

Analysis of Environmental Policies in India: Simulation Using Computable General Equilibrium Model

Poulomi Mukherjee

poulomikigan@gmail.com

+91 80171 58980

Department of Economics (3rd Year)

St. Xavier's College (Autonomous), Kolkata

Kaustav Sen

questionpaper072@gmail.com

+91 89020 09799

Department of Economics (3rd Year)

St. Xavier's College (Autonomous), Kolkata

Abstract

A comprehensive assessment on the effect of pollutants on economy has revealed that the market impact of air and water pollution leads to significant economic cost and hence annual global welfare cost.

We hence develop a General Equilibrium Model which shows socially optimum levels of production by different firms and their effects on the consumption under the environmental impacts. This provides the theoretical framework of our model. Now, the policies regarding environmental protection will lead to sustainability as pollution affects health which in turn affects productivity of the human agents of the economy. Thus, productivity of agents will remain intact or may increase in the model due to the application of those policies rather than having a decay due to bad air quality owing to pollution.

Besides air pollution this paper also highlights the status of sewage and wastewater treatment in a similar fashion.

Then we simulate the effects of such policies with data on Indian Economy in a Computable General Equilibrium (CGE) model by building Social Accounting Matrix (SAM) based on different microeconomic aspects according to our model. We extend the traditional SAM by incorporating the following environmental factors. Firstly, we include the emission of pollutants from different sectors. Secondly, we consider water treatment plants as a unique sector of the economy. Finally, with environmentally extended SAM in the CGE model we compare different policies which a government can take and also analyses and quantify the costs and benefits of the policies using GAMS software.

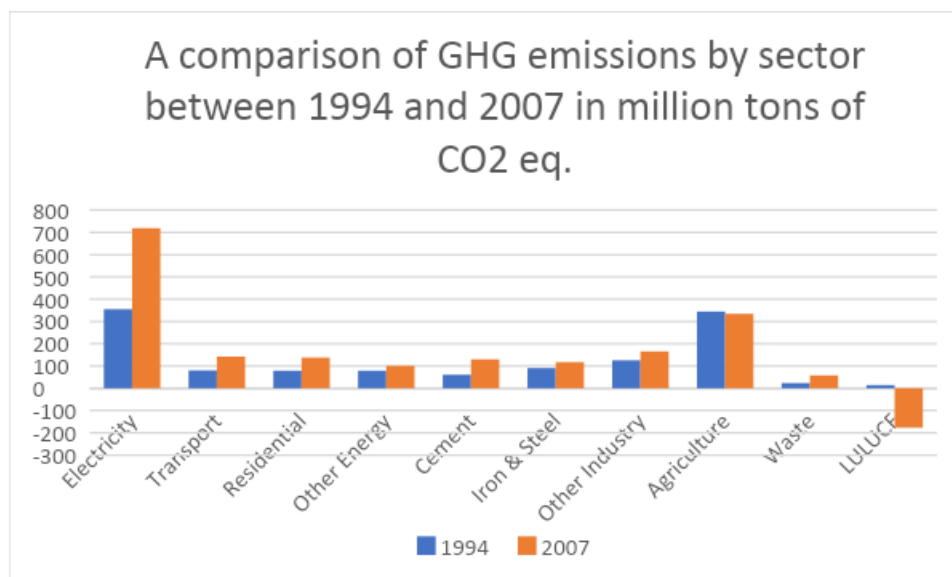
Keywords- CGE Models, General equilibrium, Pollution Control, Abatement Cost, Government Policy

JEL classification- C68,D58,Q52,Q58

Introduction

Often something which is invisible, causes harm at a greater extent. Air pollution is such a threat to mankind. The standard way of determining air pollution severity is to measure PM2.5 readings.

On the other hand, sewage disposal and wastewater treatment are serious issues in developing countries. Untreated sewage water not only contaminates the environment but also hampers the health of people.



Source: INCAA report

Thus, it becomes important to analyse how the economy will be affected when emissions are reduced. A reason for the sluggish behaviour of the economic agents to switch over from carbon fuel to more renewable and non-conventional energy sources is that such shocks can be detrimental to the health of the economy. Thus, we don't take initiative to develop such technology which can be used for better and greener environment.

The paper is structured in the following way: Section I presents a general equilibrium model which provides a theoretical background of effects of pollution. Section II provides the construction of the SAM, CGE modelling and extension to its environmental aspect. Section III shows the first simulation of a decrease in carbon emission. Section IV gives the extension of basic SAM to another ESAM by incorporating water pollution and abatement sector and provides a simulation of a decrease in COD emissions by different sector. Section V gives a policy review and conclusion.

Literature Review

There is a growing literature on compilation of social accounting matrices and computable general equilibrium models as we want to analyse policy options, though there has been less emphasis on environmentally extended SAMs literature in India.

Keuning (1993) in his paper 'National Accounts and The Environment: The Case for A System's Approach' proposed pollution effects should be incorporated and accounted for in the traditional SAM to extend into a national accounting matrix (NAMEA). Xie (1995) constructed an EESAM or environmentally extended SAM which includes pollution abatement sectors which have been included in our analysis on India. Xie extended the SAM in many ways which accounted for the pollution taxes, subsidies in separate accounts and gives a comprehensive outlook on Environmentally extended SAM. Horridge et al. (2005) developed the TERM CGE model to consider the economic impact of drought. Onil Bannerjee et al. also provide a nice framework of including natural resources in the analysis of SAM construction.

CGE modelling has been used in many policy simulations in India. A. Ganesh Kumar et al. showed dynamic recursive simulations for increase in government consumption expenditure

on various endogenous variables for the Indian economy which includes GDP growth, export import values, domestic demand etc.

Koushik Das et al. in their paper 'General Equilibrium Analysis of Strategic Trade: A Computable General Equilibrium Model for India' show several policy simulations on international trade. Import liberalization, increase in capital inflow and technological change and consumers preferences were simulated.

Section-I Theoretical Model

We first present a simple model which explains and describes the functioning of an economy taking into account emissions and pollution. The general idea is we can think emissions as an input of the firm which if it uses more leads to more output. Emission permits the firm to use of more energy and fuel (low cost) and thus leads to more output. Thus, we take emissions as an input which accounts for different production activities necessary. We suppose there are N number of firms and M number of agents in the economy and each firm produces only one good

The production function of j^{th} firm among N firms in the economy is given by

$$Q_j = AF_j(L_j, K_j, E_j, x_{1j}, \dots, x_{Nj}) \quad , \quad j = 1(1)N$$

This represents the total output produced by the j-th firm in the economy using three inputs labour (L) , capital(K) , emissions(E).

x_{ij} represents the intermediate inputs where input of i^{th} industry is used to produce the output of the j^{th} industry, where $i = 1(1)N$

A is the level of technology used by the firm.

The assumptions of the production functions are

$$Q_{jL_j} > 0, Q_{jK_j} > 0, Q_{jE_j} > 0, Q_{jx_j} > 0, \quad i = 1(1)N$$

$$\frac{\partial Q_{jL_j}}{\partial L_j} < 0, \frac{\partial Q_{jK_j}}{\partial K_j} < 0, \frac{\partial Q_{jE_j}}{\partial E_j} < 0, \frac{\partial Q_{jx_{ij}}}{\partial x_{ij}} < 0, \quad i = 1(1)N \quad \frac{\partial Q_{jL_j}}{\partial E_j} < 0, \frac{\partial Q_{jK_j}}{\partial E_j} > 0$$

We suppose the following pollution function which describes the amount of pollution occurring due to emission,

$$P = P(E), P > 0,$$

where E is that amount of total emissions chosen from all firms' the profit maximizing conditions.

$$E = \sum_j E_j$$

The profit maximising j^{th} firm maximises the following problem.

$$\Pi_j = p_j AF_j(L_j, K_j, E_j, x_{1j}, \dots, x_{Nj}) - (wL_j + rK_j + \sum_i p_i x_{ij})$$

p_j is the price of the j^{th} output, w is the wage level of labour and r is the rent of capital. The first order conditions are

$$\frac{d\Pi_j}{dL_j} = AF_{jL_j} - w = 0; \frac{d\Pi_j}{dK_j} = AF_{jK_j} - r = 0; \frac{d\Pi_j}{dE_j} = AF_{jE_j} = 0; \frac{d\Pi_j}{dL_j} = AF_{jL_j} - p_i = 0;$$

Solving these equations, we obtain the optimum level of inputs, L_0, K_0, E_0 .

