TRADE-OFF BETWEEN CARBON EMISSIONS, ECONOMIC GROWTH AND POVERTY REDUCTION IN INDIA

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Abstract

This study examines the consequences of a domestic carbon tax policy and participation in an internationally tradable emission permits regime like the one suggested in the Kyoto protocol on carbon emissions, GDP growth and poverty ratio, using a top-down CGE model for the Indian economy, which is implemented sequentially over the 30-year time span, 1990-2020. The model has eleven sectors, of which five are the energy sectors – electricity, coal, natural gas, refined oil and crude petroleum. CO_2 is emitted in the burning of the latter four fossil fuels. Carbon taxes are based on the proportion of each fuel's content. The substitution among the fossil fuels is specifically accounted for in the nested production structure of the model. The model also incorporates an income distribution mechanism and endogenously determines the poverty ratio. The results show that a domestic carbon tax policy which recycles the tax revenues to the households, imposes heavy costs in terms of lower GDP and higher poverty. However, for modest emission reduction targets, GDP losses are considerably reduced, and with simultaneous targeted transfers poverty increases only marginally. With targeted transfers, the fall in GDP and rise in poverty can be minimised or even prevented, provided the emission restriction target is a very mild one. A soft emission reduction target is all that India can be expected to and needs to set for itself, given that even a five percent annual reduction in its aggregate emission will bring down its per capita emission, already lower than the global per capita emission, to a level far below the latter. On the other hand, participation in the tradable emission permits regime opens up an opportunity for India to sell surplus permits and use the revenues from these permits to speed up its GDP growth and poverty reduction, with its per capita emission remaining below the per capita global emission in 1990.

Key words : CGE model, carbon emissions, economic growth, poverty reduction, India, global climate change, Kyoto protocol, carbon tax policy, internationally tradable emission permits.

Trade-Off Between Carbon Emissions, Economic Growth and Poverty Reduction in India

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1. Introduction

The linkage between carbon emission reduction, economic growth and poverty alleviation is an issue of immense relevance for India. India is highly vulnerable to global warming and global climate change caused by emissions of greenhouse gases such as carbon dioxide. The adverse effects of climate change would in all likelihood retard the developmental process and aggravate poverty. At the same time, India's per capita carbon emission is already very low. It is 0.26 tonne per annum, which is one-fourth of the world average per capita emission of one tonne per annum. (Parikh *et al*, 1991). In other words, India's per capita contribution to global warming problem is a relatively minor one. However, because of its large and growing population, its total emissions are large. Internationally, India is expected to stabilise its energy related carbon emissions. Moreover, the fact that India has a real stake in a global policy regime to stabilise global carbon emissions is being realised in Indian policy circles. More specifically, Indian policy makers are beginning to see the need to understand the implications for India of a Kyoto-type emissions trading regime.

At the domestic level, India is concerned with the reduction of carbon emissions whether Kyoto happens or not. This concern, however, is a very long term one. Switching over to non-polluting sources of energy such as, hydro and nuclear, is often mentioned as a strategy that will sweep away the problem of carbon emissions. A medium term policy option such as a carbon tax, however, is viewed with suspicion, largely because of its likely adverse impact on economic growth and poverty reduction. For a low-income country like India, the more pressing need obviously is achieving poverty reduction rather than controlling carbon emissions. Nevertheless, it would be worthwhile exploring how much, if at all, carbon taxes trade-off growth and poverty reduction, and what compensatory mechanisms can be built into the system to mitigate the undesirable effects of carbon taxes on GDP growth and poverty alleviation.

1.1 The energy and emissions scene in India

In India, about 30% of the total energy requirements are still met by the traditional or non-commercial sources of energy like fuelwood, crop residue, animal waste and animal draught power. The share of these non-commercial forms of energy in the total energy consumption has, however, been on decline. It was as high as 50% in 1970-71, but came down to only 33% in 1990-91. In other words, the energy consumption pattern has been increasingly shifting in favour of the commercial forms of energy like coal, refined oil , natural gas, and electricity. So much so, that in the last four decades, growth rate of commercial energy consumption has been higher than that of the total energy consumption. Coal itself accounts for more than 37% of the total energy consumption in 1990-91, with the share of refined oil and natural gas being about 18% and 5% respectively. The non-fossil sources of energy, such as, hydro-electricity has a small share of about 6.5%, with the remaining 0.5% share of the total energy consumption being accounted for by the non-conventional energy sources, such as, nuclear, wind and solar power.

In the two decades from 1970 to 1990 energy consumption in India, has more than doubled (table 1). More importantly, during this period biomass, which is a carbon neutral fuel (Ravindranath and Somsekhar, 1995), has been increasingly substituted by the fossil fuels, mainly coal. This has resulted in a major increase in the level of carbon emissions in India (table 2).

Table 1 : Energy consumption in India (petajoules)

Year	1970	1975	1980	1985	1990
Lignite	19 *(0.39)*	29 *(0.48)*	44 *(0.62)*	77 *(0.85)*	130 *(1.12)*
Coal	1466 *(29.77)*	1910 *(31.81)*	2222 *(31.07)*	3124 *(34.49)*	4201 *(36.10)*
Refined Oil & LPG	622 *(12.63)*	799 *(13.31)*	1082 *(15.13)*	1480 *(16.34)*	2035 *(17.49)*
Natural Gas	42 *(0.85)*	79 *(1.32)*	86 *(1.20)*	270 *(2.98)*	606 *(5.21)*
Biomass	2492 *(50.61)*	2821 *(46.98)*	3202 *(44.77)*	3518 *(38.83)*	3866 *(33.22)*
Hydropower	258 *(5.24)*	334 *(5.56)*	484 *(6.77)*	540 *(5.96)*	723 *(6.21)*
Other	25 *(0.51)*	33 *(0.55)*	32 *(0.45)*	49 *(0.54)*	74 *(0.64)*
Total	4924 *(100)*	6005 *(100)*	7152 *(100)*	9059 *(100)*	11636 *(100)*

Notes: 1. Refined Oil and LPG includes non-energy use of gas and fuel oil for fertiliser and petrochemical production.
2. For hydro, nuclear and renewables, energy is the coal equivalent for electricity generation
3. Other includes nuclear, wind, solar etc.
4. The italicised figures in the parantheses show the percentages with respect to the total.
Source **:** Fisher-Vanden *et al* (1997)

Table 2 : Energy consumption and carbon emission trends

Year	1970	1975	1980	1985	1990
Energy consumption (PJ)	4923	6005	7152	9059	11636
Net carbon emission (MT)	61.58	79.54	95.78	134.63	183.39
Gross carbon emission (MT)	129.64	156.59	183.23	230.72	288.99

Notes : Net carbon emission excludes emissions from biomass combustion.
Gross carbon emission includes emissions from biomass combustion.
Source: Fisher-Vanden *et al* (1997):

In the 1980s, the Indian economy grew at an average annual rate of 5%, with industrial output rising at about 6.3% per year. During this time, India's commercial energy sector grew at about 6% a year, with electricity use growing faster at 9% annually. In the post-liberalisation (i.e., after 1990-91) phase, the Indian economy averaged an higher annual growth rate of about 6%. India's energy demand can only grow even more rapidly in the future on account of high prospective economic growth, spreading industrial base, a rapid population growth and increasingly energy-intensive consumption patterns that results from higher incomes. Infact, projections show that India's energy demand could increase fourfold by 2025, while its carbon emissions could increase sixfold as traditional biomass fuels are replaced by higher fossil fuel use.

1.2 Policies for carbon emissions reduction

The standard policy measures for greenhouse gases abatement are basically four - energy efficiency improvement measures, command-and-control measures (i.e., implementing emission reduction targets by decree), domestic carbon taxes and an international emissions trading regime of the kind envisaged in the Kyoto protocol. Of these while the first one is, so to say, desirable *per se*, the other three are regarded as policy alternatives.

A lot of avoidable CO_2 emissions is due to the rampant energy inefficiency, which, in turn is the result of energy subsidies still prevailing in India, as in many other countries. However, since the early nineties, there is an increasing realisation of the link between energy inefficiency and unnecessary CO_2 emissions leading to a worldwide decline in energy subsidies. In India also the energy subsidies have been reduced since the onset of econonmic reforms in 1991. The reduction in the energy subsidies notwithstanding final-use energy prices in India, again as in many other countries, are still well below the opportunity cost (Fischer and Toman, 2000). In fact, the energy price reforms in India are far from complete, and not surprisingly, they have, as yet, had only an insignificant impact on energy efficiency and, thereby, on carbon emissions (Sengupta and Gupta, 2003).

Unlike the energy efficiency improvement measures, the other three measures for emissions abatement - command-and-control, carbon taxes and international emissions trading - are in India not yet at the implementation stage. As far as international emissions trading is concerned, India threw its hat in the Kyoto ring a little too late. By the time India acceded to the Kyoto protocol in August 2003 as a prelude to the eighth annual Conference of Parties, which it was hosting, the protocol had already gone into abeyance because of USA's withdrawal from it. Gupta (2002) has infact argued that had India been more proactive in its approach and acceded to the Kyoto protocol in its early phases, the American stand of not joining the protocol without any commitment from the developing countries would have become difficult to maintain. And the turn of events could have been completely different. Though India can now take comfort in the fact that Kyoto protocol was never to be and so nothing has been lost, the fact is that its late reaction to the protocol is primarily due to the belated realisation in its policy community of the potential gains from the protocol for India .

The command-and-control measure, i.e., enforcing carbon emission reduction targets by fiat is, not surprisingly, not regarded in India as feasible or desirable. Firstly, there are the usual arguments of command-and-control measures being statically and dynamically inefficient as compared to say market-based instruments, such as, carbon taxes (Pearson, 2000). Secondly, under the command-and-control measure, the economic cost of emission abatement (arising mainly due to curtailment of output, given limited input substitution possibilities) represents a *deadweight* loss in welfare. On the other hand, in case of a market-based instrument like carbon taxes, the government can use the tax revenue in a variety of ways to generate benefits for the economy in addition to those resulting from reduced emissions, thereby, reducing the net loss in welfare. It can use the carbon tax to replace some other more distorting tax and thus garner efficiency gains for the economy, i.e., reap double-dividend (Pearson, 2000). Or what is more pertinent, in case of a developing economy like India, it can use the tax revenue for targeted transfers to reduce poverty, or more specifically, recycle the carbon tax revenue to the low-income groups to compensate the latter for the burden imposed on them by the carbon emission reduction strategy.

It follows that, although policy action in India for carbon emissions abatement, apart from the ongoing energy price reform, has not yet materialised, the status-quo cannot be maintained for long. Fortunately, the prelude to policy action, i.e., informed policy discussion has been initiated in the literature on carbon emission reduction strategies in India. Two policy instruments – domestic carbon taxes and internationally tradable emission permits – have been discussed in the literature on India. For the latter, Murthy, Panda and Parikh (2000) have shown, using an activity analysis framework, that India stands to gain both in terms of GDP and poverty reduction, if the emission permits are allocated on the basis of equal per capita emission. Fischer-Vanden *et al* (1997) have used a CGE model to compare the impacts of the two policy instruments on GDP, and found that tradable permits are preferable to carbon taxes. In a comparison of the two types of schemes for emission permits – the grandfathered emission allocation scheme in which permits are allocated on the basis of 1990 emissions, and the equal per capita emission allocation scheme – they found the latter to be more beneficial for India. Incidentally, the CGE model of Fischer-Vanden *et al* (1997) is based on the assumption of a single representative household. Hence, it does not reflect the impact of carbon taxes on income distribution or on the poverty ratio.

1.3 The present study

In the present study we have used a top-down, quasi-dynamic CGE model, with an endogenous income distribution mechanism, for the Indian economy. Our model has been formulated with a view to capture the adverse effects of carbon taxes on GDP losses and the poverty ratio through increased prices of fossil fuels (coal, refined oil and natural gas). The non-uniform increases in the prices of fossil fuels will lead to some fuel switching as well as an overall fuel reducing effect. Our model will effectively capture the net impact of these effects on GDP as well as income distribution. Compared to the model of Murthy, Panda and Parikh (2000), ours is a neoclassical price driven CGE model, ideally suited for simulating the impact of a carbon tax and of a system of global trade in carbon emission quotas. And compared to the SGM's India model which is based on the assumption of a single representative household, our model has an elaborate income and consumption distribution mechanism, in which factoral incomes are first mapped onto 15 income percentiles and then onto 5 consumption expenditure classes. The bottom consumption expenditure class corresponds to those below the poverty line so that we get a measure of the poverty ratio as well.

As is usually done in a CGE modeling analysis, we first generate a base-line (business-as-usual) scenario, and then simulate alternative policy scenarios for assessing the consequences for growth and poverty in India of different carbon emission reduction strategies. The specific policy questions to which the policy scenarios are addressed are the following :

(i) What is the impact of imposing carbon taxes to ensure carbon emissions do not exceed the 1990 levels in each period during the time span 1990-2020 given that the carbon tax revenues for each period are recycled to the households by way of additions to personal disposable income just like the government transfers ?

(ii) What is the impact of imposing carbon taxes to bring about a 10% annual reduction in carbon emission levels during the time span 1990-2020 given that the carbon tax revenues for each period are recycled to the households ?

(iii) What is the impact of participating in an internationally tradable permits scheme in which the carbon emission allowances are allocated on the basis of equal per capita emissions allocation which are kept fixed to the participating country's 1990 population, when the revenues earned, if any, from the permits are recycled to the households ?

Note that for each of the policy questions mentioned above we develop two policy scenarios, one in which the revenues earned from the carbon taxes or the sale of permits are distributed across household groups in proportions same as those for the government transfers, and the other in which these revenues are transferred *exclusively* to a target group - i.e., the bottom class of the five expenditure classes.

1.2 The organisation of the paper

The rest of the paper is organised as follows. Section 2 presents the overall structure of the model, with special emphasis on the production structure, the production-CO_2 emission linkages and the income distribution mechanism. Section 3 presents the main features, such as GDP growth and emissions growth, of the base-line or the business-as-usual (BAU) scenario. In section 4, we report the simulation results of eight alternative policy scenarios in comparison with the BAU scenario. Section 5 concludes and suggests policy implications of our results. In Appendix 1 we give the tables and figures related to the base-line scenario and the policy simulations. Appendix 2 gives the nested production structure diagrams for the various sectors, while in Appendix 3 we present the equations of the model. Appendix 4 describes the database of the model.

2. Model Structure

Our model is based on a neoclassical CGE framework that includes institutional features peculiar to the Indian economy. It is multi-sectoral and quasi-dynamic. The overall structure of our model is similar to the one presented in Mitra (1994). However, in formulating the details of the model - the production structure, the CO_2 emission generation and the income distribution mechanism - we follow an eclectic approach, keeping in mind the focus on the linkages between inter-fossil-fuel substitutions, CO_2 emissions, GDP growth and poverty reduction.

The model includes the interactions of producers, households, the government and the rest of the world in response to relative prices given certain initial conditions and exogenously given set of parameters. Producers act as profit maximisers in perfectly competitive markets, i.e., they take factor and output prices (inclusive of any taxes) as given and generate demands for factors so as to minimise unit costs of output. The factors of production include intermediates, energy inputs and the primary inputs - capital, land and different types of labour. For households, the initial factor endowments are fixed. They, therefore, supply factors inelastically. Their commodity-wise demands are expressed, for given income and market prices, through the Stone-Geary linear expenditure system (LES). Also households save and pay taxes to the government. Furthermore, households are classified into five rural and five urban consumer expenditure groups. The government is not asssumed to be an optimising agent. Instead, goverment consumption, transfers and tax rates are exogenous policy instruments. The total CO_2 emissions in the economy are determined on the basis of the inputs of fossil fuels in the production process, the gross outputs produced and the consumption demands of the households and the government, using fixed emission coefficients. The rest of the world supplies goods to the economy which are imperfect substitutes for domestic output, makes transfer payments and demands exports. The standard small-country assumption is made implying that India is a price-taker in import markets and can import as much as it wants. However, because the imported goods are differentiated from the domestically produced goods, the two varieties are aggregated using a constant elasticity of substitution (CES) function, based on the Armington assumption. As a result, the imports of a given good depends on the relation between the prices of the imported and the domestically produced varieties of that good. For exports, a downward sloping world demand curve is assumed. On the supply side, a constant elasticity of transformation (CET) function is used to define the output of a given sector as a revenue-maximising aggregate of goods for the domestic market and goods for the foreign markets. This implies that the response of the domestic supply of goods in favour or against exports depends upon the price of those goods in the foreign markets *vis-à-vis* their prices in the domestic markets, given the elasticity of transformation between goods for the two types of markets. The model is Walrasian in character. Markets for all commodities and non-fixed factors - capital stocks are fixed and intersectorally immobile - clear through adjustment in prices. However, by virtue of Walras' law, the model determines only *relative* prices. The overall price index is chosen to be the numeraire and is, therefore, normalised to unity. With the (domestic) price level fixed exogenously, the model determines endogenously both the nominal exchange rate and the foreign savings in the external closure (Robinson, 1999). Finally, because the aggregate investment is exogenously fixed, the model follows an investment-driven macro closure, in which the aggregate savings - i.e., the sum of household, government and foreign savings - adjusts, to satisfy the saving-investment balance.

