The Impact of Carbon Taxes on Growth Emissions and Welfare in India: A CGE analysis

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ABSTRACT

This paper aims to analyse the impact of two post-Kyoto climate policy regimes on GDP growth, CO_2 emissions, and welfare in India. Both regimes aim to limit the long-term average global temperature increase below 2°C. The first policy regime is a global carbon tax. The second policy regime is based on emission trading permits; their distribution is based on the Common but Differentiated Convergence approach (Hohne et al. 2006). This study uses a recursive dynamic CGE model that incorporates features of the energy system for the analysis. The results suggest that significant reductions in CO_2 emissions can be achieved under the two policy regimes. The maximum loss in GDP occurs during 2045–50. The growth rate falls from 4.3 per cent in the business-as-usual scenario to 3.2 per cent in the carbon tax scenario and 3 per cent in the Common but Differentiated Convergence scenario. In other periods, the decline in GDP growth rate is not more than 0.3 percentage points. The maximum welfare loss in terms of equivalent variation is estimated at 6.4 per cent in the carbon tax scenario and 5.2 per cent in the Common but Differentiated Convergence scenario in 2050.

Keywords: Carbon tax, CGE model, India, growth, welfare

JEL codes: Q5, O13

1. INTRODUCTION

There is growing concern around the world about the impact of greenhouse gases (GHGs) on the environment and economy. Primarily responsible for global warming, GHG emissions (especially CO_2 emissions) are closely linked to the consumption (burning) of fossil fuels. Countries have not been able to de-link the association between the use of fossil fuels and economic growth until now (Narain et al. 2009). The scientific evidence points to increasing risks of serious, irreversible impacts of climate change (global warming) associated with business-as-usual (BAU) paths for emissions (Stern 2007). There is an urgent need to bring down the level of emissions to scientifically acceptable levels since the costs associated with climate change are significantly higher than the costs of mitigation (Stern 2007).

Climate change is a global issue and therefore requires a high level of international cooperation to tackle it. International negotiations have been launched to address the issue of climate change. The UN Framework Convention on Climate Change (UNFCCC, also known as the Kyoto Protocol) came into effect in 1997 with the purpose of limiting GHG emissions. Under the Kyoto Protocol (KP), industrialised countries agreed to cut their emissions by 5.2 per cent of 1990 levels by 2008–12. However, they missed this target by a significant margin. The Copenhagen Accord (2009) recognises the scientific view that the increase in average global temperature should be below 2°C over the long term. Most countries have accepted the Copenhagen Accord and pledged to reduce emissions. The Fourth Assessment Report (FAR; IPCC 2007) of the Intergovernmental Panel on Climate Change (IPCC) holds that atmospheric concentration of GHGs could stabilise at around 450 parts per million (ppm) of CO_2-equivalent if Annex 1 (industrialised) countries reduced their 1990 emission levels by 25–40 per cent by 2020 and major developing economies reduced their emissions substantially. This GHG concentration is associated with a medium likelihood (at least 50 per cent chance) of limiting global average temperature to less than 2°C. The targets and actions pledged by different countries in the Copenhagen Accord are less than the emission reductions suggested by the IPCC to limit average global temperature increase to below 2°C (OECD 2010).

India's position (Ministry of External Affairs, Government of India 2009) on climate change is based on the principle of common but differentiated responsibilities and respective capabilities and on the concept of equity (every citizen of the globe has equal entitlement to the planetary atmospheric resource). Further, India gives the highest priority to social and economic development even in the context of climate change, and has advocated the convergence of per capita emissions in the future. India believes that efforts to use cleaner technologies in developing economies should be facilitated by developed countries through

the transfer of technology and financial resources to developing countries. The use of cleaner technologies could lead to the creation of new industries and jobs.

Per capita GHG emissions are lower in India than in industrialised countries. The average per capita GHG emissions in 2005 was 4.22 metric tonnes (MT) of CO_2-equivalent globally and about 1.2 MT for India. A 2009 Ministry of Environment and Forests (MoEF) report has stated that per capita GHG emissions of India will be 2.1 MT of CO_2-equivalent in 2020 and 3.5 MT of CO_2-equivalent in 2030 (average of five studies). According to a CGE study by the National Council of Applied Economic Research (NCAER) that is part of the 2009 MoEF report, per capita emissions would be 2.77 MT of CO_2-equivalent in 2030–31. The report points out that per capita emissions of India are likely to remain lower than that of developed countries despite high growth rates. India has set a voluntary target (Copenhagen pledge) to reduce the emission intensity of GDP by 20–25 per cent of the 2005 level by 2020. Both the government and firms are taking several initiatives to achieve this objective. For example, there is a National Action Plan on Climate Change that encourages the use of alternative sources of energy and focuses on achieving energy efficiency.

This paper aims to estimate the costs of climate change mitigation policies for India in two different global climate policy scenarios using a recursive dynamic CGE model. Section 2 outlines the background of the study and presents some key findings from the literature. Section 3 discusses the model developed for this study. Section 4 is devoted to results and discussion. Section 5 summarises the main findings and discusses their relevance from a policy perspective.

2. BACKGROUND AND LITERATURE REVIEW

This paper is part of a larger ongoing study that analyses the impact of different future climate policy regimes (post-Kyoto) on large developing countries like China and India. Two different global emissions pathways were constructed that are compatible with meeting the 2°C target with a probability of about 50 per cent.

The first pathway is an early action pathway where the global net present value cost of meeting the target in 2100 is minimised. The second pathway is created keeping in view the Copenhagen pledges until 2020 (i.e., emissions until 2020 follow the Copenhagen pledges) and thereafter a cost-minimising emissions path towards meeting the target in 2100. The global emissions pathways are implemented through two instruments—global carbon tax (CT) and emission trading permits (ETPs) where the distribution of the permits is based on the Common but Differentiated Convergence (CDC) approach (Hohne et al. 2006).

The CDC approach assumes that per capita emissions of all countries converge, but developing countries can start their convergence trajectory only after reaching a certain threshold. Global carbon taxes imply the global equalisation of marginal abatement costs. The CDC regime is a staged implementation of per capita convergence regimes. In this approach, the per capita emission allowances of Annex 1 countries converge within a certain time (e.g., from 2010 to 2050) to an equal level for all countries. Individual non-Annex I countries' per capita emissions also converge within 40 years to the same level, but convergence starts from the date when their per capita emissions reach a certain percentage threshold of the (gradually declining) global average. Non-Annex 1 countries that do not pass this percentage threshold do not have binding emission reduction requirements—they either participate in the Clean Development Mechanism (CDM) or voluntarily take on 'positively binding' emissions reduction targets. The CDC approach aims at equal per capita allowances in the long run but considers historical responsibility, in contrast to the better-known contraction-and-convergence (CAC) approach.

Environmental policies have two components: (1) identification of an overall goal (such as emission levels); and (2) some means to achieve that goal. There are two main methods for achieving environmental goals (Stavins 1998): through (1) market-based mechanisms (such as carbon taxes) and (2) command-and-control policies (such as explicit directives regarding pollution levels or methods of production). Market-based mechanisms have certain advantages over traditional command-and-control approaches for achieving environmental objectives—they can help to achieve environmental objectives at the lowest possible overall cost to society by providing incentives for the greatest reductions in pollution by those firms that can achieve these reductions most cheaply. Rather than equalising pollution levels among firms, market-based instruments equalise the incremental amount that firms spend to reduce pollution and could also provide incentives for companies to adopt cheaper and better pollution control technologies.

Numerous studies have been conducted to analyse the impact of market-based instruments on the environment as well as the economy in general. Garbaccio et al. (1998) have examined the use of carbon taxes to reduce CO_2 emissions in China. The authors found that after initial declines, GDP and consumption exceeded baseline levels and that revenue-neutral carbon taxes to transfer income from consumers to producers and then into increased investment. The study shows that a 'double dividend' (lower CO_2 emissions and a long-run increase in GDP and consumption) could be achieved under certain assumptions (such as inelastic labour supply and revenue-neutral taxes). Parry et al. (1999) examined the efficiency impacts of revenue-neutral carbon taxes and quotas (grandfathered carbon permits) in a second-best setting with pre-existing labour taxes. The efficiency costs are

considerably higher for each of these policies than would be the case in the absence of prior taxes. The authors conclude that policies like carbon quotas and grandfathered carbon permits are welfare-reducing, regardless of the carbon abatement level. In contrast, carbon tax policies can be, because the marginal social costs of emissions reduction start at zero. The findings suggest that ignoring pre-existing tax distortions can lead to highly misleading conclusions about both the sign and the magnitude of the welfare impacts of carbon abatement policies.

Liang et al. (2007) have used a CGE model to examine the macroeconomic effects of carbon taxes on energy- and trade-intensive sectors. The study reveals that the negative impact of carbon taxes on the economy and on energy- and trade-intensive sectors could be alleviated by subsidising the production sector. Kee et al. (2010) examined the implications of climate change policies (such as carbon taxes and energy efficiency standards) on competitiveness across industries and also issues related to the leakage of carbon-intensive industries to developing countries. The study finds no evidence that carbon taxes affect the competitiveness of energy-intensive industries; it finds that exports of most energy-intensive industries increase when a carbon taxes is imposed by exporting countries or by both importing and exporting countries. The implication is that the recycling of taxes back to energy-intensive industries by means of subsidies and exemptions may be over-compensating for the disadvantage to them.