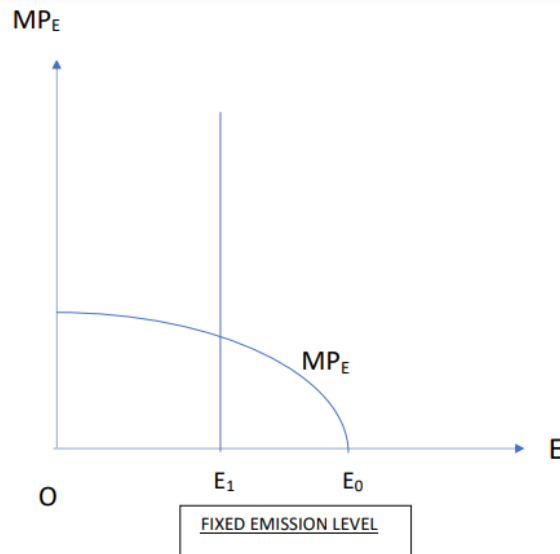
In the consumer side the utility function of the k th individual is given by $U(f_{1k}, f_{2k}, \dots, f_{Nk}, P)$ where f_{ik} is the final demand of the i^{th} good by households.

The assumptions are $U_{f_k} > 0, i = 1(1)N, U_p < 0$

The consumer wants to perform the following maximisation problem.

$\text{Max } U(f_{1k}, f_{2k}, \dots, f_{Nk}, P) \text{ s.to } M = \sum_{k=1}^N p_i f_{ik}$ Where M = money income of the consumer

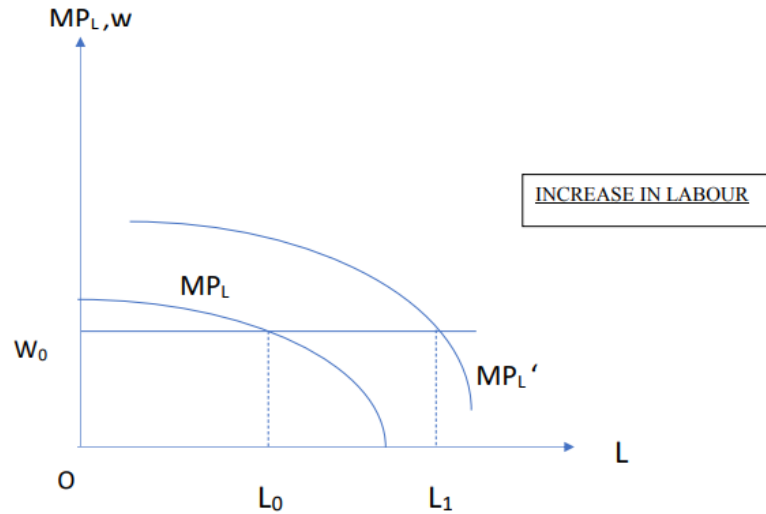
Suppose emission target are set for all the j firms at some specified level E_1 which is obviously binding condition. The changes in the optimum input level are shown graphically. The level of emission is fixed at E_1 from the initial value E_0 .



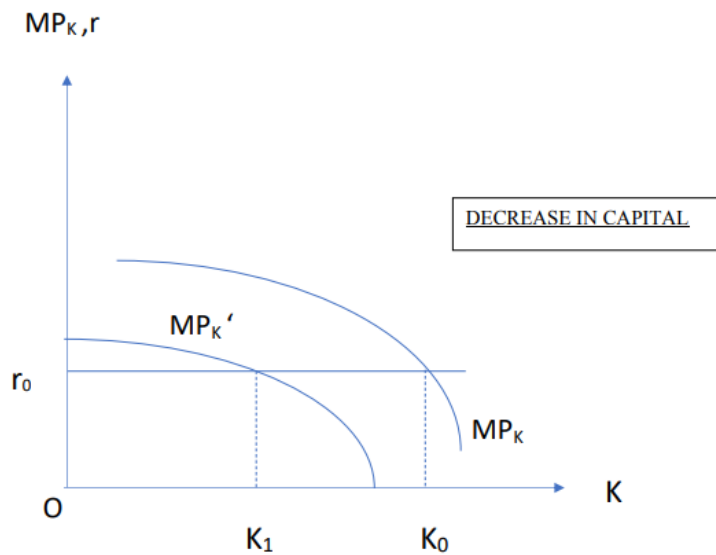
Decrease in emission leads to increase in labour productivity causing shift of MP_L curve to the right since

$$\frac{\partial Q_{jL_j}}{\partial E_j} < 0$$

So, the labour usage is increased from L_0 to L_1 thus leading to an increasing tendency to output. Though in reality such changes don't take place in the very short period of time. Moreover, with modern technologies and energy intensive industries the downward trend on output is more.



Decrease in emission leads to decrease in the level of capital from K_0 to K_1 since our assumption is $\frac{\partial Q_{jK_j}}{\partial E_j} < 0$



Since the labour is increasing and capital and emission level are decreasing, so in reality the change in output depends on the magnitude of the relative change.

Section-II

II.1 Construction of SAM

A social accounting matrix represents the transaction flows of an entire economy and its activities by different agents in a particular year, where the columns represent the outflows and the rows represent the inflows to the economy. It thus forms our base of the analysis presented over here.

First, we provide the basic structure of a SAM on the basis of description given in Pradhan et al., 2006.

	Production	factor	household	private	government	indirect	capital	rest of
production	input output table		private consumption		government consumption		investment	exports
Factor	value added							net factor income
household		value added income			government transfers, interest on debt			net current transfers
private		operating profits			interest on debt			
government		income from enterprises	income and wealth taxes	corporate taxes		total indirect taxes		net capital transfers
indirect taxes	taxes on intermediates		taxes on purchases		taxes on purchases		taxes on investment goods	taxes on exports
capital account		depreciation	household savings	corporate savings	government savings			foreign savings
rest of world	imports							

We have constructed the SAM of year 2007-08 to analyse the effect of different policies on the economy. The different components of the SAM and their sources can be mentioned as follows:

1. **Input Output Table** – Input output table establishes the sale-purchase relationship in an economy. We have obtained the input output table which is a commodity×commodity table from the MOSPI. The MOSPI provides the input output table for 130 sectors in a detailed manner. For our analysis, we have aggregated those 130 sectors into 5 broad sectors maintaining some similar characteristics among them. The aggregation scheme was made on the basis of data of emissions of CO₂ as given below.

SERIAL NO	SECTOR CODE	SECTORS FOR SAM	SECTORS OF IO TABLE
1	AGRI	AGRICULTURE, PISCICULTURE AND FORESTRY	1-26,67
2	FUEL	FUGITIVE, MINING AND MINERALS	27-37,63,64,74,76
3	CHEM	CHEMICALS, FOOD PROCESSING AND OTHER CHEMICAL MATERIALS	38-62,65,66,68-73,75,107
4	MET	METALS AND MACHINERY	77-105
5	OTH	TRANSPORT AND ALL OTHER SERVICES	106,108,109-130

We performed the aggregation procedure for the input output table by matrix multiplication method. The process is - $A^* = SAS'$ where A^* is the new aggregated input output table we formed. S is the aggregation matrix whose elements are s_{ij} where s_{ij} is 1 if the particular sector is included within the aggregated sector and 0 if not. S' is the transpose matrix of S . A is the initial matrix obtained from the MOSPI website. This aggregated input output table forms the backbone of SAM.

2. **Value Added Income Of Labour And Capital**– Gross value added of each sector is obtained from the input output table itself. The aggregation has followed the same method as mentioned above. Now to decompose in into labour and capital, first we estimated the net value added of each sector by subtracting the rate of depreciation from gross value added of that sector. Depreciation of each sector is estimated from the ratio of gross value added and depreciation of each sector. We obtain the wage and non-wage income from the National Account Statistics.
Then we add the non-wage income obtained along with the total depreciation to estimate the total value added of capital.
3. **Other Income Accounts**– Income from enterprises of Government sector which include the Government administration as well as public sector units and non-departmental firms, have been obtained from the National Accounts of Statistics, Government of India of 2007-08. Operating profits by different private firms are added as a balancing item of the SAM.
4. **Tax And Savings Account**– Data on personal taxes by households includes Income and Wealth tax obtained from households. Data is obtained from the NAS of India of 2007-08. Data on Corporate taxes by corporate private firms is retrieved in the same way. Input output table provides the Net Indirect Taxes sector wise. Thus, these indirect taxes are net of subsidies and cover all kinds of production taxes. Indirect tax like sales tax, VAT etc. on Consumption, Investment, Government final purchase and Exports are also provided by Input output table.

