Introduction to the E3-India model

Authors

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Abstract

E3-India is a new state-level model of India, developed from the global E3ME macro-econometric model, linking the economic, energy and environmental emissions systems. The model is designed to assess energy and climate policy through a highly empirical structure, whereby historical data is used to feed in to econometric estimations of model interactions, forming a consistent modelling framework. Policies can be introduced into this framework at a state level, and the energy system and economic impacts assessed both within that state and (through trade) spillovers into other states.

The model is macro-econometric in nature, based on a post-Keynesian framework within which optimisation is not assumed (i.e. it is not a general equilibrium model). Through accounting identities, demand must equal supply, but demand can be less than or equal to total potential supply; the implication of this framework is that, under the right conditions, it is possible for regulation to increase output and employment.

E3-India also includes explicit treatment of technology, using the Future Technology Transitions (FTT) modelling framework for the power sector. This approach is qualitatively different from the optimisation tools that are used in other analyses and draws on theories from post-Keynesian and evolutionary economics. Instead of trying to find least-cost pathways, the model simulates the responses to policy inputs (including both regulation and market-based instruments) and is parameterized on real-world time-series data.

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Introduction

E3-India model is a new macro-econometric E3 (energy-environment-economy) model of India that can be used to assess policy at the level of the 32 states and territories. 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 India. As the model operates at state level, policies in individual states can be addressed and the distribution of impacts across India can be considered for national policy.

- The E3-India model has the following dimensions:
- 32 Indian states and territories
- 20 economic sectors
- 8 users of 5 different energy carriers
- CO2 emissions from 8 sources
- annual projections out to 2035

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

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

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

As a general model of the economy, E3-India 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 the energy sector. Policies that the model can assess include:

- changes in the power sector energy mix, including the share of renewables in the mix
- policies to promote renewable uptake, such as Feed-in-Tariffs or direct subsidies
- direct regulation on energy efficiency
- energy and carbon pricing instruments.

E3-India produces a wide range of socio-economic outputs at state and national level, for example:

- employment and unemployment
- GDP and sectoral output
- investment
- international trade and trade between states
- household income (by income group) and consumption
- public balances
- prices and inflation.

The model results also include a full set of energy balances (and prices), detailed power sector results by technologies, and energy-related emissions.

Method

The theoretical background

Economic activity undertaken by persons, households, firms and other groups in society has effects on other groups after a time lag, and the effects persist into future generations, although many of the effects soon become so small as to be negligible. But there are many actors and the effects, both beneficial and damaging, accumulate in economic and physical stocks. The effects are transmitted through the environment (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.

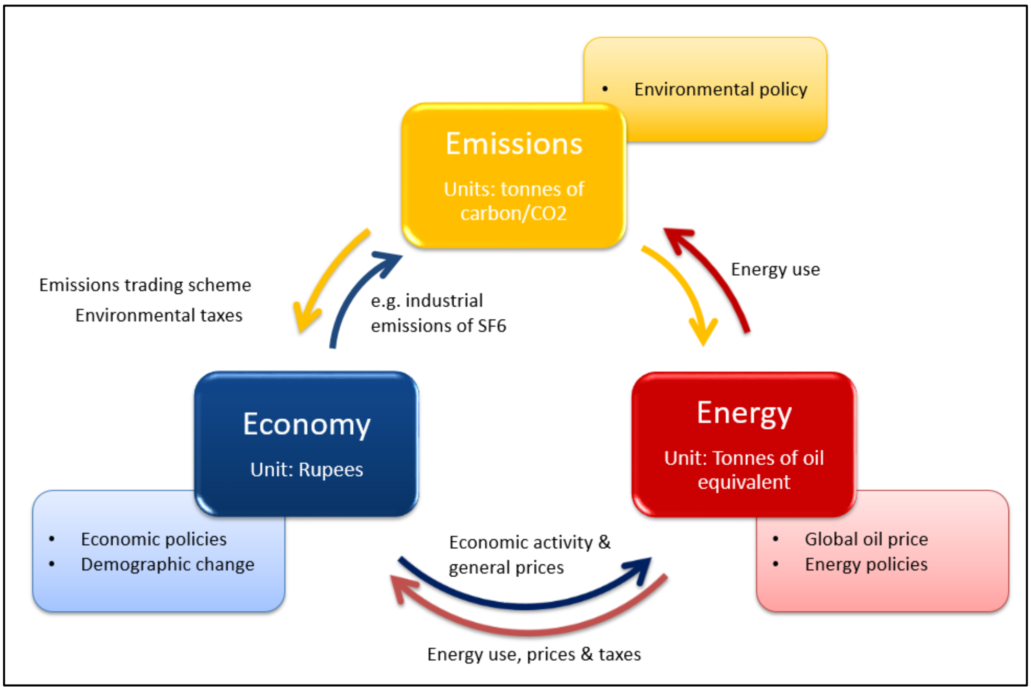
Model structure

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 shows how the three components (modules) of the model (energy, environment and economy) fit together.