Ojha (2008) has found that a domestic carbon tax policy that recycles carbon tax revenues to households imposes heavy costs in terms of lower economic growth and higher poverty. However, the negative impact can be reduced if the emission restriction target is modest and carbon tax revenues are transferred exclusively to the poor. The study further reveals that India's participation in an international tradable permit regime with grandfathered emissions allocation is preferable to any domestic carbon tax option if the international price of permits remains low. Further gains to the economy are possible if the emissions allocation regime is based on equal per capita emissions. Fisher-Vanden et al. (1997) have analysed two alternative policy instruments (carbon taxes and tradable permits) to determine the comparative costs of stabilising emissions at (1) 1990 levels; (2) two times the 1990 levels; and (3) three times the 1990 levels. The study finds that tradable permits represent a lower cost method to stabilise Indian emissions than carbon taxes.

Climate change mitigation strategies such as trade in emission permits are associated with international capital inflows/outflows, and therefore could affect a country's trade competitiveness and domestic prices. McKibbin et al. (1999) found that international trade and capital flows alter projections of the domestic effects of emissions mitigation policy significantly in comparison to analyses that ignore international capital flows, and that the

US could become a significant seller of emission permits under some systems of international permit trading.

Shukla et al. (2008) examined two alternative paradigms for a low-carbon future in India. According to the study, renewable energy sources emerge as the preferred choice for carbon mitigation in both the carbon tax and sustainable development scenario, although their drivers are different. In the carbon tax scenario, the relative price difference between renewables and fossil fuels is reduced by a carbon tax, which enables faster penetration of renewables. In the sustainable development scenario, renewable resource penetration is propelled by the co-benefits of renewable energy, higher deployable potential, and lower transaction costs due to cooperation among stakeholders. The authors conclude that the conventional pathway would exert enormous pressure on natural resources and ecosystems due to a higher growth trajectory, while the sustainable pathway would reduce resource competition, conflicts, and prices of resources and permit sustained higher economic growth.

Finally, some studies have focused on the impact of climate change on agriculture. Auffhammer et al. (2006) have studied the impact of brown clouds and GHG emissions on rice production in India. The results indicate that adverse climate change due to brown clouds and GHGs contributed to the slowdown in harvest growth that occurred during the past two decades.

The literature thus suggests that climate change mitigation strategies could significantly affect production and consumption choices in an economy. Carbon taxes adversely affect growth and income distribution. However, transferring resources (carbon tax revenues or capital inflows) to the weaker sections of society or subsidising other sectors of the economy could reduce (or reverse) the adverse effect. The present paper differs from other studies in this area in, mainly, its use of policy parameters derived from global climate models that consider the 2ºC objective, and also in its analysis of the relationship between climate change mitigation policies and trade in the Indian context.
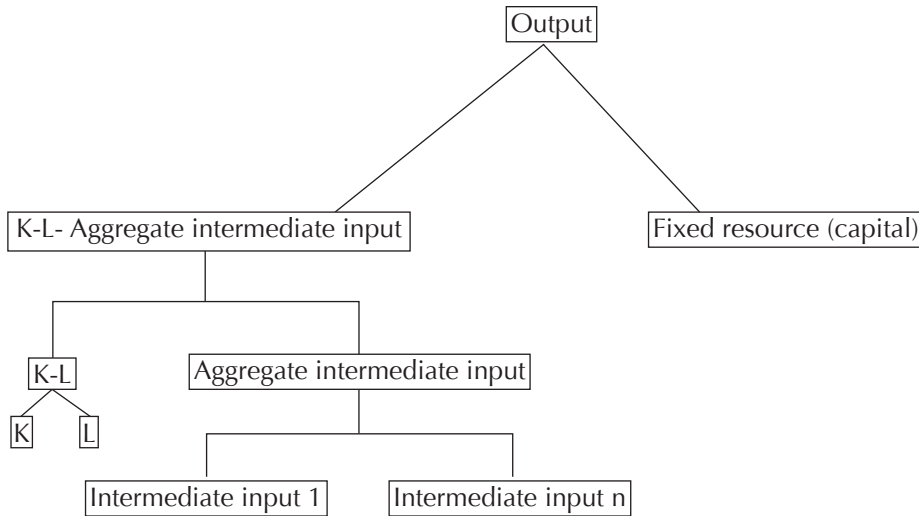
3. MODEL

Our model is a multisectoral, neoclassical-type, price-driven, recursive dynamic CGE model that captures linkages with the energy system. The static part of the model is similar to Lofgren et al. (2002). The features related to the energy system are based on models like DART (Klepper et al. 2003), EPPA (Paltsev et al. 2005) and EMPAX-CGE (RTI International 2008). The model consists of 18 sectors—agriculture, coal, oil, gas, manufacturing I (food and beverages, textiles, wood, minerals), manufacturing 2 (paper, fertilisers, cement, iron and steel, aluminium, chemicals), manufacturing 3 (plant and machinery), oil products,

electricity (thermal, carbon capture and storage (CCS), hydro, nuclear, wind/solar, biomass), construction, road transport, rail/sea/air transport, and other services. There are two factors of production—capital and labour.

Producers are assumed to maximise profits and to operate in perfectly competitive markets. The production structure of fossil fuel (coal, oil, and gas) and non-fossil fuel sectors (sectors other than coal, oil, and gas) are modelled differently.

In the case of fossil fuel sectors (Figure 1), the top nest is a CES aggregation of capital–labour–aggregate intermediate input composite and the fixed fossil fuel resource (part of the capital of the sector). The capital–labour–intermediate composite is a Leontief function of the capital–labour composite and aggregate intermediate input. The capital–labour composite (aggregate value added) is in turn a CES aggregation of capital and labour. The production structure of the fossil fuel sectors thus considers the limited availability of fossil fuels in the economy.
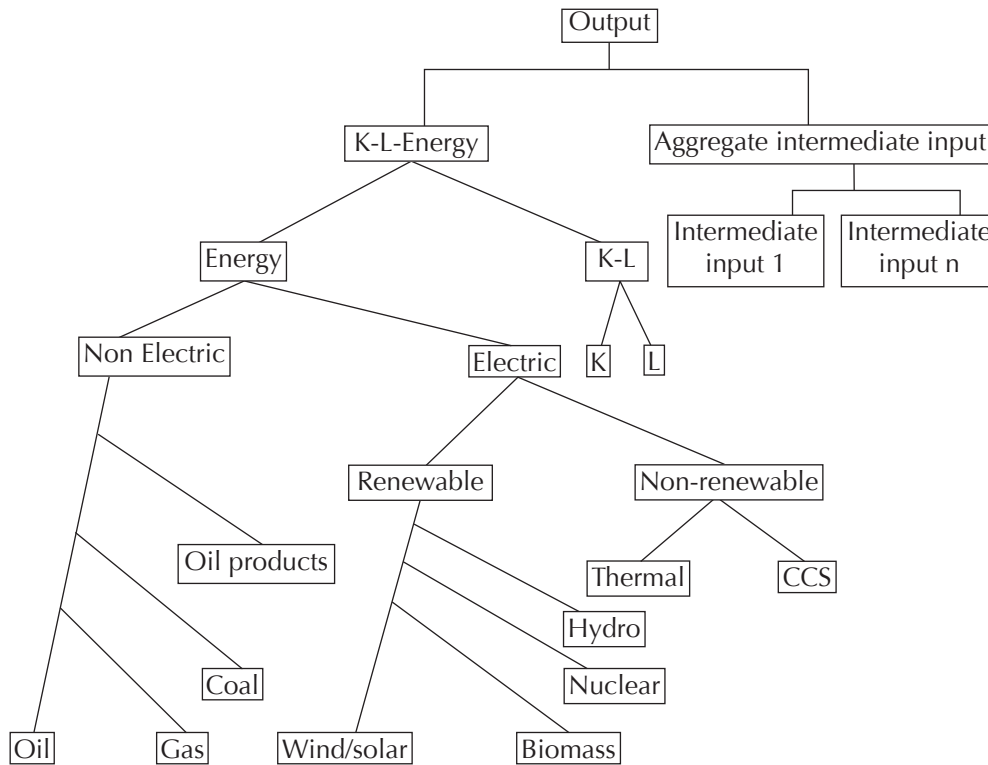
Figure 1: Production structure of fossil fuel sectors (coal, oil, and gas)

In the case of non-fossil fuel sectors (Figure 2), the top nest is a Leontief function of aggregate intermediate input and energy–capital–labour composite. The energy–capital–labour composite is a CES function of the energy composite and capital–labour composite. The energy composite is a CES function of the non-electric composite and electric composite. The non-electric composite is a CES aggregation of coal, oil, gas, and oil products. The electric composite is a CES aggregation of renewable electricity composite and non-renewable electricity composite. The renewable electricity composite is a CES aggregation of hydro,

nuclear, wind/solar and biomass electricity while the non-renewable electricity composite is a CES aggregation of thermal and CCS electricity. The capital–labour composite is a CES function of capital and labour.

Figure 2: Production structure of non-fossil fuel sectors

The aggregate intermediate input is a Leontief function of intermediate inputs. The main features of the production structure of the non-fossil fuel sectors are, on the one hand, the substitution possibilities between energy, capital, and labour and, on the other, the substitution possibilities between renewable and non-renewable sources of electricity.

Households maximise utility subject to income and prices, and the household demand for commodities is modelled through the linear expenditure system (LES). Household income comprises income derived from labour and capital and transfers from the government and the rest of the world. Households also save part of their income and pay taxes to the government. Further, households are classified into nine categories: five are rural (self-employed in non-agriculture, agricultural labour, other labour, self-employed in agriculture and other households) and four are urban (self-employed, regular salaried, casual, and other households).

