OECD DEVELOPMENT CENTRE

Working Paper No. 182

(Formerly Technical Paper No. 182)

CLEARING THE AIR IN INDIA: THE ECONOMICS OF CLIMATE POLICY WITH ANCILLARY BENEFITS

by

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Research programme on:
Responding to Global and Local Environmental Challenges

OECD OCDE

November 2001
CD/DOC(2001)14

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ACKNOWLEDGEMENTS

Without implicating them, we would like to thank Pierre Audinet and Cedric Philibert of the IEA for comments on an earlier draft. We also gratefully acknowledge the work of Mohamed Chemingui on the preparation of the data underlying the regional economic models for India.

PREFACE

Today's developing countries face challenges and potential constraints that developed countries never encountered during their own industrialisation. Foremost among these is the threat of global climate change that requires all countries to be sensitive to the link between economic growth and fossil fuel energy consumption. The international community clearly recognises the paramount importance of developed countries' acting to limit their own greenhouse gas emissions. Developing countries have a legitimate claim to be allowed to expand their energy use to fuel economic development — hence, to be compensated for foregoing this option. Nevertheless, the global nature of the problem and of any eventual solution means that they, too, must do what they can to limit emissions without undermining social welfare. Given the vulnerability of resource-dependent developing countries to climate change, they also have a strong self-interest in seeing the problem effectively addressed.

This Technical Paper by Maurizio Bussolo and David O'Connor focuses on India, one of the most important developing economies of the 21st century. The second largest country in terms of population, with more than one billion people, India has been enjoying brisk if not supercharged growth over the past decade. Since the 1991 reforms, India is becoming more open to the outside world, and integrating more closely into the world economy. While fast growth is putting strains on the environment, by reducing the generosity of subsidies to resource use — notably, energy and water — economic reforms are increasing the efficiency of resource allocation.

The Indian Government is an active participant in international discussions on how best to respond to the challenge of climate change. It is one of the strongest advocates of the position that developed countries must demonstrate credible commitment to limit their own greenhouse gas emissions before expecting developing countries to agree to quantitative targets. At the same time, its efforts to remedy serious inefficiencies in its economy and to bring its industries closer to the technological frontier are seen as making a significant contribution to slowing growth of its own emissions.

This paper highlights one important synergy that is sometimes overlooked: that between slowing greenhouse gas emission growth and improving local environmental quality. India's cities have some of the dirtiest air in the world, and people's health suffers as a result. Burning of fossil fuels is a major contributor to the problem, and measures to curtail emissions from this source are an important element of any solution. Climate policy focuses centrally — if not exclusively — on reducing an economy's fossil fuel intensity. In so doing, it can yield important ancillary benefits in terms of better local environmental quality and improved health of the population. The results of the analysis suggest that the size of these synergies is not negligible and that, if these health benefits are properly valued, they could provide a useful gauge to policy makers of the level of greenhouse gas abatement effort that is consistent with overall improvements in social welfare. The welfare criterion used includes both those welfare components that standard national accounts fully monetise and those externalities that they do not.

The paper focuses on the specific case of India — the newest member of the OECD Development Centre. Nevertheless, the lessons can find application in other fast-growing developing countries. As part of the Development Centre's programme on "Responding to Global and Local Environmental Challenges", the paper makes a substantial contribution to the search for incentives for implementing environmentally friendly economic policies.

Jorge Braga de Macedo
President
OECD Development Centre
30 November 2001

RÉSUMÉ

Ce Document technique propose une estimation des retombées d'une limitation des émissions de gaz à effet de serre sur la qualité de l'air et la santé de la population urbaine en Inde. Il utilise pour ce faire un modèle calculable d'équilibre général. Les retombées les plus notables concernent la réduction des émissions de particules qui se traduit par un recul de la mortalité et de la morbidité. En évaluant ces retombées (ou avantages indirects), les auteurs les comparent avec les coûts pour le bien-être des politiques relatives au changement climatique et estiment — sur la base d'hypothèses conservatoires — que les émissions pourraient être diminuées de quelque 10 pour cent par rapport à leur niveau de base de 2010, sans entraîner de coût net. Si l'on prend en compte les élasticités de substitution et la propension de la population à payer pour améliorer sa santé, alors cette réduction « sans coût » des émissions pourrait atteindre 17-18 pour cent de leur niveau de base pour 2010. L'analyse permet également d'évaluer les variations des coûts et des bénéfices sur une base régionale et montre que les coûts de réduction des émissions sont assez faibles et les avantages secondaires élevés dans le nord et le nord-est du pays. Ainsi, si l'on impose une taxe sur le CO_2 uniforme à l'échelle nationale, ces régions réduiront davantage leurs émissions en proportion, tandis que dans le même temps et en l'absence d'un mécanisme de redistribution explicite, l'une des régions (le sud) ne tirerait aucun avantage des mesures liées au changement climatique. Cependant, même dans ce cas, le sud et l'ouest tirent un plus grand profit d'une taxe uniforme que de taxes ciblées par régions qui viseraient un niveau d'émission homogène.

SUMMARY

With the aid of a computable general equilibrium model, this paper estimates for India the magnitude of spillovers from limiting growth of greenhouse gas emissions to local air quality and the health of the urban population. The most important spillovers are reductions in emissions of particulates with associated declines in mortality and morbidity. By valuing these spillovers (or ancillary benefits), we can compare them with the welfare costs of climate policy, estimating that — on conservative assumptions — emissions could be reduced by somewhat more than 10 per cent from their 2010 baseline level without incurring net costs. With central estimates of substitution elasticities and willingness-to-pay for health improvements, "no regrets" abatement could reach around 17-18 per cent of baseline emissions. The analysis also permits assessment of the inter-regional variation in costs and benefits, finding that abatement costs are relatively low and ancillary benefits high in North and East-Northeast. Thus, with a uniform national carbon tax, these regions would reduce emissions proportionately more. At the same time, without an explicit redistributive mechanism, one region (the South) would enjoy no net benefits from climate policy. Even so, South and West are slightly better off with a uniform tax than with region-specific taxes designed to attain a uniform emission target.

I. INTRODUCTION

India is a signatory to the 1992 United Nations Framework Convention on Climate Change (UNFCCC)[1] though not to the 1997 Kyoto Protocol (KP) that sets greenhouse gas (GHG) emission targets for Annex I (developed country) signatories. It thereby affirms the principle of "common but differentiated responsibilities" of Annex I and non-Annex I countries to take measures to slow the growth of — and eventually to stabilise — anthropogenic GHG emissions to the atmosphere. It has been among the strongest proponents of the position that Annex I countries have a moral obligation to curtail their own emissions, while developing countries have a moral right to pursue economic development without being bound by restrictions on their own emissions. India remains a poor country, for which raising per capita income from its current low level ($2 230 at 1999 PPPs) and reducing poverty from its current high level (roughly one-third of its one billion people) is an overriding priority. What place, if any, can climate policy have in its national priorities?

As a non-Annex I Party to the UNFCCC (and even if it were to sign and ratify the Kyoto Protocol), India would come under no legal obligation to impose quantitative restrictions on its GHG emissions, at least during the initial commitment period from 2008 to 2012. Its obligations are in the area of monitoring and reporting information on its GHG emissions, and general efforts to promote more climate-friendly economic activities. An October 1999 joint statement of US Secretary of Energy, Bill Richardson, and Indian Minister for External Affairs, Jaswant Singh, reads in part: "the Government of India recognises the need for voluntary 'no-regrets measures' at the national level, which will have the additional benefits of dealing with air and water pollution, urban transportation and other important sectors of the domestic economy"[2]. This paper is an attempt to estimate in an economy-wide framework the magnitude of no-regrets options in India, focusing specifically on the link between climate policy and local air pollution with its associated health impacts. To do this, we must be able to quantify and value not only these so-called *ancillary benefits* of climate policy (e.g. fewer premature deaths, lower incidence of respiratory illness) but also the costs of adjustment towards a less carbon-intensive economic structure.

The analysis explicitly ignores the longer term and more uncertain benefits that might accrue to India from averting climate change, on the assumption that — given the long time horizon and the remaining uncertainties — these are unlikely to have much impact on current policy making. Policy makers might, however, be responsive to better information about a set of benefits that are near term, well documented through epidemiological studies, and captured almost exclusively by the population of the country adopting the policy.

The analysis makes use of a computable general equilibrium (CGE) model of the Indian economy (described in greater detail in Bussolo *et al.,* 2001) to simulate climate policy. Of the six greenhouse gases regulated by the Kyoto Protocol, only CO_2 — which accounts for about half of India's 1990 CO_2-equivalent emissions — is incorporated into the model. Fuel combustion and fugitive emissions from the energy sector account for

87 per cent of gross CO_2 emissions and 95 per cent of net emissions (after accounting for CO_2 capture through land-use changes and changes in forest stock). Methane (CH_4) is the major omitted gas, accounting for almost 40 per cent of CO_2-equivalent emissions, 68 per cent of which come from agricultural and livestock sources (ADB/GEF/UNDP 1998). While there is a brief discussion below of the technical options for reducing methane emissions from the livestock and rice sectors, it was decided not to model formally climate policy *vis-à-vis* those sectors. In effect, then, climate policy is treated as policy to regulate growth of CO_2 emissions from energy use (and cement production).

The organisation of the paper is as follows. The next section describes the economic and energy structure of India and provides basic data on GHG emissions as well as air quality in major metropolises. Section IV describes the modelling approach taken and the data used in analysing climate policy in India. Section V presents the baseline simulation and Section VI alternative policy scenarios. Section VII presents the results of sensitivity analysis, while Section VIII compares results to those of other studies on Indian climate policy. Section IX reviews evidence on possible trade-offs between cost effectiveness in abating greenhouse gases and costs effectiveness in controlling local air pollution. Section X concludes with a discussion of policy implications.

II. OVERVIEW OF INDIA'S ECONOMY, ENERGY USE AND POLLUTANT EMISSIONS

India is the second largest developing country after China, with a population that has recently crossed the 1 billion mark, and a per capita income roughly two-thirds of China's. Its population density of 330 people per km^2 is 2.5 times China's. As its urbanisation rate is somewhat lower than China's (28 per cent *vs.* 31 per cent), this suggests a rather high rural population density. (Of course, rural population density in China's fertile eastern provinces is also very high.)

Over the past few decades, India's economy has experienced steady but unspectacular growth, averaging 5.3 per cent per year since 1976 (compared with China's 9.6 per cent). Given significantly higher population growth in India than in China (2.0 per cent *vs.* 1.3 per cent, 1976-98), India's per capita income growth has lagged even farther behind China's.

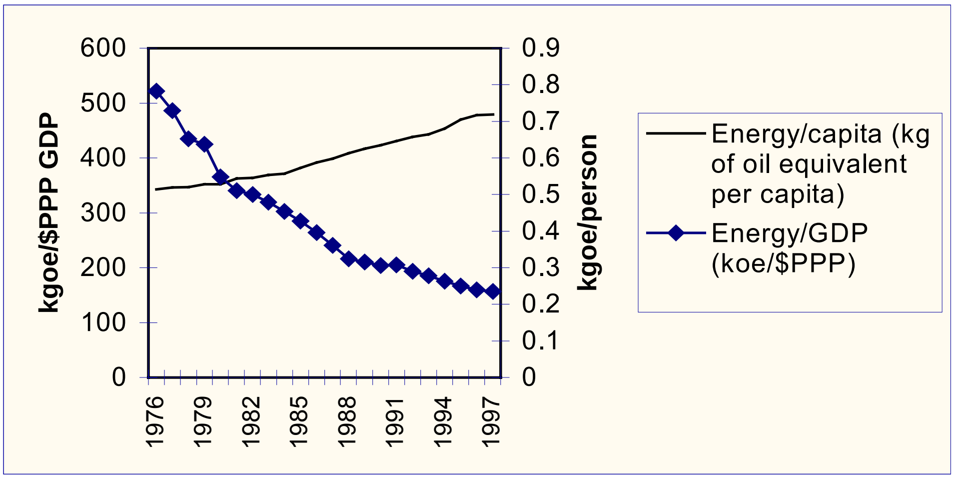
Over the past decade, India has instituted important economic reforms aimed at domestic liberalisation and closer integration into the world economy. These have been rewarded by faster GDP growth in recent years, averaging 6.5 per cent in 1998-99. The process of regulatory reform is ongoing, having barely begun in the electricity sector, though here as elsewhere individual states have served as reform pioneers *cum* laboratories.

II.1 India's Economic and Energy Structure

The economies of both India and China are undergoing a process of structural transformation, with agriculture's GDP share shrinking and those of industry and services growing. In India's case, agriculture's share of GDP fell from 38 per cent to 29 per cent, 1976-98, with most of the increase occurring in the services sector (industry's share rose only modestly from 23 to 25 per cent). (China's economy is much more highly industrialised, with industry accounting for almost half of GDP by 1998.)

As incomes rise further, urbanisation progresses, and industry's share of GDP continues to rise, it can be expected that commercial energy demand will increase fairly briskly in India, even if the energy intensity of GDP does not. Normally, energy intensity of GDP falls with economic development (though per capita consumption tends to rise, albeit at a declining rate). This has indeed been the case in India (see Figure II.1). Over the past decade, Indian commercial energy demand has grown by around 3.8 per cent per year (compared with 3.5 per cent in China), indicating that while the energy intensity of GDP has fallen in the former it has done so much more rapidly in the latter (albeit from a higher initial level). As a sizeable share of Indian energy needs continues to be met by traditional biomass (roughly 40 per cent of primary energy supply), the switch from this source to commercial fuels is likely to sustain strong commercial energy demand growth for some time. (See, for example, Shukla, 2000).

Figure II.1. **Energy Intensity Indicators for India**



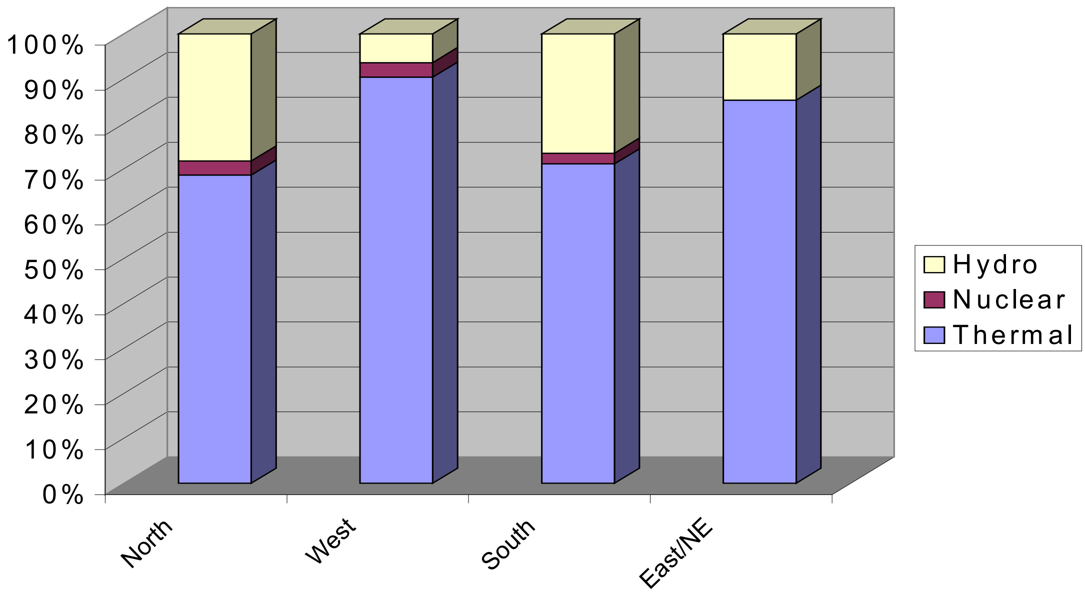
Source: based on *World Development Indicators* (WDI) 2000, World Bank.

The growth in commercial energy use has been accompanied by an even faster growth in electricity use, reflecting the switch from direct consumption of fossil fuels to the consumption of electricity in both the industrial and the household sectors (mostly generated by fossil fuels, though with hydroelectricity accounting for about 16 per cent of total production). From 1987-97, India's electricity production rose significantly faster than GDP, by 7.8 per cent per year (China's rose 8.4 per cent per annum, slightly more slowly than GDP). Even then, demand has outstripped grid-based supply, especially during peak periods, giving rise to a combination of periodic power rationing and supply from own stand-by generator sets at higher cost per kWh. During the 1990s, the country suffered an average annual power deficit of around 6 per cent (TERI, 1999).

While electricity demand growth remains high in India, the elasticity of electricity production with respect to GDP appears to have fallen quite markedly, from 1.94 (1980-90) to 1.25 (1990-97) (calculated from WDI, 2000). It remains well above China's elasticity figure of 0.71 for the latter period, with the higher elasticity in India presumably reflecting a lower initial rate of electrification, particularly in rural areas.