2.1 Sectoral disaggregation

Our model is based on an eleven sector disaggregation of the Indian economy :
(i) Agriculture (agricult),
(ii) Electricity (elec),
(iii) Coal (coal),
(iv) Refined Oil (refoil),
(v) Natural Gas (nat-gas),
(vi) Crude Petroleum (crude-pet),
(vii) Transport (trans),
(viii) Energy Intensive Industries (enerint),
(ix) Other Intermediates (otherint),
(x) Consumer goods (cons-good),
(xi) Services (services) .

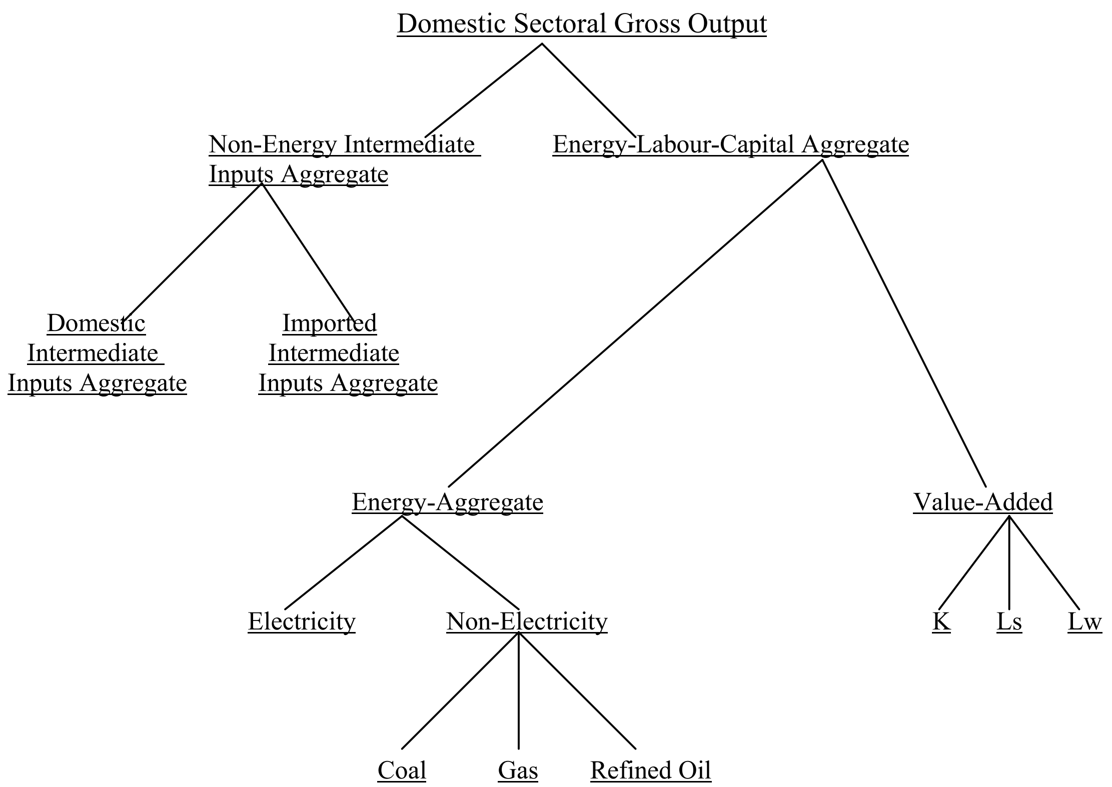
There are 5 energy sectors – elec, coal, refoil, nat-gas, crude-pet – and 6 non-energy sectors - agricult, trans, enerint, otherint, cons-good and services. The sectoral divison of the economy was decided after a perusal of the sectoral disaggregation in various other models - such as EPPA, SGM and Murthy, Panda and Parikh (2000) - and bearing in mind the focus of our model on the possibilities of fuel switching in the provision of energy inputs in the production process.

2.2 The production structure

Production technologies for all sectors are defined using nested CES functions, with the nesting structure of inputs differing across the sectors, or groups of sectors as in the EPPA model (Babiker *et al*, 2001 and Yang *et al*, 1996).

For the transport, energy intensive industries, other intermediates, consumer goods and services sectors, the following tree describes the production structure.

Fig. 1 : The production structure



Note : K – Capital ; Ls – Self-employed Labour ; Lw – Wage-labour.

For agriculture, electricity, coal, natural-gas, crude petroleum and refined oil, there are minor variations in the nesting structure (see Appendix 2).

In other words, for each sector there is a nested tree-type production function. At each level of the nested production function, the assumption of constant elasticity of substitution (CES) and constant returns to scale (CRS) is made[1]. For every level, the producer's problem is to minimise cost (or

[1] Although, the domestic and intermediate inputs' aggregates themselves are fixed-coefficients aggregates of domestic and imported inputs respectively from the non-energy sectors.

maximise profit) given the factor and output prices and express demands for inputs. It follows that for every level, the following three relationships hold : the CES function relating output to inputs, the first order conditions, and the product exhausation theorem. For all the levels taken together, the production system thus determines, for each sector, the gross domestic output, the input demands, value-added as well as the demands for wage-labour and self-employed labour[2].

2.3 Technological change

Energy-saving technological progress is incorporated in our model by making the autonomous energy efficiency improvement (AEEI) assumption used in other carbon emission reduction models such as, GREEN (Burniaux *et al*, 1992) and EPPA (Babiker *et al*, 2001). As in the EPPA and GREEN models, we also assume that AEEI occurs in all sectors except the primary energy sectors (coal, crude petroleum and natural gas) and the refined oil sector. The GREEN model assumes a one percent annual increase in energy efficiency, while in the EPPA model there is an even higher annual growth rate of energy efficiency – 1.4 percent initially, though it slows down over time according to a logistic function. However, we are of the opinion that the exogenous annual growth rates of energy efficiency assumed for India in these models are overly optimistic. India has embarked on the path towards energy efficiency after 1991, but its record in energy efficiency improvement in the last one decade is far from encouraging (Sengupta and Gupta). We have thus assumed a much more modest annual growth rate of energy efficiency for the Indian economy – i.e., 0.5 percent.

2.4 Carbon emissions

CO_2 is emitted owing to burning of fossil fuel inputs. The major fossil fuels used in India are coal, natural gas, refined oil and crude petroleum[3]. In addition to CO_2 emitted by fuel combustion, there may be CO_2 emanating from the very process of output generation. For example, the cement sector (a part of the enerint sector in our sectoral classification) releases CO_2 in the limestone calcination process. Finally, CO_2 emissions also result from the final consumption of households and the government.

We use fixed CO_2 emission coefficients to calculate the sector-specific CO_2 emissions from each of the three sources of carbon emissions. For the total CO_2 emissions generated in the economy, we first aggregate the emissions from each of the sources over the eleven sectors and subsequently sum up the aggregate emissions across the three sources.

2.5 Emission payments

Carbon taxes are applicable only on the CO_2 emitted in the production process (i.e., on the first two sources of carbon emissions), not on the final consumption of households and the government (the third source of carbon emissions). Carbon taxes are based on the proportion of each fuel's carbon content, i.e., Rs per ton of carbon emitted. The carbon tax rate multiplied by a sector's carbon emission gives the emission payments by that sector. Summing across sectors we get the total emission payments, which is then recycled to the household sector as additional transfer payments by the government. (In the base-line scenario, the carbon tax rate is fixed at zero and there are therefore no emission payments). It may be noted that, the producer's cost function is modified to include the

[2] The capital stock in a particular period is given, so that the first-order condition effectively determines the sectoral return on capital.

[3] Note that crude petroleum is used exclusively as an input in the refined oil sector (see Appendix 2).

emission payments so that carbon taxes induce substitution in favour of lower carbon-emitting fossil fuels.

2.6 Investment

Public and private investment are fed into the model as two distinct constituents of the total investment. There are fixed share parameters for distributing the aggregate investment across sectors of origin. However, the allocation mechanisms for sectors of destination are different in the two cases of public and private investment. For public investment there is discretionary allocation, and the allocation ratios are set exogenously. On the other hand, for private investment the allocation ratios are *given* in a particular period, but are revised from period to period on the basis of the sectoral relative return on capital. The relative return on capital in any sector is given by the normalisation of the implicit price of capital in that sector to the economy-wide returns. This rule does not imply full factor price equalisation, but only a sluggish reallocation of investment from sectors where rate of return is low to ones having higher rates of return.

Needless to say, this bifurcation of total investment into its public and private components with their differing allocation mechanisms is an attempt to approximate the way investments are actually made in the Indian economy. Incidentally, it also allows for public investments to be directed towards "strategic" sectors disregarding short-run considerations of profit maximisation.

2.7 Capital stocks

Sectoral capital stocks are exogenously given at the beginning of a particular period. However, our model is recursively dynamic, which means that it is run for many periods as a sequence of equilibria. Between two periods there will be additions to capital stocks in each sector because of the investment undertaken in that sector in the previous period. More precisely, sectoral capital stocks for any year t are arrived at by adding the investments by sectors of destination, net of depreciation, in year $t-1$ to the sectoral capital stocks at the beginning of the year $t-1$.

2.8 Labour markets and wage rates

For the non-agricultural sectors (i.e. sectors 2-11), the total labour supply available for employment is exogenously given. From this stock of labour those who are unable to find wage-employment resort to self-employment. In the agricultural sector, on the other hand, there is a fixed supply of self-employed labour (those owning land of whatever size) and, over and above, there is a pool of labour (landless) waiting to to find employment. Those who are unable to find wage employment become openly unemployed, rather than resort to self-employment.

The real wage rates, for wage labour, in the current period are indexed to the previous period's wage rates. This rule is applied to both the agricultural and non-agricultural wage rates. In the non-agricultural sectors, those unable to find wage employment (at the adjusted wage rate) spill over into the pool of self-employed labour to clear the labour market. In other words, there is inflexible wage (keynesian) in the "organised sector" and a market-clearing remuneration rate for the self-employed in the "unorganised" sector (neo-classical).

2.9 Factor, household incomes and transfers

Factor incomes - i.e, self-employment incomes, wage incomes, incomes from rent accruing to fixed factors including land, and capital (profit) incomes are generated as factor returns times employment in the relevant sectors, and then summing over all the sectors. From these, taxes are netted out to arrive at disposable incomes. To these 5 types of income is added a sixth type – transfer payments by government and rest of the world. Through these 'transfer payments' the government can recycle the total emission payments to the households. Household incomes by region – rural & urban – are worked out from the above 6 types of income using *fixed* shares to split these factor incomes into 2 parts, one for the rural and the other for the urban household.

2.10 Income distribution

The treatment of income and consumption distribution in our model is quite elaborate, as it should be. However, it needs to be stressed that there is hardly any degree of freedom in modeling the distribution of income in India. The mechanics of the income distribution is strictly guided by the type of data available. A detailed account of the income distribution module is provided in Mitra (1994). Here we outline the mian steps. (In what follows the account is the same for the rural and urban areas, and so we shall not make a distinction between the two).

Step 1 - We start with the factoral incomes and map them onto incomes accruing to 15 income classes (percentiles) using a constant share income allocation scheme (known from data sources) for all the 6 types of income – self-employment income, wage income, capital income, income from land and fixed factors and transfer payments[4]. Given Y_h, the income accruing to class h, and θ_h, the share of households in class h in the total population (also known from data sources), we compute the mean and variance of household income .

Step 2- We first make the assumption that the distribution of population according to per capita income and per capita consumption is bivariate log-normal.

(a) Since the distribution of income and consumption expenditure is assumed to be bivariate log-normal, the mean and variance of the logarithm of per capita income is computed from the mean and variance of household income of step 1.
(b) The bivariate lognormality assumption implies that log income and log consumption expenditure are linearly related, so the mean and variance of log per capita consumption expenditure can be easily calculated.

Step 3 – Given the mean and standard deviation of log income and log consumption expenditure, we derive the distributions of population, consumption and total income by 5 consumption classes. (The upper boundaries of the 5 consumption classes – cel_1, cel_2, cel_3, cel_4, cel_5 are taken from the consumption expenditure data published by the NSSO (National Sample Survey Organisation)). More specifically, we find the shares of (i) population (ii) consumption and (iii) total income accruing to the households that fall under expenditure level cel_k, for k = 1,2,…,5, using the standardised cumulative normal distribution.

[4] The constant shares for each income-type add up across the 15 income classes to one.

Step 4- From the cumulative shares of the 5 consumption expenditure classes we arrive at the per capita expenditure and income for each these classes by simply taking the difference between the cumulative shares of the class in question and the preceding class.

Step 5 – Once we have the per capita consumption expenditure for each of the 5 consumption classes, we use the Stone-Geary linear expenditure system to determine separately the sectoral per capita consumption demands for each of these classes.

Step 6 – The sectoral per capita consumption demands for each class are then multiplied by the class-specific population, and the resulting product aggregated, first, over the five classes and, then over, the two regions to arrive at the commoditywise consumption demands.

2.11 Savings

Total household savings in the economy is an aggregate of the savings of the 10 urban and rural consumption expenditure classes. For each of the five rural and five urban classes, household savings is determined residually from their respective budget constraints, which state that household income is either allocated to household consumption or to household savings. Government savings is obtained as sum of the tax and tariff revenues, less the value of its consumption and transfers. Government revenue originates from the following five sources : taxes on domestic intermediates, tariffs on imported intermediates, taxes on consumption and investment, taxes on final imports and income taxes - i.e., taxes on wage, self-employed and capital (profit) incomes. All taxes (excluding carbon tax) are of the proportional and *ad valorem* type, and all the tax rates are exogenously given. Government expenditure takes place on account of government consumption and transfers to households, both of which are exogenously fixed. The CO_2 emission taxes are recycled to the households *via* the government, which means that they be included in (or excluded from) both the revenue and the expenditure of the government budget. Foreign savings in the model is expressed as the excess of payments for intermediate and final imports over the sum of exports earnings, net current transfers and net factor income from abroad The latter two, it may be noted, are exogenously given values in the model.

2.12 Market equilibrium and macroeconomic closure

Market clearing equilibrium in the commodity markets is ensured by the condition that sectoral supply of composite commodity must equal demand faced by that sector. In the production structure of the model the domestic gross output of a sector is defined to be a combination of domestic sales and exports, based on a CET transformation function. In turn, the domestic sales part of the sectoral gross output and the final imports of that sector are aggregated through an Armington-type CES function to arrive at the sectoral composite commodity supply[5]. On the other hand, the demand for the composite commodity consists of intermediate demand, final demand - which in turn is an aggregation of consumption, investment and government demands - and change in stocks.

The model is Walrasian in spirit with the sectoral prices being the equilibrating variables for the market-clearing equations. The Walras' law holds and the model is, therefore, homogeneous of

[5] Note that in the nesting structure diagram given above (fig. 1), these 2 functions are *not* shown. The nesting diagram starts with the sectoral gross output at the top, and goes down the vertical linkages of inputs.

degree zero in prices determining only relative prices. The price index – defined to be a weighted average of the sectoral prices – serves as the numeraire, and is, therefore, fixed at one.

Finally, note that although the model is neoclassical in nature, it follows investment-driven macro closure in which aggregate investment is fixed and the components of savings - household savings, government savings and foreign savings - are endogenous variables and adjust to equalize saving and investment.

3. The Baseline Scenario

Our CGE model has been calibrated to the benchmark equilibrium data set of the Indian economy for the year 1989-90. The basic data set of the Indian economy for the year 1989-90 has been obtained from the Central Statistical Organisation - National Accounts Statistics of India (various issues) and the CSO (1997) - Input-Output Transactions Table - 1989-90. Other parameters and initial values of different variables have been estimated from the data available in various other published sources.

Given the benchmark data set for all the variables and the elasticity parameters, the *shift* and *share* parameters are calibrated in such a manner that if we solve the model using the base-year data inputs, the result will be the input data itself (Shoven and Whalley, 1992).

Finally, using a time series of the exogenous variables of the model, we generate a sequence of equilibria for the period 1990-2020. From the sequence of equilibria, with 5-year time intervals[6], the growth paths of selected (macro) variables of the economy are outlined to describe the base-line scenario.

3.1 The macro variables

In the base-line scenario, real GDP growth throughout the period 1990-2020 varies in the range 4%-6%. The GDP growth rate, which is 5.7% per year during 1990-95, slows down to less than 5% in the period 1995-2005 (table 4). After that the growth rate picks up again to more than 5% per year till 2020 (figure 2). The driving force of GDP growth in our model comes from growth in the two main exogenous variables - investment and labour supply. Investment adds to the capital stock, inducing a substitution away from labour into capital. This results in an increase in labour productivity, measured as GDP per unit of labour (figure 3). Growth in labour productivity coupled with the simultaneous growth in labour supply is what provides the main impetus to GDP growth.