Government expenditure is on the consumption of goods and services, transfers to households and enterprises, and subsidies. Government income is from taxes (direct and indirect), capital, public and private enterprises, and the rest of the world. Indirect taxes include excise duty (production tax), import and export tariffs, sales, stamp, service, and other indirect taxes. Government savings (the difference between government expenditure and income) is determined residually.

Imperfect substitution between domestic goods and foreign goods is allowed for in CGE models. In other words, producers/consumers are free to sell or consume goods from the domestic or foreign market based on relative prices. The Armington function is used to capture the substitution possibilities between domestic and imported goods. The import demand function, derived from the Armington function, specifies the value of imports based on the ratio of domestic and import prices. The CET function is used to capture substitution possibilities between domestic and foreign sales. The export supply function, derived from the CET function, specifies the value of exports based on the ratio of domestic prices to export prices. The elasticity of substitution determines the relative ease of substitution between domestic and foreign goods in response to changes in relative prices.

The model is Walrasian in character. Markets for all commodities and factors clear through adjustment in prices. The consumer price index (CPI) is chosen as the numeraire and is, therefore, fixed. The model follows an investment-driven closure, that is, aggregate investment is fixed. The saving-investment balance is maintained through adjustments in aggregate savings (sum of household, government, corporate and foreign savings).

Macro closures play an important role in determining the results of CGE models. The model assumes foreign savings to be fixed and the real exchange rate to be flexible. Government consumption expenditure is fixed within a period, and government savings is residually determined. Both direct and indirect tax rates are fixed. As mentioned earlier, the model is investment-driven and, therefore, aggregate investment is fixed. The household savings rate is also fixed. Finally, full employment along with intersectoral mobility is assumed in the case of the two factors of production.

Initially, a baseline (business-as-usual or BAU) scenario is created by assuming exogenously determined growth in total factor productivity (TFP), labour force, government consumption expenditure and aggregate investment. Capital accumulation takes place by adding aggregate investment to capital in the previous period. An energy efficiency growth rate is assumed to capture future increases in energy efficiency. Future technological developments in the renewable electricity sectors are modelled by assuming efficiency

growth in these sectors. Changes in the international price (exogenous) of fossil fuels are modelled considering the future price projections of these commodities.

Two baseline scenarios are created to model two different GDP growth paths of the economy. The first baseline scenario considers the growth projection of the Organisation for Economic Cooperation and Development (OECD) for India until 2050 (OECD 2012); the second baseline assumes a higher growth rate relative to the OECD projection.

The main source of data for the analysis is the social accounting matrix (SAM) for 2003–04 developed by Ojha et al. (2009), based on the SAM constructed by Pradhan et al. (2006). The main difference is the decomposition of the electricity sector into three separate sub-sectors—hydro, nuclear, and non-hydro—in the SAM developed by Ojha. The non-hydro energy sector includes thermal, wind, and solar electricity. However, given India's energy mix, thermal electricity is the main constituent of this group.

Two modifications were made in the non-hydro sector for the purpose of this study. The first modification pertains to the disaggregation of non-hydro electricity into thermal and wind/solar electricity. The second modification pertains to the creation of a sector (from thermal) that uses CCS technology (coal) to produce electricity. The CCS electricity sector is assumed to be similar to the thermal electricity sector but less efficient. It produces electricity using clean coal (no emissions), although at a much higher cost.

4. RESULTS AND DISCUSSION

The results of some of the simulations are presented in this section. Initially, two baseline (BAU) scenarios are created considering the two projected growth paths of the economy. The first growth path is based on the OECD growth projection for India until 2050 (Table 1); the second growth path incorporates a higher growth path relative to the OECD growth projection (Table 3). The growth paths were created by assuming growth in TFP, labour force, government consumption expenditure, and aggregate investment. Other assumptions related to the growth paths include assumptions on energy efficiency, productivity of the renewable electricity sectors and international prices of fossil fuels (coal, oil, and gas). The growth rate during 2005–10 roughly corresponds to the actual growth rate achieved during this period. The growth rate for the period 2010-15 (7.6 per cent) is based on current growth rates and the target for the Twelfth Plan (8.2 per cent). The annual growth rate during 2005–30 is 7.7 per cent in the OECD scenario and 8.3 per cent in the high growth scenario. For the entire time horizon (2005–50), the growth rate is 6.7 per cent in the OECD scenario and 7.6 per cent in the high growth scenario.

Two different policy regimes (instruments) compatible with meeting the 2°C target over the long term were analysed. The first regime is a global carbon tax (CT); the second regime is based on ETPs where the distribution of permits is based on the CDC approach. The data required to implement the policy regimes were obtained from a global climate CGE model called DART (Klepper et al. 2003; see Appendix A for tax rates and emission allowances/permits by year). The global CO_2 emissions pathways of DART follow the global CO_2 emissions pathways of the Framework to Assess International Regimes (FAIR) model (PBL Netherlands Environmental Assessment Agency 2005). In the case of the CDC regime, international capital flows take place because of trade in emission permits. In our model, international capital flows are modelled as foreign savings (i.e., foreign investments in India). The policy regimes are imposed on or after 2012. The carbon tax is applied on the consumption of coal, gas, and oil products because their consumption is directly linked to CO_2 emissions.

4.1 OECD Growth Scenario

In this scenario, the GDP growth rate slows down under both climate policy regimes (Table 1) after 2020.

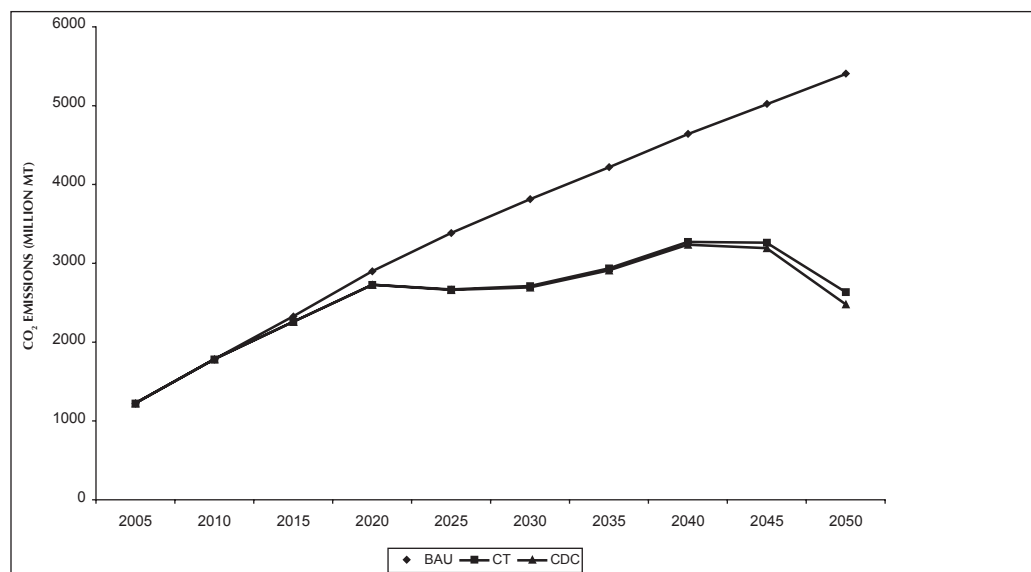**Table 1:** CAGR of GDP (OECD scenario)

Period	BAU (%)	CT (%)	CDC (%)
2005–10	8.5	8.5	8.5
2010–15	7.6	7.6	7.6
2015–20	8.2	8.2	8.2
2020–25	7.4	7.3	7.3
2025–30	6.8	6.7	6.7
2030–35	6.5	6.4	6.4
2035–40	6.3	6.2	6.2
2040–45	4.6	4.4	4.3
2045–50	4.3	3.2	3.0

During 2020–25, growth falls under both regimes from 7.4 per cent to 7.3 per cent; during 2045–50, it falls from 4.3 per cent to 3.2 per cent in the carbon taxes regime and to 3 per cent in the CDC regime. Energy prices increase and the real wage rates of both labour and capital fall under both climate policy regimes. The upward pressure on prices leads to lower demand in the economy. The relatively larger impact on GDP growth in the CDC

regime could be attributed to higher carbon prices (tax rates) in the CDC regime relative to the carbon taxes regime. The CDC regime leads to transfer payments to countries that are able to sell permits, such as India. This in turn usually leads to higher growth in such countries and lower growth in industrialised countries. Carbon prices are higher in the CDC regime since developing countries grow faster and production is more CO_2-intensive in these countries on average. Carbon prices rise over time, and the rise is significant after 2040. The economic intuition behind the rapid increase in carbon prices after 2040 is that there are many opportunities for abatement in the beginning while it becomes increasingly difficult over time to find additional abatement opportunities. Technically, this stems from the CES production functions, which make substitution away from a certain input increasingly expensive.

Carbon dioxide emissions increase from 1220 million MT (1.1 MT per capita) in 2005 to 5403 million MT (3.3 MT per capita) in 2050 in the BAU scenario (Figure 3).