On the other hand, Household savings, Total Government savings and Corporate savings are obtained from NAS.
5. **Final Demand Account**– The final demand by two agents– households and government are obtained from input output table. Taxes on such purchases and total investment expenditure are also obtained from the same source while the Depreciation data is obtained from NAS.
6. **Foreign Account**– The column of ROW includes the exports and the row of ROW includes the imports of different sectors obtained from the input output table. Net factor income for both labour and capital, net current transfers to household and net capital transfer to government are obtained from the National Accounts Statistics. Foreign savings has been added as a balancing item.

Finally, we present the SAM computed for India for the year 2007-08.

	AGRI	FUEL	CHEM	MET	OTH	LAB	CAP	HOH	PVT	GOV	IDT	CAC	ROW	TOTAL
AGRI	2893 2784 .52	53033 0.0382	24366 562.59	16463 5.5118	105374 53.45			64648 867.09		10043 09.592		488714 .1261	281513 8.676	133488 795.6
FUEL	2349 710.9 73	34330 246.43	838841 6.572	10848 000.81	24983 418.22			10528 499.77		831389 .0431		375150 6.013	129081 14.62	108919 302.5
CHEM	4132 677.6 06	28324 35.463	477361 73.48	744813 5.91	250877 03.38			520221 78.33		35726 66.334		12089 383.35	176583 15.29	172579 669.1

MET	6022 81.96 1	132087 6.807	375812 4.46	64091 848.28	27336 470			104273 42.77		180615 1.531		69968 636.29	157647 70.12	195076 502.2
OTH	11793 709. 54	59530 67.069	34083 285.78	28476 946.3	83248 080.16			135557 505.4		42947 351.34		96544 840.72	46679 997.95	48528 4784.2
LAB	4140 0931 .87	513940 9.811	139287 56.37	116227 19.67	130558 424.3								- 22760 0	20242 2642
CAP	4395 5072 .22	165566 47.79	25453 835.93	177209 29.29	151805 508.5								- 18840 00	253607 993.7
HOH						2024 2264 2	159521 555			28249 456			101943 00.38	40038 7953.4
PVT							134799 38.73			48955 541				62435 479.73
GOV							311369 00	100762 53.05	19276 656		4050 0493		62222 495	163212 797.1
IDT	- 3505 806. 26	24937 84.358	23703 40.004	74064 20.27	108618 25.68			51052 07		114023 2		734972 7	727876 3	40500 493.05
CAC							49469 600	112022 100	43158 823.7	34705 700			- 49163 416.82	190192 806.9
ROW	3827 433.1 69	397625 04.23	124941 73.96	47296 866.26	20865 900.59									124246 878.2
TOTAL	1334 8879 5.6	108919 302	172579 669.1	195076 502.3	48528 4784.3	2024 2264 2	25360 7993.7	40038 7953.4	62435 479.7	163212 796.8	4050 0493	190192 807.5	12424 6878.2	

II.2 CGE Model

CGE or computable general equilibrium models are defined on the basis of certain equations describing the production frontier of factor usage in the production process. It can be used to simulate different policies showing how different sectors of the economy react. We have used GAMS win64 28.2.0 software for the calibration and simulation purpose in both the simulations performed.

Different modules of CGE model are

- 1. Production Module-** Production module consists of the 5 broad sectors. In the second simulation we have included an additional sector, Abatement sector which describes the cleaning activity of wastewater in the economy. The production process in the model is described by multistage nested production functions. As in the real-world economy in this model we specify production process takes place by transforming intermediate inputs by different factors used to desired output using a given level of technology. Final production function aggregates different inputs and factors. Other than that, we have specified the intermediate demand functions and factor demand functions separately. Carbon emissions are also added in the functions to note the fact of pollution permit a firm gets from authority (or Government). The intermediate demand functions are given by equation 3 according to the input output co-efficient and output produced from j^{th} sector. The input output coefficients are calibrated in the calibration section from the given ESAM.

Factor demands are described by three equations in each simulation which also include the emissions requirements or can be interpreted as pollution permits. Thus, the

production sector gets connected with environmental factors. We have neglected carbon tax here as studies have been made regarding them, also in 2007 there was no carbon tax in India.

Unit cost function has been described by the total cost of intermediate demand and total cost of factor demand.

2. **Government Module**– This module just describes the receipts and outlays of the government. Government receives taxes from different sources as total indirect tax, direct taxes from household and private enterprises which serve as income of the Government. Government final consumption are also described equation 9 in both the simulations.

Equation 6 represents the direct tax paid by household and equation 7 represents corporate tax paid by private enterprises. We have calibrated for the both the simulations the few required parameters from the constructed ESAM. In case of government the calibrated parameters are direct tax rates for household and private enterprises as these will be necessary for framing equations. Other parameters estimated from the demand side of government behaviour are government's share for total consumption and government's propensity to save.

3. **Household Module**– Here we explain two-stage consumption analysis. Sources of income for the household are factor endowments from labour and capital, transfer payments from government and net current transfer payments from the rest of the world. First, we specify a household demand function. Next, we use a utility function as shown in equation 27 which is a function of consumption levels for each sector. Income of household is given in the bracketed portion of the equations. For that purpose, we have calibrated the required share parameter of the utility function which measures the constant income or budget share for the household from the ESAM in both the cases. We assume a Cobb Douglas utility function with fixed share parameter.
4. **Savings-Investment Module**– This module has primarily three equations of total savings by the three agents of the model viz, Household, Government and Private enterprises. Savings propensity is calibrated in both the simulations. Equations 11,12,13 give the savings functions in both the simulations. Investment behaviour of the economy i.e., investment demand function is given by equation 10. Total investment is basically, the sum of the change in stocks and gross capital formation though the separate accounts are not shown in SAM and are accounted in the similar fashion. The Savings Investment identity holds in this case as well.
5. **International Trade Module** – This module characterizes the open economy nature of the Indian economy which is studied in this analysis. The Armington function combines the domestic demand function and the import demand function. Thus it combines both produced goods within and outside the economy. It also specifies that both the goods are not perfect substitutes, rather imperfect substitutes. The functional form is of CES type gives a constant elasticity of substitution. Thus, a CES aggregation function is used to aggregate the demand side. The parameters of the Armington function i.e., share parameters of domestic and import demand and shift parameters are estimated by calibration for the both the simulations.

The Import demand function is given by equation 19. This equation actually gives the ratio of import consumption obtained from the Armington composite demand function multiplied with the total Armington composite demand.

This is the demand side of the economy with foreign elements.

Coming to supply side, the transformation function combines the goods which are supplied to or for domestic consumption and goods exported for consumption to the rest of the world which is given in equation 21. Thus, it combines the domestic supply function and export supply function. The aggregation function used is a CET or constant elasticity of transformation function. The different shift and share parameters required for framing the equation are calibrated from data of the ESAM in both cases.

The Export supply function gives the ratio of the exports of the total supply from the transformation function multiplied by the total supply obtained from the transformation function. Thus, it gives the total supply of exports from the rest of the world.

The Balance of Payments is given by equation 17 which maintains the foreign exchange market. Here total foreign exchange receipts or supply is determined by net current transfer payments and net capital transfer, exports and net factor income from abroad. Total demand of foreign exchange receipts is given by imports. This determines equilibrium in international trade sector.

6. **Domestic Module**– Here we specify the domestic demand and supply equations. Domestic demand is given by equation 20 in the similar way as import demand by determining the ratio of it from the Armington function and then multiplying total demand (Q) to it.

Domestic supply is also determined in the similar way by determining the ratio from the transformation function and then multiplying it with total supply obtained from transformation function in equation 22.

7. **Macro Closure Module**– This module specifies the equilibrium of different markets of the model thus making the model a general equilibrium one. The foreign exchange or BOP equation is already described in the international trade module. The product market equilibrium is given in equation in 24. In this case we have total demand and supply of composite good taking both the domestic and foreign elements. Total demand (Q) is determined by total intermediate demand, consumption expenditure, investment expenditure and government final consumption expenditure.

Factor market equilibrium for both labour and capital are given by equation 25. Here total factor endowment of household, total factor endowment of government and private enterprises and net factor income from abroad determine the total supply of labour. Total labour demand is given by the earnings from all the sectors of the economy and both demand and supply equalize to maintain factor market equilibrium.

8. **Emission Module** – This is an extension of the traditional modules to incorporate environmental factors. We have already taken into account the pollution permit or emissions the firm in the production module. Here in equation 26 in Simulation I we have noted the change in carbon dioxide emissions. In Simulation II we have noted the change in COD emissions for the water pollution module in equation 26.