Fossil fuels account for over half of India's primary energy supply, with coal accounting for a third (IEA, 1999*d*). Considering only *commercial* energy, coal accounts for 61 per cent of primary supply and fossil fuels combined for 97 per cent (TERI, 1999). In terms of power generation, thermal is by far the largest source, ranging from two-thirds to fourth-fifths of total supply, depending on region (Figure II.2), with the bulk of that coming from coal[3]. India has vast domestic coal reserves, located mostly in the eastern part of the country, making it the world's third largest coal producer. Low quality, unwashed coal dominates local supply, so the country still imports significant amounts of higher quality coking coal, with total coal imports coming to 15 million tonnes (MT) in 1999 (about 5 per cent of domestic requirements). In 1998, thermal power plants consumed 72 per cent of coal output, with cement and steel making consuming the bulk of the rest.

Figure II.2. **Sources of Electric Power by Region**



India's coal, like China's, has a high ash content (30-35 per cent)[4], but it has a significantly lower sulphur content than China's. Moreover, ash content has risen over time with growing reliance on open-cast mining[5]. As a result, the average calorific value has fallen sharply, from 5900 kcal/kg in 1960 to 3500 kcal/kg in 1995/96 (UNDP/ESMAP, 1998). The high ash poses potential pollution problems, both to air (in the absence of dust capture equipment) and to soil and water (in the absence of recycling or proper disposal facilities).

Historically, coal washeries have been very limited in India, largely because the properties of Indian coal make washing costly (perhaps 20-30 per cent of the cost of mining the coal)[6]. Since the mid-1990s, a few large washeries have been established, whose estimated recovery rate is only 75-85 per cent. Existing power plants are designed to burn high-ash, low quality coal, so washed coal may prove more cost-effective in new plants — assuming that these plants can secure an adequate supply. Current government policies to liberalise the coal market should help in this regard.

India's oil and gas reserves are rather limited and its import dependency has been growing steadily. In the case of oil, it has risen from 29.6 per cent in 1984 to 57.3 per cent in 1997, and it is expected to reach 64 per cent by 2002. Demand is growing especially rapidly in the transport sector.

In an effort to conserve foreign exchange and enhance energy security, the government has pursued a policy of encouraging substitution away from petroleum products towards coal — e.g. diesel pumps in agriculture have been systematically replaced by electric ones and oil-fired boilers by coal-fired ones (Parikh and Goharn, 1993). Also, subsidised railway freight rates have increased domestic demand for coal, notably low quality coal, even coming from remote locations. Since the early 1970s, the share of Indian electric power generated by coal has risen steadily, from slightly under half to almost three-quarters by 1997 — an evolution very similar to China's (WDI, 2000).

Certain types of energy products and services remain heavily subsidised, though overall subsidy rates have been declining over the past decade. The kerosene subsidy, for instance, is around 52 per cent of the reference price, that of coking coal 42 per cent, LPG 32 per cent, and electricity 24 per cent (64 per cent for household use and even higher for agriculture). In some states, electricity is still supplied free-of-charge to farmers (for irrigation pumps), though nation-wide the agricultural tariff averages about 15 per cent of the average tariff (TERI, 1999). Across all states, revenues from electricity sales amount to only about 79 per cent of average supply costs. The World Bank (1999) estimates that, given the high price elasticity of electricity demand by farmers and households, raising prices to these users to long-run marginal cost would effectively eliminate the current electricity deficit.

Whatever the benefits to consumers of low electricity charges, there have been several adverse effects of the subsidies to agriculture and domestic users. Firstly, and most obviously, incentives for these sectors to economise on electricity use are very weak if not absent. Second, by rendering the State Electricity Boards (SEBs), responsible for electricity distribution, financial loss-makers, electricity subsidies have compromised system operation and maintenance, thereby contributing to India's high transmission and distribution losses. Whereas in China these losses as a share of output were only about 8 per cent in 1997 (and the world average is estimated at 10 per cent; EIA, 1999), in India they were nearer 18 per cent (WDI, 2000) — or even higher by some estimates[7]. Also, given the SEBs' weak financial condition[8], state governments have had to provide official guarantees of the power purchase agreements made by the SEBs with private independent power producers invited to invest in grid expansion. Given India's perennial fiscal imbalances, state governments have done so only reluctantly. Subsidies have thus been an important deterrent to a stronger flow of private capital into the power sector.

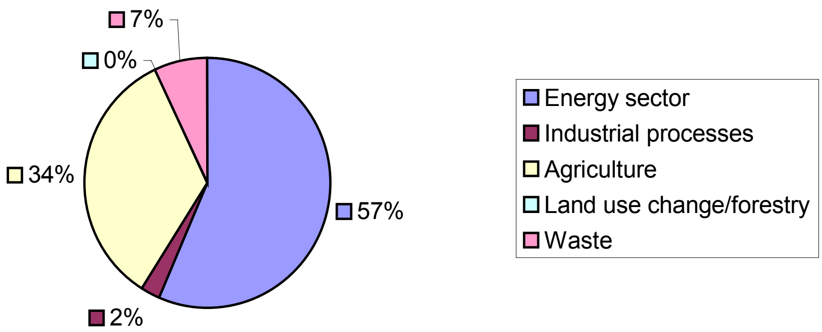
II.2. India's GHG Emissions Profile

Among non-Annex I countries, India is second only to China in its contribution to GHG emissions. As of 1995, India's energy-related CO_2 emissions were roughly half those of the Russian Federation and on a par with Japan's (i.e. around 1 billion metric tonnes (mT) per year, which translates to a per capita rate of about 1 mT, or 1/9th of Japan's and 1/20th of the United States' rate (WRI, 1998). Over the past 30 years, India's CO_2 emissions have grown by 6 per cent per annum, compared to China's 6.5 per cent. In consequence, the carbon intensity of India's GDP has been rising by about 1.3 per cent per annum during this period[9].

The carbon intensity of India's economy is quite sensitive to whether one uses market or PPP exchange rates for converting GDP into US dollars. Arguably, the latter is more appropriate. At market exchange rates and 1990 US dollars, in 1997 India emitted 1.98 kg CO_2 per $GDP to China's 3.83 and the United States' 0.83. At PPP exchange rates, the rankings change and the carbon intensities of the three economies are much closer, at 0.66, 0.74 and 0.83 respectively (IEA, 1999*a*). Of the three, India also has the lowest ratio of CO_2 emissions to total primary energy supply — 1.91 tCO_2 per tonne of oil equivalent (toe) versus 2.53 for the United States and 2.84 for China — presumably reflecting the high share of biomass fuels in India.

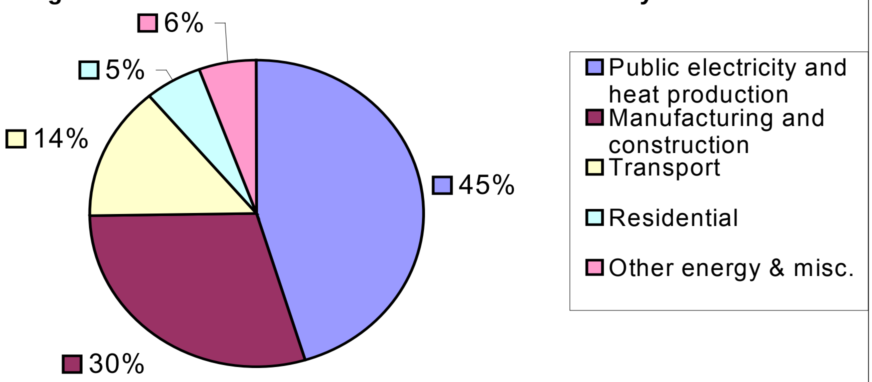
Figures II.3A. to II.3C. provide sectoral and fuel-wise breakdowns of GHG and specifically CO_2 emissions for India. The energy sector clearly predominates, though industrial CO_2 emissions are also significant. These exclude cement manufacture, with emissions amounting to just under 1/20th of total CO_2 emissions. Coal accounts for over two-thirds of fuel-related emissions and gas for a minor share. The dominance of coal is a function of its overwhelming importance as primary energy source and of its high carbon content relative to oil and even moreso gas.

Figure II.3A. 1990 Sectoral Shares of GHG Emissions (in CO2 equivalent units)



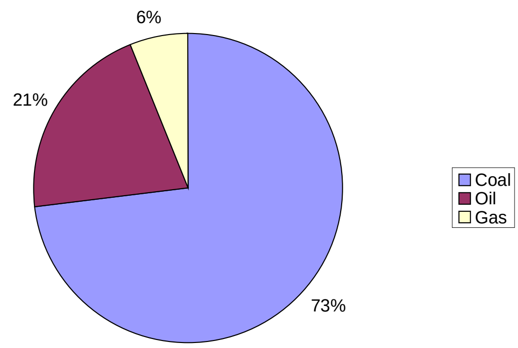
Source: ADB/GEF/UNDP (1998), Table I.1.

Figure II.3B. 1997 Fuel-Related CO2 Emissions by Sector



Source: IEA (1999*a*).

Figure II3.C: CO2 Emissions by Fuel, India, 1994/95



Source: estimates based on model.

Carbon emissions per kWh of electricity are high in India by comparison with both China and the United States. In 1997, for example, Indian carbon emissions from electricity and heat production amounted to 0.32 kgC/kWh, compared with 0.14 kgC/kWh in the United States and 0.21 kgC/kWh in China[10]. While in comparison with the United States, the Indian figure reflects in part a greater reliance on coal for power generation, in comparison with China it reflects largely the greater inefficiencies in India's power sector, notably the high transmission and distribution losses mentioned above.

What sorts of measures might help reduce the inefficiencies in energy use in India? While in theory one can distinguish inefficiencies in power generation from inefficiencies in use, in practice reform of energy subsidies can go some way towards addressing both. On one set of estimates (IEA, 1999*d*), energy subsidy in India could yield energy savings of 7.2 per cent of primary supply and near-term CO_2 reductions of as much as one-third in the case of kerosene, almost one-fourth in the case of coking coal, and 14.1 per cent overall. Khanna and Zilberman (1999) simulate the effects of energy market liberalisation in India on coal consumption and CO_2 emissions. They find that, with removal of the electricity subsidy, free trade in coal, and marginal-cost pricing, emissions can be cut by up to 6.6 per cent at negative welfare cost (measured as consumer surplus plus producer surplus net of the output subsidy). A full assessment of the longer term impact would, however, need to take account of the effect of fuller cost recovery in the electricity sector on investment in capacity expansion and of that, in turn, on electricity tariffs and demand.

II.3. Local Air Quality in India's Metropolises

In a ranking of all environmental risks facing Indians, unsafe drinking water and poor sanitation would probably come first in terms of both population exposure and severity of consequences. In a back-of-the-envelope calculation, Brandon and Hommann (1995) confirm this, estimating that surface water pollution accounts for 59 per cent of total environmental damage costs in India (see their Figure 6). Yet, there can be no doubt that air pollution poses serious health risks in both rural and urban areas, though the source of the risks differs by location. In terms of effective exposure, indoor pollution (principally from cooking smoke) weighs much more heavily than outdoor pollution in rural areas (see Smith, 1993). Biomass (including fuelwood but also crop residue and dung cakes) remains the dominant cooking fuel in rural India as well as among low-income urban households, and in 1998 it still accounted for more than half of total final energy consumption in the country as a whole (IEA, 2000*a*). Nevertheless, outdoor urban air pollution can be very severe in many cities during extended periods of the year, and it is very likely — based on evidence elsewhere — that high outdoor ambient measurements translate into comparably high indoor exposure as well.

Fossil fuels are the major source of many local and regional air pollutants. These include sulphur dioxide (SO_2), nitrogen oxides (NOx), suspended particulate matter[11] (SPM), volatile organic compounds (VOCs), carbon monoxide (CO), and ozone (O_3) (a product of the reaction of precursor gases — NOx, VOCs and SO_2 — in the presence of sunlight). These pollutants in turn are associated with certain adverse effects on human health, crop yields, and materials. In terms of health, the clearest and most consistent associations have been found between SPM and O_3 exposure, on the one hand, and both mortality (from acute exposure) and morbidity, on the other (Davis, Krupnick and Thurston, 2000).

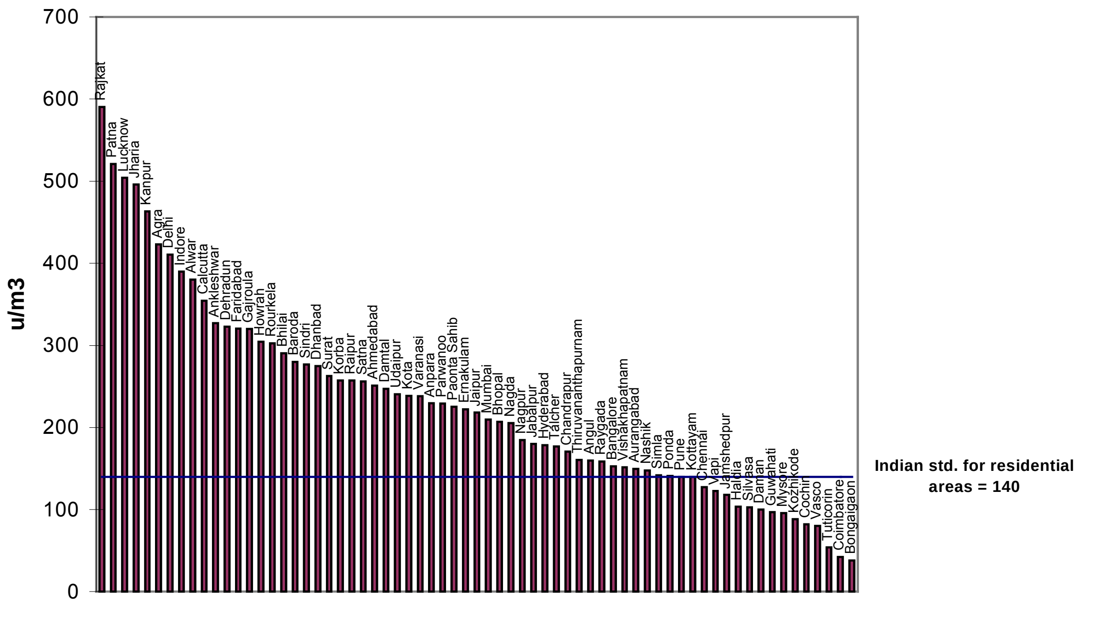
Many of India's cities have severe air pollution problems, with average ambient concentrations of noxious gases far in excess of WHO guidelines and/or Indian ambient standards[12] (see Table II.1). In the case of particulates, for example, Figure II.4 shows the 1995 mean ambient concentrations of total suspended particulate matter at monitoring stations in some 67 Indian cities and towns. Two-thirds of those registered concentrations above the Indian standard for residential areas of 140 micrograms per cubic metre (μ/m^3) (the horizontal line), and 18 had average levels at least double the standard (with Delhi recording an average level of 410 μ/m^3).

Table II.1. **Air Quality Standards of India's Ministry of Environment and Forestry**

Air Quality	Residential and Rural Areas			Industrial and Mixed Areas		
Std. ($\mu g/m^3$)	SO_2	NOx	SPM	SO_2	NOx	SPM
24-hr avg.	80	80	200	120	120	500
Annual avg.	60	60	140	80	80	360

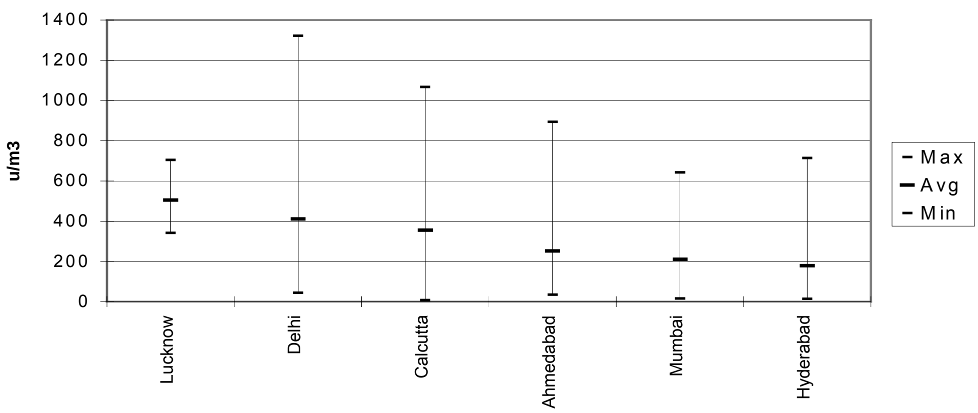
Source: World Bank (1999), *Meeting India's Future Power Needs*, Washington, D.C.

Figure II.4. **Annual Mean Particulate Concentrations, Major Indian Cities/Towns, 1995**



Sources: Data from Central Pollution Control Board, Delhi, reported in CSE (1999*c*) and CPCB (1998).