Figure 3: CO_2 emissions (OECD scenario)

According to the NCAER CGE study (MoEF 2009), per capita emissions would be 2.77 MT of CO_2-equivalent in 2030–31. According to the present study, the figure is 2.57 MT of CO_2 emissions in 2030; this implies that the BAU emissions path is very similar to the NCAER projections until 2030. The imposition of climate policy regimes significantly brings down CO_2 emissions in the atmosphere. However, there is an upward trend until 2040, and

thereafter a downward trend in emissions. In the carbon taxes scenario, emissions peak at 3267 million MT (2.1 MT per capita) in 2040, and thereafter decline to 2631 million MT (1.6 MT per capita) in 2050. In the CDC scenario, emissions peak at 3232 million MT (2.1 MT per capita) in 2040, and thereafter decline to 2475 million MT (1.5 MT per capita) in 2050.

There is welfare loss under both policy regimes (Table 2); however, the loss is more under the carbon taxes regime than in the CDC regime.

Table 2: Welfare impact: equivalent variation (OECD scenario)

Year	CT (%)	CDC (%)
2015	-0.05	-0.05
2020	-0.15	-0.08
2025	-0.89	0.02
2030	-1.64	0.42
2035	-1.99	-0.49
2040	-2.10	-1.47
2045	-2.96	-2.64
2050	-6.35	-5.16

For example, the equivalent variation in percentage terms is -6.35 under the carbon tax regime in 2050 but -5.16 under the CDC regime. The welfare loss is lower in the CDC scenario due to price effects. In the CDC scenario, the inflow of capital due to trade in emission permits causes the exchange rate to appreciate more relative to the carbon tax scenario, and this leads to lower consumer prices. The exchange rate appreciates by 8 per cent in the CDC scenario relative to the baseline, while it appreciates by only 2.9 per cent in the carbon tax scenario, in 2050.

Between 2005 and 2020, the energy intensity of GDP falls approximately 35 per cent in the baseline scenario and 38 per cent in the carbon tax regime. Between 2005 and 2050, the fall is 83 per cent in the baseline scenario and 85 per cent in the carbon tax regime. The fall in energy intensity is almost the same in both CDC and carbon tax regimes. In general, the fall in energy intensity of GDP is due to the growth in energy efficiency over time. In the climate policy regimes, there is a shift towards more energy-efficient methods of production and this leads to lower energy intensity.

The share of renewable energy in total primary energy consumption increases from 8 per cent in 2005 to 20 per cent in 2050 in the OECD baseline scenario. The share increases to 28 per cent in the carbon tax scenario and 29 per cent in the CDC scenario in 2050. The carbon taxes increases the relative price of thermal electricity, which increases the share of renewable energy and also decreases the share of thermal electricity significantly over time. The higher share of renewable energy in the CDC regime is due to higher carbon taxes relative to the carbon tax scenario. The implication is that higher carbon taxes levels lead to higher levels of substitution of non-renewable electricity (thermal) by renewable sources of electricity. Thus, climate policies lead to structural changes in the economy as well as changes in the energy mix.

4.2 High Growth Scenario

Under the high growth scenario (Table 3), the GDP growth rate roughly corresponds to the actual growth rate during 2005–10. For the period 2010-15, the growth rate is assumed to be 7.6 per cent, as explained above. However, a higher growth rate relative to the OECD scenario is assumed thereafter.
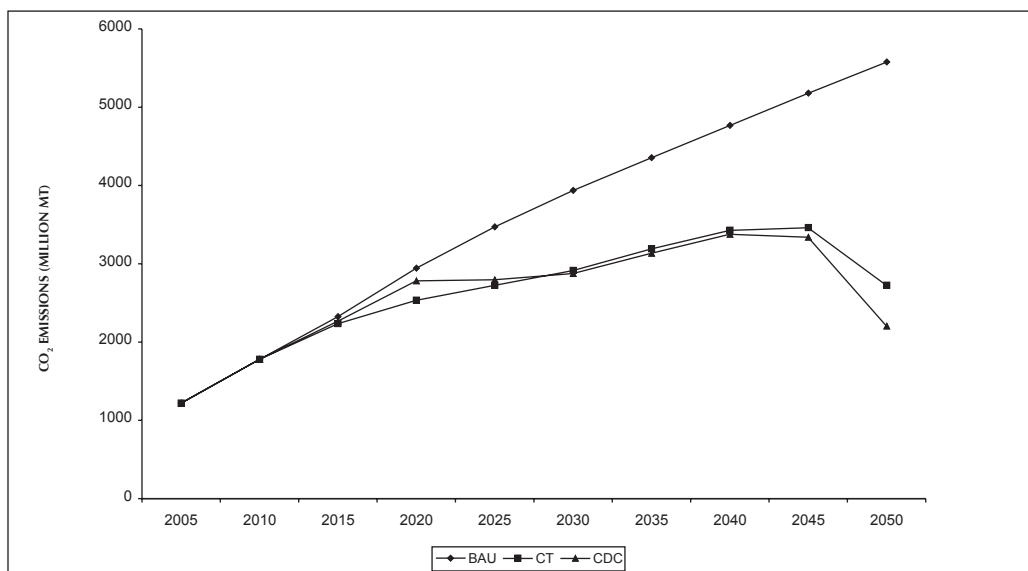
Table 3: CAGR of GDP (high growth rate scenario)

Period	BAU (%)	CT (%)	CDC (%)
2005–10	8.5	8.5	8.5
2010–15	7.6	7.6	7.6
2015–20	9.1	9.0	9.1
2020–25	8.4	8.3	8.3
2025–30	8.0	7.8	7.8
2030–35	7.3	7.2	7.2
2035–40	7.0	6.8	6.8
2040–45	6.4	6.1	6.0
2045–50	5.9	4.7	4.1

The growth rate falls from 8.4 per cent to 8.3 per cent under the climate policy regimes during 2020-25. The growth rate falls from 5.9 per cent to 4.7 per cent in the carbon taxes regime and 4.1 per cent in the CDC regime, respectively, during 2045–50.

Emissions of CO_2 (Figure 4) increase from 1220 million MT (1.1 MT per capita) in 2005 to 5573 million MT (3.5 MT per capita) in 2050 in the BAU scenario; they are higher in the high growth scenario than in the OECD scenario.

Figure 4: CO_2 emissions (high growth rate scenario)

However, the difference in per capita emissions between the two growth paths is only 0.2 MT (in 2050). This implies that higher growth is achieved by increasing renewable energy consumption. In the carbon tax scenario, emissions peak at 3459 million MT (2.2 MT per capita) in 2045 and decline thereafter to 2724 million MT (1.7 MT per capita) in 2050. In the CDC scenario, emissions peak at 3376 million MT (2.2 MT per capita) in 2040 and thereafter decline to 2203 million MT (1.4 MT per capita) in 2050.

As in the OECD scenario, the welfare loss (Table 4) is more under the carbon tax regime than in the CDC regime. For example, the equivalent variation in percentage terms is -7.92 under the carbon tax regime in 2050 and -7.23 under the CDC regime. The welfare loss is higher in the high growth scenario due to higher tax rates relative to the OECD scenario.

Table 4: Welfare impact: equivalent variation (high growth rate scenario)

Year	CT (%)	CDC (%)
2015	-0.07	-0.03
2020	-0.44	-0.01
2025	-1.03	0.38
2030	-1.69	1.08
2035	-2.17	-0.11
2040	-2.86	-1.61
2045	-3.83	-3.35
2050	-7.92	-7.23

The energy intensity of GDP falls approximately 36 per cent between 2005 and 2020 in the baseline scenario and 43 per cent under the carbon tax regime. Between 2005 and 2050, the fall is 88 per cent in the baseline scenario and 91 per cent under the carbon tax regime. Under the CDC regime, the fall in energy intensity is 39 per cent between 2005 and 2020 and 92 per cent between 2005 and 2050.

The share of renewable energy in total primary energy consumption increases in the high growth baseline scenario from 8 per cent in 2005 to 24 per cent in 2050, in the carbon tax scenario to 30 per cent, and in the CDC scenario to 33 per cent.

4.3 Alternative Closures

Two different scenarios were run to compare the results of different closure rules. In the first scenario, a revenue-neutral closure was applied. In the second scenario, the exchange rate is assumed to be fixed, and foreign savings is flexible.

4.3.1 Alternative Closure: Revenue-neutral (Carbon Taxes Scenario)

In the revenue-neutral closure, government income is held fixed and the tax rates on production are allowed to vary proportionately. The results are presented in Tables 5 and 6.

Table 5: Revenue-positive vs revenue-neutral closures (GDP growth)

Period	BAU (%)	CT (revenue-positive, %)	CT (revenue-neutral,%)
2005–10	8.5	8.5	8.5
2010–15	7.6	7.6	7.6
2015–20	8.2	8.2	8.2
2020–25	7.4	7.3	7.3
2025–30	6.8	6.7	6.7
2030–35	6.5	6.4	6.4
2035–40	6.3	6.3	6.3
2040–45	4.6	4.4	4.4
2045–50	4.3	3.2	3.2

Table 6: Revenue-positive vs revenue-neutral closures (welfare-equivalent variation)

Year	Carbon tax (Revenue-positive, %)	CDC (Revenue-neutral, %)
2015	-0.05	-0.05
2020	-1.15	-1.15
2025	-0.89	-0.89
2030	-1.64	-1.64
2035	-1.99	-1.99
2040	-2.10	-2.10
2045	-2.96	-2.96
2050	-6.35	-6.35

The results for the revenue-neutral closure are identical to the revenue-positive scenario, implying that the gains from lower tax rates on production are completely neutralised by the effects of carbon taxes. Production tax rates are relatively lower in the policy scenario because of the carbon tax revenues that are generated and form part of government income in the policy scenario.