3.2 Poverty ratio

The poverty ratio in the base-line scenario declines from 37.5% in 1990 to 2% in 2020 (table 12). However, the noteworthy fact is that the decline in poverty ratio is very much linked to the growth in GDP. That is to say, with the GDP growing faster after 2005, the decline in poverty also speeds up. In the first 15-year period, 1990-2005, the poverty ratio declines quinquennially by about 4-5 percentage

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[6] Since Indian database is on an annual basis, we solved the model annually for thirty years. However, the results are reported for five-year intervals. This is because, results presented on a year-to-year basis for thirty years, would not be amenable to any meaningful analysis.

points; in the later 15-year period 2005-2020 it declines quinquennially by about 7-8 percentage points.

3.3 Energy use

Total energy use increases by about 320% over the 30-year period 1990-2020. However, the annual growth rate of energy use along with the annual growth rate of GDP declines each quinquennium untill 2005, with the decline being sharper in case of the former after 2005 (table 7). Increased employment of capital in the production process as well as modest autonomous energy efficiency improvement results in an economy of the energy inputs in the production process as reflected in the declining energy use per unit of GDP.

3.4 Carbon emissions

Total carbon emissions in the period 1990-2020 rise from 168 million tonnes to 559 million tonnes at an average rate of 4.1% per year (table 9). However, the growth rate is not uniform. It drops from more than 4% in the pre-2005 period to less than 3% in the post 2005 period. This is largely explained by the decline in the energy-GDP ratio after 2005 (table 7). In the Indian economy carbon is emitted predominantly - as much as 72% of the total emissions - from the combustion of coal. The share of coal in the total emissions remains unchanged throughout the period (table 10).

In assessing India's contribution to global carbon emisions, it is important to look at the per capita carbon emissions[7]. India's per capita emissions in 1990 turn out to be 0.21 tonnes. It increases quite rapidly over the 30-year period and goes up to 0.69 tonnes by the year 2020 (table 11). Even this level of per capita emissions is considerably less than the global per capita emissions which is approximately 1 tonne per year.

4. Policy Simulations

We develop eight alternative policy scenarios for two basic policy instruments for carbon emission reduction - domestic carbon tax and internationally tradable permits based on equal per capita emissions allocation. Specifically, we have four policy scenarios - simulations 1, 1(TT), 2 and 2(TT) - for the carbon tax policy. Policy simulations 1 and 2 deal respectively with the two cases of fixing the carbon emission at the 1990 level all through the 30-year period, and of 10% annual reduction in emissions, with 2 variants in each - one in which the carbon tax revenues are recycled to the households like additional government transfers, and the other in which the tax revenues are exclusively transferred to a target group - i.e. the bottom class of the five consumption expenditure classes of households. For the internationally tradable permits, we have again four policy scenarios - simulations 3, 3(TT), 4 and 4(TT) - representing the same 2 variants, with the difference that instead of carbon tax revenues, we have, in this case, revenues earned from the sale of permits. For the policy scenarios 3 and 3(TT), the emissions quota is fixed at 1 tonne per capita[8] based on 1990 population as

[7] Note that the per capita emissions have been calculated on the basis of the 1990 population for all the years, so that a higher population in the years subsequent to 1990 is not allowed to undermine the total emissions in the economy.

[8] This is approximately equal to the world per capita emission in 1990.

suggested by Parikh and Parikh (1998), who have argued that this would encourage the developed countries from signing a Kyoto-type agreement quickly and simultaneously, discourage the developing countries from increasing their population. The permit price for the simulations 3 and 3 (TT) is exogenously given to be US$ 6 per tonne of carbon emission, which is Rs 100 per tonne at the 1989-90 exchange rate of Rs 16.60 per dollar. In reality, the permit price will emerge from a global trading system of permits, which, for example, has been modeled by Edmonds *et al* (1993) in the SGM. However, ours is a country-specific exercise focusing on how it stands to gains or lose from an internationally tradable regime of permits. We, therefore, take the world market price of permits as given, but do consider alternative permit prices in different policy simulations. Hence, the policy simulations 4 and 4(TT) are simply repeat exercises of simulations 3 and 3(TT) respectively, with the permit price exogenously fixed at Rs 200 per tonne.

The eight policy simulations are summarised in table 3 given below.

Table 3 : The policy simulations

	Policy Instrument	Carbon Emission Restriction	Reveues from Carbon Tax/ Internationally Tradable Permits
Policy Simulation 1	Domestic Carbon Taxes	Fixed at 1990 level	Recycled to the households like additional government transfers
Policy Simulation 1 (TT) [TT : Targeted Transfers]	Domestic Carbon Taxes	Fixed at 1990 level	Recycled exclusively to a target group of households - i.e. the bottom class of the 5 household expenditure classes
Policy Simulation 2	Domestic Carbon Taxes	10 % annual reduction	Recycled to the households like additional government transfers
Policy Simulation 2 (TT) [TT : Targeted Transfers]	Domestic Carbon Taxes	10 % annual reduction	Recycled exclusively to a target group of households - i.e. the bottom class of the 5 household expenditure classes
Policy Simulation 3	Internationally Tradable Permits [Permit Price= $6 / tonne, i.e., Rs 100 /tonne]	1 tonne of carbon per capita based on the 1990 population	Recycled to the households like additional transfers from the rest of the world
Policy Simulation 3 (TT) [TT : Targeted Transfers]	Internationally Tradable Permits [Permit Price= $6 / tonne, i.e., Rs 100 / tonne]	1 tonne of carbon per capita based on the 1990 population	Recycled exclusively to a target group of households - i.e. the bottom class of the 5 household expenditure classes
Policy Simulation 4	Internationally Tradable Permits [Permit Price= $12 /tonne, i.e., Rs 200/tonne]	1 tonne of carbon per capita based on the 1990 population	Recycled to the households like additional world transfers
Policy Simulation 4 (TT) [TT : Targeted Transfers]	Internationally Tradable Permits [Permit Price= $12/tonne, i.e., Rs 200/tonne]	1 tonne of carbon per capita based on the 1990 population	Recycled exclusively to a target group of households - i.e. the bottom class of the 5 household expenditure classes

4.1 Policy simulations 1 and 1(TT)

In this simulation the procedure followed is to fix the carbon emission level at the 1990 level and to endogenise the carbon tax rate (which was fixed at zero in the base-line scenario). The sequential equilibrium solution of the model then generates, among other values, the appropriate carbon tax rates for each of the years subsequent to 1990. The tax rates rise from Rs 417 per tonne in 1995 to Rs 2765 per tonne in 2020. The growth rate of the carbon tax rate is lower 2005 onwards, because of the lower energy consumption growth rates in this period (table 8). Carbon taxes raise the price of the fossil fuels differentially – the increase in price is maximum for coal which has the highest carbon content, followed by that of refined oil and natural gas – and thus induce fuel switching. The share of coal in total emissions, which was almost 73% throughout the period in the base-case, declines considerably, particularly after 2005. There are corresponding increases in the share of refined oil. The share of natural gas increases only marginally (table 10).

The aggregate emission levels fall relative to the base-line scenario from 19% in 1995 to 70% in 2020. Cumulative emissions in the 30-year period fall by 50% (table 9). Per capita carbon emissions, based on the 1990 population, also fall drastically. In 2020, it is down to 0.21 tonne per capita while it was 0.69 tonnes per capita in the base-line scenario (table 11).

The energy use and GDP trends of simulation 1 in suggest that upto 2000, the fuel-reducing effect dominates, and subsequently fuel-saving becomes more important in determining the impact on GDP. Upto 2000, the decline in GDP is more than that in the use of energy inputs. However, from 2005 to 2020, energy use declines much faster than GDP. The energy-GDP ratio in simulation 1 is significantly lower than that in the base-line 2005 onwards (table 7).

Losses in consumption are higher than losses in GDP even though the carbon tax revenues are recycled to the consumers (table 6). This is because the reduced economic activity (reflected in a lower GDP) results in a decrease in the demand for labour and wages causing disposable personal incomes to fall. Moreover, higher energy prices are passed on to consumers through higher consumer goods prices which in turn lower real consumption. The addition to household incomes from the recycled carbon tax revenues are not sufficient to compensate for the fall in their incomes.

The poverty ratio in simulation 1 increases drastically and progressively from 1995 to 2020. In the base-line scenario, the poverty ratio is 32% in 1995, but declines to 2% in 2020. In simulation 1, the poverty ratio is 34% in 1995 and declines to only 8% in 2020 (table 12). In other words, the number of poor in 2020 in scenario 1 is 4 times that in year 2020 in the base-line scenario (table 13).

In the targeted transfers case of scenario 1 (TT)[9], the poverty ratio improves a little *vis-à-vis* the plain transfers case of scenario 1, but with respect to the base-line scenario it is progressively higher from 1995 to 2020 (table 12). Moreover, the number of poor in the year 2020 under scenario 1(TT) is almost 3.4 times that in the base-line scenario in the same year (table 13).

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[9] Note that for simulation 1(TT), and likewise for all other TT versions of the remaining 3 simulations, the results are shown for poverty ratio and the number of poor only. This is because the figures for the macrovariables in case of the "targeted transfers" versions of the simulations do not differ much from those in their respective "plain transfers" versions Reporting these figures would merely increase the numbers already shown manifold without enhancing in any way the understanding of the impact of the targeted transfers policies.

4.2 Policy simulations 2 and 2(TT)

Policy simulation 2, on the whole, is a milder version of policy simulation 1. In simulation 1, the average annual reduction in carbon emission works out to be 50%, while, in simulation 2, the annual reduction in carbon emissions is fixed to be only 10% (table 8). Per capita emissions, fall progressively from 1990 to 2020. As compared to the base-line scenario, they are 0.02 tonnes less in 1990 and 0.07 tonnes less in 2020 (table 11).

Expectedly, the carbon tax rates in simulation 2 are of much lower orders of magnitude. The carbon tax rate is Rs.218 per tonne in 1990, rises a little in 1995, and, thereafter, declines gradually to Rs.174 per tonne, because of lower energy consumption growth rates in the latter period (table 8).

GDP and consumption losses in scenario 2, as compared to the base-case, are of much lower orders of magnitude than those in scenario 1 (tables 5 and 6). However, consumption losses are more than GDP losses as in scenario 1. In scenario 2, GDP losses vary from 0.75% to 1.20%, while consumption losses vary from 1.20% to 1.55%.

The poverty ratio in scenario 2 increases only marginally with respect to the base-line scenario. It increases by 1.34 percentage points in 1990, and by only 0.1 percentage point in 2020 (table 12). However, the real adverse impact of simulation 2 on poverty comes out in terms of the number of poor. The number of poor in simulation 2 is 10.8 million more in 1990 and 1.28 million more in 2020 (table 13).

Under targeted transfers of simulation 2(TT), the poverty scenario is much less adverse than under simulation 2. Poverty ratio, as compared to that of the base-case, increases by 0.56 percentage point in 1990, and by only 0.02 percentage point in year 2020 (table 12). The number of poor in simulation 2(TT) is 4.53 million more in 1990, and only 0.24 million more in the year 2020 (table 13).

The results of this simulation clearly show that the costs to GDP and poverty reduction imposed by a carbon tax can be reduced to a great extent by moderating the carbon emission reduction target and at the same time recycling the carbon tax revenues to those living below the poverty line.

4.3 Policy simulations 3 and 3(TT)

In policy simulation 3, the carbon emission quota is fixed at 1 tonne per capita based on the 1990 population of 810 million. In other words, the maximum permitted total emission of carbon is fixed at 810 milllion tonnes annually for the Indian economy. For every tonne of carbon emitted less than the permitted 810 million tonnes, the Indian economy earns $6, which is Rs100 at the base-year exchange rate, through the sale of a permit in a global market of permits, and the total revenue form the sale of permits is recycled to the households as transfers from the rest of the world.

The exact procedure followed in this simulation is to fix an upper bound for total emissions - i.e., 180 million tonnes for each year. The actual total emissions of carbon turns out to be much less than the upper bound for each period. (The upper bound is not binding in any of the years). The difference between the permitted emissions and the actual emissions is then multiplied by the permit price to arrive at the total revenue from the sale of permits, which is then recycled to the households like additional transfer payments from the rest of the world. In the process, the model generates a set of equilibrium values for GDP, consumption, poverty ratio etc.

In simulation 3 the carbon emissions increase as compared to the base-line scenario. The increase in emissions is almost 14% in the year 1990, but, in the later years, declines to be in the range of 5.50-9.00% (table 9). Per capita emissions also increase throughout the period, with the increases being in the range of 0.03-0.04 tonnes (table 11). However, even in the last year, 2020, per capita emissions are only 0.73 tonnes, which are less than the world average of 1 tonne per capita.

The infusion of additional transfer payments from the rest of the world, in the form of permit revenue, leads to substantial increases in GDP and consumption in this simulation. GDP increases by 6.7% in the year 1990. However, in the later years the GDP increases are progressively smaller. In the final year, 2020, GDP increases by only 1.8%. The consumption gains are higher than the GDP gains in each of the periods (tables 5 and 6). Apart from the increases in consumption resulting from the increased transfers to households, there are 'second-round' increases in consumption when there is additional income generated from the demand-induced increase in production activities.

The poverty ratio declines significantly in scenario 3. It declines by 2.43 percentage points in the year 1990, and by 0.38 percentage points in the year 2020 (table 12). The number of poor in 1990 decreases by 6.5%, and in the year 2020, the number of poor decreases by 18.8%. That is, in the final year, 2020, the number of poor is only 21.24 million in this simulation, as compared to 26.15 million in the base-line scenario (table 13). Poverty declines even faster under the targeted transfers version of simulation 3. The number of poor in this scenario declines by 11% in 1990 and by 50% in 2020. By the year 2020, the number of poor in this simulation is only 13.18 million, i.e., half of the number of poor in the base-line scenario (table 13).

4.4 Policy simulations 4 and 4(TT)

Simulation 4 is worked out exactly like the simulation 3, with the difference that, in the former, the permit price is given to be $12 per tonne of carbon emitted.

The increase in carbon emissions in this simulation is as high as 19% in 1990, but declines progressively over the 30-year period. By the end of the period, in year 2020, the increase in emission is around 6% (table 9). Per capita emission in the last year is also almost the same as that in the previous simulation (table 11).

GDP gains in this simulation are expectedly larger than that in the simulation 3. GDP, as compared to the base-case, increases by almost 12% in 1990, and 2% in 2020. Consumption gains are even bigger. Consumption increases by more than 12% in 1990, and 3.12 % in 2020 (tables 5 and 6) .

There is a very substantial decline in the poverty ratio in simulation 4. Poverty ratio is only 30.02% in 1990, as compared to 37.45% in the base-line in that year. In 2020, poverty ratio is 0.87%, as compared to 2.01% in the base-line (table 12). The number of poor in 2020 declines by 57% and is only 11.28 million, as against 26.15 million of the base-case (table 13). In simulation 4(TT), there is an even speedier decline of poverty. Poverty ratio is 25.45% in 1990, and only 0.08% in 2020 (table 12). The number of people in poverty, relative to the base-line, decreases by 32% in 1990 and by 96% in 2020. In that year, the number of poor is only 1.02 million as against 26.15 million of the base-line scenario (table 13).

4.5 Policy simulations : caveats

In the interpretation of the simulation results, the limitations of our model must be borne in mind. One limitation of our model is that in the production of electricity, the input substitution possibilities are confined to be only within the fossil fuels – coal, refined oil and natural gas. Carbon free options such as hydro, wind, solar and nuclear electricity are not considered in the model. The contributions of these energy sources in the total energy consumption in India are not likely to increase significantly within the time frame of our model, 1990-2020. As can be seen from table 1, the contribution of "other" energy sources which include wind, solar and nuclear energy, to total energy consumption in India in 1990 is only 0.6 %. Hydropower provides 6.21% of the total energy consumed in 1990. But its percentage share does not seem to grow over time. It was 5.24% in 1970, increased to 6.77% in 1980, but starts declining after that till it reaches 6.21% in 1990. Even, the post-economic reforms period of 1991-92 to 1997-98, Sengupta and Gupta (2003) find a declining share of hydro power and an increasing share of thermal power in the total gross generation of electricity. They conclude that "there has been no success in raising the share of carbon free options of hydro and nuclear in gross power generation by the introduction of reforms". Bearing in mind the limited relevance of the carbon free options in the next two or three decades in India, we have kept our model structure simplified and avoided the unnecessary complication of introducing the options of hydro, wind and nuclear in the generation of power. That said, we do recognise that the model, in its present form is "incomplete" if it has to be implemented over a longer time horizon of fifty years or more, and should be extended for further study. The absence of clean energy options such as hydro electricity, means that the the adverse effects of emission restriction on economic growth and poverty reduction shown in simulations 1 and 1(TT) are somewhat exaggerated. However, even with hydro electricity they would remain large, given the high orders of magnitude of losses in GDP and poverty alleviation in this simulation. In case of policy simulations 2 and 2(TT), with a softer carbon emission reduction target, the relatively small losses in GDP and poverty alleviation could not possibly be compensated by introducing the hydropower option, except, perhaps in the last few years of the thirty year period.