Figure II.5. **Range of Particulate (TSP) Concentrations, 1995**



The major health risk from particulates is thought to be associated with PM10 (respirable particles with diameter < 10µ) and especially PM2.5 (fine particles with diameter < 2.5µ). Neither PM10 nor PM2.5 is systematically monitored in India, so the only measurement data is for total suspended particulates (TSP). In US studies, a default conversion factor of 0.55 is used to estimate PM10 levels based on measured TSP. Whether this is appropriate in India depends to some degree on location: for northern areas, it has been suggested that the adjustment factor from TSP to PM10 should be 0.40, reflecting the high levels of background dust transported from the arid western region (that dust consisting, on average, of coarser particles than those generated by fossil fuel combustion)[13]. The main sources of respirable and fine particles in India's cities are thought to be coal-fired power plants, industrial boilers, diesel exhaust, and wood-burning stoves, not necessarily in that order.

There can be no doubt that significantly reducing particulate concentrations (whether averages, peaks, or both — see Figure II.5 for TSP concentration ranges in several major cities) would save lives and improve the health status and productivity of the population. Cropper *et al.* (1997) find, based on mortality records and ambient air quality readings for Delhi between 1991-94, that a 100 $\mu g/m^3$ reduction in TSP reduces non-traumatic deaths by 2.3 per cent, only one-third as large as the estimated effect in the United States but still sizeable. Besides mortality risk reductions, improved air quality should also yield reductions in morbidity of various sorts, notably respiratory ailments (see more detailed discussion below).

While most of the health benefits from improved air quality are expected to come from reduced particulate emissions and concentrations (including secondary particle formation as sulphate and nitrate aerosols), there are other air pollutants known, with varying degrees of certainty, to pose health risks. Several were mentioned above. One category of pollutant that has received attention of late in India are hydrocarbons. Benzene, for example, is a known carcinogen with a strong association with leukaemia. While measurement data are scant, one study (Varshney, n.d.) finds a 50 per cent rise in benzene levels in Delhi's air after unleaded gasoline was made mandatory for all categories of vehicles in September 1998 (if all goes according to plan, leaded gasoline is to be phased out nation-wide in 2000). Benzene is often maintained at high levels (5 per cent in India) in "super unleaded" gasoline to increase octane and maintain engine performance (Colls, 1997). An informal survey of benzene levels in another Indian city — Janpath — has found concentrations ranging from 115 μ/m^3 to 139 μ/m^3, depending on location. This compares with the WHO annual average ambient air guideline for benzene of 5-20 μ/m^3 (WHO, 1999).

The case of benzene points to the possibility of tradeoffs between different pollution control objectives. In this case, an effort to phase out lead may be having serious unintended side effects[14]. Similarly, climate policy measures that have the positive effect of reducing particulate and sulphur emissions may have the adverse effect of increasing NOx and VOC emissions relative to baseline — e.g. by inducing a shift away from coal towards natural gas. Thus, to the extent possible, both positive and negative effects of a given policy need to be evaluated to determine net costs or benefits.

III. THE ECONOMIC MODEL

This study employs a computable general equilibrium (CGE) model of the Indian economy for the purpose of assessing and comparing costs and benefits of climate policy. This type of model has become a standard tool — though not the only one — for integrated assessment of climate change (whether at a global, regional, or national level). Its principal advantage lies in its ability to capture feedback effects and market interdependencies that may either mute or accentuate first-order effects, say, of a carbon tax. Possible disadvantages include a lack of technological detail and the sensitivity of results to alteration of certain parameter values that are not known with any certainty. Bottom-up models can provide a check on the realism of technology assumptions (see, for example, Burtraw and Toman, 1997, for a comparison of energy sector specific models and CGE models in estimating ancillary benefits for the United States). In the current study, sensitivity analysis is performed on those parameters and assumptions thought to have an important influence on results.

Economy-wide models have been used for assessing ancillary benefits of climate policy (see Boyd *et al.*, 1995, for a US application; also Scheraga and Leary, 1993), but rarely in a developing country context. Dessus and O'Connor (1999, 2001) employ a CGE model to assess ancillary health benefits in Chile, and Garbaccio *et al.* (2000) do so for China. To our knowledge, this is the first study to incorporate regional detail that allows a more differentiated analysis of climate policy's economic effects below the national level.

III.1. Structure and Main Features

The model employed for this analysis is a dynamic recursive CGE model of the Indian economy based on a 1994/1995 four-region, 35-sector social accounting matrix (SAM) which was constructed from detailed industrial and household expenditure survey data. (The regions coincide with India's regional electric power grids, but with East and Northeast combined.) It has a basic structure similar to a number of others built at the OECD Development Centre (e.g. Beghin *et al.,* 1996) and used in studies of optimal environmental policy in an open economy (cf. Beghin *et al.,* 1994). (For a more detailed technical description of the model, see Bussolo *et al.,* 2001.)

The use of a multi-region model is motivated by two considerations: *i)* the need to provide sufficient geographic resolution to examine impacts of climate policy on local/regional air pollution; *ii)* the possibility of significantly different abatement costs across regions, due for example to differences in the energy structure of regional economies.

The dynamic nature of the model is reflected in a putty-clay capital stock, i.e. with higher substitution elasticities for new investment than for existing capital. This implies that, in the medium to long run, abatement costs should be lower than in the short run, as the turnover of the capital stock makes possible a gradual shift to a less energy- and fossil-fuel-intensive economic structure.

The recursive structure — implying that investment decisions are not based on forward-looking expectations of future profitability — is more a modelling convenience than an attempt to capture reality, but given the relatively short time horizon of the simulations (ten years forward to 2010), it is not thought to be a serious limitation.

The current version of the model has only a single representative consumer, so there is no possibility to examine cross-household distributional impacts, though inter-regional distribution can be considered. Also, at present, the model contains only a single vector of net indirect taxes, so it is not possible to separate out taxes and subsidies, nor is it possible to consider differential tax/subsidy rates levied on different consumers of the same sector's output (e.g. household *versus* industrial users of electricity).

III.2. Key Parameters

The model calculates economy-wide costs of reducing the growth rate of CO_2 emissions. These are a function principally of the substitution among fuels, factors and intermediate inputs within a nested constant elasticity of substitution (CES) production structure. (See Appendix Figure A.1 for the central values of "old vintage" and "new vintage" elasticities — higher for new capital stock than for old.) Within the energy bundle, substitution is possible among coal, petroleum products, natural gas, and electricity. Similarly within the electricity sector itself, inter-fuel substitution is possible, though clearly easier with new capital investment than with existing stock. Biomass fuels are not explicitly incorporated in the model because it is not possible to disentangle them from other agriculture and forestry products in the input-output data.

Unlike for SO_2 or particulates, no cost-effective technology currently exists for end-of-pipe capture of CO_2, so reduction of CO_2 emissions at the sector level requires either a reduction in output, a change in the input mix away from carbon-intensive fuels, or increased conversion efficiency of fuel into useable energy. Only the first two options are endogenous to the model; the last is modelled in terms of a rate of exogenous (or autonomous) energy efficiency improvement (AEEI). In principle it would be possible to endogenise this rate by making it a function, e.g. of energy prices, assuming adequate empirical estimates of the functional link.

At the economy-wide level, a reduction in CO_2 emissions may also result from a shift in production structure towards less energy-intensive sectors. In our CGE modelling framework, sectoral output changes — e.g. as the result of a carbon tax — are the net result of changes in relative prices and factor returns that occasion shifts in resource allocation.

The CES elasticity values in the model were taken from the GREEN model developed at the OECD (see Burniaux *et al.* 1992). The higher elasticity values for new investment than for existing capital stock reflect the "lock-in" effect of existing technology — e.g. the relatively high cost (per unit carbon reduction) of retrofitting a coal-fired power plant to burn natural gas *versus* building a new gas-fired plant. As the value of these parameters matters greatly to the overall welfare costs of carbon reduction, sensitivity analysis is performed around the central values.

IV. MODELLING THE EMISSIONS-CONCENTRATIONS-HEALTH LINKS

Our analysis is limited by virtue of data constraints to a few pollutants: particulates, SO_2 and NOx. Moreover, we consider only their health impacts, leaving aside any other impacts noted in Table IV.1, which summarises main known environmental impacts of various air pollutants.

Table IV.1. **Major Air Pollutants, Their Sources and Their Environmental Impacts**

Pollutant	Major Sources	Transformations in Atmosphere	Major End-Points	Nature of Effects
Particulates	Fossil fuel combustion (exc. natural gas); construction, natural dust (small proportion inhalable)		*i)* Health *ii)* Materials	*a)* Mortality *b)* Morbidity: respiratory and cardiovascular complications Soiling
Sulphur dioxide (SO_2) and sulphate aerosols (SO_4)	Coal and diesel fuel combustion	SO_2 transported, transformed into and suspended/ deposited as SO_4	*i)* Health *ii)* Soils, forests, aquatic ecosystems	*a)* Mortality *b)* Morbidity: respiratory illness Acidification
Nitrogen oxides (NO_x) and nitrates (NO_3 and HNO_3)	Fuel combustion	Precursor to acid rain; Constituent in formation of photochemical smog and of tropospheric O_3	*i)* Health *ii)* Visibility	Respiratory problems Reduced enjoyment
Volatile organic compounds (VOCs)	Fuel combustion	Constituent in formation of photochemical smog	*i)* Visibility *ii)* Health	Reduced amenity value Cancer
Ozone (O_3)		Formed from oxidation of NO_x in the presence of sunlight and reactive VOCs	*i)* Health *ii)* Vegetation	Acute respiratory distress at high concentrations (asthma) Reduced crop yields
Lead (Pb)	Gasoline		Health	*a)* Adults: hypertension; stroke *b)* Children: reduced IQ
Carbon monoxide (CO)	Fuel combustion, including biomass		Health	*a)* Asphyxiation *b)* Stillbirth

IV.1. Estimating Emissions

Modelling the effect of climate policy on emissions of local and regional air pollutants requires, as a starting point, credible estimates of baseline emissions. At present, there is no published source of emissions inventory data for India. The closest thing is a 1997 publication by the Central Pollution Control Board (CPCB, 1997), entitled *National Inventory of Large and Medium Industry and Status of Effluent Treatment &*

Emission Control System, but this reference contains only general information on whether a plant has pollution control equipment and whether it is “adequate and operational”. It contains no data on emission levels of specific pollutants by source. An unpublished data set of selected pollutants for 1995 is, however, available electronically[15]. Emissions of SO_2, NOx, and CO_2 are reported by fuel type and by location (district/state). Aggregating the state-level emissions permits comparison with the base-year regional emissions generated by our economic model. The two sets of numbers are broadly consistent.

In the case of particulates, for which no Indian emissions inventory data were available, an approximation was made based on coal ash content and other fuel characteristics, combined with power sector emission estimates of SO_2 and particulates (UNDP/ESMAP, 1998) that can be used to estimate the proportion in which the two are emitted by the energy sector. Chinese sector-wise emissions data for both pollutants also permit a rough approximation of the proportion in which they are emitted by Indian industries, allowing for the fact that sulphur content of Chinese coal is higher and ash content slightly lower than India’s[16], also assuming that technologies and intra-industry structures are roughly comparable across the two countries and that the physical/chemical composition of oil products burned in the two countries’ industrial sectors is roughly similar (as would appear to be the case[17]).

One significant difference between India and China is in the mix of fuels used in the transport sector, where India uses roughly six times as much diesel fuel as gasoline while in Chinese transport gasoline consumption is about one-third larger than diesel consumption. This has major implications for particulate emissions from this sector, as burning diesel emits sizeable amounts of particulates while particulate emissions from burning gasoline are quite small by comparison (especially once lead is phased out. as the Indian government has decreed). Pechan & Associates (1997) use a PM2.5 emission factor for unleaded gasoline in developing countries that is roughly 1/20th that for diesel fuel (measured in grams/km). In calculating the transport-sector particulate emission coefficient for India, the India-specific transport fuel shares were used as weights to apply to the emission factors of each fuel type.

Table IV.2. **Power Sector SO_2 and TSP Emissions, 2015, India**
(‘000 tonnes)

	SO_2	TSP	TSP/SO_2
North	1500	1300	0.87
South	1080	920	0.85
West	1950	1630	0.84
E & NE	810	820	1.012

Source: UNDP/ESMAP (1998).

Since the epidemiological studies on health impacts of particulate exposure focus either on PM10 (or, more recently, PM2.5), it is necessary to estimate, based on the TSP data, emissions (and eventually concentrations) of these smaller particles. As noted above, where independent measurement data are not available for PM10, the standard practice is to apply a conversion factor to TSP. Since for reasons explained above it may be reasonable to assume that PM10 in India makes up a smaller share of TSP than in the United States (where the conversion factor commonly used is 0.55), we apply a conversion factor of 0.50 for India, i.e. PM10 = 0.5 TSP.

Our analysis of ancillary benefits depends critically on how emissions of local air pollutants can be expected to vary with emissions of CO_2. The co-variation generated by the model is of two sorts: quantity-based and price-based. In the baseline, where the price of carbon is assumed to remain constant (at zero, since there is no carbon tax), economic growth and structural change will yield changes in emissions of various pollutants, including CO_2 and TSP. Thus, for a given percentage change in the former one can calculate the associated percentage change in the latter. If climate policy is then introduced, the price of carbon will increase, causing some substitution away from carbon energy and also some change in overall consumption as a result of real income effects. If TSP is a complement to CO_2, then the carbon price rise should also lower TSP emissions. In this case, one can calculate a cross-price elasticity of TSP emissions with respect to the carbon price. In short, the more closely complementary the two pollutants are, the greater the effect will be of a given climate policy on TSP emissions. This implies that, in countries where the two have *not* been previously de-linked through effective controls on local pollution, the impact of a given carbon tax on the volume of local pollution is likely to be greater than in countries where local pollution controls have been effectively implemented. India comes closer to falling into the former group than the latter.

IV.2. Linking Emissions to Ambient Concentrations and Exposure

Ideally, air dispersion modelling would be used to map emissions by location into ambient concentrations at different receptors (e.g. in a metropolitan area). Neither the economic model nor the available emissions data are suited to this spatially differentiated approach. Only four regional economies are modelled, each containing several states. Thus, the emissions yielded by the model are region-wide, and it is these that must be linked to concentrations in major cities within each region (for which base-year concentration data is available). In practice, we do not know exactly where major emission sources are located in relation to those cities — are they concentrated in or near them (a reasonable assumption perhaps for most industrial sources and certainly for mobile sources) or are they situated more remotely (a possibility with thermal power plants)? Depending on which type of source is most affected by a given policy like a carbon tax, the change in emissions may have very different effects on ambient concentrations.

Despite the lack of spatial detail in the emissions data generated by the model, the dispersion modelling approach adopted here does provide a degree of differentiation among source types, according to the presumed average stack height of emissions from different sectors — high, medium, and low. Since electric power plants are considered “high stack” sources, the dispersion coefficient applied to their emissions assigns to them a relatively small contribution to ambient concentrations compared to “low stack” sources like construction, transport and the household sector. In effect, stack height proxies to a degree for location in the dispersion model.

The dispersion function is of the form:

$$C_{TSP} = a + b_1 (E_{High}) + b_2 (E_{Medium}) + b_3 (E_{Low}),$$

where C_{TSP} refers to the city-wide average concentration of TSP, $E_{High,, Medium, Low}$ the region-wide TSP emissions from each of three groups of sectors differentiated by typical stack height. The constant *a* is an approximation of the effect of background emissions on ambient air quality (in short, what concentration would obtain assuming zero attributable sectoral emissions). The b_is are the dispersion coefficients for emissions from each stack height, calculated using a simple dispersion model in which different atmospheric conditions are assumed to occur with given frequencies[18] and the key piece of additional data required is a metropolitan area's radius (see WHO, 1989 for the original model and Lvovsky *et al.* 1999 for an application in six cities). This model yields the following results: *i)* for low and medium height sources, the concentration/exposure per unit of emissions is strictly inversely related to the city's radius — in other words, the wider the area over which emissions are dispersed, the smaller their effect on average ambient concentration; *ii)* the emissions-exposure relationship for high-stack emissions follows an inverted-U shape in the city's radius, as high stacks contribute more widely to area emissions than low- or medium-stack emissions, so the contribution to area-average exposure rises at first with city size; and *iii)* high-stack sources yield a concentration/exposure per unit of emissions very far below low-stack emissions for virtually any size of city and significantly below medium-stack emissions until city size approaches a radius of 30 km (in other words, a very large city). This suggests that, in terms of reaping ancillary health benefits from energy use changes, it clearly matters where those changes occur — in which sectors.

IV.3. Estimating Health Effects

The epidemiological literature is the main source of estimates of the relationship between exposure to various types of pollution and different health endpoints. Of these, the relationship between acute exposure to particulates and health — in particular, premature mortality — is probably the most firmly established, with repeated studies at different locations finding broadly similar quantitative effects of exposure on mortality risk, viz., roughly a 6-8 per cent increase in mortality risk from a 100 μ/m^3 increase in PM10 concentration. For Delhi, India, however, Cropper *et al.* (1997) find a weaker relationship between particulate concentration and mortality, with a 100 μ/m^3 increase raising mortality risk by only 2.3 per cent. Given the preponderance of evidence from various study sites, including some developing country cities where ambient concentrations are high like Delhi's, we choose to use the higher "consensus" figure in our analysis rather than the Cropper *et al.* Figure[19].