4.3.2 Alternative Closure: Fixed Exchange Rate And Flexible Foreign Savings (CDC Scenario)

In this scenario, the exchange rate is fixed and foreign savings adjusts to clear the current account balance. The results are presented in Tables 7 and 8.

Table 7: Flexible vs fixed exchange rate closures (GDP growth)

Period	BAU–flexible exchange rate (%)	CDC–flexible exchange rate (%)	BAU–fixed exchange rate (%)	CDC–fixed exchange rate (%)
2005–10	8.5	8.5	8.6	8.6
2010–15	7.6	7.6	7.6	7.6
2015–20	8.2	8.2	8.3	8.3
2020–25	7.4	7.3	7.5	7.4
2025–30	6.8	6.7	6.9	6.8
2030–35	6.5	6.4	6.6	6.5
2035–40	6.3	6.2	6.5	6.5
2040–45	4.6	4.3	4.8	4.6
2045–50	4.3	3.0	4.8	3.9

Table 8: Flexible vs fixed exchange rate closures (welfare-equivalent variation)

Year	Flexible exchange rate (%)	Fixed exchange rate (%)
2015	-0.05	-0.0
2020	-0.08	-0.17
2025	0.02	-0.63
2030	0.42	-0.89
2035	-0.49	-0.81
2040	-1.47	-0.33
2045	-2.64	1.68
2050	-5.16	22.56

The growth rate in this closure falls less than the flexible exchange rate closure. For example, during 2045–50, the growth rate falls from 4.3 per cent to 3 per cent (a 1.3-percentage-point decline) in the flexible exchange rate closure and from 4.8 per cent to 3.9 per cent (a 0.9-percentage-point decline) in the fixed exchange rate closure. Welfare gain is observed in the fixed exchange rate closure towards the end of the time horizon. In the fixed exchange rate scenario, exports of the agriculture, coal, oil, gas, and service sectors increase while exports of the manufacturing sector decline; and imports of most sectors decline. In the flexible exchange rate scenario, exports of most sectors decline while imports of sectors such as agriculture and manufacturing increase. The currency appreciation due to capital inflows makes exports expensive and imports cheaper. The fall in exports has an adverse impact on GDP. Capital inflows due to emissions trading thus have a less negative impact on growth and welfare in the fixed exchange rate closure relative to the flexible exchange rate closure. The results suggest that climate policies could influence the country's trade balance, and the degree of influence depends on the exchange rate regime.

5. SUMMARY AND CONCLUSIONS

The main objective of this paper was to analyse the impact of two post-Kyoto climate policy regimes on GDP growth, CO_2 emissions, and welfare in India. Both climate policy regimes are consistent with the objective of limiting the increase in average global temperature below 2°C over the long term. The first policy regime is a global carbon tax. The second is based on emissions trading permits; their distribution is based on the CDC approach (Hohne et al. 2006). The policy parameters were obtained from a global climate model called DART (Klepper et al. 2003). A recursive dynamic CGE model that incorporates features of the

energy system was used in the study. Two different baseline (BAU) scenarios were constructed considering GDP projections of the Indian economy. The first baseline is based on OECD projections while the second baseline is based on a slightly higher growth rate.

The results suggest that CO_2 emissions can be reduced significantly under both policy regimes. Under the OECD growth scenario (BAU), per capita CO_2 emissions increase from 1.1 MT in 2005 to 3.3 MT in 2050. The global average per capita GHG emissions was 4.22 MT of CO_2 equivalent in 2005, implying that per capita emissions in India in 2050 are likely to be less than the global average in 2005. In the carbon tax scenario, per capita emissions peak at 2.1 MT in 2040, and thereafter decline to 1.6 MT in 2050 (more than 50 per cent reduction in emissions relative to BAU). In the CDC scenario, per capita emissions also peak at 2.1 MT in 2040, and thereafter decline to 1.5 MT in 2050. The relatively larger impact on CO_2 emissions is due to higher tax rates on CO_2 emissions in the CDC scenario. The maximum loss in GDP occurs during 2045–50. The growth rate loss falls from 4.3 per cent in the BAU scenario to 3.2 per cent in the carbon tax scenario and to 3 per cent in the CDC scenario. In other periods, the decline in GDP growth rate is not more than 0.3 percentage points. The maximum welfare loss in 2050 in terms of equivalent variation is estimated at 6.35 per cent in the carbon tax scenario and at 5.16 per cent in the CDC scenario. The results are similar for the high growth scenario.

The energy intensity of GDP falls significantly under both scenarios. Under the OECD growth scenario, the energy intensity of GDP falls 35 per cent between 2005 and 2020 in the baseline scenario and 38 per cent under the carbon tax regime. Under the high growth scenario, the energy intensity of GDP falls approximately 36 per cent between 2005 and 2020 in the baseline scenario and 43 per cent under the carbon tax regime. The results show that the share of renewable energy in the total energy mix increases over time and the imposition of climate policy regimes facilitate the substitution of fossil fuels by renewable energy. However, fossil fuels retain their dominant position in the energy mix even in 2050.

Finally, the results suggest that climate policies could influence the country's trade balance, and that the degree of influence depends on the exchange rate regime. A stable (fixed) exchange rate is relatively beneficial for the economy.

The imposition of global climate policy regimes can thus significantly reduce CO_2 emissions over the long term at a moderate cost to the economy. The rapid development of the renewable energy sector is vital for this transition to a green economy. The costs of climate change mitigation policies could be higher if affordable renewable energy is absent. As observed in the baseline scenario, even a high level of renewable energy penetration is not sufficient to stabilise or reduce the emission levels. Therefore, to reduce emission levels,

the renewable energy sector needs to grow and carbon mitigation policies are required. Technology and financial resources are required to develop the renewable energy sector. A possible source of finance is through trade in emission trading permits. However, the inflow of capital is dependent on factors such as emission allowances and levels—a country gains by selling permits only when the level of emissions is lower than the allowance. If emissions are higher than the allowance, the country will have to buy permits, involving the outflow of capital. Therefore, the choice of mitigation strategy is important. The conclusion is that the transition to a green economy depends crucially on the rapid development of the renewable energy sector and the design of appropriate carbon mitigation policies.

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Appendix A

Table A1: Policy parameters (carbon prices and emission allowances) for different climate policy regimes

	2015	2020	2025	2030	2035	2040	2045	2050
Carbon price ($ per MT of CO_2) (CT–OECD)	1.9	6.8	34.4	69.7	104.9	141.9	212.6	408.0
Carbon price ($ per MT of CO_2) (CT–high growth)	2.5	15.9	40.4	77.1	117.6	174.2	262.9	462.4
Carbon price ($ per MT of CO_2) (CDC–OECD)	1.9	6.8	34.7	71.1	107.2	145.7	222.4	440.8
Carbon price ($ per MT of CO_2) (CDC–high growth)	1.6	6.8	36.8	79.6	122.2	178.8	277.7	542.1
Allowance (million MT of CO_2) (CDC–OECD)	2316	2944	3589	4233	3997	3762	3526	3290
Allowance (million MT of CO_2) (CDC–high growth)	2440	3193	4036	4824	4490	4196	3821	3487

Appendix B

MODEL EQUATIONS

SETS

A All sectors

AC/ACP Global set

AF Sectors with fixed resources (fossil fuel sectors)

ANF Sectors without fixed resources (other than fossil fuel sectors)

C/CP Commodities

CINT Intermediate inputs for sectors without fixed resources

CINTFC Intermediate inputs for sectors with fixed resources

CNE Non-exported commodities

CNM Non-imported commodities

EMM CO_2 emitting commodities

F/FP Factor

H Households

INSD Domestic institution

RES Fixed resource

PARAMETERS

alphaa(AC) shift parameter for CES production function for fixed resource sectors (between fixed resource and value added intermediate aggregate)

alphaq(AC) Armington function shift parameter for commodity c

alphat(AC) CET function shift parameter for commodity c

alphava(AC) shift parameter for CES function (between labour and capital)

alphavaen(AC) shift parameter for CES function (between electric and non-electric)

alphavaen1(AC) shift parameter for CES function (between aggregate energy and aggregate value added)

alphavaen2(AC) shift parameter for CES function (between coal/oil/gas and oil products)

alphavaen3(AC) shift parameter for CES function (between non-renewable and renewable electric)

alphavaen31(AC) shift parameter for CES function (between wind/solar/biomass/nuclear and hydro)

alphavaen32(AC) shift parameter for CES function (between wind/solar/biomass and nuclear)

alphavaen33(AC) shift parameter for CES function (between wind/solar and biomass)

alphavaen4(AC) shift parameter for CES function (between oil and gas)