Another more serious limitation of the model in its present form is the fact that it is recursively dynamic and, not fully dynamic. We regard this as a more serious limitation because it restricts the scope of policy analysis that can be carried out within the framework of the model. A recursively dynamic model basically generates a sequence of static equilibria and is, therfore, suitable for analysing the consequences for GDP and poverty of annual emission reduction targets. However, an equally viable policy option is a dynamically optimum strategy with cumulative emission reduction targets. This, in fact, can be less costly in terms of GDP loss and poverty reduction foregone because it allows the economy to define an inter-temporal adjustment path. But such a strategy cannot be examined through a recursively dynamic model. It needs an inter-temporal optimising framework. Our only justification for using a quasi-dynamic instead of a fully dynamic model is the the economy of effort necessitated by the time constraint specified for this study. We hope to overcome this limitation in a later version of the model.

5. Conclusions and Policy Implications

We conclude by highlighting the main policy lessons from our simulation exercises. The policy lessons that emanate from our policy scenarios are fairly clear. They are, however, in two parts.

In the first part, i.e., in policy scenarios 1 and 2, the lessons learnt are about the efficacy of a domestic carbon tax policy to reduce carbon emissions without seriously compromising the growth and poverty reduction goals of the Indian economy. In this regard, the results of the policy scenario 1 are very discouraging. That is to say, the employment of a carbon tax to restrict the carbon emissions in the Indian economy to the 1990 level, imposes heavy costs in terms of lower GDP and higher poverty. With targeted transfers to the poor, the costs in terms of higher poverty are somewhat mitigated, but they remain quite high - i.e., the number of poor in 2020 increases by 3.4 times. It needs to be stressed that, these high costs in terms of GDP losses and poverty reduction foregone in this policy scenario cannot be significantly reduced by including the contribution of clean energy options, such as hydro electricity. Hydropower constitutes a very small and stagnant share (5%-6%) of the total energy consumed in India. The share of other clean energy sources (nuclear, wind and solar) is even smaller – less than 1 percent. More importantly, the costs to GDP and poverty alleviation in this policy scenario are not unexpectedly high. In fact, such high costs are a natural consequence of an unduly restrictive carbon emissions policy. The latter is obvious from the fact that, the per capita emissions (based on the 1990 population) in this simulation in 2020 sre 0.21 tonnes as compared to 0.69 tonnes in the base case in the same year.

In policy scenario 2, a milder restriction of 10% annual reduction in carbon emission is achieved through the imposition of a carbon tax. The GDP losses are still significant, though not very large. More importantly, poverty is higher throughout the 30-year period. However, with targeted transfers the number of people in poverty increases by about 4-5 million in the first half of the period, and, subsequently, by less than 2 million for a decade. Towards the end of the period the number of people in poverty is only 0.24 million more than that in the business-as-usual scenario. This result suggests that targeted transfers is a contrivance that can be effectively used to dodge the trade-off between poverty reduction and carbon emissions, provided the emission reduction target is a very modest one. The emission target can be further moderated to, say, a 5% annual reduction. A five percent annual reduction in total emissions would imply that per capita emissions (based on 1990 population) in 2020 will be 0.66 tonnes[10]. This is no mean target for per capita emissions given that the average world per capita emissions in 1990 is 1 tonne.

In the second part, i.e., in policy scenarios 3 and 4, the implications of India's participation in a global trading system of emission permits are analysed. In these scenarios, India is allowed a maximum emission of 180 million tonnes of carbon annually. The actual annual emissions in these scenarios, however, are much less than the maximum limit. In an internationally tradable permits regime, India stands to gain by keeping its emissions as much less than the stipulated maximum as possible. In other words, India does not have a perverse incentive to emit more in a tradable emission permits regime, as is sometimes feared. Nor is it true that, India can perpetually induce a resource flow from the developed countries through the sale of emission permits, by virtue of having per capita emissions which are lower than the world average per capita emissions of 1 tonne of carbon. On the contrary, with actual emissions increasing faster in the policy scenarios 3 and 4 than in the business-as-usual scenario, it is safe to expect that the turnaround for India- from being a net seller of permits to a net buyer of permits - will come before 2050.

Be that as it may, India gains immensely in terms of higher GDP growth and lower poverty in the tradable emission permits scenarios In case of scenario 3, in which the permit price is $6 per tonne, in the 30-year period, GDP increases on an average by 3.7% and the number of people in poverty goes down by about 19% by 2020. In the targeted transfers variant of this scenario, the number of people in poverty is in fact halved. In case of scenario 4, in which the permit price is $12 per tonne, GDP increases in the 30-year period, on an average by 5.7% , and the number of people in poverty is reduced by 57% by 2020. Moreover, in case of the targeted transfers version of this scenario, poverty virtually vanishes.

It is obvious, that the Kyoto protocol opens up a unique opportunity for India and other developing countries, to sidestep the trade-off between carbon emissions, economic growth and poverty reduction.

[10] Note that 0.66 = (0.95*559.46) / 810, where 559.46 million tonnes is the total carbon emissions in 2020 in the base-line scenario, and 810 million is the 1990 population.

If the Kyoto protocol does not materialise, and this opportunity is missed, India is unlikely to take the hard decision of imposing a domestic carbon tax to reduce carbon emissions, even though a carbon tax, with targeted transfers, for a very modest reduction in carbon emissions is not necessarily detrimental to economic growth and poverty alleviation.

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APPENDIX 1

Table 4 : Macrovariables and carbon emissions of the base-line scenario

	In billion Rupees			In million tonnes	*GDP (Growth Rate)*	*Cons. (Growth Rate)*	*Inv. (Growth Rate)*	*Carbon Emissions (Growth Rate)*
	GDP	Cons.	Inv. (exo.)	Carbon Emissions				
1990	4380.11	3211.25	1539.41	168.00				
1995	5835.89	3927.65	2182.17	208.09	*5.74*	*4.03*	*6.98*	*4.28*
2000	7489.40	4856.58	2944.81	257.74	*4.99*	*4.25*	*5.99*	*4.28*
2005	9160.77	6201.46	3704.05	315.75	*4.03*	*4.89*	*4.59*	*4.06*
2010	11865.33	8312.96	4947.21	383.74	*5.17*	*5.87*	*5.79*	*3.90*
2015	15290.51	10939.08	6580.08	464.50	*5.07*	*5.49*	*5.70*	*3.82*
2020	20130.18	14730.50	8729.03	559.46	*5.50*	*5.95*	*5.65*	*3.72*

Note : The growth rates for each of the quinquenniums are the annual growth rates.

Table 5 : GDP

	In billion Rupees	*Percentage difference from base-line*			
	Base-line	*Sim. 1*	*Sim. 2*	*Sim. 3*	*Sim. 4*
1990	4380.11	*0.00*	*-0.76*	*6.69*	*11.83*
1995	5835.89	*-1.64*	*-0.82*	*4.90*	*9.00*
2000	7489.40	*-3.95*	*-1.20*	*4.04*	*6.47*
2005	9160.77	*-5.25*	*-1.17*	*3.38*	*4.31*
2010	11865.33	*-3.82*	*-1.13*	*2.61*	*3.43*
2015	15290.51	*-4.46*	*-1.06*	*2.24*	*2.75*
2020	20130.18	*-4.61*	*-0.76*	*1.83*	*1.98*

Table 6 : Consumption

	In billion Rupees	*Percentage difference from base-line*			
	Base-line	*Sim. 1*	*Sim. 2*	*Sim. 3*	*Sim. 4*
1990	3211.25	*0.00*	*-1.24*	*6.81*	*12.01*
1995	3927.65	*-2.25*	*-1.36*	*6.19*	*10.47*
2000	4856.58	*-4.42*	*-1.55*	*5.64*	*8.31*
2005	6201.46	*-6.40*	*-1.46*	*3.66*	*4.96*
2010	8312.96	*-6.80*	*-1.38*	*3.55*	*3.69*
2015	10939.08	*-7.68*	*-1.28*	*2.90*	*3.61*
2020	14730.50	*-8.28*	*-1.20*	*2.53*	*3.12*

Table 7 : Energy use

	E	*E (Growth Rate)*	E/GDP	E/GDP	E	*GDP*
	Base-line	*Base-line*	Base-line	Sim. 1	*Sim. 1 (%age diff. from base-line)*	*Sim. 1 (%age diff. from base-line)*
1990	565.46	*5.72*	0.1291	0.1291	*0.00*	*0.00*
1995	752.84	*5.17*	0.1290	0.1293	*-1.39*	*-1.64*
2000	975.07	*4.16*	0.1302	0.1304	*-3.83*	*-3.95*
2005	1200.72	*3.04*	0.1311	0.1304	*-5.77*	*-5.25*
2010	1397.54	*2.64*	0.1178	0.1149	*-6.16*	*-3.82*
2015	1594.84	*2.40*	0.1043	0.0980	*-10.27*	*-4.46*
2020	1798.64	*5.72*	0.0894	0.0830	*-11.35*	*-4.61*

Note : E : Total energy use in 10^3 terajoules
E/GDP : Energy input per unit of GDP in 10^3 terajoules per billion rupees
The growth rates for each of the quinquenniums are the annual growth rates.

Table 8 : Carbon tax rates

	Simulation 1		Simulation 2	
	Rs. per tonne	*Tax. Rate. (Growth Rate)*	Rs. per tonne	*Tax. Rate. (Growth Rate)*
1990	0.00		217.65	
1995	417.36		234.36	*1.48*
2000	828.64	*13.72*	221.44	*-1.13*
2005	1261.96	*8.41*	211.66	*-0.90*
2010	1724.20	*6.24*	202.31	*-0.90*
2015	2203.25	*4.90*	191.15	*-1.13*
2020	2765.57	*4.55*	173.87	*-1.90*

Table 9 : Carbon emissions

	In million tonnes	*Percentage difference from base-line*			
	Base-line	*Sim. 1*	*Sim. 2*	*Sim. 3*	*Sim. 4*
1990	168.00	*-0.00*	*-10.00*	*13.70*	*18.95*
1995	208.09	*-19.27*	*-10.00*	*8.90*	*13.34*
2000	257.74	*-34.82*	*-10.00*	*8.27*	*8.66*
2005	315.75	*-46.79*	*-10.00*	*5.51*	*6.15*
2010	383.74	*-56.22*	*-10.00*	*6.64*	*7.55*
2015	464.50	*-63.83*	*-10.00*	*7.29*	*7.75*
2020	559.46	*-69.97*	*-10.00*	*5.83*	*6.24*
Cumulative	**2357.28**	***50.11***	***-10.00***	**7.30**	***8.54***

Table 10 : Carbon emissions (percentage share of fossil fuels)

	Base-line			Simulation 1		
	Coal	Ref. Oil	Nat Gas	Coal	Ref. Oil	Nat Gas
1990	72.23	22.66	5.11	71.34	23.66	5.00
1995	72.46	22.54	5.00	70.36	24.37	5.27
2000	73.11	22.23	4.66	71.06	23.72	5.21
2005	73.25	22.52	4.23	71.39	24.33	4.28
2010	73.35	22.50	4.15	71.18	24.50	4.32
2015	73.14	23.80	3.06	70.37	26.01	3.62
2020	72.98	23.98	3.03	70.42	26.18	3.40

Table 11 : Per capita carbon emissions

	In tonnes per capita				
	Base-line	Sim. 1	Sim. 2	Sim. 3	Sim. 4
1990	0.21	0.21	0.19	0.24	0.25
1995	0.26	0.21	0.23	0.28	0.29
2000	0.32	0.21	0.29	0.34	0.35
2005	0.39	0.21	0.35	0.41	0.41
2010	0.47	0.21	0.43	0.51	0.51
2015	0.57	0.21	0.52	0.62	0.62
2020	0.69	0.21	0.62	0.73	0.73

Note : Per capita emissions have been calculated on the basis of the 1990 population for all the years.

Table 12 : Poverty ratio (in percent)

	Base-line	Sim. 1	Sim. 1 (TT)	Sim. 2	Sim. 2 (TT)	Sim. 3	Sim. 3 (TT)	Sim. 4	Sim. 4 (TT)
1990	37.45	37.45	37.45	38.79	38.01	35.02	33.30	30.02	25.45
1995	32.48	34.01	33.37	33.73	33.08	30.37	28.83	25.74	19.54
2000	28.41	31.10	30.17	29.55	28.96	26.75	24.63	22.69	16.51
2005	24.86	28.18	27.12	25.75	25.25	22.87	20.88	18.84	13.82
2010	16.26	21.69	19.87	16.81	16.43	15.37	14.02	13.29	10.64
2015	09.04	15.22	13.66	09.39	09.14	08.53	07.11	06.86	05.30
2020	02.01	08.05	06.87	02.11	02.03	01.63	01.01	00.87	00.08

Table 13 : Number of poor (in million)

	Base-line	Sim. 1	Sim. 1 (TT)	Sim. 2	Sim. 2 (TT)	Sim. 3	Sim. 3 (TT)	Sim. 4	Sim. 4 (TT)
1990	303.35	303.35	303.35	314.20	307.88	283.66	269.76	243.14	206.13
1995	292.35	306.09	300.33	303.57	297.72	273.29	259.44	231.66	175.88
2000	278.43	304.78	295.67	289.59	283.81	262.14	241.34	222.37	161.78
2005	263.54	298.71	287.47	275.07	267.65	242.39	221.29	199.75	146.54
2010	185.39	247.27	226.52	193.69	187.30	175.17	159.88	151.47	121.34
2015	110.31	185.68	166.65	115.53	111.51	104.02	86.77	83.67	64.64
2020	26.15	104.65	89.31	27.43	26.39	21.24	13.18	11.28	1.02