Figure 1 India-E3 as an E3 model



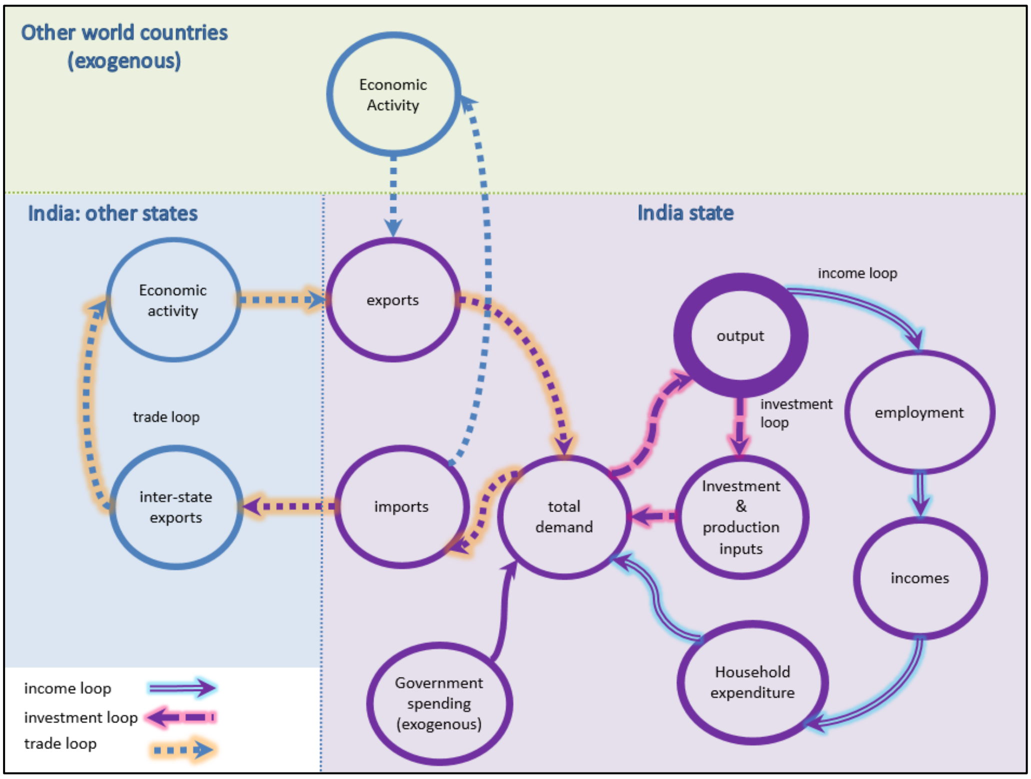
Each component is shown in its own box with its own units of account and sources of data. Each data set has been constructed by statistical offices to conform to accounting conventions. Exogenous factors coming from outside the modelling framework are shown on the outside edge of the chart as inputs 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.

E3-India's economic module

Figure 2 shows how E3-India's economic module is solved for each state. 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 2 E3-India's basic economic structure



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.

The components of demand

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

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.

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 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.

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.

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

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:

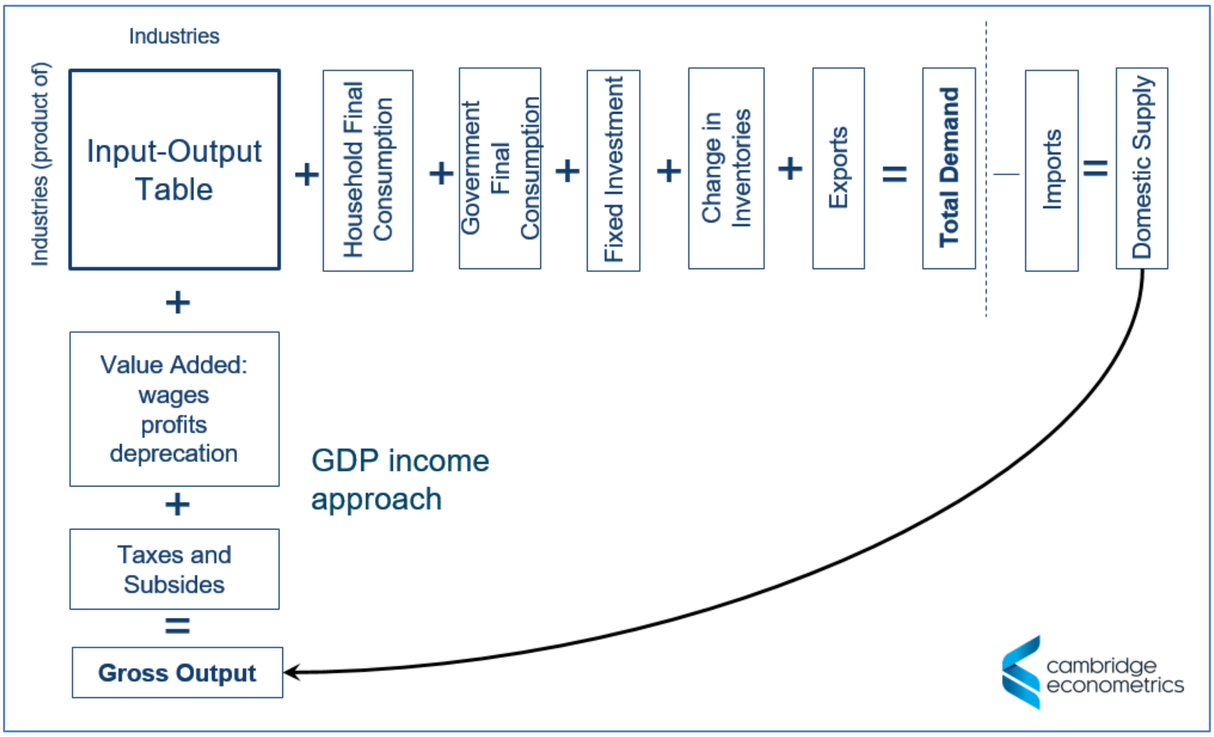
- International exports are estimated at state level, based on the production prices within each state.
- International imports are estimated at national level and applied to the states, based on estimates of current and baseline future state-level imports.
- Trade between states is estimated using production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