25

alphavaen5(AC) shift parameter for CES function (between oil/gas and coal)

alphavaenccs(AC) shift parameter for CES function (between thermal and CCS electricity)

assnemm emission allowance

betam(ACP,AC) marginal share of household consumption spending on commodity c

cwts(AC) weight of commodity c in the CPI

deltaa(AC) share parameter for CES function for fixed resource sectors (between fixed
 resource and value added intermediate aggregate)

deltaq(AC) Armington function share parameter for commodity c

deltat(AC) CET function share parameter for commodity c

deltava(AC,ACP) share parameter for CES function (between labour and capital)

deltavaen(AC) share parameter for CES function (between electric and non-electric)

deltavaen1(AC) share parameter for CES function (between aggregate energy and aggregate value added)

deltavaen2(AC) share parameter for CES function (between coal/oil/gas and oil products)

deltavaen3(AC) share parameter for CES function (between non-renewable and renewable electric)

deltavaen31(AC) share parameter for CES function (between wind/solar/biomass/nuclear and hydro)

deltavaen32(AC) share parameter for CES function (between wind/solar/biomass and nuclear)

deltavaen33(AC) share parameter for CES function (between wind/solar and biomass)

deltavaen4(AC) share parameter for CES function (between oil and gas)

deltavaen5(AC) share parameter for CES function (between oil/gas and coal)

deltavaenccs(AC) share parameter for CES function (between thermal and CCS electricity)

emmfactor(emm) emission factor for CO_2 emitting commodities (coal, gas and oil products)

gammam(ACP,AC) per capita subsistence consumption of marketed commodity c for household h

 ica(ACP,AC) quantity of commodity as intermediate input per unit of aggregate intermediate

intaen(AC) Leontief function coefficient for non-fossil fuel sector (intermediate aggregate)

ivaen(AC) Leontief function coefficient for non-fossil fuel sector (energy value added aggregate)

inta1(AC) Leontief function coefficient for fossil fuel sector (intermediate aggregate)

iva1(AC) Leontief function coefficient for fossil fuel sector (value added aggregate)

pcarbon price (tax rate) of CO_2 emissions for the simulations

qbarinv(AC) base-year quantity of investment demand for commodity c

rhoa(AC) CES function exponent for fixed resource sectors (between fixed resource and value
 added intermediate aggregate)

rhoq(AC) Armington function exponent for commodity c

rhot(AC) CET function exponent for commodity c (stage 1)

rhova(AC) CES production function exponent (value added)

rhovaen(AC) CES production function exponent (between electric and non-electric)

rhovaen1(AC) CES production function exponent (between aggregate energy and aggregate value added)

rhovaen2(AC) CES production function exponent (between coal/oil/gas and oil products)

rhovaen3(AC) CES production function exponent (between non-renewable and renewable electric)

rhovaen31(AC) CES production function exponent (between wind/solar/biomass/nuclear and hydro)

rhovaen32(AC) CES production function exponent (between wind/solar/biomass and nuclear)

rhovaen33(AC) CES production function exponent (between wind/solar and biomass)

rhovaen4(AC) CES production function exponent (between oil and gas)

rhovaen5(AC) CES production function exponent (between oil/gas and coal)

rhovaenccs(AC) CES production function exponent (between thermal and CCS electricity)

shif(AC,ACP) share of institution INS in the income of factor f

tm (c) import tariff

te (c) export tariff

tsal (c) sales tax

tstm (c) stamp duty

toth (c) other taxes

tser (c) service tax

texc (c) excise duty

tsub (c) subsidy

trnsfr(ACP,AC) transfers from institution INS or factor f to institution INS

VARIABLES AND FIXED VARIABLES

CPI consumer price index

EG government expenditure

EH(AC) household consumption expenditure

EXR exchange rate

GSAV government savings

IADJO investment adjustment factor (fixed)

MPS(AC) marginal (and average) propensity to save for household h (fixed)

PDD(AC) demand price of output produced & sold domestically

PDS(AC) supply price of output produced & sold domestically

PINTA(AC) price of intermediate aggregate

PE(AC) export price

PM(AC) import price

PWE(AC) world price of exported commodity (fixed)

PWM(AC) world price of imported commodity (fixed)

PQ(AC) composite commodity price for c

PVA(AC) value added price for activity a

PX(AC) producer price for commodity c

QD(AC) quantity sold domestically of domestic output c

QE(AC) export quantity

QF(ACP,AC) quantity demanded of factor f from activity a

QVA(AC) quantity of aggregate value added

QH(ACP,AC) quantity consumed of commodity c by household h

QINT(ACP,AC) quantity of commodity c as intermediate input to activity a

QINTA(AC) quantity of aggregate intermediate input for activity a

QINV(AC) quantity of investment demand for commodity c

QM(AC) import quantity

QQ(AC) quantity of goods supplied domestically (composite supply)

QX(AC) quantity of domestic output of commodity c

TABS total absorption

TINS(AC) direct tax rate on households (fixed)

WF(AC) economy-wide wage of factor f

YF(AC) factor income

YG government income

YIF(AC,ACP) income of institution ins from factor f

YI(AC) income of institution ins (domestic non-govt)

CORPSAV corporate saving

QFS(AC) factor supply

PVTENTSAV private enterprise savings

PUBENTSAV public enterprise savings

FSAVO foreign savings (fixed)

QVAINTA(AF) value added and intermediate input aggregate composite

PVAINTA(AF) price of value added and intermediate input aggregate composite

QVAEN(A) value added and energy composite

PVAEN(A) price of value added and energy composite

QEN(A) energy (electric and non-electric) composite

PEN(A) price of energy composite

GADJO government consumption adjustment factor (fixed)

QG(AC,ACP) government consumption of commodity

QELEC(AC) aggregate electricity quantity

PELEC(AC) aggregate electricity price

QELINT(AC,ACP) quantity of electricity input

QNELEC(AC) quantity of aggregate non-electric input

PNELEC(AC) price of aggregate non-electric input

QNEINT(AC,ACP) quantity of non-electric input

QOILGAS(ANF) quantity of oil gas composite

POILGAS(ANF) price of oil gas composite quantity

QFOSS(ANF) quantity of oil gas coal composite

PFOSS(ANF) price of oil gas coal composite

QEREN(ANF) quantity of renewable electricity aggregate

PEREN(ANF) price of renewable electricity aggregate

QRENBIONUC(ANF) quantity of wind solar biomass nuclear aggregate

PRENBIONUC(ANF) price of wind solar biomass nuclear aggregate

QRENBIO(ANF) quantity of wind solar biomass aggregate

PRENBIO(ANF) price of wind solar biomass aggregate

QRES(AC,ACP) quantity of fixed resource

PRES(RES) price of fixed resource

YRES(AC,ACP) institutional income from fixed resource

QELECCCS(ANF) quantity of thermal and CCS electricity aggregate

PELECCCS(ANF) price of thermal and CCS electricity aggregate

WALRAS dummy variable equal to zero

CAPFLOW capital flows in CDC regime

PRICE BLOCK

$$PM(C) = (1+indtax(C,'tm'))*EXR*pwmo(C) \tag{1}$$

$$PE(C) = (1-indtax(C,'te'))*EXR*pweo(C) \tag{2}$$

$$PDD(C) = PDS(C) \tag{3}$$

$$PQ(C)*(1-indtax(C,'tsal')-indtax(C,'tstm')-indtax(C,'toth')-indtax(C,'tser'))*QQ(C) = PDD(C)*QD(C) + PM(C)*QM(C) \tag{4}$$

$$PQ(emm)*((1-indtax(EMM,'tsal')-indtax(EMM,'tstm')-indtax(EMM,'toth') -indtax(EMM,'tser'))-emmfactor(EMM)*pcarbon/PQ(EMM))*QQ(EMM) = PDD(EMM)*QD(EMM)+ PM(EMM)*QM(EMM) \tag{5}$$

$$PX(C)*QX(C) = PDS(C)*QD(C) + PE(C)*QE(C) \tag{6}$$

$$PINTA(ANF) = SUM(CINT,PQ(CINT)*ica(CINT,ANF)) \tag{7}$$

$$PINTA(AF) =SUM(CINTF,PQ(CINTF)*ica(CINTF,'AF')) \tag{8}$$

$$PX(ANF)*QX(ANF)*(1 - indtax(ANF,'texc')+ indtax(ANF,'tsub')) = PVAEN(ANF)*QVAEN(ANF) +PINTA(ANF)*QINTA(ANF) \tag{9}$$

$$PX(AF)*QX(AF)*(1 - indtax(AF,'texc')+ indtax(AF,'tsub')) = SUM(RES,PRES(RES)*QRES(RES,AF)) + PVAINTA(AF)*QVAINTA(AF) \tag{10}$$

$$CPI = SUM(C,cwts(C)*PQ(C)) \tag{11}$$

PRODUCTION BLOCK

$$QINTA(ANF) = intaen(ANF)*QX(ANF) \tag{12}$$

$$QVAEN(ANF) = ivaen(ANF)*QX(ANF) \tag{13}$$

$$QINTA(AF) = inta1(AF)*QVAINTA(AF) \tag{14}$$

$$QVA(AF) = iva1(AF)*QVAINTA(AF) \tag{15}$$

$$QX(AF)=alphaa(AF)*(deltaa(AF)*QVAINTA(AF)^{-rhoa(AF)}+\big(1\text{-}deltaa(AF)\big)*\textstyle\sum\big(RES, QRES(RES, AF)\big)^{-rhoa(AF)})^{-1/-rhoa(AF)} \tag{16}$$

$$QVAINTA(AF)=\textstyle\sum\big(RES,QRES(RES,AF)\big)* (\left(\frac{PRES(AF)}{PVAINTA(AF)}\right) * \left(\frac{deltaa(AF)}{\big(1\text{-}deltaa(AF)\big)}\right))^{1/(1+rhoa(AF))} \tag{17}$$

$$QVAINTA(AF)*PVAINTA(AF) = QVA(AF)*PVA(AF) + QINTA(AF)*PINTA(AF) \tag{18}$$

INTERMEDIATE DEMAND

$$QINT(CINT,ANF) = ica(CINT,ANF)*QINTA(ANF) \tag{19}$$

$$QINT(CINTFC, AF) = ica(CINTFC, AF)*QINTA(AF) \tag{20}$$

AGGREGATE ENERGY AND AGGREGATE VALUE ADDED COMPOSITE

$$QVAEN(ANF)=alphavaen1(ANF)*(deltavaen1(ANF)*QVA(ANF)^{-rhovaen1(ANF)}+(1\text{-}deltavaen1(ANF))*QEN(ANF)^{-rhovaen1(ANF)})^{-1/rhovaen1(ANF)} \tag{21}$$

$$QVA(AF)=QEN(AF)*(\left(\frac{PEN(AF)}{PVA(AF)}\right)*\left(\frac{deltavaen1(AF)}{(1\text{-}deltavaen1(AF))}\right))^{1/(1+rhovaen1(AF))} \tag{22}$$

$$QVAEN(ANF)*PVAEN(ANF)=QVA (ANF)*PVA(ANF)+QEN(ANF)*PEN(ANF) \tag{23}$$

VALUE ADDED

$$QVA(A) = alphava(A)*(\sum F,deltava(F,A)*QF(F,A)^{-rhova(A)})^{-1/rhova(AF)} \tag{24}$$

$$WF(F) = PVA(A)*QVA(A)*\sum(FP,deltava(FP,A)*QF(FP,A)^{-rhova(A)})^{-1}*deltava(F,A)*QF(F,A)^{(-rhova(A)-1)} \tag{25}$$