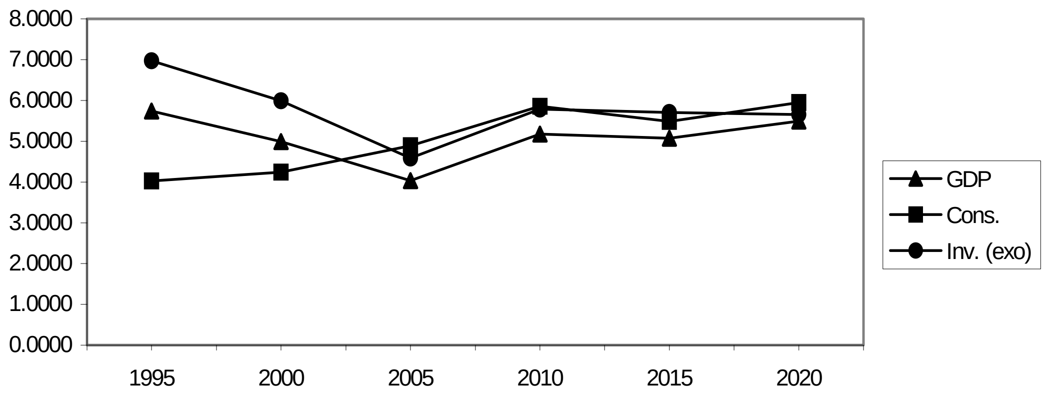


Fig. 2 : Baseline : Growth rates of macrovariables

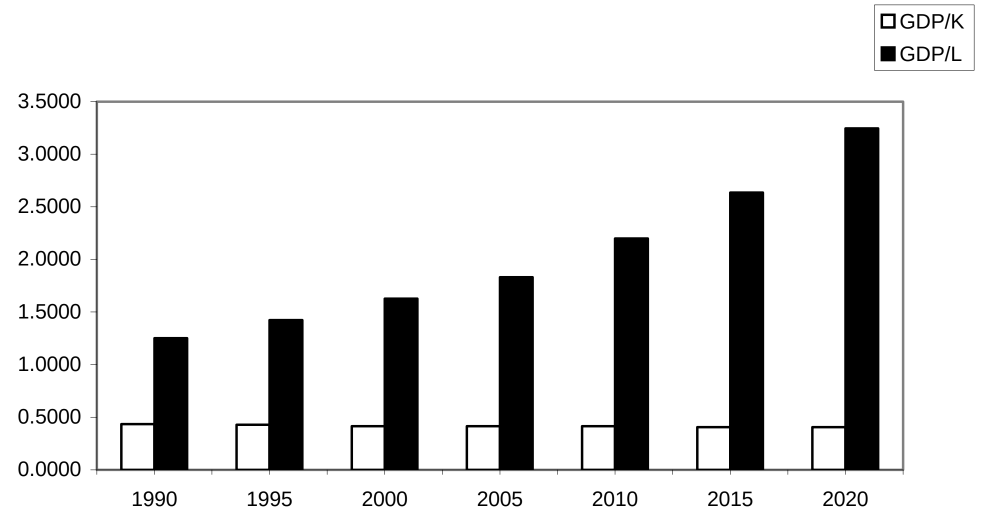
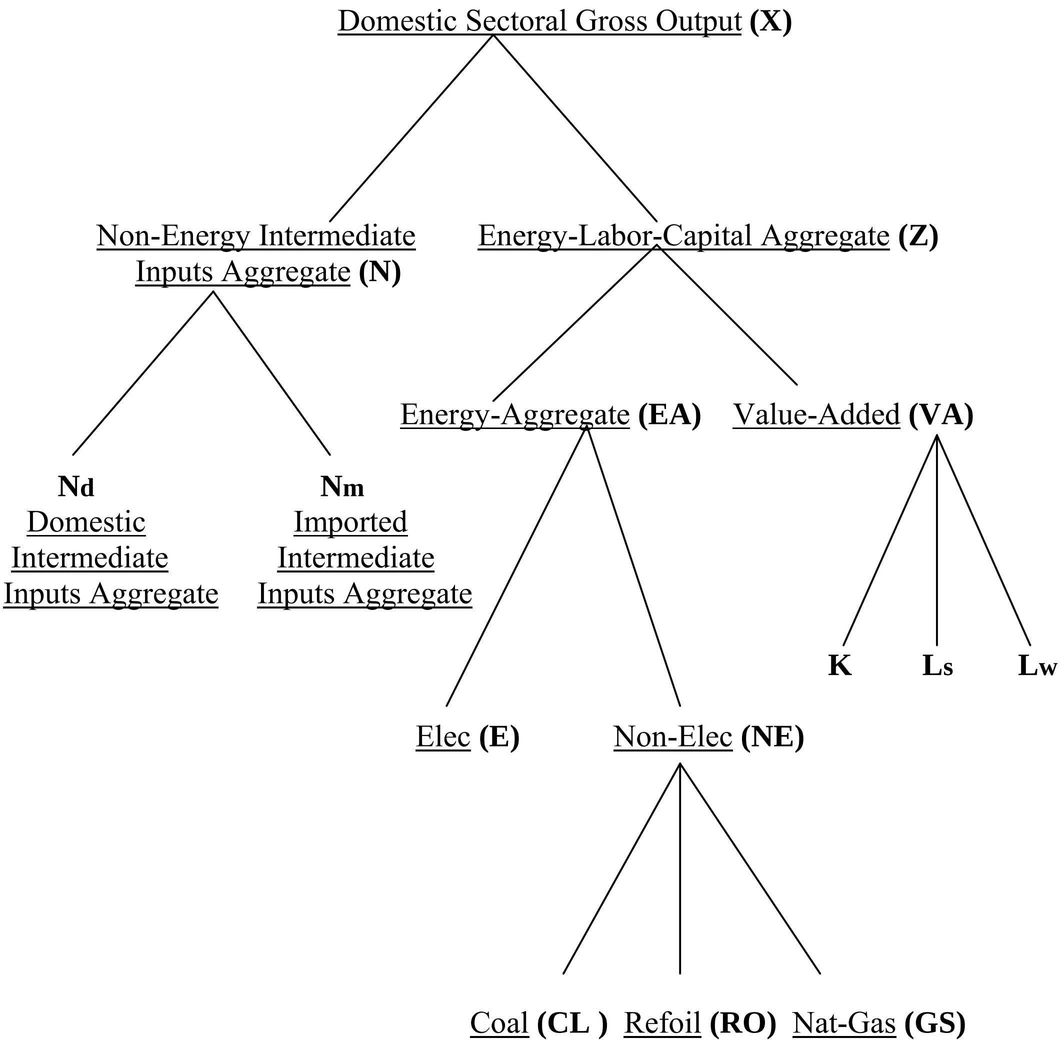


Fig. 3 : Baseline : GDP/K & GDP/L

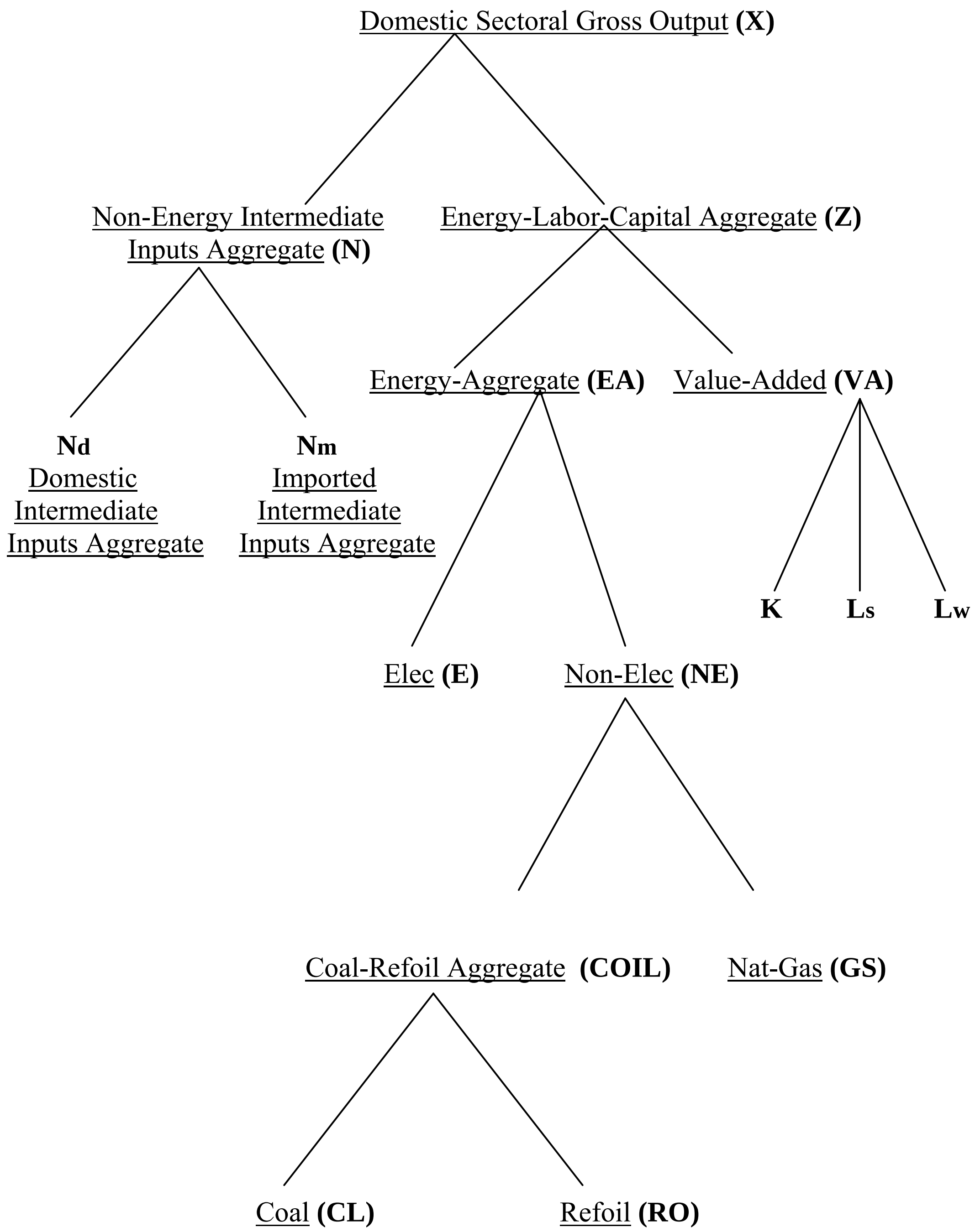
APPENDIX 2

Nested Production Structure for Transport, Enerint, Otherint, Consumer Goods and Services Sectors

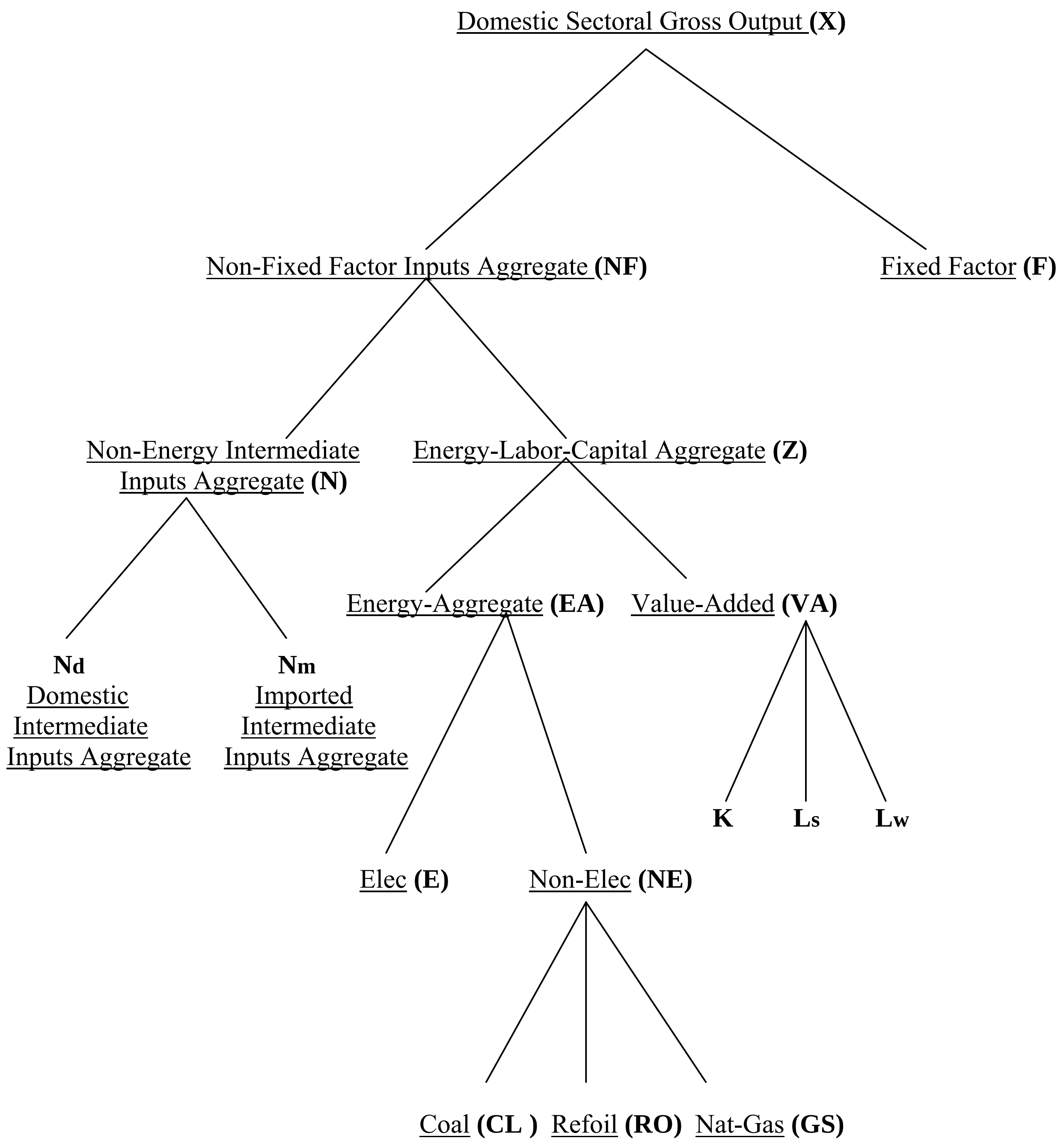


[Note : (i) **K** – Capital ; **Ls** – Self-employed Labour ; **Lw** – Wage-labour.
(ii) **Nd** and **Nm** are fixed-coefficients (Leontief) aggregate of domestic and imported inputs respectively from the non-energy sectors.]

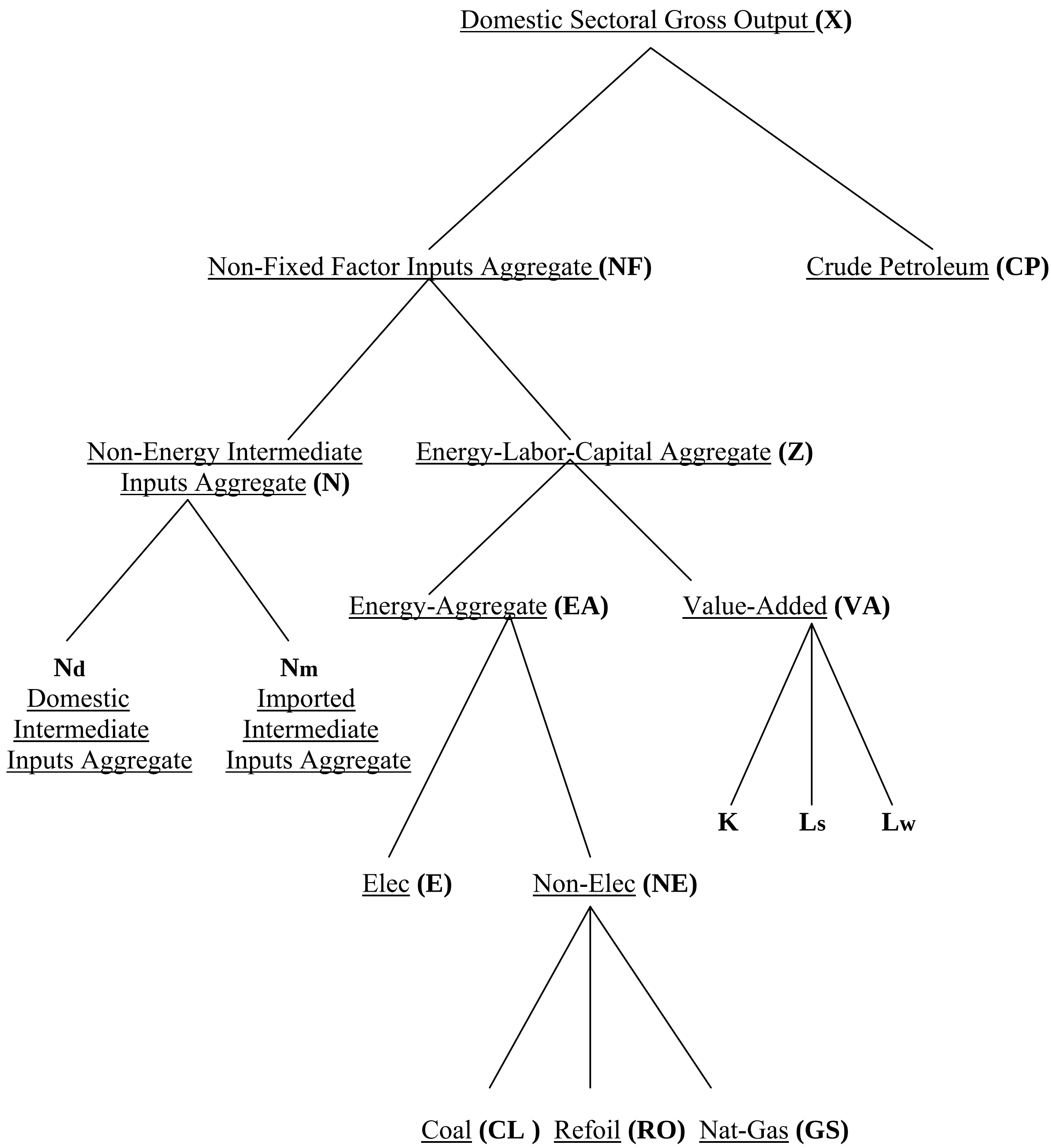
Nested Production Structure for the Electricity Sector