II.3 Environmentally Extended SAM

We provide the scheme of the environmentally extended SAM.

	production	factor	household	private	government	indirect taxes	capital account	rest of world	emission
production	input output table		private consumption		government consumption		investment	exports	production emission
factor	value added							net factor income	
household		value added income			government transfers, interest on debt			net current transfers	
private		operating profits			interest on debt				
government		income from enterprises	income and wealth taxes	corporate taxes		total indirect taxes		net capital transfers	
indirect taxes	taxes on intermediates		taxes on purchases		taxes on purchases		taxes on investment goods	taxes on exports	
capital account		depreciation	household savings	corporate savings	government savings			foreign savings	
rest of world	imports								
emission	removal								

Section III First Simulation

The first problem which is addressed is air pollution.

We perform the simulation for a 50 % decrease in emissions of the GHG gases by different industries. The base period taken in our analysis is 2007-08 SAM. We have considered a Standard CGE model in this case which is a static model and provides a one period solution of the simulation. Such a measure must have a negative impact on the output of different sectors. We have to see by how much such changes affect and which of the sectors are getting affected. Kyoto protocol and many UN environment programmes have concentrated to emission reduction programmes. However, there is a scary outlook for firms to switch over carbon neutral fuels which may increase their costs because reducing fuel may increase costs and thus lesser profits and may even lead to lesser output. We include the total emissions of GHG gases in the environmental SAM for different sectors. The data is obtained from INCAA report.

	AGRI	FUEL	CHEM	MET	OTH	LAB	CAP	HOH	PVT	GOV	IDT	CAC	ROW	TOTAL	CO
	289	5303	24366	164	10537			6464		1004		48871	28151	13348	519
	327	30.03	562.5	635	453.4			8867.09		309.592		4.1261	38.676	8795.6	255.5
AGRI	84.5	82	9	.511	5										

	2			8											
FUEL	234 9710 .973	3433 0246. 43	83884 16.572	108 480 00. 81	2498 3418. 22			10528 499.7 7		83138 9.043 1		37515 06.01 3	1290 8114. 62	10891 9302. 5	196 476
CHE M	4132 677. 606	2832 435.4 63	47736 173.48	744 813 5.91	2508 7703. 38			5202 2178. 33		3572 666.3 34		12089 383.3 5	17658 315.2 9	17257 9669. 1	917 555 .3
MET	602 281. 961	13208 76.80 7	37581 24.46	640 918 48. 28	27336 470			10427 342.7 7		18061 51.53 1		6996 8636. 29	15764 770.1 2	19507 6502. 2	122 736 .9
OTH	1179 370 9.54	5953 067.0 69	34083 285.7 8	284 769 46. 3	8324 8080. 16			13555 7505. 4		4294 7351. 34		9654 4840. 72	4667 9997. 95	4852 8478 4.2	371 879
LAB	4140 0931 .87	51394 09.81 1	13928 756.37	1162 2719 .67	13055 8424. 3								- 2276 00	2024 2264 2	
CAP	439 550 72.2 2	16556 647.7 9	25453 835.9 3	1772 092 9.29	15180 5508. 5								- 1884 000	2536 0799 3.7	
HOH						202 4226 42	1595 2155 5			2824 9456			10194 300. 38	4003 87953 .4	
PVT							13479 938.7 3			4895 5541				6243 5479. 73	
GOV							31136 900	10076 253.0 5	1927 6656		405 004 93		6222 2495	16321 2797.1	
IDT	- 350 580 6.26	2493 784.3 58	23703 40.00 4	740 642 0.27	10861 825.6 8			51052 07		11402 32		73497 27	72787 63	4050 0493. 05	
CAC							4946 9600	11202 2100	4315 8823 .7	3470 5700			- 4916 3416. 82	19019 2806. 9	
ROW	382 743 3.16 9	39762 504.2 3	12494 173.96	472 968 66.2 6	2086 5900. 59									12424 6878. 2	
TOTAL	1334 887 95.6	10891 9302	17257 9669.1	195 076 502 .3	4852 8478 4.3	202 4226 42	2536 0799 3.7	4003 8795 3.4	6243 5479 .7	16321 2796. 8	405 004 93	19019 2807. 5	1242 4687 8.2		
CO	275 358	0	0	0	0										

We have considered 5 sectors as given in our SAM, three agents viz. household, private sector (corporate) and government. The two inputs used in production are capital and labour. So, the four sets are

Sectors	AGRI, FUEL, CHEM, MET, OTH	Factors	LAB, CAP
Emission	CO	Agents	HOH, PVT, GOV

III.1 Calibration

The parameters calibrated from the base SAM in this model are given in the following table.

	share parameter in utility function	$\gamma(i)$	scale parameter in Armington
--	-------------------------------------	-------------	------------------------------

$\alpha(i)$			function
$\beta(h,j)$	share parameter in production function	$\psi d(i)$	share parameter in transformation function
$b(j)$	scale parameter in production function	$\psi e(i)$	share parameter in transformation function
$ax(i,j)$	intermediate input requirement coefficient	$\theta(i)$	scale parameter in transformation function
$ay(j)$	composite factor input requirement coefficient	ssh	average propensity for household saving
$\mu(i)$	government consumption share	ssp	average propensity for private saving
$\lambda(i)$	investment demand share	ssg	average propensity for govt saving
$\delta m(i)$	share parameter in Armington function	τd	direct tax rate
$do(i)$	share parameter in Armington function	τc	corporate tax rate

Next, we obtain the **elasticity parameters**.

σ_i	'elasticity of substitution' = 2
ψ_i	'elasticity of transformation' = 2
η_i	'substitution elasticity parameter' = $(\sigma_i - 1) / \sigma_i = 0.5$
φ_i	'transformation elasticity parameter' = $(\psi_i + 1) / \psi_i = 1.5$

III.2 Variables

The **endogenous variables** used in this model are

Y_j	composite factor of j-th firm	S_f	foreign saving
$F_{h,j}$	the h-th factor input by the j-th firm	T_d	direct tax
$X_{i,j}$	intermediate input	T_c	corporate tax
Z_j	output of the j-th good	T_{z_j}	production tax
E_i	exports	T_{ph}	tax on purchase of household
M_i	imports	T_{pg}	tax on purchase of government
Q_i	Armington's composite good	T_i	tax on investment goods
D_i	domestic good	T_e	tax on exports
pf_h	the h-th factor price	I_g	income from enterprises
py_j	composite factor price	Op	operating profit
p_{z_j}	supply price of the j-th good	G_t	government transfers
p_{q_i}	Armington's composite good price	I_d	interest on debt
pe_i	export price in local currency	N_f	net factor income
pm_i	import price in local currency	N_{ct}	net capital transfer to government

pd_i	the i -th domestic good price	N_c	net current transfer
ε	exchange rate	De	depreciation rate
Sh	household saving	Co_i	CO2 emission
Sp	private saving	dCO_i	change in CO2 emission
Sg	government saving	UU	utility [fictitious]

III.3 Equations

1. eqpy(j) 'composite factor agg. func.'

$$Y_j - CO_j = b_j * \prod_h F_{h,j}^{\beta_{h,j}}$$

2. eqF(h,j) 'factor demand function'

$$F_{h,j} = \beta_{h,j} * py_j * Y_j / pf_h$$

3. eqX(i,j) 'intermediate demand function'

$$X_{i,j} = ax_{i,j} * Z_j$$

4. eqY(j) 'composite factor demand function'

$$Y_j - CO_j = ay_j * Z_j$$

5. eqpzs(j) 'unit cost function'

$$pz_j = ay_j * py_j + \sum_i (ax_{i,j} * pq_i)$$

6. eqTd 'direct tax revenue function'

$$Td = \tau_d * \sum_h (pf_h * FF_h)$$

7. eqTc 'corporate tax function'

$$Tc = \tau_c * (\sum_h (pf_h * Op_h) + Id)$$

8. eqTz(j) 'production tax revenue function'

$$Tz_j = \tau_z * pz_j * Z_j$$

9. eqXg(i) 'government demand function'

$$Xg_i = \mu_i * (Td + Tc + \sum_h (pf_h * Ig_h) + \sum_j Tz_j + Nct - Sg - Tpg) / pq_i$$