ENERGY AGGREGATE-ELECTRIC AND NON-ELECTRIC

$$QEN(ANF)=alphavaen(ANF)*(deltavaen(ANF)*QELEC(ANF)^{-rhovaen(ANF)}+(1-deltavaen(ANF))*QNELEC(ANF)^{-rhovaen(ANF)})^{-1/rhovaen(ANF)} \tag{26}$$

$$QELEC(ANF)=QNELEC(ANF)*\left(\left(\frac{PNELE(ANF)}{PELEC(ANF)}\right)*\left(\frac{deltavaen(ANF)}{(1-deltavaen(ANF))}\right)\right)^{1/(1+rhovaen1(ANF))} \tag{27}$$

$$QEN(ANF)*PEN(ANF) = QELEC(ANF)*PELEC(ANF)+QNELEC(ANF)*PNELEC(ANF) \tag{28}$$

NON-ELECTRIC AGGREGATE

COAL/OIL/GAS AND OIL PRODUCTS AGGREGATION TO FORM NON-ELECTRIC AGGREGATE

$$QNELEC(ANF)= alphavaen2\ (ANF)*(deltavaen2\ (ANF)*QFOSS\ (ANF)^{-rhovaen2(ANF)}+(1-deltavaen2(ANF))*QNEINT('PET',ANF)^{-rhovaen2(ANF)})^{-1/-rhovaen2(ANF)} \tag{29}$$

$$QFOSS(ANF)=QNEINT('PET'\ ANF)*\left(\left(\frac{PQ('PET')}{PFOSS(ANF)}\right)*\left(\frac{deltavaen2(ANF)}{(1-deltavaen2(ANF))}\right)\right)^{1/(1+rhovaen2(ANF))} \tag{30}$$

$$QNELEC(ANF)*PNELEC(ANF) = QFOSS(ANF)*PFOSS(ANF)+QNEINT('PET',ANF)*PQ('PET') \tag{31}$$

OIL/GAS AND COAL AGGREGATION

$$QFOSS(ANF)= alphavaen5\ (ANF)*(deltavaen5\ (ANF)*QOILGAS(ANF)^{-rhovaen5(ANF)}+(1-deltavaen5(ANF))*QNEINT('COAL',ANF)^{-rhovaen5(ANF)})^{-1/-rhovaen5(ANF)} \tag{32}$$

$$QOILGAS(ANF)=QNEINT('COAL',\ ANF)*\left(\left(\frac{PQ('COAL')}{POILGAS(ANF)}\right)*\left(\frac{deltavaen5(ANF)}{(1-deltavaen5(ANF))}\right)\right)^{1/(1+rhovaen5(ANF))} \tag{33}$$

$$QFOSS(ANF)*PFOSS(ANF) = QOILGAS(ANF)*POILGAS(ANF) + QNEINT('COAL',\ ANF)*PQ('COAL') \tag{34}$$

OIL AND GAS AGGREGATION

$$QOILGAS(ANF) = alphavaen4(ANF)*(deltavaen4(ANF)*QNEINT('OIL',ANF)^{-rhovaen4(ANF)} + (1-deltavaen4(ANF))*QNEINT\ ('GAS'\ ANF)^{-rhovaen4(ANF)})^{-1/rhovaen4(ANF)} \tag{35}$$

$$QNEINT('OIL',ANF)=QNEINT('GAS',\ ANF)*\left(\left(\frac{PQ('GAS')}{PQ('OIL')}\right)*\left(\frac{deltavaen4(ANF)}{(1-deltavaen4(ANF))}\right)\right)^{1/(1+rhovaen4(ANF))} \tag{36}$$

$$QOILGAS\ (ANF)*POILGAS\ (ANF) = QNEINT\ ('OIL',\ ANF)*PQ('OIL')+ QNEINT('GAS',ANF)*PQ('GAS') \tag{37}$$

ELECTRIC AGGREGATE

THERMAL/CCS ELECTRICITY AND RENEWABLE ELECTRICITY AGGREGATION TO FORM ELECTRIC AGGREGATE

$$QELEC(ANF)= alphavaen3\ (ANF)*(deltavaen3\ (ANF)*QELECCCS(ANF)^{-rhovaen3(ANF)} + (1-deltavaen3(ANF)) * QEREN(ANF)^{-rhovaen3(ANF)})^{-1/-rhovaen3(ANF)} \tag{38}$$

$$QELECCCS(ANF)=QEREN(ANF)*\left(\left(\frac{PEREN(ANF)}{PELECCCS(ANF)}\right)*\left(\frac{deltavaen3(ANF)}{(1-deltavaen3(ANF))}\right)\right)^{1/(1+rhovaen3(ANF))} \tag{39}$$

$$QELEC(ANF)*PELEC(ANF) = QELECCCS(ANF)*PELECCCS(ANF)+ QEREN(ANF)*PEREN(ANF) \tag{40}$$

THERMAL/CCS ELECTRICITY AND RENEWABLE ELECTRICITY AGGREGATION

$QELECCCS(ANF)=alphavaenccs(ANF)*(deltavaenccs(ANF)*QELINT('EFOSS1',ANF)^{-rhovaenCCS(ANF)} + (1-deltavaenccs(ANF))*QELIENT('ECCS',ANF)^{-rhovaenCCS(ANF)})^{-1/-rhovaenCCS(ANF)}$ (41)

$QELINT('EFOSS1',ANF)=QELINT('ECCS',ANF)* \left(\left(\dfrac{PQ('ECCS')}{PQ('EFOSS1')}\right) * \left(\dfrac{deltavaenccs(ANF)}{(1-deltavaenccs(ANF))}\right)\right)^{1/(1+rhovaenccs\ ANF))}$ (42)

$QELECCCS(ANF)*PELECCCS(ANF) = QELINT('EFOSS1',ANF)*PQ('EFOSS1') + QELINT('ECCS',ANF)*PQ('ECCS'$

(43)

WIND/SOLAR/BIO/NUCLEAR AND HYDRO AGGREGATION TO FORM RENEWABLE ELECTRICITY AGGREGATE

$QEREN(ANF)=alphavaen31(ANF)*(deltavaen31(ANF)*QERENBIONUC(ANF)^{-rhovaen31(ANF)} +(1-deltavaen31(ANF))*QELIENT('EHYD',ANF)^{-rhovaen31(ANF)})^{-1/-rhovaen31(ANF)}$ (44)

$QRENBIONUC(ANF)=QELINT('EHYD',ANF)*\left(\left(\dfrac{PQ('EHYD')}{PRENBIONUC(ANF)}\right) * \left(\dfrac{deltavaen31(ANF)}{(1-deltavaen31(ANF))}\right)\right)^{1/(1+rhovaen31(ANF))}$

(45)

$QEREN (ANF)*PEREN(ANF) = QRENBIONUC(ANF)*PRENBIONUC(ANF) + QELINT('EHYD',ANF)*PQ('EHYD')$

(46)

WIND/SOLAR/BIO AND NUCLEAR ELECTRICITY AGGREGATION

$QRENBIONUC(ANF)= alphavaen32(ANF)*(deltavaen32(ANF)*QRENBIO(ANF)^{-rhovaen32(ANF)} +(1-deltavaen32(ANF))*QELINT('ENUC',ANF)^{-rhovaen32(ANF)})^{-1/-rhovaen32(ANF)}$ (47)

$QRENBIO(ANF)=QELINT('ENUC'\ ANF)*\left(\left(\dfrac{PQ('ENUC')}{PRENBIO(ANF)}\right) * \left(\dfrac{deltavaen32(ANF)}{(1-deltavaen32(ANF))}\right)\right)^{1/(1+rhovaen32(ANF))}$ (48)

$QRENBIONUC (ANF)*PRENBIONUC (ANF) = QRENBIO(ANF)*PRENBIO(ANF) + QELINT('ENUC',ANF)*PQ('ENUC')$ (49)

WIND/SOLAR AND BIO ELECTRICITY AGGREGATION

$QRENBIO(ANF) = alphavaen33(ANF)*(deltavaen33(ANF)* QELINT ('EREN', ANF)^{rhovaen33(ANF)} +(1-deltavaen33(ANF))*+ QELINT ('BIO', ANF)^{-rhovaen33(ANF)})^{-1/-rhovaen33(ANF)}$ (50)