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 3 for how this is implemented within the National Accounts structure). The most obvious constraint is the labour market; 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.

Figure 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), 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.

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 5.

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.

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

Income = Wages – Taxes + Benefits + Other income

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

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

Due to data constraints, E3-India only includes a limited treatment of income distribution across different household groups.

Price formation

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:

- domestic production prices
- import prices
- export prices

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

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

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

Social indicators

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 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 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.

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.

Energy-emissions modelling in E3-India

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.

Aggregate energy demand 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

Price elasticities

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 road transport, a higher value of -0.7 is used, taken from Franzen and Sterner (1995) and Johansson and Schipper (1997, p.289) and confirmed by our own analysis. Short-run elasticities are based on the time-series data and are usually close to zero.

Fuel substitution

Fuel use equations are estimated for four energy carriers (coal, 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 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.

Emissions

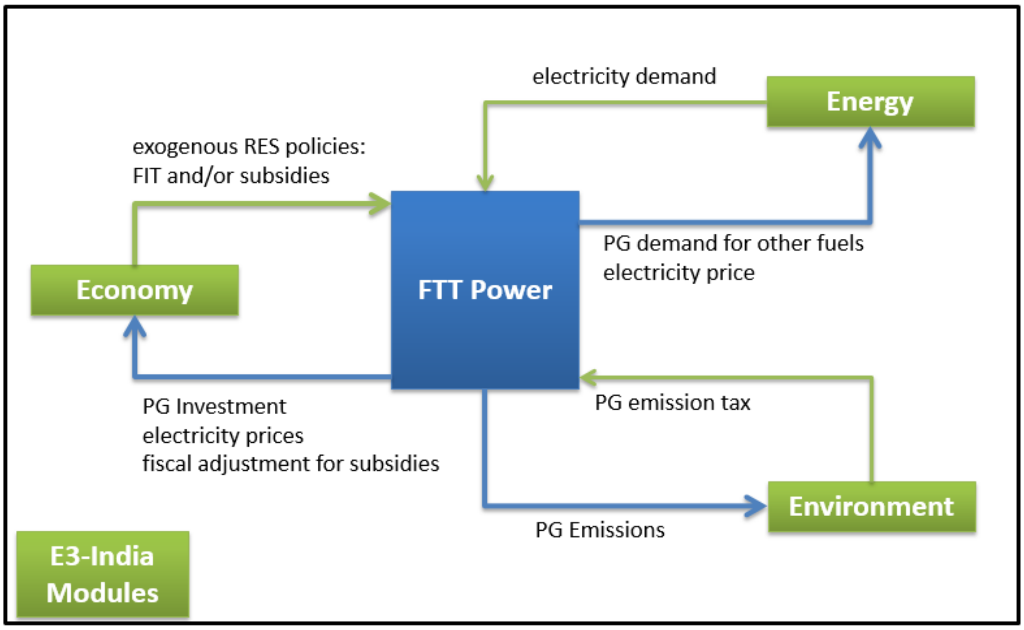
The emissions module calculates carbon dioxide emissions generated from end-use of different fuels and from primary use of fuels in the energy industries themselves, particularly electricity generation. The current E3-India version does not cover other non-CO2 atmospheric emissions due to data limitations at state-level.

Emissions data for CO2 from energy consumption are available for each of the energy users in the model. Coefficients (tonnes of carbon in CO2 emitted per toe) are implicitly derived using historical data (and sometimes also baseline projections). This forms the relationship between energy consumption and emissions.

The power sector model

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). 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; adapted for the states of India). 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 4 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).

Non-renewable resources are treated as exogenous in E3-India since the rest of the world is not included. Due to data restrictions, it is only possible to introduced state-level constraints for some renewable technologies:

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

Innovation and endogenous technological progress

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.

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.

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.

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.

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.

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.

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.

Comparative advantages of E3-India

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-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.

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