10. eqXv(i) 'investment demand function'

$$Xv_i = \lambda_i * (Sh + Sp + Sg + \varepsilon * Sf - De - Ti) / pq_i$$

11. eqSh 'household saving function'

$$Sh = ssh * (\sum_h (pf_h * FF_h) + \sum_h (pf_h * Nf_h))$$

12. eqSg 'government saving function'

$$Sg = ssg * (Td + Tc + \sum_h (pf_h * Ig_h) + Nct + \sum_j Tz_j)$$

13. eqSp 'private saving function'

$$Sp = ssp * (\sum_h (pf_h * Op_h) + Id)$$

14. eqXp(i)	'household demand function'	$Xp_i = \alpha_i * ((\sum_h (pf_h * FF_h) + \sum_h (pf_h * Nf_h) - Sh - Tph - Td)/pq_i)$
15. eqpe(i)	'world export price equation'	$pe_i = \varepsilon * pWe_i$
16. eqpm(i)	'world import price equation'	$pm_i = \varepsilon * pWm_i$
17. eqepsilon	'balance of payments'	$\sum_i pWe_i * E_i + Sf = \sum_i pWm_i * E_i$
18. eqpqs(i)	'Armington function'	$Q_i = \gamma_i * (\delta m_i * M_i^{\eta_i} + \delta d_i * D_i^{\eta_i})^{\frac{1}{\eta_i}}$
19. eqM(i)	'import demand function'	$M_i = (\gamma_i^{\eta_i} * \delta m_i * pq_i / pm_i^{(1/(1-\eta_i))}) * Q_i$
20. eqD(i)	'domestic good demand function'	$D_i = (\gamma_i^{\eta_i} * \delta d_i * pq_i / pd_i^{(1/(1-\eta_i))}) * Q_i$
21. eqpzd(i)	'transformation function'	$Z_i = \theta_i * (\xi e_i * E_i^{\varphi_i} + \xi d_i * D_i^{\varphi_i})^{(1/\varphi_i)}$
22. eqDs(i)	'domestic good supply function'	$D_i = (\theta_i^{\varphi_i} * \xi d_i * (1 + \tau z_i) * pz_i / pd_i)^{(1/(1-\varphi_i))} * Z_i$
23. eqE(i)	'export supply function'	$E_i = (\theta_i^{\varphi_i} * \xi e_i * (1 + \tau z_i) * pz_i / pe_i)^{(1/(1-\varphi_i))} * Z_i$
24. eqpqd(i)	'market clearing cond. for comp. good'	$Q_i = Xp_i + Xg_i + Xv_i + \sum_j X_{i,j}$
25. eqpf(h)	'factor market clearing condition'	$\sum_j F_{h,j} + Nf_h = FF_h + Op_h + Ig_h$
26. eqdCO(i)	'change in CO2 emission function'	$dCO_i = (CO_i / CO0_i - 1) * 100$
27. obj	'utility function [fictitious]'	$UU = \prod_i (Xp_i * \alpha_i)$

III.4 Results

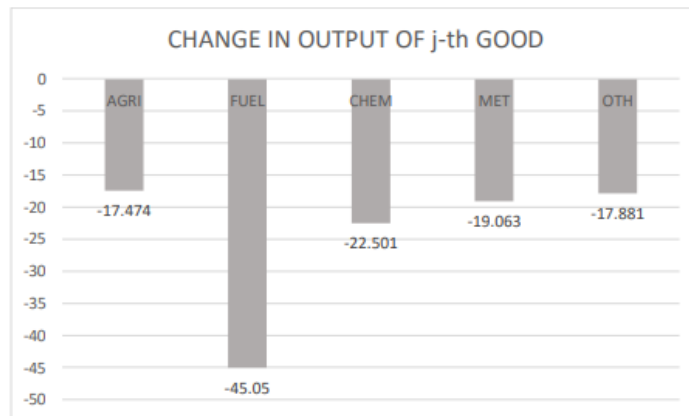
The simulation provides results which goes with the economic logic and the model presented above. All the results are shown in tabular and graphical form. We show the changes for all the variables for all the sectors.

1. Change in output-

Output of all the sectors are adversely affected with the policy. The most affected industry will be fuel. Fuel consists of all kinds of fugitive sources of emissions like coal

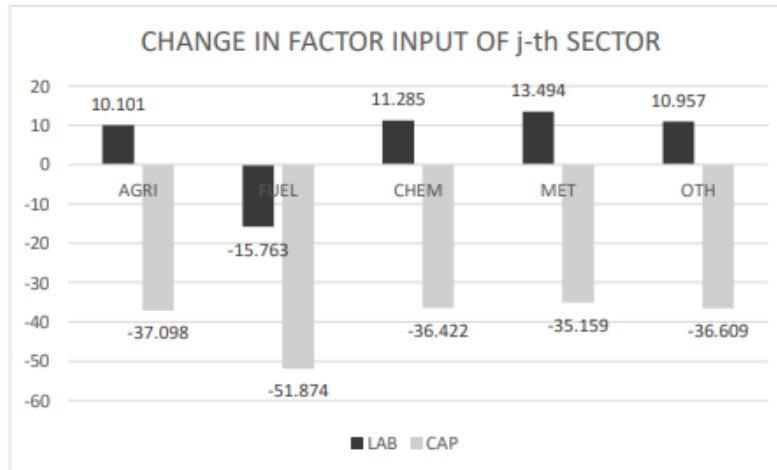
and petroleum mining etc. Thus, the output of the major primary source of carbon emission gets reduced. Hence, there will be an impetus for the economy if such restrictions are imposed over carbon emission to switch over to renewable sources

dZ		
	AGRI	-17.474
	FUEL	-45.05
	CHEM	-22.501
	MET	-19.063
	OTH	-17.881



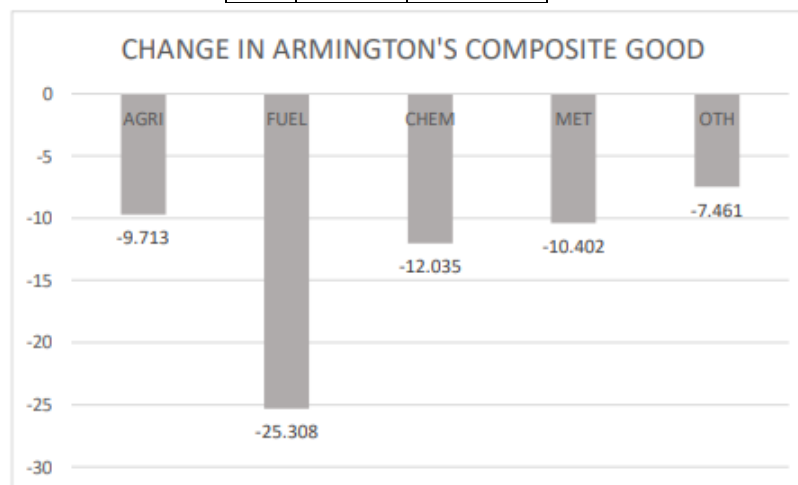
2. **Change in factor inputs**– There is a labour capital substitution which can be readily seen from the table and the graph, because labour for each sector except fuel increases after the implementation of the policy while capital input has decreased. So, we cannot say such a policy will lead to decrease in employment. But in actual economy with such high output fall, there may be fall in investment and other things.

dF		LAB	CAP
	AGRI	10.101	-37.098
	FUEL	-15.763	-51.874
	CHEM	11.285	-36.422
	MET	13.494	-35.159
	OTH	10.957	-36.609



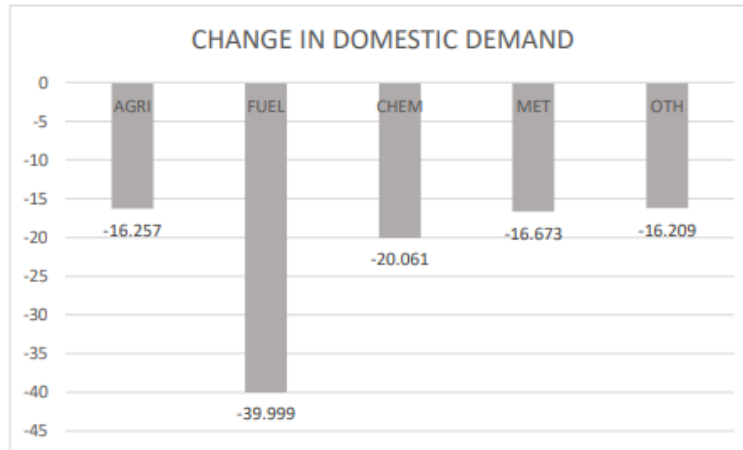
3. **Change in Armington's Composite good**– We see a negative change in the total demand of the Armington's Composite good for all the sectors, which implies fall in both domestic and export demand.

