way causation.

2 Example policy scenarios

2.1 Introduction

In this section we consider two common types of scenarios, building on the links described above:

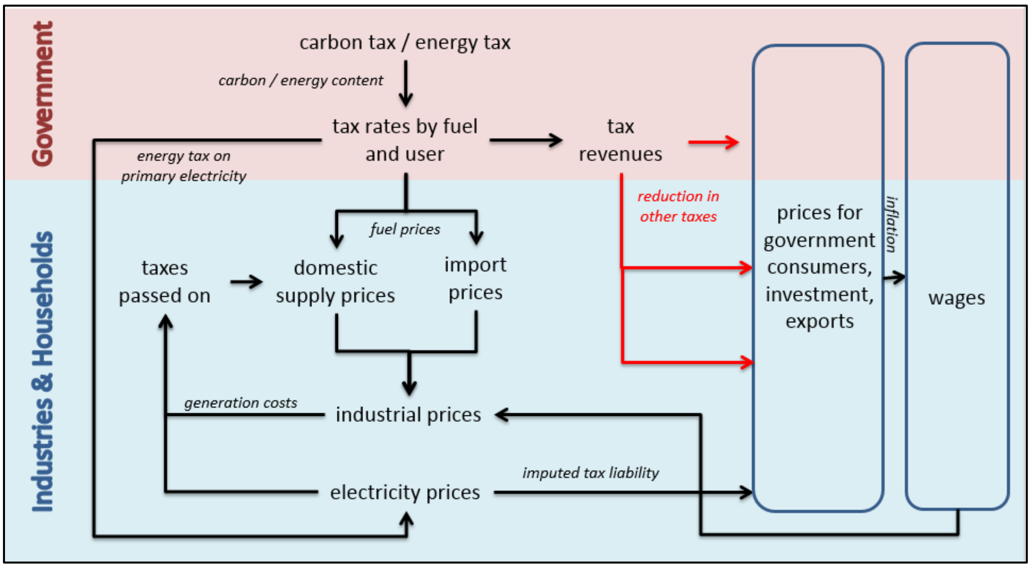
- a carbon/energy tax
- policies to improve energy efficiency

The aim of this section is not to present specific results, but to show how these policies are represented in the E3-India modelling framework, and the necessary assumptions involved.

2.2 A carbon or energy tax

One of the most common uses of the model is to provide a consistent and coherent treatment of fiscal policy in relation to greenhouse gas emissions. Some form of carbon/energy tax is an important component of such policy and E3-India can explore scenarios involving such a tax, as well as other fiscal policies and alternative means of reducing emissions. Figure 2-1 shows how the tax affects prices and wage rates in the model.

Figure 2-1: The impact of the carbon/energy tax on prices and wage rates



Assumptions and price effects

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

The first assumption is that the effects of the tax in the model are derived entirely through the impact of the tax on fuel prices, and through any use of the subsequent revenues from the tax in reducing other tax rates (i.e. revenue recycling). Other effects, including awareness or announcement effects, are not modelled. For example, if the introduction of a high carbon tax caused the electricity industry to scrap coal plants in advance of the tax being levied, this effect would have to be imposed on the model results[7].

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

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

The third assumption is that any increase in fuel prices due to carbon/energy taxes are treated as the same as changes in fuel prices for any other reason. This means that the same price elasticities may be applied to determine the behavioural response (see Volume 4, Section 4). A share of cost increases will be passed on to final users through the estimated pass-through rates in the model (see Volume 4, Section 9).

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

Real effects

Figure 1-12 shows the consequent effects of these price and wage rate changes. Energy consumption and fuel mixes will adjust, depending on price and substitution elasticities. The energy price increases will be passed on to more general increases in prices, which will cause substitution in consumers' expenditure, in exports and between imports and domestic production. These changes will feed back to fuel use.

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

Revenue recycling

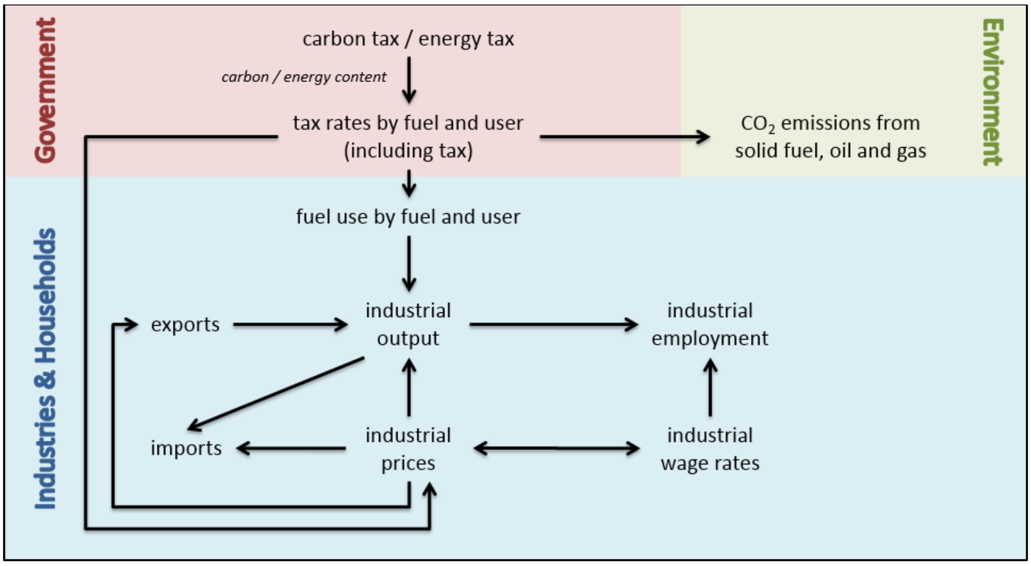
Depending on how the tax revenues are used, they may also affect real outcomes; standard options for revenue recycling include:

- reductions in standard income tax rates
- reductions to employees' national insurance contributions
- reductions to employers' national insurance contributions (labour taxes)
- reductions in sale taxes or VAT rates
- increases in social benefits
- increases in public investment or R&D spending
- paying for renewable energy subsidies
- increases in government consumption, e.g. of education or health

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

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

Figure 2-2: The impact of the carbon/energy tax on fuel use, CO_2 emissions and industrial employment



2.3 Investment in energy efficiency

Energy efficiency is a key component of decarbonisation strategies and has further advantages in terms of competitiveness and energy security. The global E3ME model has been used several times to model energy efficiency scenarios, including input to the Impact Assessment of the EU's Energy Efficiency Directive. As it is based on similar principles, E3-India can be applied in the same way.

The level of detail in the modelling is determined by the available data. At a most basic level, E3-India needs as inputs:

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

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

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

Scenarios that assess energy efficiency therefore typically show gains in investment and output of the sectors that supply investment goods. The sectors that supply energy lose out. Investment in household energy efficiency allows a shift in consumer spending patterns. In some states, there is a reduction in fossil fuel imports, which leads to a modest increase in GDP. Figure 1-13: The main economic interactions of energy efficiency Figure 1-13 summarises the main economic interactions.

Figure 2-3: The main economic interactions of energy efficiency