The specific slope coefficients for the exposure-response functions employed in this paper are presented in Table IV.3.

Using the Ostro (1994) mortality dose-response coefficients, Brandon and Hommann (1995) perform a rough calculation of the number of premature deaths in India attributable to air pollution. They calculate these as the excess predicted deaths associated with pollution concentrations above the WHO guidelines. Based on 1991-92 air quality and population data, this number totalled 40 351, of which 7 491 premature deaths were in Delhi. CSE (1999*a*) updates these results using 1995 air quality data, estimating the number of India-wide air pollution related deaths to have risen to 51 779 and those in Delhi to 9 859.

Table IV.3. **PM-10, SO_2, and NO_2 Dose-Response Coefficients**

Concentration Changes and Health End-points	Central Slope Estimate
PM10 (1 $\mu g/m^3$ change in ambient concentration)	
Premature mortality per 100,000 people	0.672
Respiratory hospital admissions per 100,000 people	1.2
Emergency room visits per 100,000 people	23.5
Restricted activity days per 1000 people	57.5
Respiratory symptoms/person	0.183
Lower respiratory illness per 1000 children/asthmatics	1.69
Asthma attacks per 1000 asthmatic people	32.6
Chronic bronchitis per 100,000 persons age > 25 years	6.12
SO_2 (1 $\mu g/m^3$ change in ambient concentration)	
Respiratory symptoms per 1000 children	0.018
Chest discomfort/adult	0.01
NO_2 (1 pphm change in ambient concentration)	
Respiratory symptoms/adult	0.10

Sources: Schwartz and Dockery, 1992; Ostro, 1994.

How do our model results compare? First it is necessary to distinguish the nature of our experiment from that of Brandon and Hommann. The latter consider the effects of compliance with WHO guidelines, but epidemiological studies suggest that there is no threshold in mortality effects of PM10. In other words, exposure appears to result in increased risk of mortality even at concentrations below those guidelines. Second, our analysis yields changes in PM10 concentration as a by-product of climate policy, so there is no specific target reduction. Thus, we need to compare *ex post* the size of the change in PM10 concentration resulting from a carbon tax with the size of the reduction specified by Brandon and Hommann to comply with the WHO guideline. The numbers of premature deaths averted under different climate scenarios with our model are reported in Section VI below.

IV.4. Valuing Health Impacts

Whenever valuation studies of air quality improvements include both mortality and morbidity benefits, the largest estimated monetary benefit is found to be that associated with reduced mortality risk. Underlying this is the estimated value of a statistical life, or *VSL*.

There is a large literature providing *VSL* estimates for OECD countries (see Viscusi, 1993 for a useful review). The two main methods used for this purpose are hedonic wage studies and contingent valuation surveys. The former use regression techniques to isolate the effect of differential risk of occupational fatality on wage levels, holding other things equal (hence, *revealed* preferences). The latter employ questionnaires about willingness to pay (WTP) for specified reductions in mortality risk (hence, *stated* preferences), again using statistical methods to isolate various determinants of WTP, of which income is clearly an important one.

The paucity of either type of study for developing countries means that, when it comes to choosing a *VSL* to use in the analysis of environmental benefits, estimates are normally transferred from studies for the United States or other OECD countries, appropriately adjusted to reflect differences in per capita income. Where the ratio of per capita incomes alone is used for the adjustment, there is an implicit assumption that the elasticity of *VSL* with respect to income equals unity — an assumption not strongly supported by empirical evidence. In a study of mortality risk valuation in India, Simon *et al.* (1999) find evidence that the WTP for reduced mortality risk is higher relative to per capita income than in the United States. Estimating compensating wage differentials as the measure of WTP (or, more precisely, willingness to accept compensation), and then using this to calculate the value of a statistical life (*VSL*), the study finds that the estimated Indian *VSL* is between 20 and 48 times foregone earnings, whereas US studies would predict a range of 8.63 to 25.2 times. The authors suggest that, while a greater degree of risk aversion of Indian workers than American workers is one possible explanation for this discrepancy, the more significant factor is probably the low income elasticity of the *VSL* (citing income elasticity estimates from studies of WTP to avoid illness in a range from 0.26 to 0.60; Loehman and De, 1982 and Alberini *et al*., 1997).

Using the compensating wage differential approach, Simon *et al.* estimate *VSL* values for India ranging from $153 000 to $358 000 at the 1998 exchange rate of 42 rupees/US dollar ($365 714 to $857 143 at the 1990 exchange rate). The wide variation in *VSL*s depending on exchange rate chosen raises doubts about the appropriateness of using market exchange rates for *VSL* transfer. Brandon and Hommann (1995) employ exceedingly low values for *VSL*, ranging from $4 210 to $40 020 (in 1991-92). The former is based on the human capital approach, amounting to the discounted value of foregone earnings for the 10 years they assume to be lost on average from premature pollution-related mortality. The latter is based on a simple adjustment of the *VSL* value (based on US studies) of $3 million by the ratio of Indian to US per capita income (evaluated at market exchange rates). Had incomes been compared in purchasing power terms, India's would have been significantly higher relative to that of the United States (around 6 per cent of the latter rather than 1.4 per cent), and the Indian *VSL* would have been roughly $180 700 (in 1991-92). Adjusted to 1995 relative PPP incomes, it would have been roughly $202 400, again assuming an income elasticity of *VSL* equal to unity. If instead we used an elasticity value of 0.5, imputed Indian *VSL* would turn out to be approximately $342 860 (or very close to the upper end of the range of estimates of Simon *et al*.). In our analysis, we take the mid-point of the range from $202 400 to $343 860, or $273 000, as our central *VSL* estimate for India in the base year, 1995. We then perform sensitivity analysis by considering the impact of using *VSL* values at the high and low ends of the range.

It is worth noting that the choice of income elasticity of *VSL* will affect also the rate of change in *VSL* over time, as per capita income rises. With unitary elasticity, the two would grow at the same rate, while with an elasticity of 0.5, *VSL* would rise only half as fast as per capita income. So, even if an assumed base-year elasticity of 0.5 raises significantly the base-year *VSL* in India relative to the unitary elasticity case, by the end-year (2010), the *VSL*s under the two assumed elasticities should have substantially converged.

V. THE BASELINE SIMULATION

The baseline simulation is intended to present a “most likely” path of development of the Indian economy over the scenario period (from 1995 to 2010) in the absence of climate policy measures. The construction of the baseline is intended to capture the influence not only of underlying demographic and economic factors but also of key policy measures and reforms on India’s development path and on the evolution of the economy’s energy and pollution intensities. The effects of climate policy can then be compared to what would (probably) have happened in its absence.

V.1. Current Economic and Energy Policies and Expected Reforms

India’s economy has been undergoing wide-ranging reforms over the past decade. Precipitated by an external payments crisis, these reforms are designed to rein in government deficits, lessen public ownership of productive assets, strengthen competition, and gradually open the economy to the outside world. The pursuit of these objectives has far-reaching implications for India’s economy, its energy sector, and, by implication, baseline trends in emissions of GHGs and various local pollutants.

Given the political complexity of the reform process, it is extremely difficult to predict the ultimate fate no less the timing of specific reform proposals. Yet, some assumptions about likely outcomes are necessary in order to define a plausible baseline for the purpose of conducting policy simulations. First we describe the key policies currently in place and those with a high probability of being introduced in the near future. The farther one looks ahead, the more speculative any discussion of policy initiatives becomes. Our policy simulations extend only to 2010, so it seems a reasonable assumption that any policy expected to have a significant impact in that timeframe would have to be put in place in the first half of this decade.

Perhaps the single most important set of reforms for climate policy are those occurring in and planned for the electricity sector (see Audinet *et al.,* 2000, for an extended discussion). As explained above, the sector is plagued by inefficiencies at all stages from generation to distribution. The tariff structure has been a major constraint on more efficient operation of the electricity grid, and that has gone hand-in-hand with restrictions on entry and competition. Reforms are intended to move the system to one based on separate markets for generation, transmission and distribution, something approaching long-run marginal cost pricing, keener competition, and a major role for the private sector. A few states (e.g. Andhra Pradesh and Karnataka) have pioneered electricity pricing and regulatory reforms, but the measures taken to date remain hotly contested[20]. Assuming similar measures are eventually put in place nation-wide, they are likely to affect both electricity demand and the choice of fuel and technologies for electricity supply. While on the one hand price and subsidy reform could raise prices and dampen demand growth in the near term, on the other, new entry and investment in response to more favourable incentives, greater competition, and utility regulation should hold prices in check. The net effect on energy prices and on growth in energy consumption relative to a no-reform ("business-as-usual") scenario is hard to predict, though it seems likely that demand growth would be slower with reform than without due to stronger price incentives to energy conservation. Meanwhile, the fuel mix in power generation could well be altered more rapidly than under BAU towards cleaner fuels, notably gas[21]. One set of estimates for Bihar (cited in UNDP/ESMAP, 1998) shows that, even before factoring in pollution mitigation costs of coal plants, a combined-cycle gas turbine plant has significantly lower capital costs (about 60 per cent of those for a new 500 MW coal plant), though fuel costs per kWh (at current prices) are still about 43 per cent higher[22]. The same study estimates, however, that a shift from financial prices to economic costs (5-12 per cent of which — depending on coal grade — represent environmental mitigation costs) would more than double the price of coal in Bihar, more than offsetting the fuel cost advantage of coal-fired plants.

A baseline simulation, then, should realistically incorporate the assumption that India's national and state governments will progressively phase out energy subsidies. Given the data available, which consists only of net taxes (including all taxes and subsidies) for each sector, it is not straightforward to implement a subsidy removal assumption.

Another energy sector development that could significantly impact on India's future GHG emissions would be a more rapid introduction of natural gas to meet India's incremental energy demand. India is in the process of building infrastructure to facilitate gas imports — e.g. the first LNG terminal, on the west coast, is due to be commissioned in late 2001 and at least 10 others are planned[23]. Since much of the natural gas supply would come from the Gulf area, the western region of India is likely to be the major destination of increased imports. These may, however, be supplemented by shipments from Southeast Asia (Indonesia and Malaysia) and Australia to India's south-eastern coast, where two LNG terminals are proposed. According to Indian government projections, demand for gas will rise by 5.2 per cent per annum from now to 2025.

V.2. Baseline Environmental Policy Assumptions

At present, India has a variety of national ambient air quality and other environmental standards. As seen from Figure II.3, they are routinely exceeded in many parts of the country, notably in the case of particulates. Is it realistic to assume that India will make little or no progress towards achieving national ambient standards in the baseline — i.e. in the absence of climate policy? This seems unlikely, based on the experience of other countries as they have undergone economic development. In particular, cross-country analyses of the link between per capita GDP and particulate pollution (measured either as concentrations or as emissions per capita) generally find an inverse-U-shaped relationship, with particulate concentrations and emissions intensity beginning to decline from fairly low levels of per capita income. If these results are a guide to the emissions path India is likely to follow, then beyond some level of development its particulate concentrations should level off and begin to decline. This represents the joint outcome of a changing composition of economic activity and abatement effort. Then, what becomes relevant for projecting India's future particulate concentration or emissions intensity are the estimated income elasticities of these pollution measures in the range of per capita income change India is projected to experience to 2010[24].

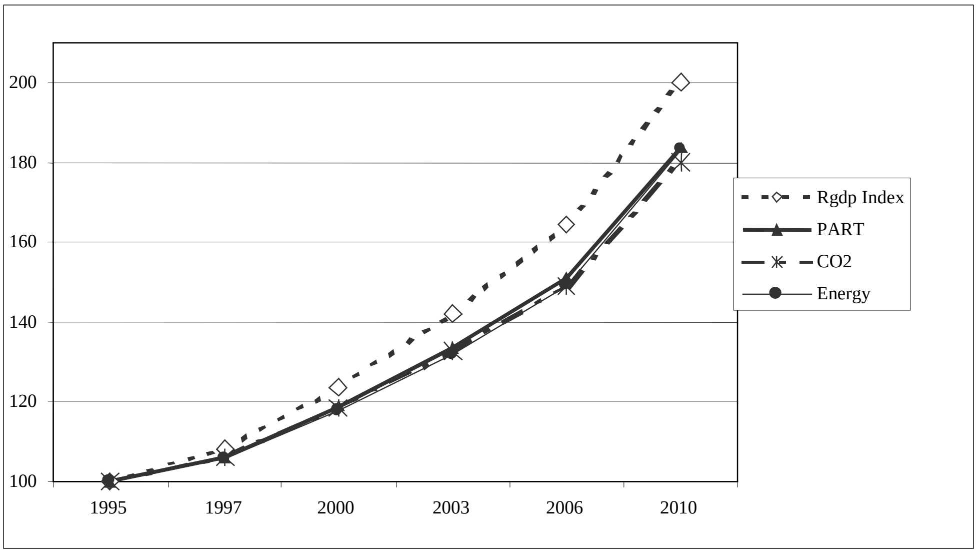
V.3. Simulation Results

Table V.1 presents the main baseline assumptions and Figure V.1 shows "business-as-usual" (*BAU*) trends in energy and emissions, as well as GDP, from 1995 to 2010. In the baseline, the growth rate of India's GDP is exogenous, assumed to average between 4.5 and 5 per cent per annum, 2000-2010; population and labour force growth are also exogenous. Labour productivity is assumed to grow by 2 per cent per annum over the simulation period. Savings rates determine investment, with household savings tending to rise over the period as a proportion of disposable income and the government budget deficit tending to decline as a share of GDP. The autonomous energy efficiency improvement for the economy is set at 1 per cent per annum which, if anything, is apt to be a conservative estimate based on recent historical experience in India. For example, in the 20-year period 1977-97, the commercial energy intensity of India's economy declined by 1.4 per cent per annum (WDI, 2000).

Table V.1. **Exogenous Variable Growth Assumptions (% per annum)**

	1996	1997	-2000	-2003	-2006	-2010
Labour productivity	0.02	0.02	0.02	0.02	0.02	0.02
Labour force	0.022	0.022	0.0206	0.019	0.019	0.015
Population	0.0166	0.0166	0.0142	0.0142	0.0116	0.0101
GDP	0.05	0.04	0.045	0.048	0.05	0.05

Figure V.1. **Trends in Energy, Emissions and GDP**



As explained above, the baseline is designed to incorporate major ongoing and expected reform measures. This should ensure that the estimates of ancillary benefits do not assign to climate policy effects that are likely to follow from other likely policy initiatives. Still, one cannot necessarily take for granted that the government will persevere with economic and energy sector reforms, especially if political opposition should prove strong, so it could be useful for policy makers to have an estimate of the expected payoff to sustained reform, in terms of local environmental benefits (or costs). Thus, one could also perform a “no reform” simulation for purposes of comparison with one of “continued reform”, but we have not done so here.

VI. BASIC CLIMATE POLICY SCENARIO

The basic policy scenario presented here employs central or "best guess" estimates of key parameters and exogenous variables. The most important of these in terms of shaping abatement costs are the substitution elasticities among various factors of production and types of energy. The most important for determining ancillary benefits is the value of a statistical life (*VSL*). The elasticity of *VSL* with respect to income can also be important, assuming one starts with a given India-specific base-year value (which is the case here) rather than relying on value transfer from *VSL* studies done in higher income countries like the United States. In the latter case, the assumed elasticity takes on less importance since, while a lower assumed elasticity would result in a higher initial value of *VSL* in India, it would also imply a slower rate of growth of *VSL* as income grows.

Sensitivity analysis is performed below to determine how robust the results of the basic policy simulation are when key parameters and exogenous variables are changed.

VI.1. Scenario Description

The basic experiment consists of a sequence of reductions of CO_2 emissions: by implementing an endogenously calculated CO_2 tax, emissions in the final year of our projections, i.e. 2010, are reduced from a minimum of 5 per cent to a maximum of 30 per cent. Initially, the following *rules* are applied: *firstly*, the green tax is implemented on a single India-wide reduction target, so that tax rates are the same for all regions; *secondly*, green tax revenues are re-distributed back to households in a revenue-neutral fashion through lump-sum transfers proportional to the initial direct taxes; *thirdly*, elasticities of substitution across factors of production, material inputs and fuels are maintained at mid-range values transferred from the GREEN model; *finally*, the value of a statistical life (*VSL*) is set equal to Rps 8.7 million ($273 000) in 1995. Given that each of these *rules* may have important effects on our simulation results, Section VII presents the results of sensitivity analysis aimed at identifying broad upper and lower bounds.