dQ		
	AGRI	-9.713
	FUEL	-25.308
	CHEM	-12.035
	MET	-10.402
	OTH	-7.461



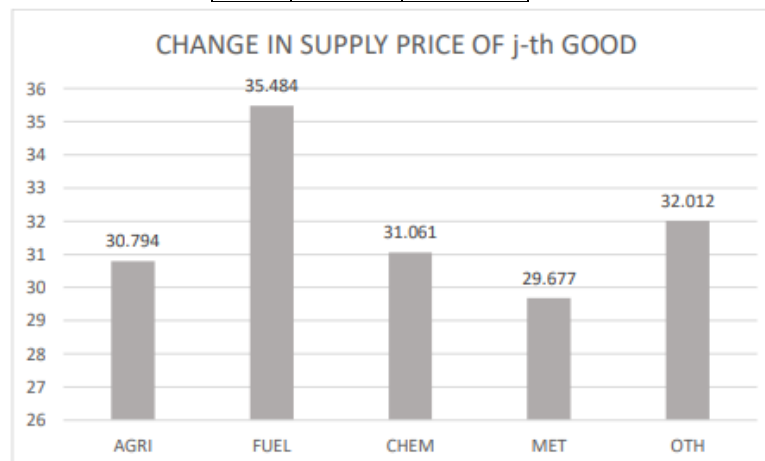
4. **Change in domestic demand**– We observe adverse effect on the domestic demand for each sector.

dD		
	AGRI	-16.257
	FUEL	-39.999
	CHEM	-20.061
	MET	-16.673
	OTH	-16.209



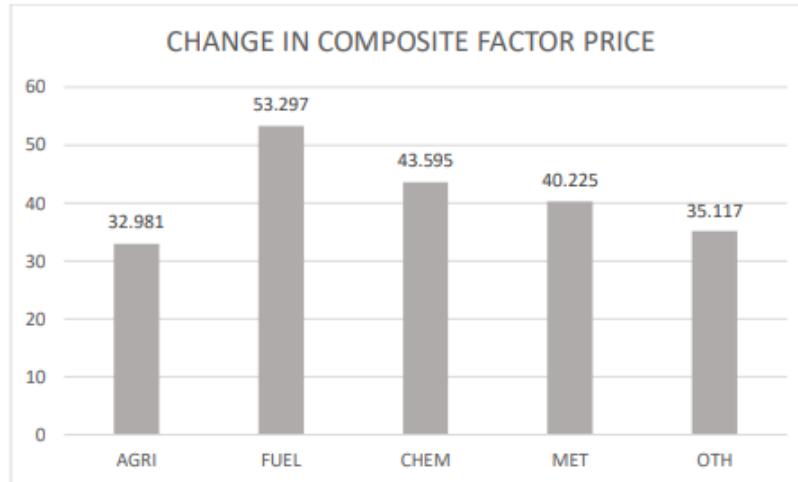
5. **Change in supply price of j^{th} good** -A target reduction in emission leads to an increase in fuel prices due to constrained supply and also it leads to constraints in the production process. As the output shortage occurs, we witness increase in prices of the goods.

dpz		
	AGRI	30.794
	FUEL	35.484
	CHEM	31.061
	MET	29.677
	OTH	32.012



6. **Change in price of composite factor input** - Here we show how the simulation resulted in increase in prices of all goods. The same picture can be seen in factor prices as well.

dpy		
	AGRI	32.981
	FUEL	53.297
	CHEM	43.595
	MET	40.225
	OTH	35.117



7. Having considered the price of labour to be unity, i.e, the labour to be numeraire, the change in price of capital is given by $dpf = 75.036$.

Section-IV Simulation II

IV.1 New ESAM

The first simulation was done on the basis of inclusion of GHG emissions of different sectors. But another side of pollution is water pollution which leads to increase in pollutants due to discharge of effluents by industries. In India, data on water pollution for different sectors are not available rather we have data on how much different rivers are polluted or available data is on state wise. Since our approach of simulation is a sectoral approach based on SAM, we couldn't use that data. D. Chakroborty and K. Mukhopadhyay in their 'Water Pollution and Abatement Policy in India' have given estimates of Chemical Oxygen Demand (COD) of different industries, which we have used to build the extended SAM-ESAM.

In India we have different effluent treatment plants as well though most of them are operating below capacity. By a selective study by CPCB the operational capacity of STPs in Delhi is 64%. Thus, most of the wastes are not treated in India. So, we have added an Abatement sector which plays an important role in controlling pollution and contributes to greener economy. Data on STPs also is available on CPCB website state wise. Chakroborty et al also provides estimates on cost of such treatment plants sector wise. It also provides estimates on labour costs which we have used for computing the value added of labour and other intermediate costs for inputs.

We have performed the simulation on reduction of COD emission by 50%.

	AGRI	FUEL	CHEM	MET	OTH	ABT	LAB	CAP	HOH	PV T	GOV	IDT	CAC	RO W	TOTAL	COD
	289	530		164	105				646							
	327	330.	24366	635	374				488				488	2815	13348	898
	84.5	038	562.5	.511	53.				67.0		1004		714.	138.	8795.	57.2
AGRI	2	2	9	8	45	0			9		310		1	676	6	5

FUEL	234 9710 .973	343 302 46.4 3	8388 416.5 72	108 480 00. 81	249 834 18. 22	0			1052 849 9.77		8313 89		375 150 6	129 0811 4.62	10891 9302. 5	251. 63
CHE M	4132 677. 606	283 243 5.46 3	47736 173.4 8	744 813 5.9 1	250 877 03. 38	391 933 5			520 2217 8.33		3572 666		120 893 83	1765 8315 .29	17649 9004. 1	2870 3.38
MET	602 281. 961	1320 876. 807	37581 24.46	640 918 48. 28	273 364 70	0			104 273 42.7 7		1806 152		699 686 36	1576 477 0.12	19507 6502. 2	1152. 03
OTH	1179 370 9.54	595 306 7.06 9	3408 3285. 78	284 769 46. 3	832 480 80. 16	0			1355 575 05.4		429 4735 1		965 448 41	466 799 97.9 5	4852 8478 4.2	0
ABT	1428 76.8 4	230 87.4 7	47431 03.61	123 702 .8		0			227 0213 31		4210 5874		1.4E +08	915 064 22	5056 82013 .7	0
LAB	4132 949 3.45	5127 866. 305	13516 872.0 6	115 608 68. 23	130 558 424 .3	1317 310 58.6							- 227 600	3335 9698 2.9		
CAP	438 836 33.8	1654 5104 .29	25041 951.6 2	176 590 77. 84	151 805 508 .5	263 462 117.1							- 188 400 0	51651 3393. 2		
HOH							333 596 982. 9	290 974 254. 7			282 494 56			1019 430 0.38	66301 4994	
PVT							0	144 932 638. 4			489 555 41				19388 8179. 4	
GOV							0	3113 690 0	1007 625 3.05	192 76 65 6		40 50 04 93		104 328 368. 8	20531 8670. 9	
IDT	- 350 580 6.26 4	249 378 4.35 8	23703 40.00 4	740 642 0.2 7	108 618 25. 68	0			510 520 7		1140 232		734 972 7	7278 763	4050 0493. 05	
CAC								494 696 00	1476 278 09.6	1.7 5E +0 8	347 057 00			- 762 062 09.5 1	3302 0842 3.5	
ROW	382 743 3.16 9	397 625 04.2 3	12494 173.96	472 968 66. 26	208 659 00. 59	106 569 503									23081 6381. 2	
TOTAL	1334 887 95.6	1089 1930 2.5	17649 9004. 1	195 076 502 .2	485 284 784 .2	505 682 013. 7	333 596 982. 9	5165 1339 3.2	663 014 994	1.9 4E +0 8	2.05 E+0 8	40 50 04 93	3.3 E+0 8	230 8163 81.2		
COD	0	0	0	0	0	0										

We have considered 6 sectors as given in our SAM, three agents viz. household, private sector (corporate) and government. The two inputs used in production are capital and labour.

So, the four sets are

Sectors	AGRI, FUEL, CHEM, MET, OTH, ABT	Factors	LAB, CAP
Emission	COD	Agents	HOH, PVT, GOV

IV.2 Calibration

The parameters calibrated in this model and the equations used for those calibrations remain the same as earlier simulation.