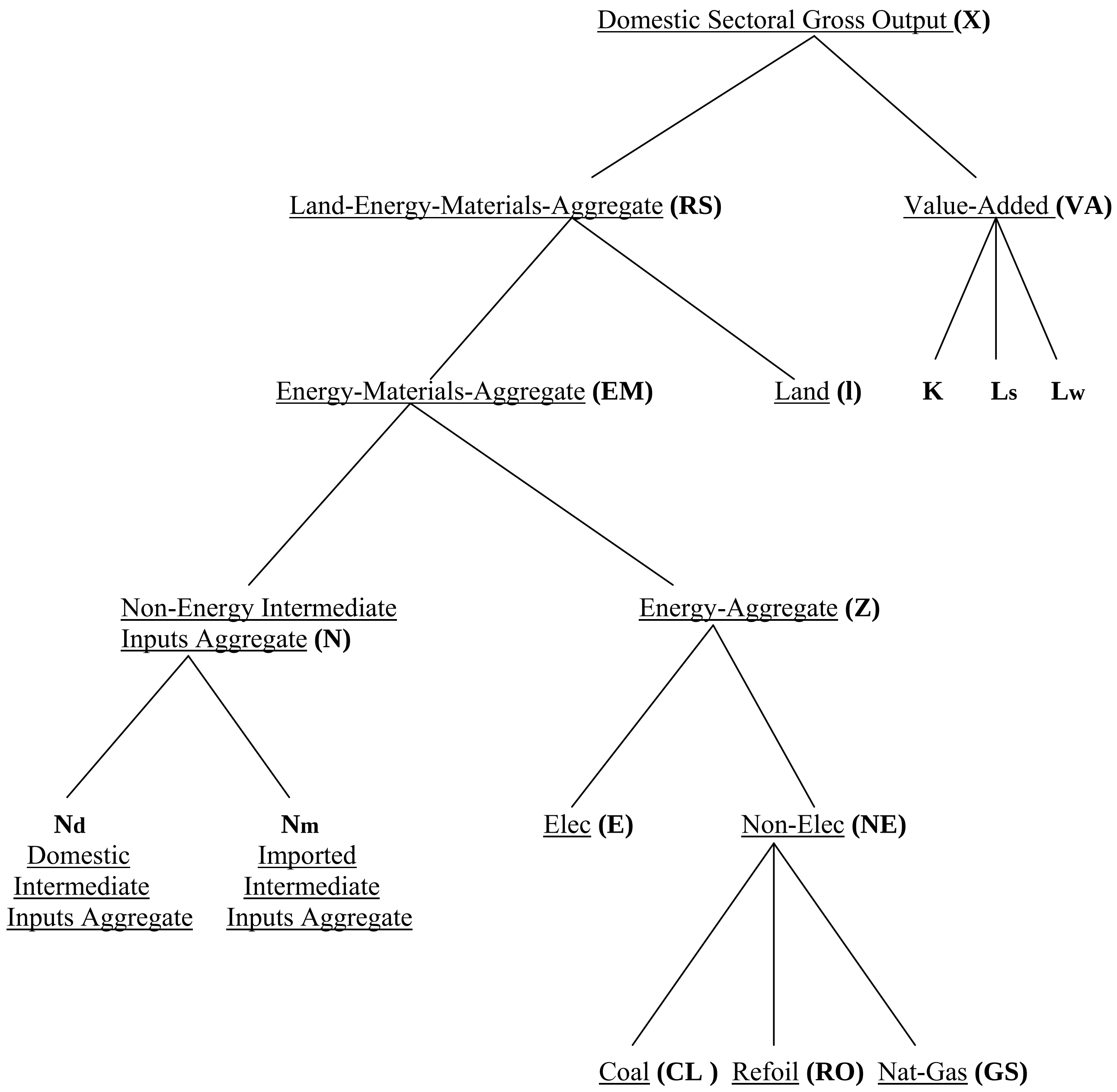
Nested Production Structure for Coal, Natural Gas & Crude Petroleum Sectors



Nested Production Structure for the Refined Oil Sector



Nested Production Structure for Agriculture



APPENDIX 3

Model Equations, Variables and Parameters

Sectors :

1. Agriculture	2. Electricity	3. Coal	4. Refined Oil
5. Natural Gas	6. Crude-Petroleum	7. Transport	8. Energy-Intensive Industries
9. Other Industries	10. Consumer Goods	11. Services	

Sets :

Sectors :
S = (Agricult, Elec, Coal, Refoil, Nat-gas, Crude-Pet, Trans, Enerint, Otherind, Cons-good, Services)

Non-Agricultural Sectors :
NAS = (Agricult, Elec, Coal, Refoil, Nat-gas, Crude-Pet, Trans, Enerint, Otherind, Cons-good)

Non-Fixed Factor Sectors :
NFS = (Elec, Trans, Enerint, Otherind, Cons-good, Services)

Non-Energy Sectors :
NES = (Agricult, Trans, Enerint, Otherind, Cons-good, Services)

Energy Sectors :
SES = (Elec, Coal, Refoil, Nat-gas, Crude-Pet)

Primary Energy Sectors :
PES = (Coal, Nat-gas, Crude-Pet)

Non-electric Energy Sectors :
NEE = (Coal, Refoil, Nat-gas, Crude-Pet)

Non-electric Fuels Sectors :
NEF = (Coal, Refoil, Nat-gas)

Exporting Sectors :
EXS = (Agricult, Coal, Refoil, Trans, Enerint, Otherind, Cons-good, Services)

Non-exporting Sectors :
NXS = (Elec, Nat-gas, Crude-Pet)

Importing Sectors :
IMS = (Agricult, Coal, Refoil, Nat-gas, Crude-Pet, Enerint, Otherind, Cons-good)

Non-importing Sectors :
NMS = (Elec, Trans, Services)

Regions :
RGN = (rural, urban)

Sources of Income (land, fixed-factor, wage-labour, self-employed-labour, capital , transfer payments) :
TYP = (l, f, w, s, k, tp)

Consumption Expenditure Classes
CEC = (1, 2, 3, 4, 5)

Income Classes (Percentiles)
H = (h1 (10%), h2(10%),…,h9(10%), h10(5%), h11(1%), h12(1%),…,h15(1%)]

Production Structure

(1) $$X_i = a_{x_i} * \left[\delta_{x_i} * N_i^{-\rho_{x_i}} + (1-\delta_{x_i}) * Z_i^{-\rho_{x_i}}\right]^{-1/\rho_{x_i}}$$ i ε NFS

(2) $$N_i = Z_i * \left[\frac{P_{z_i} * \delta_{x_i}}{P_{n_i} * (1-\delta_{x_i})}\right]^{\sigma_{x_i}} \quad , \text{ where } \sigma_{x_i} = 1/(1+\rho_{x_i})$$ i ε NFS

(3) $$P_{x_i} * X_i = P_{n_i} * N_i + P_{z_i} * Z_i + t_e * \omega_i * X_i$$ i ε NFS

(4) $$X_i = a_{x_i} * \left[\delta_{x_i} * NF_i^{-\rho_{x_i}} + (1-\delta_{x_i}) * f_i^{-\rho_{x_i}}\right]^{-1/\rho_{x_i}}$$ i ε PES

(5) $$NF_i = f_i * \left[\frac{P_{f_i} * \delta_{x_i}}{P_{nf_i} * (1-\delta_{x_i})}\right]^{\sigma_{x_i}} \quad , \text{ where } \sigma_{x_i} = 1/(1+\rho_{x_i})$$ i ε PES

(6) $$P_{x_i} * X_i = P_{nf_i} * NF_i + P_{f_i} * f_i$$ i ε PES

(7) $$X_4 = a_{x_4} * \left[\delta_{x_4} * NF_4^{-\rho_{x_4}} + (1-\delta_{x_4}) * CP^{-\rho_{x_4}}\right]^{-1/\rho_{x_4}}$$

(8) $$NF_4 = CP * \left[\frac{(Pq_6 + t_e * \mu_{cp_6}) * \delta_{x_4}}{P_{nf_4} * (1-\delta_{x_4})}\right]^{\sigma_{x_4}} \quad , \text{ where } \sigma_{x_4} = 1/(1+\rho_{x_4})$$

(9) $$P_{x_4} * X_4 = P_{nf_4} * NF_4 + (Pq_6 + t_e * \mu_{cp_6}) * CP$$

(10) $$X_1 = a_{x_1} * \left[\delta_{x_1} * RS_1^{-\rho_{x_1}} + (1-\delta_{x_1}) * VA_1^{-\rho_{x_1}} \right]^{-1/\rho_{x_1}}$$

(11) $$RS_1 = VA_1 * \left[\frac{P_{VA_1} * \delta_{x_1}}{P_{rs_1} * (1-\delta_{x_1})} \right]^{\sigma_{x_1}} , \quad \text{where } \sigma_{x_1} = 1/(1+\rho_{x_1})$$

(12) $$P_{X_1} * X_1 = P_{rs_1} * RS_1 + P_{va_1} * VA_1$$

(13) $$RS_1 = a_{rs_1} * \left[\delta_{rs_1} * EM_1^{-\rho_{rs_1}} + (1-\delta_{rs_1}) * ld^{-\rho_{rs_1}} \right]^{-1/\rho_{rs_1}}$$

(14) $$EM_1 = ld * \left[\frac{P_{ld} * \delta_{rs_1}}{P_{em_1} * (1-\delta_{rs_1})} \right]^{\sigma_{rs_1}} , \quad \text{where } \sigma_{rs_1} = 1/(1+\rho_{rs_1})$$

(15) $$P_{rs_1} * RS_1 = P_{em_1} * EM_1 + P_{ld} * ld$$

(16) $$EM_1 = a_{em_1} * \left[\delta_{em_1} * N_1^{-\rho_{em_1}} + (1-\delta_{em_1}) * EA_1^{-\rho_{em_1}} \right]^{-1/\rho_{em_1}}$$

(17) $$N_1 = EA_1 * \left[\frac{P_{ea_1} * \delta_{em_1}}{P_{n_1} * (1-\delta_{em_1})} \right]^{\sigma_{em_1}} , \quad \text{where } \sigma_{em_1} = 1/(1+\rho_{em_1})$$

(18) $$P_{rs_1} * RS_1 = P_{em_1} * EM_1 + P_{ld} * ld$$

(19) $$NF_i = a_{nf_i} * \left[\delta_{nf_i} * N_i^{-\rho_{nf_i}} + (1-\delta_{nf_i}) * Z_i^{-\rho_{nf_i}} \right]^{-1/\rho_{nf_i}} \qquad i \; \varepsilon \; NEE$$

(20) $$N_i = Z_i * \left[\frac{P_{z_i} * \delta_{nf_i}}{P_{n_i} * (1-\delta_{nf_i})} \right]^{\sigma_{nf_i}} , \quad \text{where } \sigma_{nf_i} = 1/(1+\rho_{nf_i}) \qquad i \; \varepsilon \; NEE$$

(21) $$Pnf_i * NF_i = P_{n_i} * N_i + P_{z_i} * Z_i$$ $i \; \varepsilon$ NEE

(22) $$Z_i = a_{z_i} * \left[\delta_{z_i} * EA_i^{-\rho_{z_i}} + (1-\delta_{z_i}) * VA_i^{-\rho_{z_i}}\right]^{-1/\rho_{z_i}}$$ $i \; \varepsilon$ NAS

(23) $$EA_i = VA_i * \left[\frac{P_{va_i} * \delta_{z_i}}{P_{ea_i} * (1-\delta_{z_i})}\right]^{\sigma_{z_i}} \quad , \text{ where } \sigma_{z_i} = 1/(1+\rho_{z_i})$$ $i \; \varepsilon$ NAS

(24) $$P_{Z_i} * Z_i = P_{ea_i} * EA_i + P_{va_i} * VA_i$$ $i \; \varepsilon$ NAS

(25) $$N_i = a_{n_i} * \left[\delta_{n_i} * Nd_i^{-\rho_{n_i}} + (1-\delta_{n_i}) * Nm_i^{-\rho_{n_i}}\right]^{-1/\rho_{n_i}}$$ $i \; \varepsilon$ S

(26) $$Nd_i = Nm_i * \left[\frac{P_{Nm_i} * \delta_{n_i}}{P_{Nd_i} * (1-\delta_{n_i})}\right]^{\sigma_{n_i}} \quad , \text{ where } \sigma_{n_i} = 1/(1+\rho_{n_i})$$ $i \; \varepsilon$ S

(27) $$P_{n_i} * N_i = P_{Nd_i} * Nd_i + P_{Nm_i} * Nm_i$$ $i \; \varepsilon$ S

(28) $$EA_i = a_{EA_i} * \left[\delta_{EA_i} * E_i^{-\rho_{EA_i}} + (1-\delta_{EA_i}) * NE_i^{-\rho_{EA_i}}\right]^{-1/\rho_{EA_i}}$$ $i \; \varepsilon$ S

(29) $$E_i = NE_i * \left[\frac{P_{NE_i} * \delta_{EA_i}}{P_{E_i} * (1-\delta_{EA_i})}\right]^{\sigma_{EA_i}} \quad , \text{ where } \sigma_{EA_i} = 1/(1+\rho_{EA_i})$$ $i \; \varepsilon$ S

(30) $$P_{EA_i} * EA_i = P_{q_2} * E_i + P_{NE_i} * NE_i$$ $i \; \varepsilon$ S

(31) $$VA_i = a_{VA_i} * \left[\delta_{K_i} * K_i^{-\rho_{VA_i}} + \delta_{lw_i} * Lw_i^{-\rho_{VA_i}} + \delta_{ls_i} * Ls_i^{-\rho_{VA_i}}\right]^{-1/\rho_{VA_i}}$$ $i \; \varepsilon$ S

[Note : $\delta_{K_i} + \delta_{lw_i} + \delta_{ls_i} = 1$]

(32) $$K_i = Lw_i * \left[\frac{W_{rg} * \delta_{k_i}}{P_{k_i} * \delta_{lw_i}}\right]^{\sigma_{VA_i}} \quad , \text{ where } \sigma_{VA_i} = 1/(1+\rho_{VA_i})$$ $i \; \varepsilon$ S

$$Ls_i = Lw_i * \left[\frac{W_{rg} * \delta ls_i}{P_{ls_{rg}} * \delta lw_i} \right]^{\sigma_{VA_i}} \quad , \text{ where } \sigma_{VA_i} = 1/(1+\rho_{VA_i})$$

(33) $i \; \varepsilon \; S$

(34) $$P_{VA_i} * VA_i = P_{k_i} * K_i + W_{rg} * L_{w_i} + P_{LS_{rg}} * L_{s_i}$$ $i \; \varepsilon \; S$

.

(35) $$NE_i = a_{NE_i} \left[\delta cl_i * CL_i^{-\rho_{NE_i}} + \delta gs_i * GS_i^{-\rho_{NE_i}} + \delta ro_i * RO_i^{-\rho_{NE_i}} \right]^{-1/\rho_{NE_i}}$$ $i \; \varepsilon \; S$

[Note : $\delta cl_i + \delta gs_i + \delta ro_i = 1$]

$$CL_i = GS_i * \left[\frac{\left(Pq_{gs} + t_e * \mu_{gs_i} \right) * \delta cl_i}{\left(Pq_{cl} + t_e * \mu_{cl_i} \right) * \delta gs_i} \right]^{\sigma_{NE_i}} \quad , \text{ where } \sigma_{NE_i} = 1/(1+\rho_{NE_i})$$

(36) $i \; \varepsilon \; S$

$$RO_i = GS_i * \left[\frac{\left(Pq_{gs} + t_e * \mu_{gs_i} \right) * \delta ro_i}{\left(Pq_{ro} + t_e * \mu_{ro_i} \right) * \delta gs_i} \right]^{\sigma_{NE_i}} \quad , \text{ where } \sigma_{NE_i} = 1/(1+\rho_{NE_i})$$

(37) $i \; \varepsilon \; S$

(38) $$P_{NE_i} * NE_i = (Pq_{cl} + t_e * \mu cl_i) * CL_i + (Pq_{ro} + t_e * \mu ro_i) * RO_i + (Pq_{gs} + t_e * \mu gs_i) * GS_i$$ $i \; \varepsilon \; S$

(39) $$X_i = aex_i * \left[\delta ex_i * EX_i^{-\rho_{ex_i}} + (1 - \delta ex_i) * DD_i^{-\rho_{ex_i}} \right]^{-1/\rho_{ex_i}}$$ $i \; \varepsilon \; EXS$

(40) $$EX_i = DD_i * \left[\frac{Pdd_i * \delta ex_i}{Pex_i * (1 - \delta ex_i)} \right]^{\sigma ex_i} \quad , \text{ where } \sigma ex_i = 1/(1+\rho ex_i)$$ $i \; \varepsilon \; EXS$

(41) $P_{X_i} * X_i = Pex_i * EX_i + Pdd_i * DD_i$ $i \; \varepsilon \; EXS$

(42) $EX_i = aexd_i * [PWex_i / pwes_i]^{\rho exd_i}$ $i \; \varepsilon \; EXS$

(43) $X_i = DD_i$ $i \; \varepsilon \; NXS$

(44) $P_{X_i} * X_i = Pdd_i * DD_i$ $i \; \varepsilon \; NXS$

(45) $$Q_i = a_{q_i} * \left[\delta_{q_i} * M_i^{-\rho_{q_i}} + (1-\delta_{q_i}) * DD_i^{-\rho_{q_i}} \right]^{-1/\rho_{q_i}}$$ $i \ \varepsilon$ IMS

(46) $$M_i = DD_i * \left[\frac{P_{dd_i} * \delta_{q_i}}{P_{m_i} * (1-\delta_{q_i})} \right]^{\sigma_{q_i}}$$, where $\sigma_{q_i} = 1/(1+\rho_{q_i})$ $i \ \varepsilon$ IMS

(47) $$Q_i * P_{q_i} = P_{m_i} * M_i + P_{dd_i} * DD_i$$ $i \ \varepsilon$ IMS

(48) $$Q_i = DD_i$$ $i \ \varepsilon$ NMS

(49) $$P_{q_i} * Q_i = P_{dd_i} * DD_i$$ $i \ \varepsilon$ NMS

<u>CO2 Emissions:</u>

(50) $$ECO2_{ng} = \sum_{i=1}^{11} \mu_{cl_i} * CL_i + \sum_{i=1}^{11} \mu_{gs_i} * GS_i + \sum_{i=1}^{11} \mu_{ro_i} * RO_i + \mu_{cp} * CP + \sum_{i=1}^{11} \omega_i * X_i + \sum_{i=1}^{11} \varphi_i * C_i$$