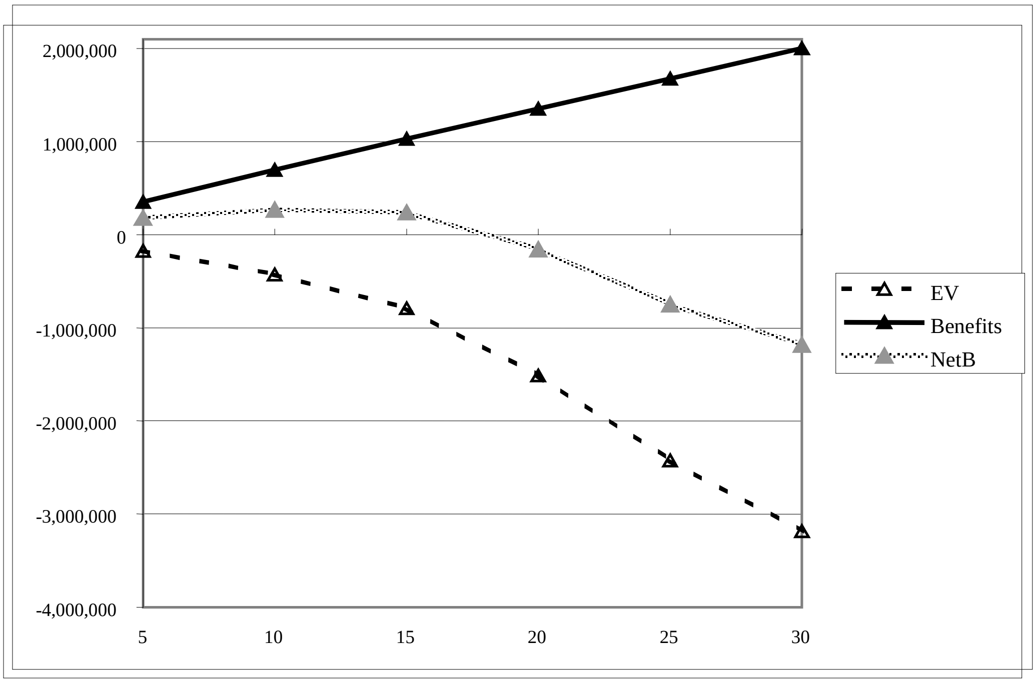
To the extent that marginal carbon abatement costs differ across regions, then a single national emission reduction target and carbon tax (*versus* region-specific targets and taxes) should yield efficiency gains by allowing greater abatement to occur in regions where it is relatively less costly.

VI.2. Scenario Results: "Optimal" and "No Regrets" Abatement

The solution of the model for different abatement rates permits the calculation, in addition to welfare costs, of ancillary benefits and net benefits for each rate, hence the identification of India-wide "optimum" and "no regrets" rates of CO_2 reduction from the baseline, given parameter and exogenous variable values. Figure VI.1 illustrates the effect of CO_2 abatement on welfare as measured by *equivalent variation*, on ancillary benefits, as measured by the value of changes in mortality and morbidity, and on net benefits measured as the difference between the two. It suggests a "no regrets" abatement rate in 2010 in the vicinity of 17-18 per cent of baseline emissions.

Figure VI.2A illustrates the importance of different abatement costs in determining the efficient inter-regional allocation of abatement effort. The figure shows the CO_2 tax rate that would be required to achieve a given percentage emissions reduction, region-by-region. The East-Northeast (ENE) shows the lowest marginal abatement costs for any given rate of abatement, followed by North (N). West (W) and South (S) are the two highest cost regions. Thus, on economic efficiency grounds, one would expect ENE and N to undertake greater abatement than W and S for a given nation-wide carbon tax. That is indeed the case, as illustrated by Figure VI.2B.

Figure VI.1. **Optimal and No Regrets CO2 Abatement, India**



Note: EV stands for Equivalent Variation, and NetB for Net Benefits

F igure VI.2A. **CO2 Tax per Tonne of CO2, Region-Specific Targets**

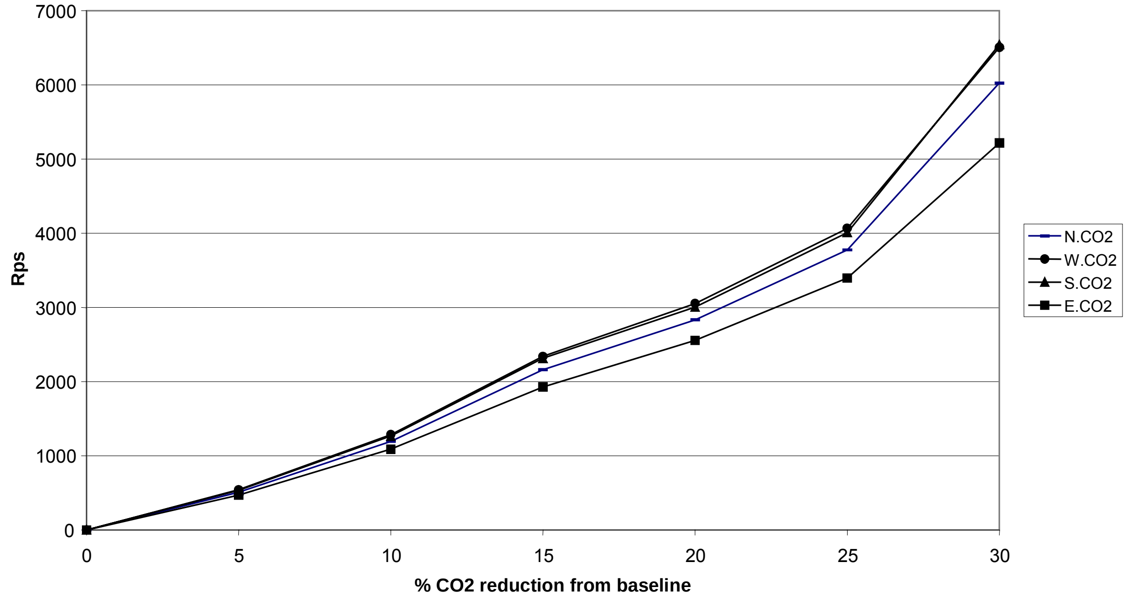
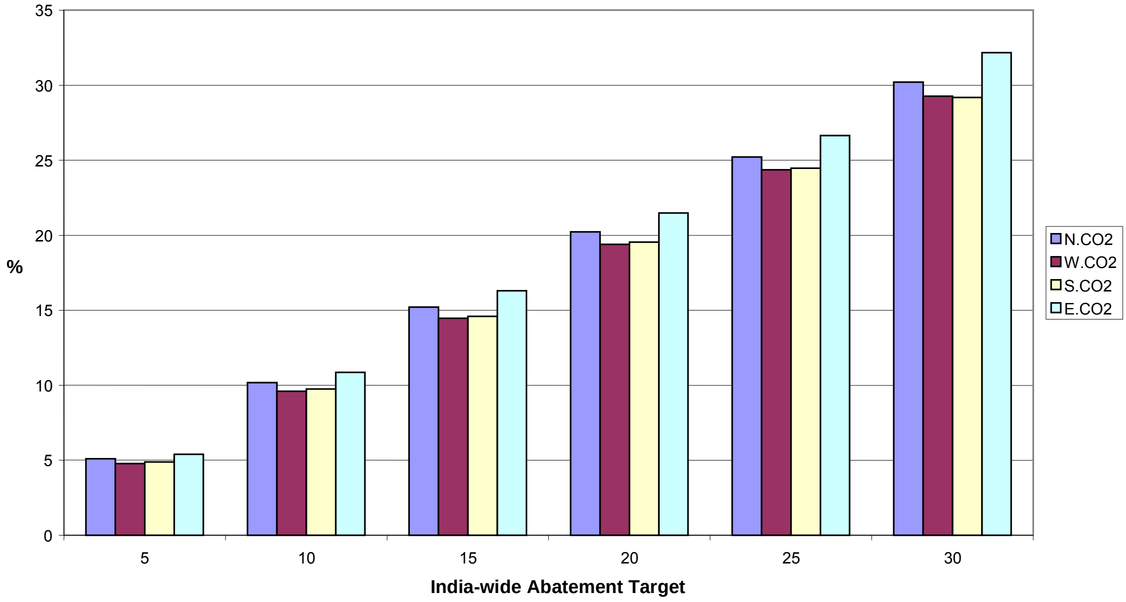


Figure VI.2B. **Percentage CO2 Reduction, by Region**



What explains the inter-regional variation in CO_2 abatement costs? While technologies within industries are assumed to be the same (i.e. identical substitution elasticities across regions), the initial proportions in which different inputs are used in a given industry can vary substantially. Thus, within the electricity sector, some regions are more dependent on carbon-intensive fossil fuels than others. Insofar as almost all electricity used in a given region is regionally generated (i.e. there is very little inter-regional electricity trade), then a given India-wide carbon tax would translate into higher electricity costs to users in the region with greater carbon-based-electricity dependence. It so happens that ENE shows a relatively low fossil-fuel input share within its electricity sector, so that the coal price induced by a carbon tax has less impact on the electricity price (Figure VI.3A), hence on downstream industries. [Since, however, ENE's baseline electricity price is higher than the other regions', the rising prices in the latter lead to upward price convergence (Figure VI.3B).] It so happens that ENE shows a relatively low fossil-fuel input share within its electricity sector, so that the coal price induced by a carbon tax has less impact on the electricity price (Figure VI.3A), hence on downstream industries. [Since, however, ENE's baseline electricity price is higher than the other regions', the rising prices in the latter lead to upward price convergence (Figure VI.3B).]

Figure VI.3A. **Evolution of Regional Electricity Prices**

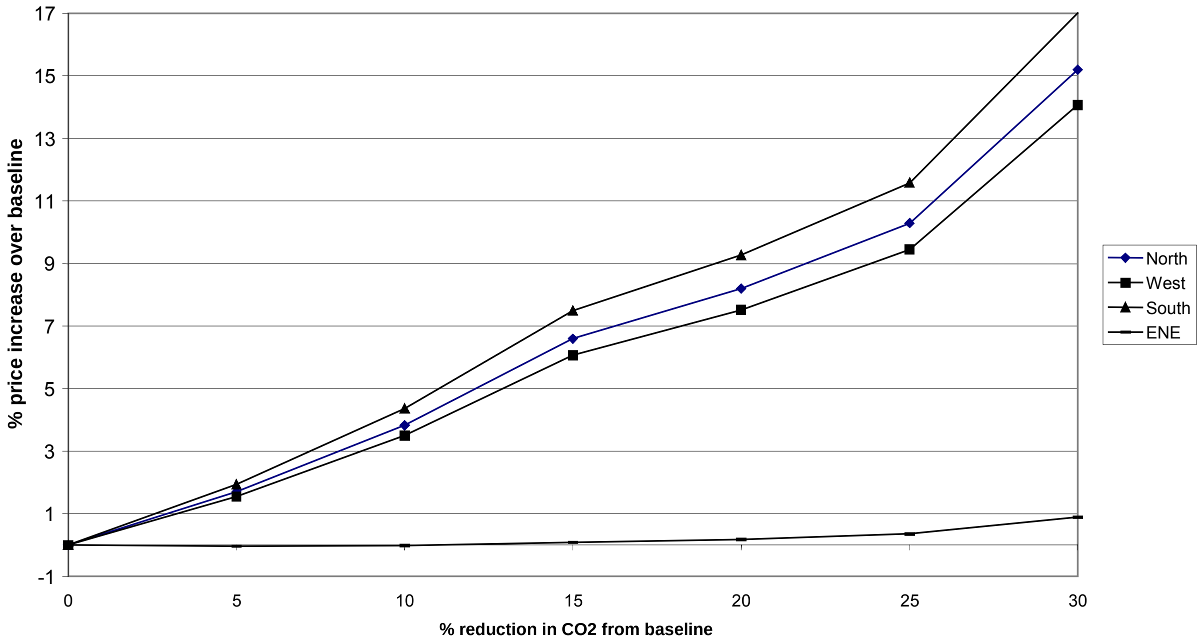
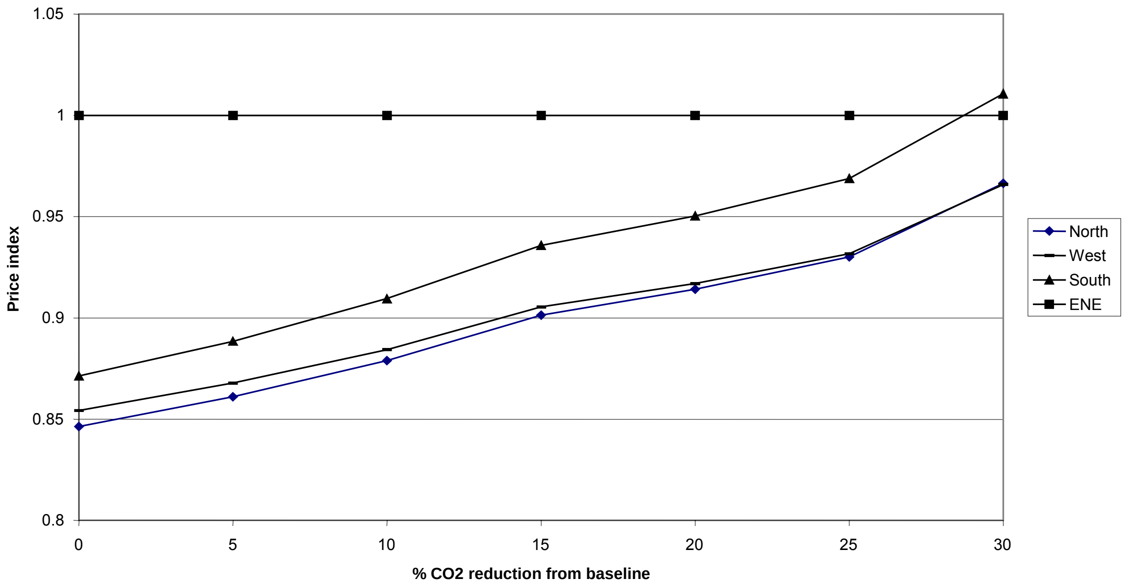


Figure VI.3B. **Normalised Electricity Prices, 2010 (ENE = 1)**



Effects of the tax on electricity prices are only a part of the adjustment story, however, as electricity represents a relatively small share of input costs in most sectors of the economy. Fossil fuels also enter as direct inputs into a number of sectors, notably metallurgy (especially coking coal for iron and steel production) and transport (mostly oil products. Since virtually all sectors depend on transport services, higher fuel costs get passed throughout the economy.

Another distinctive feature of ENE's industrial structure is the high coal-intensity of its metal products sector, reflecting the relatively high concentration of iron and steel making facilities there, with their large demand for coking coal. As a result, this sector accounts for a far higher share of CO_2 emissions than in other regions of India (i.e. almost 40 per cent *versus* 15-20 per cent elsewhere). In consequence, a larger share of emission reductions also originates from this sector (45 per cent *versus* 20-25 per cent elsewhere). Since metal products normally represent a smaller share of the input costs of other sectors than does electricity, reductions in the former's output are likely to have smaller knock-on effects than are increased electricity prices.

Table VI.1 decomposes the major factors that contribute to the reduction in CO_2 emissions by region, including changes in: *i)* the sectoral composition of output; *ii)* the carbon-intensity of energy; *iii)* the energy intensity of the economy, and *iv)* the scale of production. Consider the following identity, which simply states that total emission (for each type of pollutant) is equal to the sum of sectoral emissions:

$$E = \sum_i \left(\frac{X_i^{Output}}{X_{tot}^{Output}} \frac{E_i}{Ene_i} \frac{Ene_i}{X_i^{Output}} X_{tot}^{Output} \right)$$

The total variation in emission levels can then be measured as the sum of the mentioned four components by differentiating the shown identity:

$$\partial E = \sum_i \left[\partial\left(\frac{X_i^{Output}}{X_{tot}^{Output}}\right)\frac{E_i}{X_i^{Output}} + \partial\left(\frac{E_i}{Ene_i}\right)Ene_i + \partial\left(\frac{Ene_i}{X_i^{Output}}\right)\frac{E_i}{Ene_i}X_i^{Output} + \partial\left(X_{tot}^{Output}\right)\frac{E_i}{X_i^{Output}} \right]$$

where ∂ is the differential operator, E total emission volume, X_{tot}^{Output} total output (in real terms), E_i the sectoral emission volumes, Ene_i the sectoral fuel (energy) use, and X_i^{Output} the sectoral outputs.

By far the largest source of emission reductions is *ii)*, with substitution in energy use from high-carbon fuels to low-carbon ones (mostly a shift out of coal to less polluting fossil fuels, but also a shift towards non-fossil-fuel energy sources, notably in electricity generation). Interestingly, energy efficiency improvements *iii)* are also important sources of emissions reductions, accounting for roughly the same share as sectoral composition shifts (except in ENE where the latter are far more significant).