The calibrated values are-

Scale and share parameter

		AGRI	FUEL	CHEM	MET	OTH	ABT
α_i		0.129	0.021	0.104	0.021	0.271	0.454
β_h	LA	0.485	0.237	0.351	0.396	0.462	0.333
	CA	0.515	0.763	0.649	0.604	0.538	0.667
b_j		1.999	1.728	1.911	1.957	1.994	1.899
ay_j		0.64	0.325	0.239	0.208	0.623	0.999
μ_i		0.005	0.004	0.017	0.009	0.209	0.205
λ_i		0.001	0.009	0.03	0.172	0.238	0.345
δ		0.148	0.457	0.226	0.374	0.183	0.371
δ		0.852	0.543	0.774	0.626	0.817	0.629
γ_i		1.337	1.985	1.538	1.881	1.426	1.874
ξ		0.87	0.676	0.742	0.743	0.749	0.647
ξ		0.13	0.324	0.258	0.257	0.251	0.353
θ_i		4.039	2.19	2.527	2.441	2.546	2.184

Intermediate input requirement coefficient

ax_{ij}		AGRI	FUEL	CHEM	MET	OTH	ABT
	AGRI	2.89E+07	530330	2.44E+07	164635.5	1.05E+07	0
	FUEL	2349711	3.43E+07	8388417	1.08E+07	2.50E+07	0
	CHEM	4132678	2832435	4.77E+07	7448136	2.51E+07	3919335
	MET	602282	1320877	3758124	6.41E+07	2.73E+07	0
	OTH	1.18E+07	5953067	3.41E+07	2.85E+07	8.32E+07	0
	ABT	142877	23087.47	4743104	123702.8	0	0

Average propensity of savings and tax rates

ssh	0.223
ssp	0.901
ssg	0.188
τ_d	0.016
τ_C	0.099

IV.3 Variables

The endogenous variables used in this model remain the same as the earlier simulation except

CoD _i	COD emission
dCOD _i	change in COD emission

IV.4 Equations

1. eqpy(j) 'composite factor agg. func.'

$$Y_j - COD_j = b_j * \prod_h F_{h,j}^{\beta_{h,j}}$$

2. eqF(h,j) 'factor demand function'

$$F_{h,j} = \beta_{h,j} * py_j * Y_j / pf_h$$

3. eqX(i,j) 'intermediate demand function'

$$X_{i,j} = ax_{i,j} * Z_j$$

4. eqY(j) 'composite factor demand function'

$$Y_j - COD_j = ay_j * Z_j$$

5. eqpzs(j) 'unit cost function'

$$pz_j = ay_j * py_j + \sum_i (ax_{i,j} * pq_i)$$

6. eqTd 'direct tax revenue function'

$$Td = \tau_d * \sum_h (pf_h * FF_h)$$

7. eqTc 'corporate tax function'

$$Tc = \tau_c * (\sum_h (pf_h * Op_h) + Id)$$

8. eqTz(j) 'production tax revenue function'

$$Tz_j = \tau_{zj} * pz_j * Z_j$$

9. eqXg(i) 'government demand function'

$$Xg_i = \mu_i * (Td + Tc + \sum_h (pf_h * Ig_h) + \sum_j Tz_j + Nct - Sg - Tpg) / pq_i$$

10. eqXv(i) 'investment demand function'

$$Xv_i = \lambda_i * (Sh + Sp + Sg + \varepsilon * Sf - De - Ti) / pq_i$$

11. eqSh 'household saving function'

$$Sh = ssh * (\sum_h (pf_h * FF_h) + \sum_h (pf_h * NF_h))$$

12. eqSg 'government saving function'

$$Sg = ssg * (Td + Tc + \sum_h (pf_h * Ig_h) + Nct + \sum_j Tz_j)$$

13. eqSp 'private saving function'

$$Sp = ssp * (\sum_h (pf_h * Op_h) + Id)$$

14. eqXp(i) 'household demand function'

$$Xp_i = \alpha_i * ((\sum_h (pf_h * FF_h) + \sum_h (pf_h * NF_h) - Sh - Tph - Td) / pq_i)$$

15. eqpe(i) 'world export price equation'

$$pe_i = \varepsilon * pWe_i$$

16. eqpm(i) 'world import price equation'

$$pm_i = \varepsilon * pWm_i$$

17. eqepsilon 'balance of payments'

$$\sum_i pWe_i * E_i + Sf = \sum_i pWm_i * E_i$$

18. eqpqs(i) 'Armington function'

$$Q_i = \gamma_i * (\delta m_i * M_i^{\eta_i} + \delta d_i * D_i^{\eta_i})^{(1/\eta_i)}$$

19. eqM(i) 'import demand function'

$$M_i = (\gamma_i^{\eta_i} * \delta m_i * pq_i / pm_i^{(1/(1-\eta_i))}) * Q_i$$

20. eqD(i) 'domestic good demand function'

$$D_i = (\gamma_i^{\eta_i} * \delta d_i * pq_i / pd_i^{(1/(1-\eta_i))}) * Q_i$$

21. eqpzd(i) 'transformation function'

$$Z_i = \theta_i * (\xi e_i * E_i^{\varphi_i} + \xi d_i * D_i^{\varphi_i})^{(1/\varphi_i)}$$

22. eqDs(i) 'domestic good supply function'

$$D_i = (\theta_i^{\varphi_i} * \xi d_i * (1 + \tau z_i) * pz_i / pd_i)^{(1/(1-\varphi_i))} * Z_i$$

23. eqE(i) 'export supply function'

$$E_i = (\theta_i^{\varphi_i} * \xi e_i * (1 + \tau z_i) * pz_i / pe_i)^{(1/(1-\varphi_i))} * Z_i$$

24. eqpqd(i) 'market clearing cond. for comp. good'

$$Q_i = Xp_i + Xg_i + Xv_i + \sum_j X_{i,j}$$

25. eqpf(h) 'factor market clearing condition'

$$\sum_j F_{h,j} + Nf_h = FF_h + Op_h + Ig_h$$

26. eqdCOD(i) 'change in COD emission function'

$$dCOD_i = (COD_i / COD0_i - 1) * 100$$

27. obj 'utility function [fictitious]'

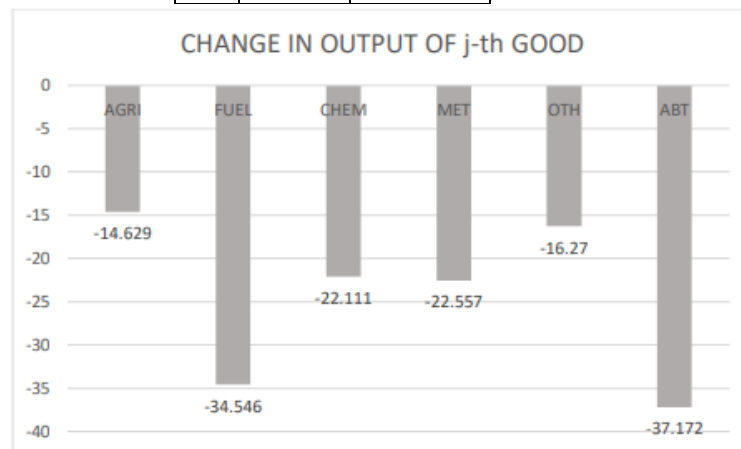
$$UU = \prod_i (Xp_i * \alpha_i)$$

IV.5 Results

1. Change in output- We see fall in output for all sectors in this simulation.

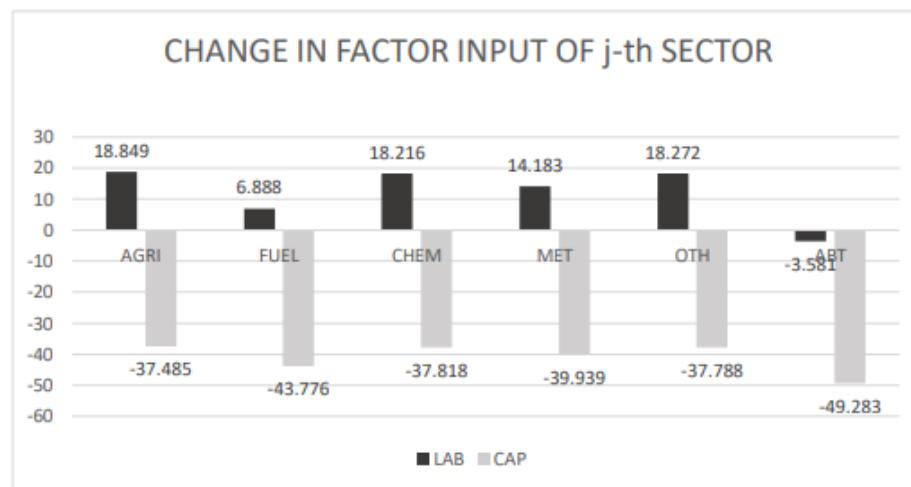
dZ		
	AGRI	-14.629
	FUEL	-34.546
	CHEM	-22.111