$QELINT('EREN',ANF)=QELINT('BIO', ANF)* \left(\left(\dfrac{PQ('BIO')}{PQ('EREN')}\right)*\left(\dfrac{deltavaen33(ANF)}{(1-deltavaen33(ANF))}\right)\right)^{1/(1+rhovaen33(ANF))}$

(51)

$QRENBIO(ANF)*PRENBIO(ANF) = QELINT('EREN',ANF)*PQ('EREN')+ QELINT('BIO',ANF)*PQ('BIO')$ (52)

ARMINGTON

$QQ(C)=alphaq(C)*(deltaq(C)* QM(C)^{-rhoq(c)}+(1-deltaq(C))*QD(C)^{-rhoq(C)})^{-1/rhoq(C)}$ (53)

$QM(C)=QD(C)* \left(\left(\dfrac{PDD(C)}{PM(C)}\right) *\left(\dfrac{deltaq(C)}{(1-deltaq(C))}\right)\right)^{1/(1+rhoq(C))}$ (54)

CET

$QX(C)=alphat(C)*(deltat(C)* QE(C)^{rhot(c)}+(1-deltat(C))*QD(C)^{rhot(C)})^{1/\ rhot(C)}$ (55)

$QE(C)=QD(C)* \left(\left(\dfrac{PDD(C)}{PE(C)}\right) *\left(\dfrac{1-deltat(C)}{deltat(C)}\right)\right)^{1/(rhot(C)-1)}$ (56)

NON-EXPORTED AND NON-IMPORTED COMMODITIES

$$QQ\ (CNM) = QD(C) \tag{57}$$

$$QX\ (CNE) = QD(C) \tag{58}$$

INSTITUTION BLOCK

$$YF\ (F) = SUM\ (A,WF\ (F)*QF(F,A)) \tag{59}$$

$$YIF\ (INSD,'LAB') = shif(INSD,'LAB')*(YF('LAB')- trnsfr('ROW','LAB')*EXR) \tag{60}$$

$$YIF\ (INSD,'CAP') = shif(INSD,'CAP')*(YF('CAP')- trnsfr('ROW','CAP')*EXR - CORPSAV) \tag{61}$$

$$YI(H) = SUM(F,YIF(H,F))+ trnsfr(H,'GOVT')*CPI + trnsfr(H,'ROW')*EXR \tag{62}$$

$$EH(H) = (1-mps(H))*(1-TINS(H))*YI(H) \tag{63}$$

$$PQ(C)*QH(C,H) = PQ(C)*gammam(C,H) + betam(C,H)*(EH(H)-SUM\ (CP,PQ(CP)* gammam\ (CP,H))) \tag{64}$$

$$YG = SUM(H,TINS0(H)*YI(H)) +SUM(A,indtax(A,'texc')*PX(A)*QX(A)) +SUM(C,indtax(C,'tm')*pwm0(C)*QM(C)*EXR) +SUM(C,indtax(C,'tsal')*PQ(C)*QQ(C)) +SUM(C,indtax(C,'tstm')*PQ(C)*QQ(C)) +SUM(C,indtax(C,'toth')*PQ(C)*QQ(C)) +SUM(C,indtax(C,'tser')*PQ(C)*QQ(C)) +SUM(C,indtax(C,'te')*pwe0(C)*QE(C)*EXR) + YIF('GOVT','CAP') +sum(res,\ yres\ ('govt',res)) +trnsfr\ ('GOVT',' PVTENT')*CPI + trnsfr\ ('GOVT',' ROW')*EXR -SUM(A, indtax(A,'tsub')* PX(A)*QX(A)) +sum(emm,pcarbon*emmfactor(emm)*QQ(emm)) -QNEINT('COAL','ECCS')*emmfactor('coal')*pcarbon \tag{65}$$

$$EG = SUM(C,PQ(C)*QG(C,'GOVT')) + SUM(H,trnsfr(H,'GOVT'))*CPI + trnsfr\ ('PVTENT',' GOVT')*CPI \tag{66}$$

$$PVTENTSAV = (YIF('PVTENT','CAP')+trnsfr('PVTENT','GOVT')*CPI+ SUM(RES,\ YRES\ ('PVTENT',\ RES)))-trnsfr('GOVT','PVTENT')*CPI \tag{67}$$

$$PUBENTSAV = (YIF('PUBENT','CAP')+ SUM(RES,YRES('PUBENT',RES))) \tag{68}$$

INSTITUTIONAL INCOME FROM FIXED RESOURCES

$$YRES('GOVT',\ RES) = SUM\ (AF,QRES(RES,AF))*PRES(RES)*0.5 \tag{69}$$

$$YRES('PVTENT',\ RES) = SUM\ (AF,\ QRES\ (RES,AF))* PRES\ (RES)*0.25 \tag{70}$$

$$YRES('PUBENT',\ RES) = SUM\ (AF,\ QRES\ (RES,AF))* PRES\ (RES)*0.25 \tag{71}$$

SYSTEM CONSTRAINT BLOCK

$$QFS(F) = SUM(A,\ QF(F,A)) \tag{72}$$

$$QQ(CINT) = SUM(ANF,\ QINT(CINT,ANF)) + SUM(H,\ QH(CINT,H)) + QG(CINT,'GOVT') + QINV(CINT) \tag{73}$$

$$QQ('PET') = SUM(ANF,\ QNEINT('PET',ANF)) +SUM(AF,QINT('PET',AF)) + SUM(H,\ QH('PET',H))$$
$$+ QG('PET','GOVT') + QINV('PET') \tag{74}$$

$$QQ('COAL') = SUM(ANF,\ QNEINT('COAL',ANF)) +QINT('COAL','COAL')+QINT('COAL','GAS') +QINT('COAL','OIL') + SUM(H,\ QH('COAL',H)) + QG('COAL','GOVT') + QINV\ ('COAL') \tag{75}$$

$$QQ('OIL') = SUM(ANF,\ QNEINT('OIL',ANF)) +QINT('OIL','COAL')+QINT('OIL','GAS') +QINT('OIL','OIL')+ SUM(H,\ QH('OIL',H)) +QG('OIL','GOVT') + QINV('OIL') \tag{76}$$

$$QQ('GAS') = SUM(ANF,\ QNEINT('GAS',ANF)) +QINT('GAS','COAL')+QINT('GAS','GAS')+QINT$$

('GAS','OIL')+ SUM(H, QH('GAS',H)) + QG('GAS','GOVT') + QINV('GAS') $\qquad$ (77)

QQ('EREN') = SUM(ANF, QELINT('EREN',ANF)) +SUM(AF,QINT('EREN',AF)) + SUM(H, QH('EREN',H))+ QG('EREN','GOVT') + QINV('EREN') $\qquad$ (78)

QQ('EHYD') = SUM(ANF, QELINT('EHYD',ANF)) +SUM(AF,QINT('EHYD',AF)) + SUM(H, QH('EHYD',H))+ QG('EHYD','GOVT') + QINV('EHYD') $\qquad$ (79)

QQ('ENUC') = SUM(ANF, QELINT('ENUC',ANF)) +SUM(AF,QINT('ENUC',AF)) + SUM(H, QH('ENUC',H))+ QG('ENUC','GOVT') + QINV('ENUC') $\qquad$ (80)

QQ('BIO') = SUM(ANF, QELINT('BIO',ANF)) +SUM(AF,QINT('BIO',AF)) + SUM(H, QH ('BIO',H)) + QG('BIO','GOVT') + QINV('BIO') $\qquad$ (81)

QQ('EFOSS1') = SUM(ANF, QELINT('EFOSS1',ANF)) +SUM(AF,QINT('EFOSS1',AF)) + SUM(H, QH('EFOSS1',H)) + QG('EFOSS1','GOVT') + QINV('EFOSS1') $\qquad$ (82)

QQ('ECCS') = SUM(ANF, QELINT('ECCS',ANF)) +SUM(AF,QINT('ECCS',AF)) + SUM(H, QH('ECCS',H)) + QG('ECCS','GOVT') + QINV('ECCS') $\qquad$ (83)

SAVINGS INVESTMENT BALANCE

SUM(C,PQ(C)*QINV(C)) = GSAV + SUM(H,mps(H)*YI(H)*(1-TINS(H))) + CORPSAV + PVTENTSAV + PUBENTSAV + EXR*(FSAV0+CAPFLOW/1000) + WALRAS $\qquad$ (84)

QINV(C) = qbarinv(C)*iadj0 $\qquad$ (85)

CURRENT ACCOUNT BALANCE

SUM(C, pwe0(C)*QE(C)) + SUM(INSD, trnsfr(INSD,'ROW')) + (FSAV0 + CAPFLOW/1000) = SUM(C, pwm0(C)*QM(C))+ SUM(F,trnsfr('ROW',F)) $\qquad$ (86)

GOVT BALANCE

GSAV = YG – EG $\qquad$ (87)

QG(C,'GOVT') = gadj0*QG0(C,'GOVT') $\qquad$ (88)

ABSORPTION

TABS = SUM((C,H),PQ(C)*QH(C,H)) +SUM(C,PQ(C)*QG(C,'GOVT')) + SUM (C, PQ (C)* QINV (C)) $\qquad$ (89)

CAPITAL INFLOW

CAPFLOW = pcarbon*assnemm - pcarbon*(QQ('COAL')*emmfactor('COAL') +QQ('PET')*emmfactor('PET') +QQ('GAS')*emmfactor('GAS') - QNEINT ('COAL','ECCS')*emmfactor('COAL')) $\qquad$ (90)