Table VI.1. **Decomposition of Emissions Changes**

	Abatement rate (%)			
	5			
Share of total CO2 reduction attributable to change in:	Nor	Wes	Sou	Eno
Sectoral composition	10.2	6.3	7.0	21.6
Carbon-intensity of energy	65.9	71.2	68.5	55.7
Energy-intensity of output	17.4	16.2	18.7	16.2
Scale of production	6.4	6.3	5.9	6.5
	10			
	Nor	Wes	Sou	Eno
Sectoral composition	11.3	7.1	7.7	23.2
Carbon-intensity of energy	65.2	70.2	68.2	54.7
Energy-intensity of output	16.7	15.9	17.7	15.2
Scale of production	6.8	6.8	6.3	6.9
	15			
	Nor	Wes	Sou	Eno
Sectoral composition	11.6	7.4	7.9	23.5
Carbon-intensity of energy	65.1	69.6	68.2	54.9
Energy-intensity of output	16.1	15.6	17.1	14.4
Scale of production	7.3	7.4	6.8	7.2

To determine the net regional gainers and losers from climate policy, one needs to consider the benefit picture as well as the cost picture. Table VI.2 presents regional welfare losses and net benefits as a share of regional GDP for different abatement rates. It also shows the percentage changes in disposable income and real GDP by region as a result of the carbon tax. The ENE region suffers the most significant welfare reduction, but along with N the net benefits (after accounting for ancillary benefits of the policy) remain positive even at 20 per cent abatement. Indeed, the N enjoys positive net benefits even at higher abatement rates, because of its rather steeply sloped ancillary benefits curve (see Figure VI.4). (Ancillary benefits per tonne of carbon abated are more than three times higher in N than in S.) This is explained in large part by the high population exposure to air pollution in N. Also noteworthy is the absence of net benefits for S even at 5 per cent abatement, again reflecting in large part the region's relatively low population exposure to the relevant pollutants. Also, given the dispersion model described above, in which low-level stack source emissions contribute more to concentrations and exposure than high-level ones, a region's distribution of emission sources also matters. As Table VI.3 shows, S starts out with the cleanest air (in terms of particulate concentrations at least) and experiences the smallest reductions in those concentrations.

The possibility that one or more regions would derive little or no net benefit from climate policy raises the question of how to persuade those regions to support such a policy. Clearly, as long as some regions are net gainers, the possibility of compensation in some form exists, but whether it is feasible to arrange in practice is essentially a question of political economy.

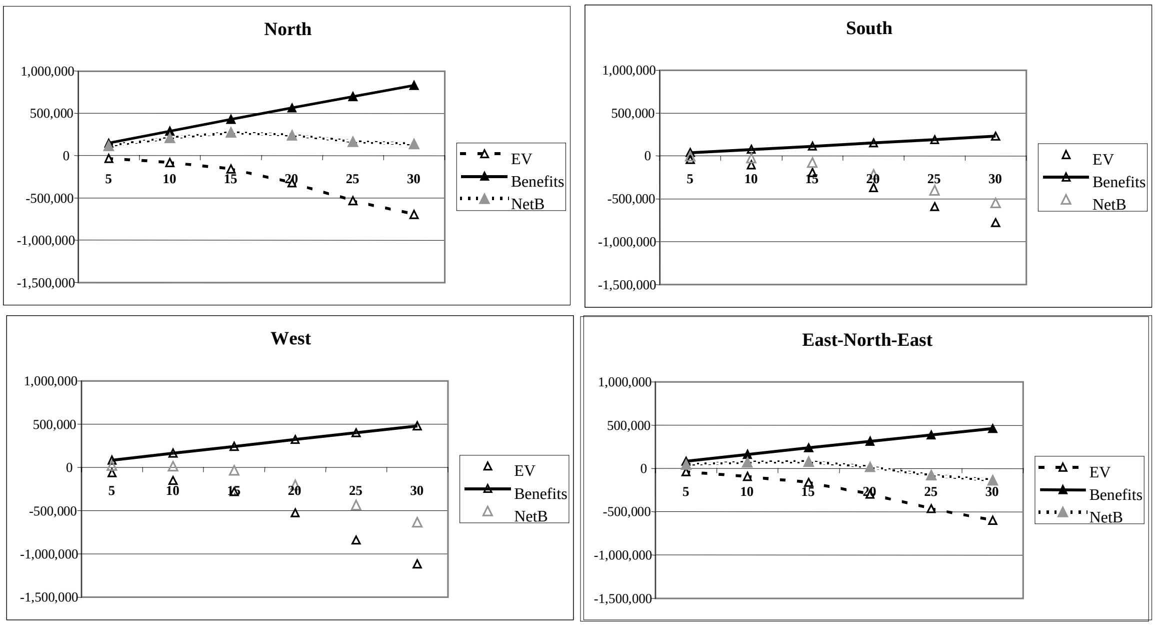
The optimal design of a carbon tax regime would take into account differences in both abatement costs and ancillary benefits across regions (assuming as we have that the longer-term primary benefits of climate policy do not influence near-term policy). In effect, the regional tax rate would be set at a level equating marginal costs and benefits. Since in S there is no positive tax rate at which they are equal, there would a zero (or even negative) tax in this region. Also, the regional tax rates would vary even more widely than in the case where regional taxes are set to achieve equiproportionate emission reductions. In short, a design rule based on cost-effectiveness of achieving a fixed target yields a very different set of tax rates (equal across regions) from an optimisation rule (wide variation across regions in the event that regions with low abatement costs also have high ancillary benefits).

Beyond the regional distribution of costs and benefits, there is also the matter of inter-household distribution. Our model, as presently constituted with a single household per region, is not well-suited to analysing the inter-household distributional impacts of climate policy. Nevertheless, one result is suggestive. Household income is derived largely from factor ownership, so a change in the rewards to capital and labour brought about by climate policy could be of some interest — this because we know that in practice household income distribution is strongly influenced by differences in factor ownership. The policy simulation shows that, while many sectors contract as a result of the carbon tax, a few expand, and these tend to be among the most labour-intensive ones (agriculture, food processing, textiles and clothing). *Prima facie*, this would suggest that the relative demand for labour is rising and, *ceteris paribus*, its relative return. This is indeed the case. *Relative* needs to be stressed, as incomes earned by both capital and labour decline with the carbon tax. Capital income, however, declines at a slightly faster rate than labour income, with the result that the wage/rental ratio rises by about 1.4 per cent for a 15 per cent CO_2 reduction. If it happens that the poorer end of the income distribution is dominated by those households relying primarily on labour income, then a carbon tax would be mildly progressive on the income side. A thorough distributional analysis would also require consideration of differential expenditure patterns across income groups. It may be, for instance, that poor households are disproportionately hurt by an increase in coal prices. There is also the question of the incidence of the ancillary benefits. Here, if — as seems plausible — the poor tend to be more heavily exposed to outdoor air pollution than those in the middle to upper income groups, then they should capture the bulk of the benefits from cleaner air. These casual observations based on stylised facts are clearly no substitute for a more detailed distributional analysis based on survey data disaggregating households into different expenditure classes.

Table VI.2. **Welfare Costs and Net Benefits, by Region -**

		Reduction in CO2 emissions % (Final year Simulation wrt Final year BAU)					
		5	*10*	*15*	*20*	*25*	*30*
As % of Real GDP							
Welfare Costs							
Nor.EV		-0.08	-0.19	-0.37	-0.76	-1.25	-1.64
Wes.EV		-0.11	-0.27	-0.50	-0.95	-1.53	-2.04
Sou.EV		-0.10	-0.25	-0.47	-0.89	-1.43	-1.89
Eno.EV		-0.13	-0.29	-0.52	-0.96	-1.51	-1.96
Total		**-0.10**	**-0.25**	**-0.46**	**-0.89**	**-1.43**	**-1.89**
Net Benefits							
Nor.NetBenefits		0.27	0.49	0.64	0.57	0.39	0.32
Wes.NetBenefits		0.04	0.03	-0.06	-0.37	-0.79	-1.16
Sou.NetBenefits		-0.01	-0.06	-0.19	-0.52	-0.97	-1.33
Eno.NetBenefits		0.14	0.23	0.25	0.06	-0.25	-0.44
Total		**0.11**	**0.16**	**0.14**	**-0.09**	**-0.44**	**-0.70**
% Change in:							
Disposable Income (After Taxes)							
Nor		-0.26	-0.61	-1.10	-1.58	-2.21	-3.10
Wes		-0.38	-0.88	-1.54	-2.17	-2.98	-4.23
Sou		-0.20	-0.49	-0.90	-1.36	-1.96	-2.75
Eno		-0.62	-1.36	-2.29	-3.13	-4.17	-5.67
Real GDP	**BAU Shares**						
Nor	**25**	-0.11	-0.26	-0.45	-0.75	-1.14	-1.50
Wes	**34**	-0.12	-0.28	-0.49	-0.81	-1.21	-1.61
Sou	**24**	-0.11	-0.26	-0.45	-0.76	-1.15	-1.52
Eno	**17**	-0.15	-0.34	-0.57	-0.91	-1.33	-1.71
India	**100**	-0.12	-0.28	-0.48	-0.80	-1.20	-1.58

Figure VI.4. **Regional Cost/Benefit Evolution (100,000 Rp)**



Note : EV stands for Equivalent Variation, and NetB for Net Benefits

Table VI.3. **Effects of Carbon Tax on Particulate Concentrations, by Region**

		Reduction in CO2 emissions % (Final year Simulation wrt Final year BAU)					
		5	*10*	*15*	*20*	*25*	*30*
	Initial Conc. Level *	Per cent variation in concentration of Pariculates					
N.Part	412.2	-4.00	-7.86	-11.61	-15.23	-18.82	-22.39
W.Part	214.2	-3.40	-6.70	-9.93	-13.14	-16.37	-19.55
S.Part	155.1	-2.94	-5.80	-8.64	-11.42	-14.24	-17.16
E.Part	347.3	-4.14	-8.10	-11.91	-15.54	-19.13	-22.87

*micrograms per cubic metre

VII. SENSITIVITY ANALYSIS

While the basic policy scenario incorporates the most plausible estimates of key parameters, these are subject to a fairly wide margin of uncertainty. Given the fundamental role that substitution elasticities play in determining the costs of economic adjustment to a carbon tax, it is important to test the sensitivity of the results to choice of elasticity values. Likewise, in estimating ancillary benefits, the assumed value of a statistical life (*VSL*) is crucial to the results. As we have seen above, estimates of *VSL* can vary widely across studies for a single country. Again, sensitivity analysis is warranted.

Policy makers in most developing countries are apt to be reluctant to implement controls on greenhouse gases in any event, even moreso in the face of significant uncertainty about the magnitude of costs and benefits. One way of addressing their concerns is to ask what level of CO_2 abatement would still be justified (on the “no regrets” criterion) under the most conservative assumptions about key parameters — i.e. the lowest plausible substitution elasticities (hence highest abatement costs) and the lowest plausible willingness to pay for improved air quality (as reflected in the *VSL*). If that abatement rate is still positive, then the policy maker could be reasonably confident that at least a modest level of abatement effort would yield positive welfare gains (ancillary benefits net of costs). Thus, we conduct a Low/Low policy simulation as well and report on the results below.

Figure VII.1 shows the results of sensitivity analysis on substitution elasticities. The high values are 1.5 times and the low values 0.5 times those used in the basic policy scenario. High (low) elasticities lower (raise) adjustment costs to any carbon tax, reflected in a less (more) steeply sloping cost curve (below the axis) than in Figure VI.1. The range of “no regrets” abatement, holding *VSL* constant and varying these elasticities, is from around 15 to 20 per cent of baseline 2010 emissions.

A similar exercise performed for the *VSL*, varying it from 0.75 times to 1.25 times the central value used in the basic policy scenario (while fixing substitution elasticities at their central value), yields the results shown in Figure VII.2. The range of “no regrets” abatement is virtually identical — i.e. 15-20 per cent of baseline emissions.

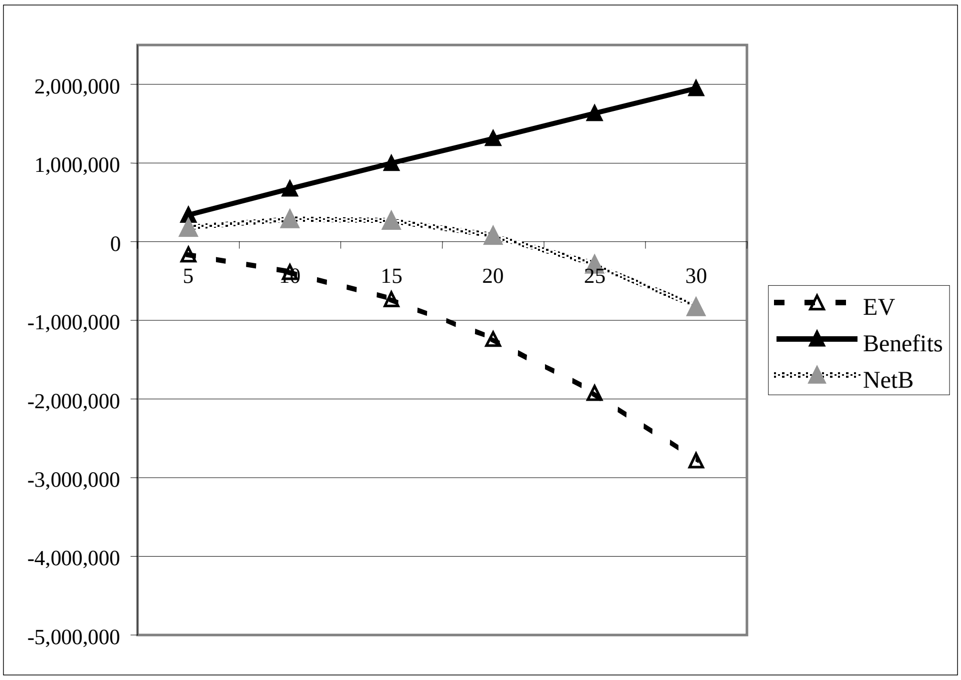
When we combine the two sorts of sensitivity analysis, we get the results shown in Figure VII.3, where the range of “no regrets” abatement is 10 percentage points, from roughly 13-23 per cent of baseline emissions. The low/low combination (low elasticities/low *VSL*) yields a scenario with the most conservative of assumptions about the scope for “no regrets” abatement, in the sense that abatement costs are at the high end of the range and valuation of health benefits at the low end. Conversely, the high/high combination yields a scenario with the most generous assumptions about “no regrets” opportunities.

As the upper and lower bounds on the substitution elasticities and *VSL* were not generated from a known sampling distribution, there is no way of assigning a probability that the actual values of these parameters and variables fall within the specified ranges. Given sufficient information, it would be desirable to try to assign such probabilities, e.g. through Monte Carlo simulations, to provide an additional piece of value information to the risk-averse policy maker.

Even without this information, it seems reasonable to assume that a substitution elasticity only half as large as the central value represents an extreme lower bound. With respect to the *VSL*, the lower and upper bounds were identified from existing studies and the central value simply taken as the midpoint between them. In the case of the lower bound, it was adjusted (by substituting a PPP exchange rate for a nominal dollar exchange rate) from one of the more conservative estimates in the literature, so it too can be safely taken as a limit (again without being able to assign a zero probability to observing a lower value). Thus, bearing in mind these *caveats*, a 12-13 per cent abatement rate in 2010 would seem to be a safe target for a risk-averse Indian climate policy maker — safe in the sense that, up to that rate, ancillary benefits would most probably exceed economic costs.