(51) $$ECO2_g = \sum_{i=1}^{11} \tau_i * cg_i$$

(52) $$TECO2 = ECO2_{ng} + ECO2_g$$

(53) $$PAYEM = t_e * ECO2_{ng}$$

<u>Prices (Exports , Imports and Intermediates)</u>

(54) $$PW_{ex_i} = (P_{ex_i} * (1-exsub_i)) / ER$$ $i \ \varepsilon$ EXS

(55) $$P_{m_i} = pw_{m_i} * (1+ t_{fm_i}) * ER$$ $i \ \varepsilon$ IMS

(56) $$P_{nm_i} = \sum_{j=1}^{11} a_{m\,ji} * pw_{m_j} * (1 + t_{nm_j}) * ER$$ $i \ \varepsilon$ S

(57) $$P_{nd_i} = \sum_{j=1\,\&\,7}^{11} a_{ji} * P_{q_j} * (1 + t_{nd_j})$$ $i \ \varepsilon$ S

Factor Prices, Consumer Prices and Price Indices

(58) $totlab = \sum_{i=2}^{11} Lw_i + Ls_i$

(59) $Pc_i = Pq_i * (1 + tfd_i + t_e * \varphi_i)$ $\quad i \in S$

(60) $CPI_{rg} = \left(\sum_{i=1}^{11} Pc_i * C_{i,rg}\right) / \left(\sum_{i=1}^{11} C_{i,rg}\right)$ $\quad rg \in RGN$

(61) $W_{rg} = (\lambda_{rg} * CPI_{rg} * dw_{rg}) / dcpi_{rg}$ $\quad rg \in RGN$

(62) $PINDEX = \sum_{i=1}^{11} pwts(i) * Pc_i$

Factor Incomes

Sectoral Factor Incomes :

(63) $Y_{l,1} = Pl * 1$

(64) $Y_{f,i} = Pf_i * f_i$ $\quad i \in PES$

(65) $Y_{w,i} = W_{rg} * Lw_i * (1 - tw_i)$ $\quad i \in S$

[Note : $W_{rg} = W_{urban}$ for $i \in NAS$ & $W_{rg} = W_{rural}$ for i = agricult]

(66) $Y_{s,i} = Pls_{rg} * Ls_i * (1 - tw_i)$ $\quad i \in S$

(67) $Y_{k,i} = Pk_i * k_i * (1 - tk_i)$ $\quad i \in S$

(68) $GTR = (gtra + gtrb) * PINDEX + PAYEM$

(69) $WTR = (nct + nfi) * ER$

(70) $Y_{tp} = (GTR + WTR)$

Rural and Urban Factor Incomes :

(71) $YH_{ty,rg} = \sum_{1}^{11} al_{ty,i,rg} * Y_{ty,i \; (ty \neq tp)} + ar_{rg} * Y_{tp}$ $\quad ty \in TYP, rg \in RGN$

[Note: $\sum_{rg} al_{ty,i,rg} = 1$ for $\forall$ i & ty ($ty \neq tp$) ; $\sum_{rg} ar_{rg} = 1$]

Income Distribution

Step 1 : Mapping of Factor Incomes onto incomes of the 15 income classes (percentiles).

(72) $Y_{h,rg} = \sum_{ty} \pi_{h,ty,rg} * YH_{ty,rg}$ $\quad h \in H,\ rg \in RGN$

[Note: $\Sigma_h\ \pi_{h,ty,rg} = 1$]

(73) $\overline{Y}_{rg} = \sum_h \theta_{h,rg} * Y_{h,rg}$ $\quad rg \in RGN$

(74) $Vy_{rg} = \sum_h \theta_{h,rg} * (Y_{h,rg} - \overline{Y}_{rg})^2$ $\quad rg \in RGN$

Step 2 : Computing the mean and variance of log income, under the assumption that the distribution of population according to per capita income and per capita consumption expenditure is bi-variate log normal.

(75) $\mu^Y_{rg} = \log\overline{Y}_{rg} - \frac{1}{2}\left(\sigma^Y_{rg}\right)^2$ $\quad rg \in RGN$

(76) $\sigma^Y_{rg} = \upsilon_{rg}\left(\log\left[1 + \frac{Vy_{rg}}{(\overline{Y}_{rg})^2}\right]\right)^{\frac{1}{2}}$ $\quad rg \in RGN$

(77) $\mu^c_{rg} = \alpha_{rg} + \beta_{rg}\,\mu^Y_{rg}$ $\quad rg \in RGN$

(78) $\sigma^c_{rg} = \kappa_{rg} * \sigma^Y_{rg}$ $\quad rg \in RGN$

Step 3 : Determining the shares of (i) population, (ii) consumption and (iii) total income accruing to the households that fall under consumption expenditure level k for k = 1,2, …,5.

(79) $\eta_{k,rg} = N\left[\frac{\log cel_{k,rg} - \mu^c_{rg}}{\sigma^c_{rg}}\ \middle|\ 0,1\right]$ $\quad k \in CEC,\ rg \in RGN$

(80) $\delta_{k,rg} = N\left[\frac{\log cel_{k,rg} - \mu^c_{rg}}{\sigma^c_{rg}} - \sigma^c_{rg}\ \middle|\ 0,1\right]$ $\quad k \in CEC,\ rg \in RGN$

(81) $\varpi_{k,rg} = N\left[\frac{\log cel_{k,rg} - \mu^c_{rg}}{\sigma^c_{rg}} - \rho^{Yc}_{rg}\sigma^Y_{rg}\ \middle|\ 0,1\right]$ $\quad k \in CEC,\ rg \in RGN$

Step 4 : Computing the per capita expenditure and income for the five expenditure classes.

(82) $\overline{C}_{rg} = \exp\left[\mu^c_{rg} + \frac{1}{2}\left(\sigma^c_{rg}\right)^2\right]$ $\quad rg \in RGN$

(83) $\overline{C}_{k,rg} = \overline{C}_{rg}(\delta_{k,rg} - \delta_{k-1,rg}) / (\eta_{k,rg} - \eta_{k-1,rg})$ $\quad k \in CEC,\ rg \in RGN$

$$(84)\qquad \overline{Y}_{k,rg} = \overline{Y}_{rg}\,(\varpi_{k,rg} - \varpi_{k-1,rg}) / (\eta_{k,rg} - \eta_{k-1,rg}) \qquad k \in CEC,\; rg \in RGN$$

Step 5 : Determining the sectoral consumption demands for each of the five expenditure classes using the Stone-Geary linear expenditure system.

$$(85)\qquad Pc_i * \overline{C}_{i,k,rg} = Pc_i\,\gamma_{i,k,rg} + \chi_{i,k,rg}\left(\overline{C}_{k,rg} - \sum_J Pc_j\,\gamma_{j,k,rg}\right) \qquad i \in S,\; k \in CEC,\; rg \in RGN$$

Step 6 : Determining the sectoral consumption demands.

$$(86)\qquad C_{i,rg} = \sum_{k=1}^{5} (\eta_{k,rg} - \eta_{k-1,rg}) * pop_{rg} * \overline{C}_{i,k,rg} \qquad i \in S,\; rg \in RGN$$

$$(87)\qquad C_i = \sum_{rg} C_{i,rg} \qquad i \in S$$

Savings

$$(88)\qquad HSAV = \sum_{rg} pop_{rg} * \sum_{k=1}^{5} (\eta_{k,rg} - \eta_{k-1,rg}) * (\overline{Y}_{k,rg} - \overline{C}_{k,rg})$$

$$(89)\qquad GSAV = \sum_{i=1}^{11} Nd_i * \left(\sum_{j=1}^{11} a_{ji} * tnd_j * Pq_j\right) + \sum_{i=1}^{11} Nm_i * \left(\sum_{j=1}^{11} am_{ji} * tnm_j * (wpm_j * ER)\right)$$
$$+ \left(\sum_{i=1}^{11} tfd_i * Pq_i\,(ID_i + C_i)\right) + \left(\sum_{i=1}^{11} tfm_i * (wpm_i * ER) * M_i\right)$$
$$+ \left(\sum_{i=1}^{11} tw_i * W_{rg} * Lw_i\right) + \left(\sum_{i=1}^{11} tw_i * Pls_{rg} * Ls_i\right)$$
$$+ \left(\sum_{i=1}^{11} tk_i * Pk_i * Lk_i\right) + PAYEM$$
$$- \left(\sum_{i=1}^{11} Pq_i * cg_i\right) - (GTR)$$

$$(90)\qquad FSAV = \sum_{i=1}^{11} (wpm_i * M_i) + \sum_{i=1}^{11} Nm_i * \left(\sum_{j=1}^{11} am_{ji} * wpm_j\right)$$
$$- \left(\sum_{i=1}^{11} PWex_i * EX_i\right) - (nct + nfi)$$

Saving - Investment Balance

$$(91)\qquad HSAV + GSAV + (FSAV * ER) = \sum_{i=1}^{11} ID_i * Pq_i * (1 + tfd_i)$$

(92) $ID_i = ad_i * (pubinv + prinv)$ $\quad i \ \varepsilon \ S$

(93) $GRINVD_i = pukv_i * pubinv + prkv_i * prinv$ $\quad i \ \varepsilon \ S$

Commodity Market Clearing

(94) $FD_i = ID_i + C_i + cg_i$ $\quad i \ \varepsilon \ S$

(95) $Q_i = \sum_{j=1\&7}^{11} a_{ij} * Nd_j + FD_i$ $\quad i \ \varepsilon \ NES$

(96) $Q_2 = \sum_{i=1}^{11} E_i + FD_2$

(97) $Q_3 = \sum_{i=1}^{11} CL_i + FD_3$

(98) $Q_4 = \sum_{i=1}^{11} RO_i + FD_4$

(99) $Q_5 = \sum_{i=1}^{11} GS_i + FD_5$

(100) $Q_6 = CP + FD_6$

Endogenous Variables :

X_i	Gross domestic output	$i \ \varepsilon \ S$
NF_i	Non-fixed factor inputs aggregate	$i \ \varepsilon \ NEE$
RS_1	Land-energy-materials aggregate in agriculture	
EM_1	Energy-materials aggregate in agriculture	
Z_i	Energy-labor-capital aggregate	$i \ \varepsilon \ NAS$
N_i	Non-energy intermediate inputs aggregate	$i \ \varepsilon \ S$
Nm_i	Imported intermediates' aggregate	$i \ \varepsilon \ S$
Nd_i	Domestic intermediates' aggregate	$i \ \varepsilon \ S$
V_i	Value-added	$i \ \varepsilon \ S$
Lw_i	Input of wage-labour	$i \ \varepsilon \ S$
Ls_i	Input of self-employed labour	$i \ \varepsilon \ NAS$
EA_i	Energy Aggregate	$i \ \varepsilon \ S$
E_i	Input of Electricity	$i \ \varepsilon \ S$
NE_i	Non-electric fuels aggregate	$i \ \varepsilon \ S$
CL_i	Input of Coal	$i \ \varepsilon \ S$
GS_i	Input of Natural-gas	$i \ \varepsilon \ S$
RO_i	Input of Refined Oil	$i \ \varepsilon \ S$
CP	Input of Crude-Pet in the Refined Oil Sector	
DD_i	Domestic demand	$i \ \varepsilon \ S$

EX_i	Export demand	i ε EXS
M_i	Final Imports	i ε IMS
Q_i	Composite output	i ε S
P_{NE_i}	Price of non-electric fuels aggregate	i ε S
Pk_i	Price of capital	i ε S
Pva_i	Price of value-added	i ε S
Pea_i	Price of energy aggregate	i ε S
Pn_i	Price of non-energy intermediate inputs aggregate	i ε S
Pz_i	Price of energy-labor-capital aggregate	i ε NAS
Pnf_i	Price of non-fixed factor inputs aggregate	i ε NEE
Prs_1	Price of land-energy-materials aggregate in agriculture	
Pem_1	Price of energy-materials aggregate in agriculture	
Pl	Price of land in agriculture	
Pf_i	Price of fixed factor	i ε PES
Pdd_i	Price of domestic demand	i ε S
Pex_i	Price of export demand	i ε EXS
Px_i	Price of domestic output	i ε S
Pq_i	Price of composite output	i ε S
$PWex_i$	Price (in foreign currency) of exports in the international market	i ε EXS
Pnd_i	Price of domestic intermediates' aggregate	i ε S
Pnm_i	Price of imported intermediates' aggregate	i ε S
Pm_i	Price of Final imports	i ε IMS
$ECO2_{ng}$	CO_2 emissions in the non-government sector	
$ECO2_g$	CO_2 emissions in the government sector	
TECO2	Total CO_2 emissions in the economy (TECO2 *is variable in the base-run, but fixed in the simulations)*	
t_e	Carbon tax (Rs. / ton of carbon emissions) *(* t_e *is fixed at zero in the base-run, but a variable in the simulations.)*	
PAYEM	Total Emission Payments	
Pls_{urban}	Remuneration to self-employed labour in the non-agricultural sectors	
W_{rg}	Wage rate for wage-labour by region	rg ε RGN
Pc_i	Consumption Prices	i ε S
CPI_{rg}	Consumer price index by region	rg ε RGN
PINDEX	Overall price index	
$Y_{ty, i}$	Factor incomes by sector	ty ε TYP, i ε S
GTR	Government transfers	
WTR	World Transfers	
$YH_{ty, rg}$	Factor Incomes by region	ty ε TYP, rg ε RGN
$Y_{h, rg}$	Incomes by income classes	h ε H, rg ε RGN
$\overline{Y}_{rg}$	Mean Income	rg ε RGN
Vy_{rg}	Variance of income	rg ε RGN

μ^{Y}_{rg}	Mean of log income	rg ε RGN
σ^{Y}_{rg}	Standard Deviation of log income	rg ε RGN
σ^{c}_{rg}	Standard Deviation of log consumption	rg ε RGN
μ^{c}_{rg}	Mean of log consumption	rg ε RGN
$\eta_{k,rg}$	Share of population that falls under per capita expenditure level $cel_{k,rg}$	rg ε RGN
$\delta_{k,rg}$	Share of consumption accruing to the population under per capita expenditure level $cel_{k,rg}$	k ε CEC, rg ε RGN
$\varpi_{k,rg}$	Share of income accruing to the population under per capita expenditure level $cel_{k,rg}$	k ε CEC, rg ε RGN
$\overline{C}_{k,rg}$	Per capita consumption by consumption expenditure class and region	k ε CEC, rg ε RGN
$\overline{Y}_{k,rg}$	Per capita income by consumption expenditure class and region	k ε CEC, rg ε RGN
$\overline{C}_{i,k,rg}$	Consumption of commodity i by consumption expenditure class and region	i ε S, k ε CEC, rg ε RGN
$C_{i,rg}$	Consumption of commodity i by region	i ε S, rg ε RGN
C_i	Consumption of commodity i	i ε S
HSAV	Household Savings	
GSAV	Government Savings	
FSAV	Foreign Savings (in dollars)	
ER	Exchange Rate	
IDi	Investment demand by sector of origin	i ε S
$GRINVD_i$	Gross real investment by sector of destination	i ε S
FD_i	Final demand by sector	i ε S