	MET	-22.557
	OTH	-16.27
	ABT	-37.172



2. Change in factor inputs-

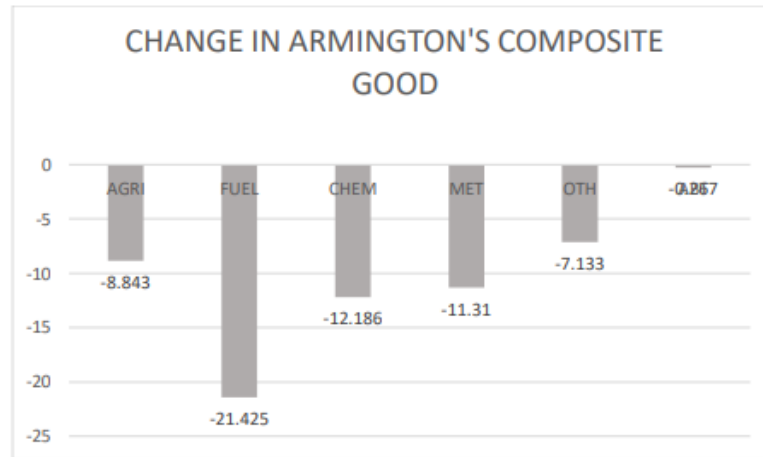
dF		LAB	CAP
	AGRI	18.849	-37.485
	FUEL	6.888	-43.776
	CHEM	18.216	-37.818
	MET	14.183	-39.939
	OTH	18.272	-37.788
	ABT	-3.581	-49.283



3. Change in Armington's Composite good-

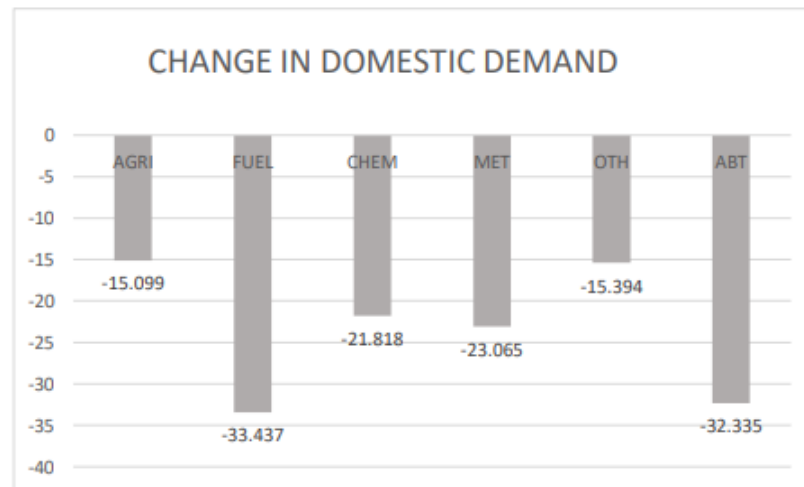
dQ		
	AGRI	-8.843
	FUEL	-21.425
	CHEM	-12.186
	MET	-11.31

	OTH	-7.133
	ABT	-0.267



4. Change in domestic demand-

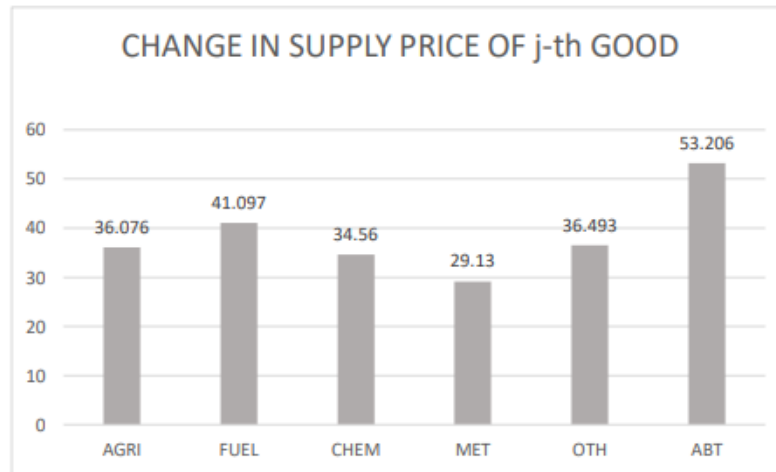
dD		
	AGRI	-15.099
	FUEL	-33.437
	CHEM	-21.818
	MET	-23.065
	OTH	-15.394
	ABT	-32.335



5. Change in supply price of j^{th} good -

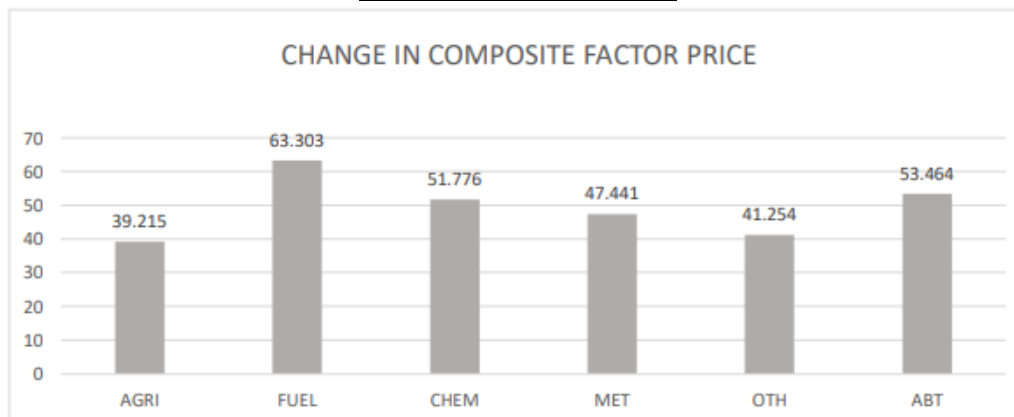
dpz		
	AGRI	36.076
	FUEL	41.097
	CHEM	34.56

	MET	29.13
	OTH	36.493
	ABT	53.206



6. Change in price of composite factor input -

dpy		
	AGRI	39.215
	FUEL	63.303
	CHEM	51.776
	MET	47.441
	OTH	41.254
	ABT	53.464



Section-V

Conclusion and Policy Prescription

As per our analysis emission targets on different industries leads to increase in prices and decrease in output. Output of all sectors have decreased as firms take carbon emissions as

full permit to increase their output as explained in our model. Prices of output and factors have increased. Domestic demand has decreased very much with decrease in output and increase in prices. The concerning issue is the increase in import demand which can lead to deficit in current account already a bigger problem for India. Such a policy if followed rigorously can lead to a stagflation scenario in the economy with more current account deficit and a big blow towards the growth process of the country. Thus, better policies can be change in technology and new better fuel. Now we used a Static CGE model to analyse the policy. The analysis on the data can be further simulated for dynamic models which may give different results and a better picture of how such policies will affect in the long run. Also, we haven't considered the inclusion of renewable energy substituting the coal energy which can be a better policy. India has been progressing a lot to substitute fossil fuel energy with solar energy. These polices can also be analysed using our database (can be extended) for future study.

Bibliography

1. Xie J. 'Environmental Policy Analysis: An Environmental Computable General Equilibrium Model For China', PhD Dissertation Cornell University, Ithaca, (1995)
2. Xue X M. 'Calculation And Comparison Study Of CO₂ Emission From China's Energy Consumption', Environ. Protect. 4 27-8,(1998)
3. Keuning S. 'National Accounts and The Environment: The Case For A System's Approach', National Accounts, Occasional Paper No. NA-053 (Netherlands Central Bureau of Statistics) (1993)
4. Pradhan BK, Saluja MR, Singh SK. 'A Social Accounting Matrix For India, Concepts, Construction And Applications', Sage, New Delhi, (2006)
5. Das Koushik, Chakroborti Pinaki. 'General Equilibrium Analysis of Strategic Trade: A Computable General Equilibrium Model for India' ,(2014)
6. Banerjee, Onil, Cicowiez, Martin; Horridge, Mark; Vargas, Renato. 'A Conceptual Framework For Integrated Economic-Environmental Modelling', (2016)
7. Horridge, M., Madden, J., & Wittwer, G. 'The Impact Of The 2002-2003 Drought On Australia'. Journal of Policy Modelling, 27(3), 285-308.(2005)
8. Ganesh-Kumar, A. and Panda M. 'Global Economic Shocks and Indian Policy Response: An Analysis Using a CGE model'. In K. S. Parikh (Ed.) Macro-Modeling (2009) for the Eleventh Five Year Plan of India, Planning Commission, Government of India/ Academic Foundation, New Delhi.
9. INCCA. India: 'Greenhouse Gas Emission 2007. Ministry of Environment and Forests—Government of India, New Delhi,(2010)
10. CSO (Central Statistical Organization) Input output table for India (2006-07), Ministry Of Statistics And Program Implementation, Government of India,(2010)
11. www.mospi.nic.in