Figure VII.1. **Sensitivity Analysis Varying Substitution Elasticities**

High elasticities



Low elasticities

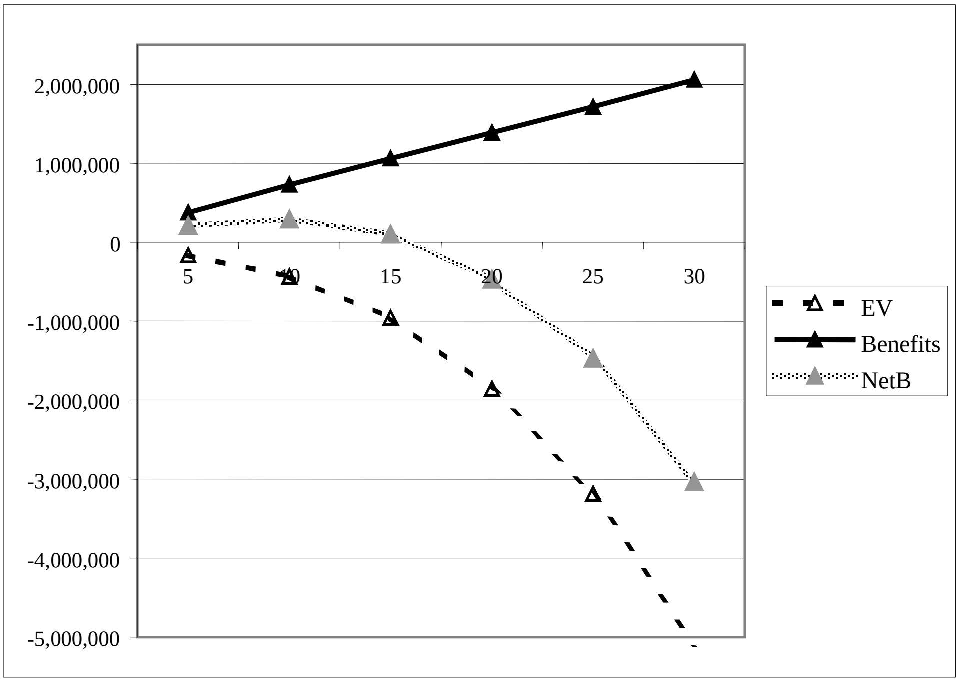
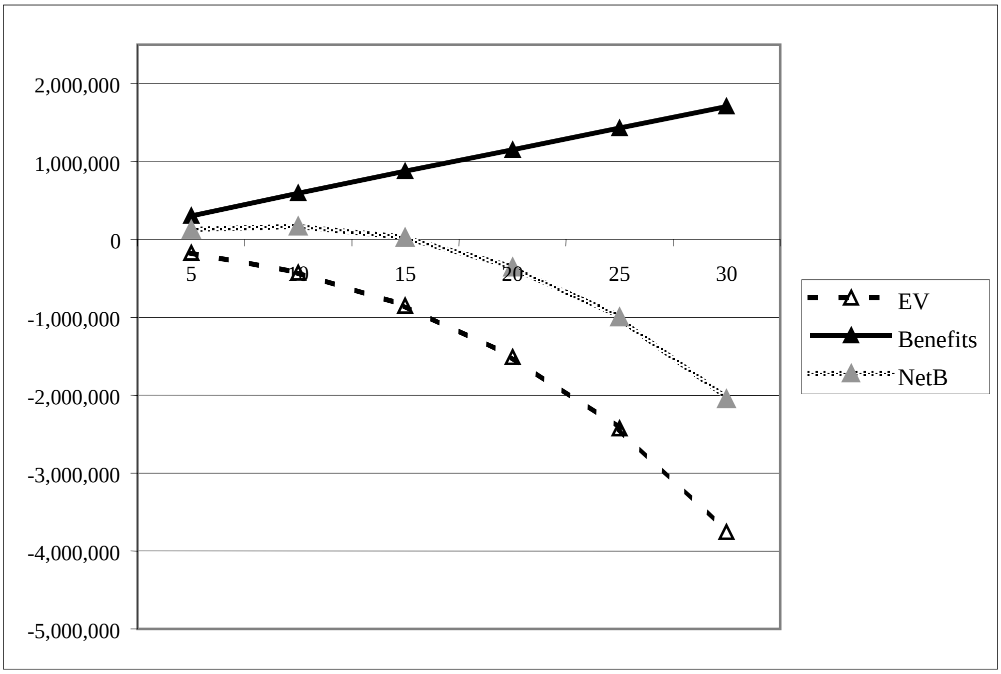


Figure VII.2. **Sensitivity Analysis varying VSL**

Low VSL



High VSL

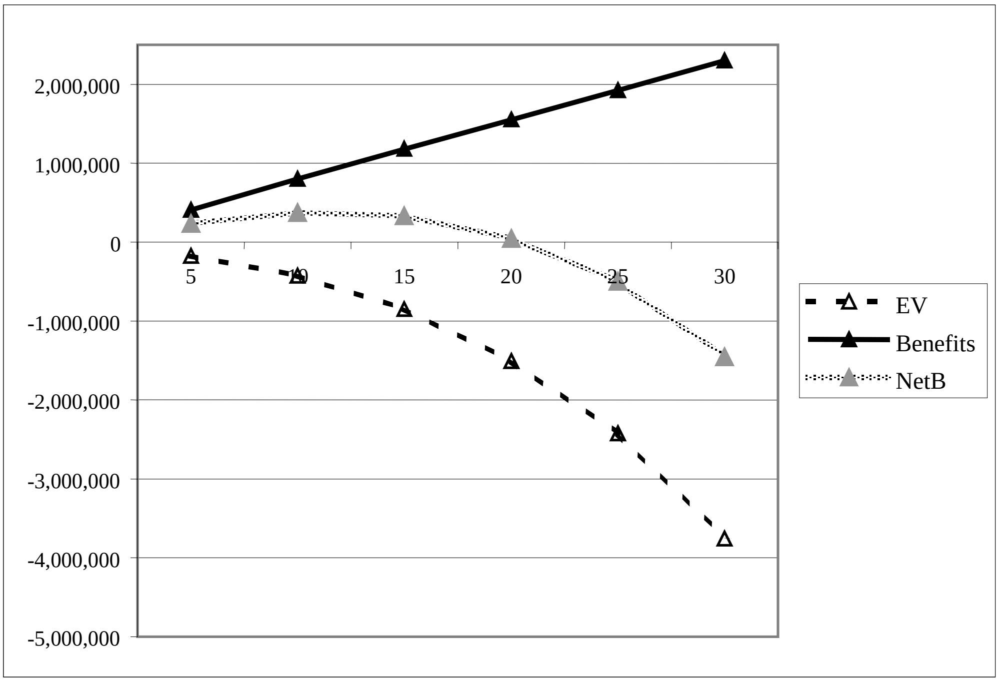
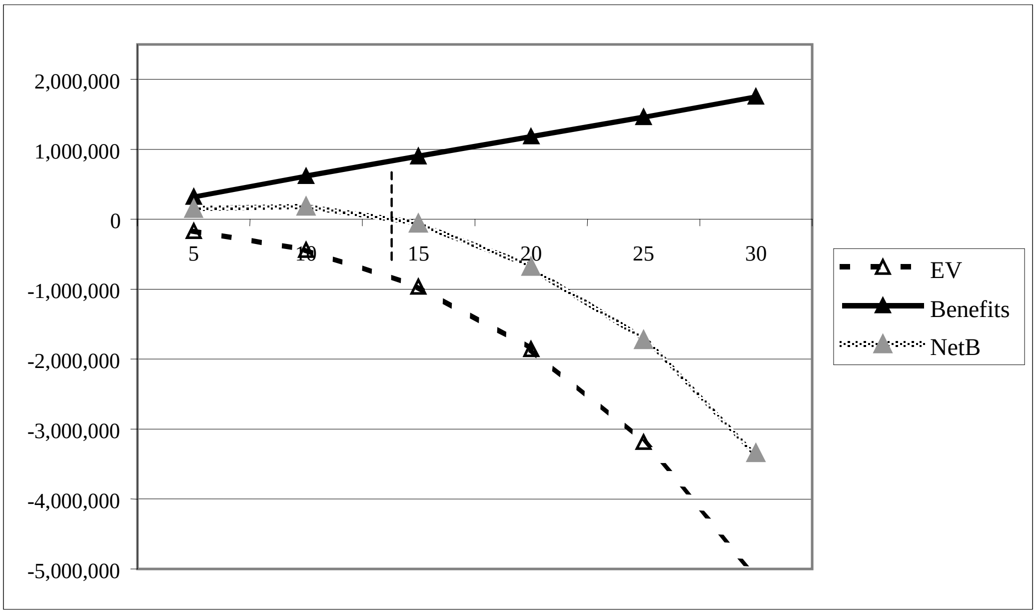
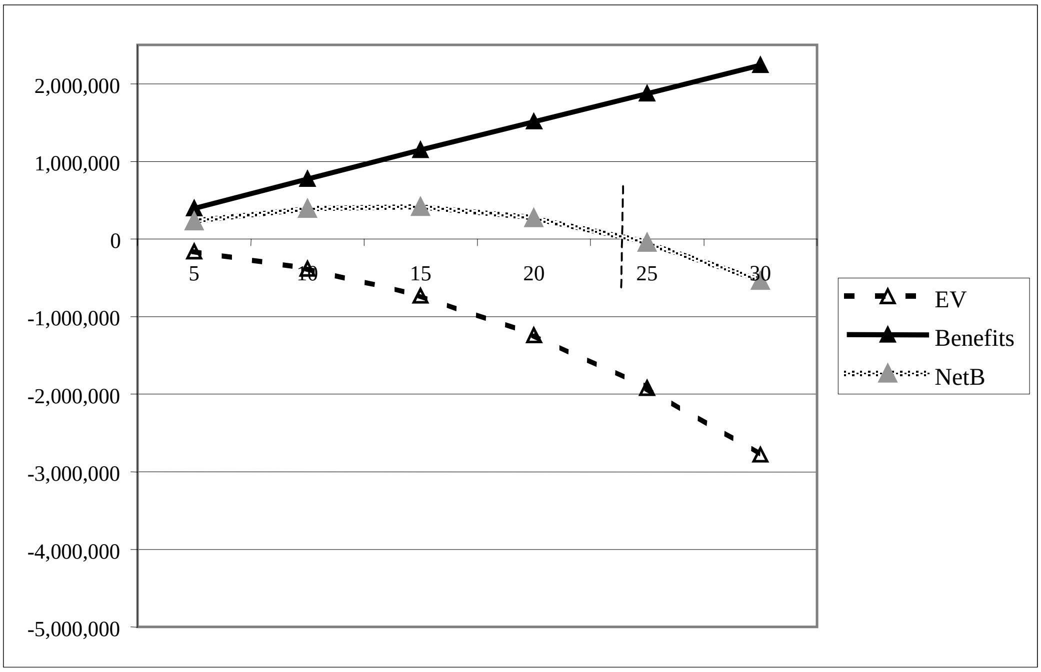


Figure VII.3. **Outer Bounds on "No Regrets"**

Low Elasticities, Low VSL



High Elasticities, High VSL



VIII. COMPARATIVE ASSESSMENT

How do these results compare to others in the literature? First we compare the costs generated by our model — as reflected in tax rates per tonne carbon (tC) to those in other studies of climate policy in India. Then we compare the ancillary benefits generated by our simulations to those of other studies, though not for India *per se.* The comparison is made both in value terms — ancillary benefits per tC abated — and in physical terms — premature deaths avoided per tC abated.

VIII.1. Abatement Cost Comparisons

First on the abatement cost side, Table VIII.1 contains the implied India-wide carbon tax rates for different levels of CO_2 abatement, at 1995 prices and exchange rate. Table VIII.2 contains a summary of the estimates contained in the main previous studies, indicating whether they are based on bottom-up energy/engineering models, top-down CGE or macro models, or a combination of the two. Comparison of results across studies and models is rendered difficult by the variety of assumptions incorporated into their baselines and policy scenarios. It is also not always evident from the studies whether the abatement cost figures cited are average or marginal ones.

Table VIII.1. **Model-Generated Carbon Tax Rates and Abatement Cost for India**

Percentage CO_2 reduction	*5*	*10*	*15*	*20*	*25*
Carbon tax (Rps/tC)	1 897	4 474	8 103	10 599	14 130
Carbon tax (US$ equiv, 1995 exchange rate)	61	144	261	342	456
Average Cost per tC reduction (US$ equiv)	30	37	46	65	84

One fairly consistent result is that, for CO_2 abatement up to around 10-15 per cent from baseline levels, abatement costs vary in the $5-150 range per tC. Our figures fall within this range up to 10 per cent abatement, but thereafter they become significantly higher.

A few of the main studies, their assumptions, methods and results are summarised here.

Mongia *et al.* (1991) consider one scenario involving energy efficiency improvements but with no explicit carbon constraint and two variants of a carbon-constraint scenario. In the first scenario, CO_2 emissions are reduced by 27 per cent in 2025 relative to the BAU baseline, with net savings of $111/tC reduction (at 1995 exchange rate). For the carbon-constraint scenario, an emission reduction of a further 22 per cent (over the energy efficiency scenario) is achieved at a marginal abatement cost of $54/tC.

Shukla (1996) estimates the marginal cost of reducing CO_2 emissions by one-third from their baseline level at close to $150 per tonne carbon by 2030 (assuming no global permit trading).

Fisher-Vanden *et al.* (1997) make use of an economy-wide model (the Second-Generation Model, or SGM) to estimate the welfare costs of various CO_2 abatement scenarios for India. In the case where India takes unilateral action to freeze its emissions at their 1990 level, the marginal abatement cost (as given by the corresponding carbon tax) reaches \$948/tC by 2030 (at 1995 prices and exchange rate). If, instead, India were to limit emissions in each period to two times the 1990 level, the marginal abatement cost would fall dramatically, to \$138/tC in 2030; in 2010 that cost would be \$17/tC, rising in 2020 to \$56/tC.

In a comparative static exercise for 1989-90, Chattopadhyay and Parikh (1993) estimate the marginal costs of carbon emission reductions from the power sector through sectoral reform to integrate the regional power grids. This is then followed by imposition of a carbon constraint. The integration of regional grids alone could save some 2.2 MtC emissions (a 5 per cent reduction from the base year level) while reducing power costs by some Rps. 12.5 billion, suggesting an average carbon reduction cost of -\$190/tC. This is clearly a win-win opportunity. Once optimal integration has occurred, further carbon reductions involve positive costs; the authors estimate that a further 5 per cent reduction would involve a marginal cost of \$65/tC, rising to \$76/tC for a 10 per cent carbon reduction. The reductions would have to occur largely through substitution of gas-fired for coal-fired electricity generation, involving sizeable reductions in SO_2, NOx, ash and fly ash as well.

One important difference in the assumptions underlying these results is the treatment in the baseline of extant energy system inefficiencies. In cases where those inefficiencies are incorporated in the baseline, the potential is much greater for low- or negative-cost emissions reductions. If, on the other hand, the baseline is already an “efficient” one, then even minimal abatement measures are likely to incur positive costs (Halsnaes, 1996). Our own approach is to incorporate efficiency assumptions in the baseline, making our method comparable to those yielding abatement cost estimates toward the upper end of the range. In general, these high-end estimates tend, like ours, to derive from computable general equilibrium models.

VIII.2. Ancillary Benefit Comparisons

On the benefit side, one can compare either physical impacts (health state improvements, for example) per tC abated or the monetary values of such improvements. Beginning with physical impacts, Table VIII.3 summarises the results of several studies that have looked at mortality benefits from climate policy. Our results show lives saved per million tonnes of carbon abated equal to 334, compared with 298 for China estimated by Garbaccio *et al.* The numbers for Chile and the United States are considerably lower. The relative magnitudes of the mortality reductions are consistent with the hypothesis advanced in O’Connor (2000) that developing countries with few initial local pollution controls (hence, little delinking of CO_2 emissions from other pollutants) are likely to benefit more in lives saved from climate policy than developed countries where such delinking is far more advanced. Another factor in the cases of China and India is the high urban population densities, hence, large exposed populations relative to Chile and the USA.

Table VIII.2. **Carbon Abatement Cost Estimates for India**

Study	Modeling approach	Scenario period	Assumptions: Carbon tax rate, % emission reduction	Quantity of carbon reduction (million tonnes)	Abatement cost (US$1995/tC)	Income (or welfare) change (%)
Shukla (1996)	Top-down: SGM CGE model	1995-2030	Stabilisation at 1X 1990 emissions level;	580	412	6 (2030) (GNP)
			Stablisation at 2X 1990 level (@20% reduction from baseline)	380	64	3 (2030) (GNP)
Shukla (1999)	Bottom-up: MARKAL	2005-2035	20% reduction of cumulative emissions;		10 (PV)	
			30% cumulative reduction		45 (PV)	
Shukla *et al.* (1999)	Bottom-up: MARKAL	2015	6.5% reduction from 2015 baseline		112 (PV)	
Gupta and Hall (1997)	Bottom-up: various engineering studies;	1990-2020	4.5-4.7% emissions reduction in 2020 (Case A);		6.1	2.3 (2020)
	Top-down: *sui generis* Keynesian macro model (Gupta 1995)		24% avg. emissions reduction, 2007-2020		108	8.0 (avg. loss)
Fisher-Vanden *et al.* (1997)	Top-down: SGM	1990-2030	2030 emissions:			2030 GDP loss:
			1X 1990 level	580	412	6.3
			2X 1990 level	380	61	2.9
			3X 1990 level	180	9.4	0.1
Mongia *et al.* (1991)	Multi-sector LP model	2005	17.6% reduction	60	10.4	
		2025	22.4% reduction	150	54	
ALGAS (1998)	Bottom-up: MARKAL	2020	10% reduction		3.15*	
			20% reduction		11*	
Chattopadhyay and Parikh (1993)	Power sector alone; comparative static	1989-90	5% reduction		96 #	
			10% reduction		113 #	
			15% reduction		148 #	
Reddy and Parikh (1997)	Bottom-up: DSM in electricity sector only	1995-2010	280 mn. tonnes of cumulative emissions		49.5 *	
					160 #	
Khanna and Zilberman (1999)	Power sector alone; comparative static	1990-91	10%		14.5	Welfare gain: 8.4
Blitzer *et al.* (1992)	CGE model: incorporates CO_2 and CH_4	1990-2040	20% reduction in radiative forcing			6 (GDP loss in 2025)

Notes: * Average cost
\# Marginal cost

Table VIII.3. **Comparison of Mortality Benefits Estimates of CO_2 Reductions**

Study	*Lives saved per MtC reduction*	*Scenario Assumptions*
Our Results (2001)	334	India, 2010 15% CO_2 reduction
Garbaccio *et al*. (2000)	298	China, 2010: 10% CO_2 reduction
Dessus and O'Connor (1999)	100	Chile, 2010: 10% CO_2 reduction
Cifuentes *et al*. (1999)	89	Chile, 2020: 13% CO_2 reduction
Abt Associates (1997)	82	USA, 2010: 15% CO_2 reduction

Source: O'Connor (2000); our results.