Exogenous Variables and Parameters :

k_i	Capital stock in sector i	i ε S
l	Supply of land in agriculture	
totlab	Total labour supply in the non-agricultural sectors	
cg_i	Government consumption of commodity i	i ε S
$\overline{Ls_l}$	Fixed supply of self-employed labour in agriculture	
f_i	Supply of fixed factors in the primary energy sectors	i ε PES
pubinv	Aggregate public sector real investment	
prinv	Aggregate private sector real investment	
dw_{rg}	Initial wage rate by region	rg ε RGN
$dcpi_{rg}$	Initial consumer price index by region	rg ε RGN
$pwes_i$	International price of export substitutes	i ε S
pwm_i	International price of imports	i ε S
Eco2q	Annual allotment of CO_2 emission quota	
peco2	Price of tradable emission permit ($ per ton)	
$pwts_i$	Weights in the price index	i ε S

gtra	Government's interest payments	
gtrb	Government's current transfers	
nct	Net current transfers from rest of the world	
nfi	Net factor income from rest of the world	
tnd_i	Rate of tax on domestic intermediates	$i \varepsilon S$
tnm_i	Rate of tax on imported intermediates	$i \varepsilon S$
tfm_i	Rate of tax on final imports	$i \varepsilon S$
$exsub_i$	Rate of subsidy on exports	$i \varepsilon S$
tfd_i	Rate of tax on final demand	$i \varepsilon S$
tk_i	Rate of tax on capital income	$i \varepsilon S$
tw_i	Rate of tax on wage and self-employed labour income	$i \varepsilon S$
$al_{ty, i, rg}$	Shares for allocation of sectoral factor incomes to regions	$ty \varepsilon TYP$, $i \varepsilon S$, $rg \varepsilon RGN$
ar_{rg}	Shares for allocation of transfer payments to regions	$rg \varepsilon RGN$
$\pi_{h,ty,rg}$	Factor income share by income class and region	$h \varepsilon H$, $ty \varepsilon TYP$, $rg \varepsilon RGN$
$\theta_{h,rg}$	Population shares by income class and region	$h \varepsilon H$, $rg \varepsilon RGN$
κ_{rg}	κ-value transforming the S.D. of log income to S.D. of log consumption	$rg \varepsilon RGN$
ν_{rg}	Variance constant in the S.D. of log income equation by region	$rg \varepsilon RGN$
α_{rg}	Intercept term in the consumption fuction by region	$rg \varepsilon RGN$
β_{rg}	Slope term in the consumption fuction by region	$rg \varepsilon RGN$
$cel_{k,rg}$	Upper limit of consumption expenditure of class k in region rg	$k \varepsilon CEC$, $rg \varepsilon RGN$
$\chi_{i,k,rg}$	Consumption expenditure shares by sector, class and region	$i \varepsilon S$, $k \varepsilon CEC$, $rg \varepsilon RGN$
$\gamma_{i,k,rg}$	Commited consumption expenditures by sector, class and region	$i \varepsilon S$, $k \varepsilon CEC$, $rg \varepsilon RGN$
pop_{rg}	Population by region	$rg \varepsilon RGN$
a_{ij}	amount of commodity i required to produce 1 unit of domestic intermediate input aggregate for sector j	$i \varepsilon S$, $j \varepsilon S$
am_{ij}	amount of commodity i imports required to fulfill 1 unit of imported intermediate input aggrgate for sector j	$i \varepsilon S$, $j \varepsilon S$
ad_i	Share of aggregate investment by sector of origin	$i \varepsilon S$
$prkv_i$	Share of private investment by sector of destination	$i \varepsilon S$
$pukv_i$	Share of public investment by sector of destination	$i \varepsilon S$
μ_{cl_i}	CO_2 emission from one unit of coal used	$i \varepsilon S$
μ_{ro_i}	CO_2 emission from one unit of refined oil used	$i \varepsilon S$
μ_{gs_i}	CO_2 emission from one unit of natural gas used	$i \varepsilon S$
μ_{cp}	CO_2 emission from one unit of crude-petroleum used	
ω_i	CO_2 emission per unit of production of commodity i	$i \varepsilon S$
φi	CO_2 emission per unit of household consumption of commodity i	$i \varepsilon S$
τ_i	CO_2 emission per unit of government consumption of commodity i	$i \varepsilon S$
σ_{x_i}	Elasticity of substitution at the X-level production function	$i \varepsilon S$

σrs_1	Elasticity of substitution at the RS-level p.f. in agriculture	
σem_1	Elasticity of substitution at the EM-level p.f. in agriculture	
σnf_i	Elasticity of substitution at the NF-level production function	$i \ \varepsilon$ NEE
σn_i	Elasticity of substitution at the N-level production function	$i \ \varepsilon$ S
σz_i	Elasticity of substitution at the Z-level production function	$i \ \varepsilon$ NAS
σva_i	Elasticity of substitution at the VA-level production function	$i \ \varepsilon$ S
σea_i	Elasticity of substitution at the EA-level production function	$i \ \varepsilon$ S
σne_i	Elasticity of substitution at the NE-level production function	$i \ \varepsilon$ S
σex_i	Elasticity of substitution at the EX-level production function	$i \ \varepsilon$ EXS
σq_i	Elasticity of substitution at the Q-level production function	$i \ \varepsilon$ IMS
δx_i	Share parameter of the X-level production function	$i \ \varepsilon$ S
δrs_1	Share parameter of the RS-level p.f. in agriculture	
δem_1	Share parameter of the EM-level p.f. in agriculture	
δnf_i	Share parameter of the NF-level production function	$i \ \varepsilon$ NEE
δn_i	Share parameter of the N-level production function	$i \ \varepsilon$ S
δz_i	Share parameter of the Z-level production function	$i \ \varepsilon$ NAS
δva_i	Share parameter of the VA-level production function	$i \ \varepsilon$ S
δea_i	Share parameter of the EA-level production function	$i \ \varepsilon$ S
δne_i	Share parameter of the NE-level production function	$i \ \varepsilon$ S
δex_i	Share parameter of the EX-level production function	$i \ \varepsilon$ EXS
δq_i	Share parameter of the Q-level production function	$i \ \varepsilon$ IMS
$a x_i$	Scale parameter of the X-level production function	$i \ \varepsilon$ S
$a rs_1$	Scale parameter of the RS-level p.f. in agriculture	
$a em_1$	Scale parameter of the EM-level p.f. in agriculture	
$a nf_i$	Scale parameter of the NF-level production function	$i \ \varepsilon$ NEE
$a n_i$	Scale parameter of the N-level production function	$i \ \varepsilon$ S
$a z_i$	Scale parameter of the Z-level production function	$i \ \varepsilon$ NAS
$a va_i$	Scale parameter of the VA-level production function	$i \ \varepsilon$ S
$a ea_i$	Scale parameter of the EA-level production function	$i \ \varepsilon$ S
$a ne_i$	Scale parameter of the NE-level production function	$i \ \varepsilon$ S
$a ex_i$	Scale parameter of the EX-level production function	$i \ \varepsilon$ EXS
$a q_i$	Scale parameter of the Q-level production function	$i \ \varepsilon$ IMS

APPENDIX 4

It is obvious that data requirements for the CGE model developed for this study are huge and diverse. In fact, published data rarely fit the requirement of the model. The data collected from various publications had to go through several stages of processing before it became applicable to the CGE model. Particularly difficult was the task of creating compatibility between different sets of data coming from varied sources, using different base-years, classifications, and degrees and types of disaggregation across sectors. The 'compatibility' problem in pooling of data from various sources was encountered at almost every step. We have given below a brief description of the adjustments made in publised data at the various steps.

Our CGE model has been calibrated to the benchmark equilibrium data set, represented in a Social Accounting Matrix for the Indian economy for the year 1989-90. The basic data set for the SAM has been obtained from the Central Statistical Organisation - National Accounts Statitstics of India (various issues) and the CSO (1997) - Input-Output Transactions Table - 1989-90. A host of other exogenous variables and parameters have been estimated from the data available in various other published sources. These are listed in the table below :

Document	Abbreviations
(i) Central Statistical Organisation (1997) – Input-Output Transactions Table – 1989-90	CSO-IOTT
(ii) Central Statistical Organisation (2001) – National Accounts Statistics of India, Back Series, 1950-51 to 1992-93	CSO-NAS (BS)
(iii) Central Statistical Organisation (1995) – National Accounts Statistics of India	CSO-NAS (1995)
(iv) Central Statistical Organisation (1994) – National Accounts Statistics – Factor Incomes (New series) – 1980-81 to 1989-90	CSO-NAS-FI
(v) Central Statistical Organisation (1994) – Annual Survey of Industries – Summary Results for Factory Sector – 1989-90	CSO-ASI
(vi) Government of India – Economic Survey (Various Issues)	GOI-ES
(vii) Dahl, Henrik : GANGES : A Computable General Equilibrium Model for India, *World Bank Mimieo, 1989*	DAHL-GANGES
(viii) Pradhan, B.K., Roy, P.K., Saluja, M.R. & Venkatram, Shanta : Rural-Urban Disparities - Inome Distribution Expenditure Pattern and Social Sector, *Economic and Political Weekly (July 15, 2000)*	EPW-PRSV
(ix) National Sample Survey Organisation: 45th Round (July 1989- June 1990) on Consumer Expenditure and Employment-Unemploment – *Sarvekshna (October - December1999)*	NSSO-45th Round
(x) Yang, Z, R.S. Eckaus, A.D. Ellerman and H.D. Jacoby : The MIT Emission Prediction and Policy Analysis (EPPA) Model, *MIT Joint Program on the Science and Policy of Global Change, Report No. 6, May 1996*	MIT-JPSPGC-6

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(xii) Murthy, N.S., M. Panda, J. Parikh : Economic development poverty reduction and carbon emissions in India, *Energy economics, 1997, 19, 327-354.*	EE-MPP
(xiii) Pradhan, B.K. and A. Sahoo : Impact of Trade liberalisation on Household Welfare and Poverty, *National Council of Applied Economic Research, New Delhi, Mimeo, 2002.*	NCAER-P&S
(xiv) Ojha, V. P. : An applied general equilibrium analysis of the transition from an inward-looking strategy to an outward-looking strategy : The case of the Indian economy in the eighties. *Unpublished Ph.D. dissertation, Delhi School of Economics.1997*	DSE-OJHA

The 11x11 input-output transactions table

Our model is based on an eleven sector disaggregation of the Indian economy :

(i) Agriculture (agricult),
(ii) Electricity (elec),
(iii) Coal (coal),
(iv) Refined Oil (refoil),
(v) Natural Gas (nat-gas),
(vi) Crude Petroleum (crude-pet),
(vii) Transport (trans),
(viii) Energy Intensive Industries (enerint),
(ix) Other Intermediates (otherint),
(x) Consumer goods (cons-good),
(xi) Services (services) .

The CSO-IOTT provides a highly disaggregated 115 x 115 input-output matrix for the Indian economy for the year 1989-90, the base-year of our model. Unfortunately, even in this 115 sectoral divison “Crude Petroleum” and “Natural Gas” are clubbed together in sector no. 24. By using guessestimates on the split ratios for the inputs and outputs of the Crude Petroleum and Natural Gas sectors, obtained from the concerned statisticians at the CSO, New Delhi, we first split the sector 24 of CSO-IOTT into two sectors, and thus generated a 116 x 116 I-O matrix. We then worked out a mapping scheme from the 116 sectors to our 11 sectors and thereafter produced and aggregated 11 x 11 I-O matrix. That gives us the inter-industry flows as well as the final demand components for the 11 sectors.

Sectoral gross and net value addeds

The input columns the CSO-IOTT gives not only the inter-industry inputs but also in the end (i.e., in the 116^{th} row) the gross value added for every sector. And finally in the last row for each sector, the the total inter-industry inputs and gross value added (GVA) are added up to give the total output. So, at the end of the aggregation exercise, we not only have the 11x11 I-O flows but also, the GVAs for our 11 sectors.

From the GVA we have to get to the Net Value Added (NVA) for each of the 11 sectors, with the view to then split the latter into the sectoral factoral incomes. For this we need to know (compute) the depreciation, and that takes us to CSO-NAS (BS) . The CSO-NAS (BS) does give depreciation by sector, but the sectoral divison there corresponds neither with the CSO-IOTT's 115 sector classification nor with our 11 sector classification, but is somewhere in between. For some sectors there is an exact match, such as Agriculture, Transport and Services and even, Electricity. The remaining sectors in CSA-NAS (BS) are hugely different. They are : Mining and Quarrying (subsuming "Coal", "Crude Petroleum and "NaturalGas"), Major Minerals and Minor Minerals - some of which go into our "ENERINT" and others into our "OTHERINT" sector. Further, there is the Manufacturing Sector (with the registered and unregistered segments given separately) which subsumes our consumer goods sector and certain parts of OTHERINT and ENERINT. For the combined GVA and depreciation of the Mining and Quarrying, we had no option but to split it into the GVAs and depreciations of Coal, Natural Gas and Crude Petroleum according to their GVA ratios in 11x11 I-O flows matrix. However, for apportioning the GVA and depreciation of Manufacturing Sector of the CSO-NAS (BS) into Consumer goods, Refined Oil, OTHERINT and ENERINT, we undertook a much more detailed exercise. We could do this because CSO-ASI[11] gives for a detaited set of industries (according to 2-digit and 3-digit National Industrial Classification (NIC) code) not only their NVA and depreciation but also a host of other charateristics such as, wages, rent, interest, profits, capital formation and capital stocks. For the registered segment of manufacturing we applied the relevant ratios of depreciation to GVA from CSO-ASI to GVAs of our Consumer goods and Refined Oil sector and parts of OTHERINT and ENERINT. The residual part of GVS of these sectors was treated as belonging to the unregistered segment. For the unregistered segment, the figure for depreciation is provided at the aggregate level only. For the unregistered part, therefore, we had to assume that the overall rate of depreciation applies uniformly across the sectors, Consumer goods, OTHERINT and ENERINT[12]. Finally, we simply added up the NVAs and depreciations computed at different stages of the calculation to get the NVAs and depreciations as per our sectoral classification.

Factor incomes

For Factor Incomes the CSO-NAS-FI , gives the sectoral factor incomes – Compensation to employees (i.e., wage-income) , Rent, Interest and Profits & Dividends clubbed together with Mixed Income of the Self-employed – separately for the "organised" and the "unorganised" segements of the various sectors. The sectoral classification, ofcourse, do not match our 11-sector classification, but, we sort of repeated what we did earlier for the depreciation and NVA calculations – i.e., split the sectors of CSO-NAS-FI into components which could be mapped onto our 11-sector classification. As far as splitting the last category of factor incomes – profits & dividends combined with mixed income of the self-employed - was concerned we made the convenient and realistic assumption that, for any sector, the

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[11] The CSO-ASI gives the figures for registered manufacturing industries only.
[12] There is no "unregistered" manufacturing in Refined Oil.

profits and dividends accrued exclusively to the organised part, and the mixed income of the self-employed was generated wholly in the unorganised part. By using this thumb-rule we, in effect, generated 5 types of income – wages, rent, interest, profits & dividends and mixed income of the self-employed – for each of 11 sectors, and thus produced a 5x11 factor income matrix.

Capital and labour stocks

Data on capital stocks are available in the CSO-NAS(BS), but again not as per our sectoral classification. We split the aggregated capital stocks with respect to our 11 sectors using the value added proportions. The resulting capital stocks' figures were not all compatible with the capital incomes' figures generated above using CSO-NAS (BS) and CSO-NAS-FI. Assuming greater reliability of the capital incomes' figures, we adjusted the capital stocks' figures so that the sectoral capital rental rates were realistic, as judged from other published data sources.

The labour stock data is available in NSSO-45th Round. The labour stock data posed less of a problem because, in their case, the sectoral distribution is not required. In the model, sectoral capital stocks are fixed at exogenously given levels, but labour supply is fixed only in aggregate terms. The only sector for which labour supply is fixed exognously is agriculture, and the data for this is available in NSSO-45th Round.

Income distribution

Factor income shares by income percentiles for each the two regions – rural and urban – are deducible from the income distribution data provided for 1975-76 and 1994-95 in EPW-PRSV. We have used the 1994-95 income distribution data for deriving the factor income shares for 1989-90, the base year of our model. It is generally agreed that income distribution pattern changes very slowly in India. Hence, it is fair to assume that the income distribution pattern of 1994-95 will approximate that of 1989-90.

LES parameters for the demand functions

In our model there are 5 rural and 5 urban consumption expenditure classes. To econometrically estimate the LES parameters for each of these 12 classes from time series data would have been a daunting task. So we decided to make use of an existing set of parameters, from another study, DAHL-GANGES. The latter gives the committed expenditures and the expenditure shares for the ten rural and urban consumption expenditure classes, as per a six-sectors classification – agriculture, capital goods, intermediate goods, public infrastrucure, consumer goods and services. Moreover, the committed expenditures are at the 1973-74 prices. These are first inflated to the 1989-90 prices using the wholesale price indices obtained from the GOI-ES. To obtain the demand function parameters for our nine sectors we first construct a 9x6 transformation matrix which maps the 6x1 vector of the demand parameters (for each expenditure group) in the six-commodities classification, onto a 9x1 vector of demand parameters for our nine commodity groups. The transformation matrix is prepared by using the final consumption demand vector of the input-output transactions table of the CSO-IOTT. From the latter we could determine the elements of the transformation matrix – i.e., proportions of each of the 6 DAHL-GANGES sectors going into the various sectors of our nine-sectors scheme.

Substitution elasticities for the production functions

The substitution elasticities of the production functions in the nested production structure have taken from MIT-JPSPGC-71, wherever possible . (We have followed closely, but not entirely, the nesting of the production structure in the EPPA model presented in MIT-JPSPGC-71). The substitution elasticites, between the domestic and imported intermediates aggregates at the N level, and between capital, wage-labour and self-employed labour at the VA level, have been taken from DSE-OJHA. Finally, the source for the CES and CET elasticities in the trade aggregation functions is NCAER-P&S.

Carbon emission coefficients

For carbon emission coefficients, the source we have used is MIT-JPSPGC-6. The MIT-JPSPGC-6 provides figures for coefficients of energy contents in India for coal, crude petroleum, natural gas, refined oil in exajoule per million US$ at 1985 prices. We convert these energy content coefficients to exajoule per million rupees at 1990 prices using the appropriate exchange rate and price indices from the GOI-ES. These are then multiplied by the coefficients of carbon contents in million tons per exajoule, also given in MIT-JPSPGC-6, to arrive at the coefficients of carbon contents in million tons per million rupees. Carbon is emitted in the process of output generation as well, in the cement industry, which is a part of the energy intensive sector, in our classification. Carbon emission coefficient per unit of output produced in this sector is obtained from EE-MPP. Carbon emission coefficients for private and government consumption is also taken from EE-MPP.