These health benefits of climate policy can also be expressed in value terms. Even if in India the number of premature deaths averted per tC abated is quadruple that in the United States, in value terms the difference will be smaller, given India's much lower per capita income, hence willingness (capacity) to pay for cleaner air. The ancillary benefits per tC abated in India come to around $58 (at 1995 exchange rate). This compares with one early US estimate of around $26/tC from emission reductions in two sectors[25] — transport and electricity — which together account for about two-thirds of carbon emissions (Ayres and Walter, 1991). A more recent review for the USA. by Burtraw and Toman (1997) reports on the results of eight studies whose mean estimate of ancillary benefits is virtually identical to the Ayres and Walter figure, with a low estimate of around $3 and a high of $89. Observing that over some range the marginal costs of GHG reductions are likely to be close to zero, Burtraw and Toman conclude that the existence of ancillary benefits even as small as $3/tC could significantly increase the volume of emissions reduction that is considered "no regrets" in the sense of having negative or zero net cost.

IX. COST CONSISTENCY BETWEEN LOCAL AND GLOBAL POLLUTION CONTROL?

One issue not directly addressed in this paper but raised by a number of other studies is the degree of consistency between methods of reducing greenhouse gas emissions and those for reducing local air pollution. Put differently, the imposition of a carbon tax may not be the most efficient way to achieve improve local air quality. What, then, is the magnitude of any efficiency loss from using this indirect instrument *versus* a more direct instrument — say, a tax on particulate emissions if that is the targeted pollutant? It is possible, for example, that certain low-cost particulate control measures would have zero or even a positive effect on CO_2 emissions. End-of-pipe particulate capture technologies are one example: not only do they *not* reduce carbon emissions; the fuel used to run the equipment may actually raise those emissions somewhat. Clearly then, a carbon tax would not induce their adoption. The question of how important such options are likely to be is ultimately an empirical one. A few studies have sought to examine the degree of correlation between cost-effective local pollution control technologies and cost-effective carbon abatement ones. While none relates specifically to India, they are still suggestive.

Eskeland and Xie (1997) compare various abatement technologies for mobile source air pollution in Mexico City, in terms of cost effectiveness in reducing a weighted local toxicity index *versus* reducing GHG emissions. They find that, excluding shifts in transport mode and demand management measures (e.g. a pollution tax on motor fuels), the rank correlation between local cost-effectiveness and global cost-effectiveness is rather weak. Out of some 26 identified control measures, stricter motor vehicle emission standards are the ones exhibiting the highest correlation in the two sorts of cost-effectiveness, largely because these standards would improve the fuel efficiency of gasoline-powered vehicles. Whether imposition of an environmental fuel tax would have to be part of a cost-effective strategy for local pollution control depends critically on the own-price elasticity of demand for polluting fuels. In another study for Mexico, Eskeland and Feyzioğlu (1997) find that both in the short term and in the medium term demand for gasoline is fairly price-elastic, suggesting that a pollution-related gasoline tax would yield a rather strong behavioural response and would thus be a cost-effective policy instrument for realising local air quality improvements. A review of demand elasticity estimates for gasoline (Dahl, 1995) supports the result that a tax could be a potent environmental policy instrument.

Cifuentes *et al.* perform a similar exercise for Santiago, Chile, but show a much stronger association between cost-effectiveness in the two dimensions (reduction in local pollution, as measured by PM2.5, and reduction in carbon emissions) (see EPA, 2000). In a diagram showing rank order of cost-effectiveness of different technical options along the two axes, a large proportion of such options (which unlike in Eskeland and Xie are not limited to transport) cluster along the 45-degree line, suggesting that those ranking high in PM2.5 cost-effectiveness do likewise in carbon cost-effectiveness. Of particular interest is the price sensitivity of some technical options, with the conversion of buses to compressed natural gas (CNG) looking very promising in terms of both types of cost-effectiveness at 1999 prices, but far less attractive in terms of PM2.5 abatement cost-effectiveness at the higher 2000 gas prices.

Another issue is the effect that a carbon tax on commercial fossil fuels might have on demand for traditional biomass fuels that cause serious indoor pollution and health problems (IEA, 2000*b*).

X. POLICY CONCLUSIONS

The first policy conclusion from our analysis is that ancillary benefits in terms of health improvements from reduced air pollution in India's major cities could justify CO_2 abatement of anywhere from 13 per cent, on a conservative estimate, to 23 per cent of baseline 2010 emissions, depending on parameter assumptions. For a risk-averse policy maker, the former value would represent a safe lower limit on "no regrets" abatement effort.

It would be naïve to expect policy makers to be persuaded to action by this analysis alone, especially if their primary mandate is to ensure sustained growth in measured GDP. For, real GDP would be adversely affected by the carbon tax, with its 2010 level reduced by one-quarter to one-half of one per cent from the baseline. While this is not negligible, it should be recalled that in the baseline India's real GDP is projected to double by 2010. With a carbon tax designed to achieve 15 per cent reduction in CO_2 emissions, it would still increase 99.5 per cent by that date.

Our region-by-region analysis does suggest, however, considerable variation in both costs and benefits across regions, with N and ENE having both the lowest abatement costs and the largest expected health benefits from imposition of a national carbon tax. Garnering support for such a policy from regions (and states) that stand to gain little if anything may require some "horse trading"; one possibility would be the recycling of carbon tax revenue so as to ensure no region is made worse off. The problem with this approach, from a political economy perspective, is that the regions that realise the smallest net benefits (including ancillary benefits) are not necessarily the same as those that experience the largest percentage decline in household disposal income (recall Table VI.1). The latter may be more compelling politically, since deteriorating real income may be more apparent than any improvement in family health status — and almost certainly more readily identified with the policy in question, viz., a new tax.

If one were to compare the welfare effects of a single national carbon tax with those of separate regional taxes designed to achieve equiproportionate CO_2 reductions across regions (see Table X.1), the S and W regions are clearly better off with the national tax than with separate regional ones. In the latter case, they would face higher carbon taxes than N and ENE and would suffer slightly larger disposable income declines than in the uniform tax case.

There remains the question of priorities, and it is certainly the case that for the near term the Indian government's environmental priorities will be to address local air and water pollution rather than global pollutants like greenhouse gases. Even so, there can be value in the sort of analysis undertaken here, since in the case of air — as we have seen — the two sorts of pollutants are rather strongly correlated. One could equally start from a policy designed to limit emissions of, say, particulates and ask how large would be any associated benefits in terms of GHG reductions. There remains a need in the Indian case for the sort of analysis done for Chile and Mexico, to determine if a focus on local air pollution problems would lead to a significantly different choice of technologies and other control measures from a focus on greenhouse gases.

Table X.1. **Incidence of National vs. Regional Carbon Tax**

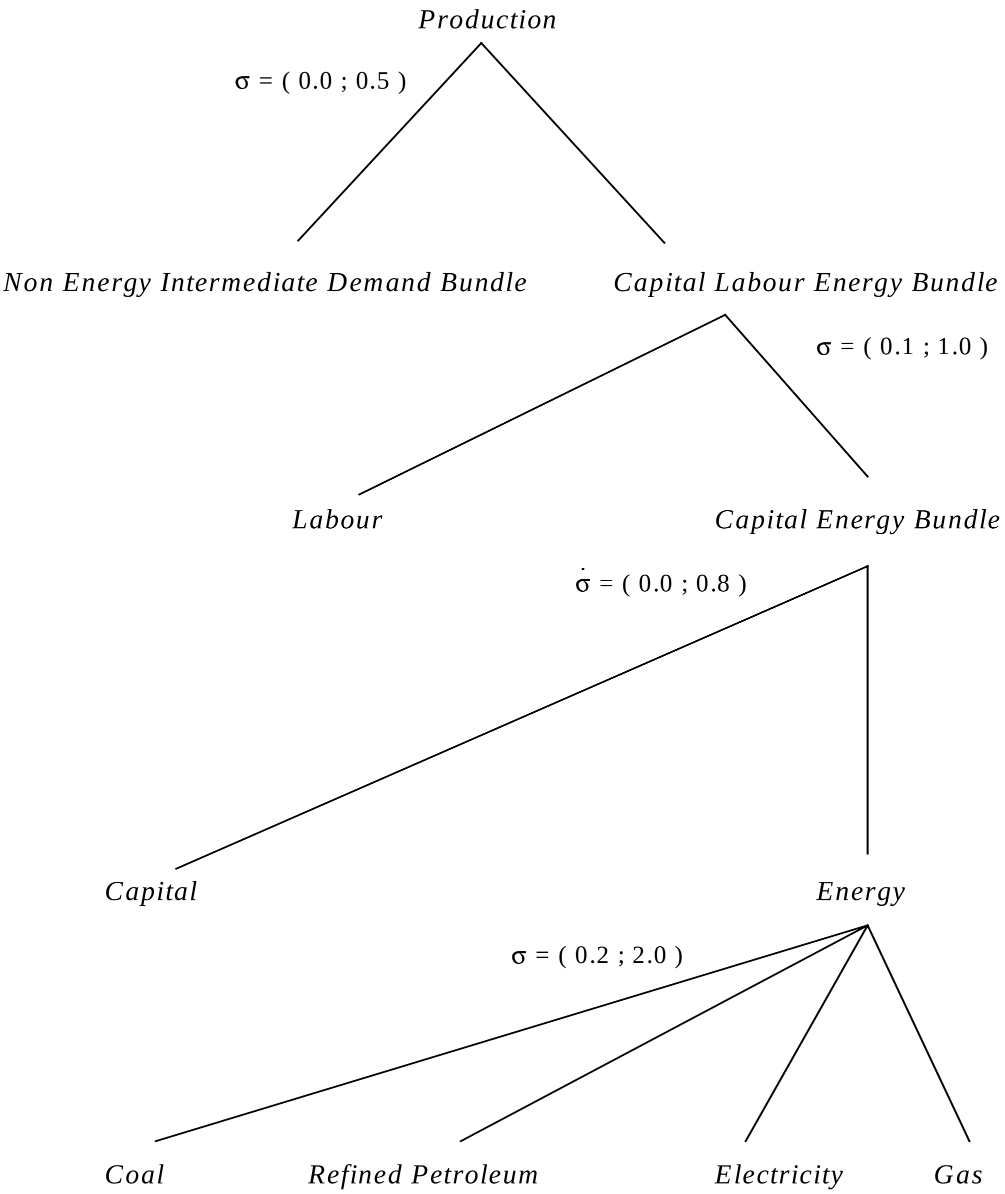
India-wide Carbon Tax

	Reduction in CO2 emission % (Final year Simulation wrt Final year BAU)					
	5	10	15	20	25	30
Tax Rate (Rps/tC)						
Nor	1,897	4,474	7,410	10,599	14,130	19,286
Wes	1,897	4,474	7,410	10,599	14,130	19,286
Sou	1,897	4,474	7,410	10,599	14,130	19,286
Eno	1,897	4,474	7,410	10,599	14,130	19,286
% Disposable Income Change						
Nor	-0.26	-0.61	-1.05	-1.58	-2.21	-3.12
Wes	-0.38	-0.88	-1.47	-2.17	-2.98	-4.14
Sou	-0.20	-0.49	-0.87	-1.36	-1.96	-2.84
Eno	-0.62	-1.36	-2.20	-3.13	-4.17	-5.58

Region-specific Carbon Tax

	Reduction in CO2 emission % (Final year Simulation wrt Final year BAU)					
	5	10	15	20	25	30
Tax Rate (Rps/tC)						
Nor	1,857	4,382	7,924	10,390	13,858	22,104
Wes	1,989	4,720	8,591	11,201	14,922	23,877
Sou	1,952	4,639	8,481	11,028	14,709	24,016
Eno	1,721	3,989	7,068	9,377	12,467	19,150
% Disposable Income Change						
Nor	-0.25	-0.58	-1.05	-1.52	-2.14	-2.99
Wes	-0.41	-0.94	-1.66	-2.30	-3.14	-4.48
Sou	-0.22	-0.53	-0.98	-1.43	-2.05	-2.98
Eno	-0.56	-1.22	-2.01	-2.85	-3.83	-5.01

Appendix Figure A.1. **Production Nesting**



Notes:

1. The elasticities are derived from the relevant literature (cf. Burniaux, Nicoletti and Oliveira-Martins, 1992).

2. Each nest represents a different CES bundle. Substitution elasticities separated by a semi-colon indicate, respectively, the central CES substitution elasticity for *old* capital and for *new* capital. The elasticity may take the value zero. Because of the putty/semi-putty specification, the nesting is replicated for each type of capital, i.e. *old* and *new*. The values of the substitution elasticity will generally differ depending on the capital vintage, with typically lower elasticities for *old* capital.
3. Intermediate demand, both energy and non-energy, is further decomposed by region of origin according to the Armington specification (Armington 1969). However, the Armington function is specified at the border and is not industry specific.

NOTES

1. India ratified the UNFCCC on 1 November 1993.
2. http://www.climatechangeindia.com.
3. Gas-fired electricity generation has been growing rapidly in recent years, from almost nothing in 1975 to around 8.5 per cent of total capacity in 1995 (Shukla *et al.* 1999*a*). The government continues to encourage further penetration of gas, among other things through construction of LNG terminals and gas pipelines.
4. UNDP/ESMAP (1998) assumes an Indian domestic coal ash content of 40 per cent and an imported coal ash content of 12.5 per cent (p. 37).
5. As open-cast mining is relatively low cost, this shift has also improved the financial health of the national coal company, CIL, and dampened upward price pressures.
6. The water pollution and waste disposal problems associated with washeries can be severe, and the net environmental cost/benefit of coal washing needs to weigh these against any benefits from lower ash emissions.
7. Agrawal and Varma (1998) calculate average transmission and distribution losses from 1985-94 of 22.2 per cent.
8. In 1998/99, only one SEB (Maharashtra) earned a positive rate of return on its net fixed assets (Planning Commission, cited in TERI, 1999).
9. The half-a-percentage-point differential in India and China's carbon emissions growth rates is much smaller than that in their GDP growth rates (4.7 per cent per annum *versus* 7.7 per cent per annum, 1965-96), reflecting the much faster decline in energy intensity of GDP in China than in India (3.8 per cent per annum *vs.* 1.1 per cent per annum, 1971-96, respectively) (based on *World Development Indicators*, 2000 CD-ROM, World Bank).
10. These ratios are calculated from data in IEA (1999*a*,*b*,*c*).
11. SPM is normally classified by particle size: TSP (total suspended particulates) includes particles of all sizes, PM10 only those < 10μ in diameter (often referred to as respirable particles), and PM2.5 only those < 2.5μ in diameter (also known as fine particles). Where data on the latter two are not available, the assumed proportions in ambient air are 1:0.55:0.30, respectively.
12. An Air Pollution Control Act was passed by the national government in 1991, followed by a series of air quality standards, extended in 1994 to include PM10, respirable particulates < 10 μ in diameter. The Central Pollution Control Board (CPCB) is responsible for monitoring ambient air quality nation-wide.
13. On the other hand, a World Bank study (Shah and Nagpal, 1997) on air quality in Mumbai uses a factor of 0.50 to convert from TSP to PM10, but this city is on the coast, so it is unlikely to have as high a background dust level as, say, Delhi.
14. Unleaded gasoline also emits almost twice as much PM2.5 as leaded gasoline per km travelled; Pechan & Associates, 1997.
15. The data, originally compiled by Garg (1999) can be viewed at http://www.climatechangeindia.com.
16. Sulphur content of coal in India ranges between 0.02 and 0.07 per cent.
17. IEA (1999*c*) data suggest some variation across industrial sectors, but for industry as a whole both China and India consume heavy fuel oil and diesel fuel in roughly the same proportion, i.e. 2 parts to 1.

18. Ideally, region- or city-specific information on atmospheric conditions can be found to determine these frequencies, but if not then certain "default" frequencies can be used as an approximation.

19. Another finding of the Cropper *et al.* study is that the mortality effects by age group are significantly different between Delhi and various US cities studied, with the elderly (65 and older) at greatest risk in the latter but the 15-44 age group at greatest risk in the former. The difference in age groups at risk implies, however, that the number of life-years saved from a given reduction in particulate concentration is almost identical in Delhi and Philadelphia (the site of the original Schwartz and Dockery 1992 study).

20. See David Gardner, "Indian PM seeks consensus for economic reform", *Financial Times*, 18 July 2000.

21. This has been the experience at least with electricity deregulation in some OECD countries — e.g. the UK and USA., where independent power producers have often adopted combined-cycle gas turbine technology.

22. These figures are broadly consistent with all-India estimates: Shukla *et al.* (1999) estimate 2000 capital cost per kW at $1 000 for subcritical pulverised coal combustion and $815 for combined-cycle gas turbine technology.

23. "India's Hearty Appetite", *Far Eastern Economic Review*, 14 September 2000.

24. Islam *et al.* (1999) decompose median particulate concentrations measured across several countries and locations into level, composition, and abatement effects, each of which yields a different functional relationship of concentrations to per capita income. The net result is a concentration curve that is downward-sloping from fairly low per capita income levels.

25. The benefits estimates are based on the assumption of a 20 per cent reduction in air pollution from 1978 levels.

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